Wind Born(e) Landscapes:

The role of wind erosion in agricultural land management and nature development

Promotor: Prof. dr. ir. L. Stroosnijder
Hoogleraar Erosie en Bodem- & Waterconservering

Co-promotor: Dr. ing. W.P. Spaan
Universitair docent bij de leerstoelgroep Erosie en Bodem- & Waterconservering

Samenstelling promotie commissie:
Prof. dr. ir. A. Veldkamp (Wageningen Universiteit)
Prof. dr. E.A. Koster (Universiteit van Utrecht)
Dr. A.M. Kooijman (Universiteit van Amsterdam)
Prof. dr. A. Warren (University College London)

Dit onderzoek is uitgevoerd binnen de C.T. de Wit onderzoeksschool PE&RC

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Michaël J.P.M. Riksen

Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
Prof. Dr. M.J. Kropff
in het openbaar te verdedigen
op 28 april 2006
des namiddags te 16.00 uur in de Aula

Michel Riksen (2006)
Wind born(e) landscapes: The role of wind erosion in agricultural land management and nature development. PhD Thesis, Wageningen University and Research Centre

ISBN 90-8504-386-7

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For Marlies, Jasper, Chiel and Teije

Cover photos:
top left: measure to reactivate wind erosion at the drift-sand area Kootwijkerzand, the Netherlands
top center: field experiment with different tillage measures to reactivate stabilized drift sand
top right: Inland drift-sand area, Kootwijkerzand, the Netherlands
bottom left: Wind erosion patterns on agricultural fields near Ilstorp, Sweden (Photo Richard Åhman)
bottom right: Upcoming dust storm on arable land, Valthermond, The Netherlands. (Photo: Proefboerderij 't Kompas/Kooijenburg PVA-NNO, the Netherlands)

Acknowledgements

At the end of 1997 I was asked by Jan de Graaff and Wim Spaan of the Erosion Soil and Water conservation group (ESW) at Wageningen University to apply for a post-Doc. position to look at the soicial-economic aspects of wind erosion on agricultural land. It concerned a part-time (0.5) position within a EU funded research project: Wind Erosion on European Light Soils (WEELS). So far I was used to studying soil erosion in tropical regions. This job gave me the opportunity to learn more about the role of erosion closer to home and combine it with my family life. Wim and Jan thank you for your confidence in me.

In March 1998 I joined the WEELS team. I travelled a lot and met most interesting people: colleagues, farmers, extension officers, students, etc. Many people from different institutes provided me with information and advice or assisted me during my field work, thank you, all. Here I specially like to thank Klaas Wijnholds, Keith Jaggard, Walter Schäfer and Lars Barring.

Several students from Wageningen University and Larenstein helped me with interviewing farmers in the four study sites: Annet de Raadt, Annemarie Klaasse and Leonie Borstlap thanks for your contribution.

A nice thing of an European project is the opportunity to work together with colleagues from different countries with different backgrounds and different experiences. Thank you Andrew Warren for your inspiring leadership and for your comments and correction of various publications, and for the great stories you shared with us. Thank you Jens Gross, Jan Sbresny, Annette Thiermann, Marie Ekström, Christine Aschberger, David Skidmore and David Gasca-Tucker, Adrian Chappell, Jürgen Böhner and Olaf Conrad. It was a real pleasure to work with you. I very much enjoyed the annual meetings and the drinks afterwards with you. Floor Brouwer thanks for guiding me in the world of policy measures.

No, Dirk Goossens I will not forget you. During the WEELS project you became a real friend to me. You became more than a friend, as we continued working together in my last project you became more or less my personal advisor.

This brings me to the next episode of my scientific career. In the last year of WEELS, our Professor Leo Stroosnijder asked me if I was interested writing a proposal for a PhD research project. Within the ESW group the idea had risen to use the existing knowledge within the group about erosion processes and soil conservation methods in an opposite way by looking if erosion could also have a positive effect. Several months exploring the possibilities contacting potential partners, visiting different sites, resulted in the proposal entitled "Making use of wind and water erosion in landscape development in the Netherlands". After approval by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC), Leo asked me if I was also interested to do the job. With the support of my wife Marlies and sons, Jasper, Chiel and Teije, I did not need much time to decide. A new challenge, an interesting new approach on looking at erosion processes, very inspiring study sites, and the knowledge that I could work for another five years with the ESW group was very attractive to me. In January 2001 my promotion from a post-doc position to a PhD studentship became a reality. I like to thank the Dr. Ir. Cornelis Lely Foundation for making this research possible by granting me a 4 year scholarship. I like to express my thanks to Wim Huijsman, Eric Kleinlebbink of Staatsbosbeheer (Sbb), Henk Siebel and Leo de Bruin of Natuurmonumenten and Peter Strijland of *recreatieschap* Utrechtse Heuvelrug, Vallei- en Kromme Rijngebied, for their partnership in this research project. Without your support I would not have been able to collect field data.

I would like to thank Claudius van de Vijver and Theo Jetten of for their contribution to the many PhD activities within the C.T. de Wit Graduate School.

Looking back, I can say that it is amazing how many people have been involved in this research project.

I would like to express my thanks to: Piet Peters, Jacquelijn Ringersma, Pieter Hazenberg, Johan Römelingh and Herman Jansen for their technical support; Philip Wenting, Roland van Zoest, John Stuiver and Jan Hein Loedeman for their assistance with GPS measurements and GIS; the MSc students Michiel Woittez, Huiberdien Sweeris, Linde Verbeek and Erik van der Lippe for collecting data and field measurements at the various study sites; Francisca Sival, Chris Segers, Ad van den Langenberg, Suzanne Stuifzand, Harry van Manen, Gilbert Maas, Bart Makaske and Victor Beumer for working together within the Beerze Pilot project.

In 2002 I got in contact with Pim Jungerius. He put me in touch with Rita Ketner-Oostra. Since then we have established fruitful co-operation that has resulted in several joint publications. Rita and Pim thank you very much .

In 2003 I became a member of a advisory team of experts and terrain managers for Coastal Dunes and Drift Sands of the Dutch ministry of Agriculture, Nature and Food Quality (*OBN deskundigenteam Droge duinen en stuifzanden, EC-LNV*). This opened a new world to me. The world of the Tawny pipit, Tree grayling, Grey hairgrass and beautiful lichen, and many other fauna and flora species. Annemieke Kooijman, Marijn Nijsen, Chris van Turnhout, Simon Deuzeman, Hans Esselink, Gerard Koopmans, Monique Hootsmans, Theo Verstrael, Ido Borkent, Frans Borgonje, Rienk Slings, Bert Takman, Han Dobben, Marijke van der Heijden and Nico Bos for sharing your expertise with me.

For my field work I spend most of the time at Kootwijkerzand. The people of Staatsbosbeheer became as a family to me. Hans Snel, Gerrit Holtslag, Alfred Harmsen, Jan Bijker, Peter Mulder and last but not least Aalt Boonen. Thank you all for helping me to establish the field experiments, the coffee and sharing lunch together.

I would also like to thank: the Swart Family for keeping an eye on the equipment, Andre Aptroot and Nicoliene Peet for monitoring vegetation and fauna; Jasper, Chiel and Teije for helping me collect marbles at Kootwijkerzand.

I should not forget my friend Dirk Goossens here, for his advice, assistance with the field work at Kootwijkerzand and many joint publications. Thanks to him I did not get stuck in the sand (only that time you tried to drive the van into the drift-sand area)…..

Special thanks to my promotor Leo Stroosnijder and co-promotor Wim Spaan for guiding me through this PhD, with fruitful discussions, tips and advice. Your critical reviews, especially in the final stage helped me enormously to finish my thesis in time.

I would also like to thank another friend, Jeroen Warner. He became a regular passenger on the way from Deventer to Wageningen and back. In his company it felt that it took us only 5 minutes instead one hour. He also proved to be a critical reader. Jeroen thanks for your improvements to the text.

Finally I would like to thank all the members of the Erosion Soil and Water Conservation group. It was and still is a real pleasure working with you. Jolanda Hendriks, Fred de Klerk, Trudy Freriks, Leo Eppink, Dirk Meindertsma, Jan de Graaff, Geert Sterk, Saskia Faye-Visser, Helena Posthumus, Olga Vigiak, Jakolien Leenders, Anton Vreelink, Ferko Bodnar, Monique Slegers, Luuk Fleskens, Aad Kesler and all other (former) members of the group, many thanks for all your support and company during the many lunches, drinks and school trips.

I like it so much that I have decided to stay for another four years working in wind erosion research. In the Netherlands we have an expression you can’t live from the wind (you can’t live on air). I am one of the happy few who can say: ‘*ik leef van de wind*’ (I can live on air).

Michel
Deventer, 28 January 2006

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Chapter 1

WIND BORN(E) LANDSCAPES
General introduction

Michel Riksen

In: Wind Born(e)Landscapes
(M.J.P.M. Riksen) Wageningen, 2006, pp. 3 - 12.

1. Wind born(e) landscapes: general introduction

1.1. Introdruction

Wind and water erosion processes are common prosesses. These processes have played, and still play, a significant role in landscape development. In many regions in Northwest Europe aeolian, fluvial and marine deposits have largely influenced present-day landscape. They form the parent material of most soils.

Before the Neolithic era, erosion was controlled by climate, physical environment and biological activity (Figure 1.1.). Natural erosion features can be seen as a part of the natural landscape. Major changes in the extent of erosion were caused by climate change and tectonics.

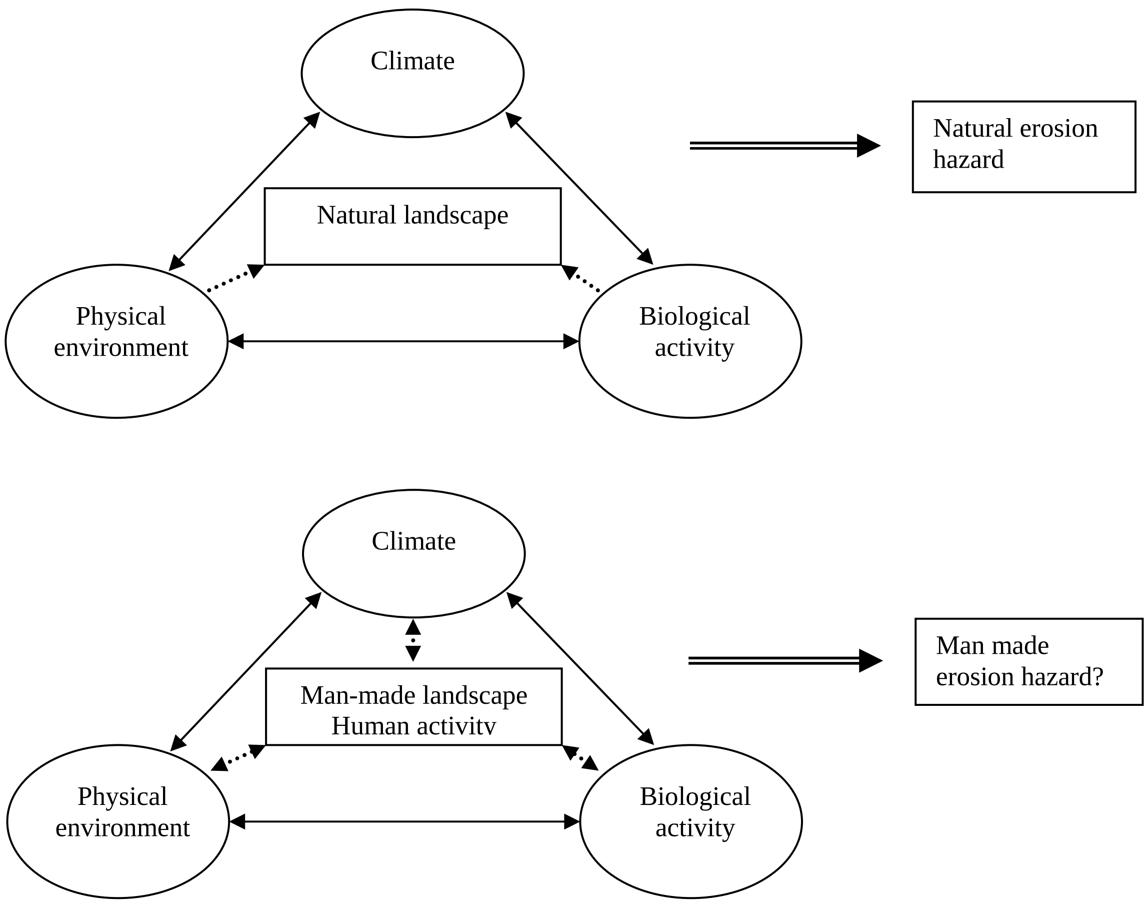


Figure 1.1. Interaction between the key factors, landscape and erosion hazard

Figure 1.2. Areal distribution of the European 'sand belt', comprising inland and river dunes, cover and drift sands, and sandy loess and loess deposits (Koster, 2005). Coastal dunes are not shown with the exception of the extensive coastal dune fields of Les Landes in south-western France. The maximum extent of the continental Pleistocene and Weichselian (Devensian, Vistulian) ice sheet are indicated.

The large-scale presence of aeolian deposits in Northwest Europe for instance (Figure 1.2.), points to the large scale extent of wind erosion in the past. Most of them were formed long before the Neolithic. Cover sands and Loess deposits were formed by aeolian activity at the end of the Last Glacial in Weichselien. The for wind erosion favourable conditions were the result of climate changes. Drift sands, on the other hand, are aeolian deposits resulting from reactivation of sandy deposits by human impact during the late Holocene (Koster, 2005). In many European regions these aeolian forms and deposits form the base of the landscape and determine for an important part present landscape characteristics, such as relief, and soil characteristics such as texture.

1.1.1. Erosion in a natural landscape

Soil erosion, the detachment, transport and deposition of soil particles by water and/or wind, itself causes a spatial variation in the landscape. The landscape will degrade on locations where mainly detachment takes place by the break-down of soil structure and the decline in soil organic matter and nutrients resulting in a reduction of the available soil moisture and decline in soil fertility. Transport and deposition can cause damage by abrasion and burying of the vegetation. The sorting effect of these processes will lead to variation in soil characteristics. These effects will locally influence the biological activity. These processes also affect the physical environment like relief and the discharge capacity of streams and rivers. The landscape will adapt according to major changes in the system like climate change. Its effect on the extent of erosion will determine whether landscape degradation or regeneration dominates until the system has reached a new equilibrium.

1.1.2. Erosion in a man-made landscape

Since the Neolithic period the Northwest European landscape have been transformed by human from natural into mainly cultural (man-made) landscape. These human activities have impact on the physical environment, climate and biological activities and result in a landscape in which the erosion hazard differs from the natural erosion hazard (Figure 1.1.). For example the large scale deforestation by man has caused an significant increase in erosion by water and wind. Human activities in upstream areas contributed significantly to an increase in (peak) river discharges and coeval increase in deposition of sediment in downstream reaches of various rivers (Koster, 2005). In Northwest Europe large scale deforestation of the cover sands changed the landscape from closed forest into open heath-land (Schimmel, 1975; Spek, 2004). In the cover sands for instance, local degradation of the heath-land by human activities triggered sand drifting by wind. With the rapid expansion of agriculture since the late Middle Ages, the area drift-sands increased rapidly (Richter, 1965; Pape, 1970; Koster, 2005).

1.1.3. Interventions to control the physical environment and its dynamics

The first successful large scale control works, the flood defence dykes along the rivers in Europe, took place between AD 1000 and the end of the fourteenth century (Koster, 2005). In other cases attempts to control natural processes and/or human induced erosion often failed like the first attempts to control the sand drifts on the Veluwe, central Netherlands. Interventions to stop the extend of the sand drifts started in the 16th century (Tesh *et al.*, 1926) with the appointment of a fireguard to control the heath and forest fires and regulate grazing in order to prevent further extension of the drift sands. Most of these attempts failed for economical and social reasons. From 1850 onward technical developments and the introduction of fertilisers have led to large-scale changes in the Northwest European landscape (Richter, 1965; Jönsson, 1992). Economically and financially it became more beneficially to control processes like flooding and wind erosion. With the introduction of fertilizers and the collapse of the wool industry the heath-landscape lost their economic value. The whish to foresee in the own wood production for the mine industry at the end of nineteen's century made the forestation of the drift-sands and heath-lands possible.

The agricultural landscape gradually changed. After the Second World War farmers were forced to work more efficient to gain enough income (Van den Bergh, 2004). Mechanisation, specialisation, re-allotment, use of fertilisers and pesticides, and scaling-up led to far-reaching consequences for the landscape. Small parcels were regrouped into large uniform fields (re-allotment). Hedges, wood stands and other obstacles disappeared, streams were canalised and the groundwater-tables lowered (Ten Brinke and De Jong, 1999). Soil degradation is an issue of growing concern in Europe. It is estimated that 12% (115 million ha) of the total European land area is affected by water erosion and another 4% (42 million ha) by wind erosion (EEA, 1998). Interventions are needed to preserve the agricultural landscape for future generations.

All these interventions also led to the loss of many natural habitats. Warren and French (2001) address substantial losses of natural habitats in Europe to the, often large-scale, interventions in the physical environment such as huge dams, straightened rivers and stabilised shorelines. In the Netherlands the man-made changes in the rural landscape, pollution and eutrophication have led to a decline or even total loss of natural habitats and loss of biodiversity (Ten Brinke and De Jong, 1999).

1.2. Research question and objectives

People are constantly adapting the landscape. A process which is steered by the society's needs, changing insights, environmental threats, politics and economical developments. This thesis focus on the role of erosion in this changing landscape. The way, intensity and scale of detachment, transport and deposition of soil material is very diverse and so the effects caused by them. The main question was:

What is the contribution, positive or negative, of erosion prosesses to our landscape and is there a need to (further) manage these physical processes and if so how?

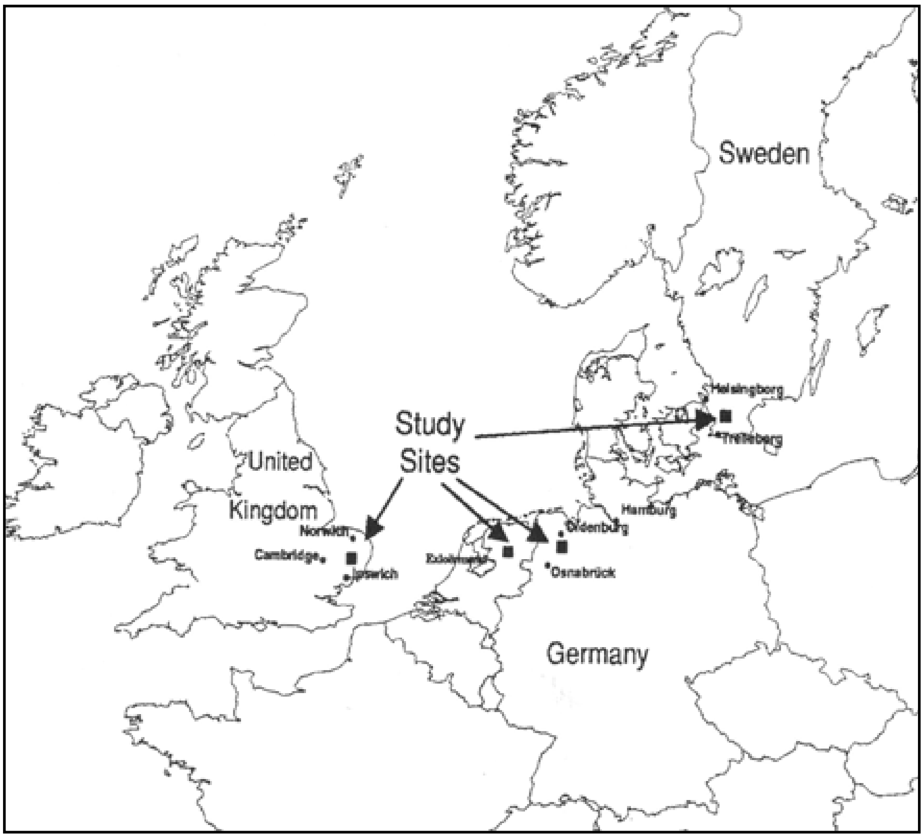


Figure 1.3. Location of WEELS project sites: Barnham (UK), Grönheim (Germany), Vombsänken (Sweden) and Exloërmond (The Netherlands)

1.2.1. The role of wind erosion in an agricultural environment; research framework and objectives

Despite wind erosion was mapped to be a serious hazard on many light soils (Oldeman *et al*., 1990), some people considered that the wind erosion problem was under control in Europe at the end of the twentieth century. However neither the effectiveness and benefits of control measures in such areas, nor the full costs of damage elsewhere have been systematically investigated. Despite the lack of systematic evaluation of the wind erosion problem, there are indications that wind erosion causes severe damage in Europe. Jönsson (1992) reported direct cost of approximately €1.5 million for resowing after one single storm in May 1984 and an average annual wind erosion damage to sugar beet in Sweden to be €1.5 million, excluding off-site and long-term costs. Eppink and Spaan (1989) give comparable figures for crops in the Netherlands.

The research described in Part I of this thesis was conducted within the framework of the EU funded research project Wind Erosion on European Light Soils (WEELS) between 1998 and 2001. WEELS aimed to provide an assessment of the contemporary problem of wind erosion in four representative parts of Europe (see Figure 1.3.) where the problem has been acknowledged to be serious: The Breckland district in England, Lower Saxony in Germany, the Vomb valley in Scania in south Sweden and on the cut-over-peat soils in the Veenkoloniën in north-east of the Netherlands. In this project we worked together with University College London (England), Lund University (Sweden) and the Institute of Soil Technology (Bremen, Germany).

The major objectives of the research carried out by the author and presented in this thesis was to develop methods and models:

1. For translating the harmful physical effects of wind erosion into economic terms: estimated financial losses to farmers and agro-industrial organisations and economic losses to society at large;
2. To evaluate the benefits of control measures; and
3. To evaluate scenarios.

Another objective of this study was to look at the implications of already existing and potentially significant government policies with regard to wind erosion and its control.

1.2.2. The role of wind erosion in a 'natural' landscape: research framework and objectives

A further loss of biodiversity needs to be stopped urgently. On the one hand by reducing environmental pollution and a more sustainable management of agricultural land and on the other hand by restoring landscape differentiating processes. In the latter the physical environment plays an important role. Since the 1980th nature conservationists in the Netherlands pay more attention to restoration of physical systems, its variability and dynamics in nature reserves. This has, among other things, resulted in the partly restoration of small streams, excavation of the fertile top soil to create nutrient poor conditions. A step further is to re-enforce geomorphological processes to create and restore spatial variability in the physical systems of nature reserves. In the Netherlands research in this field is mainly focussed on the coastal dunes and flood plains of the large rivers.

The research described in Part II of this theses was conducted within the framework of the research project entitled 'Making use of water and wind erosion processes in landscape development in the Netherlands' funded by the Dr. ir. Cornelis Lely Foundation and started in January 2001. The expertise gained from erosion research in agricultural landscapes on: erosion processes, controlling factors and control measures, is in Part II used for the inverse goal, i.e. the stimulation of erosion processes on those places where one would “create” a dynamic landscape with (desired) erosion features.

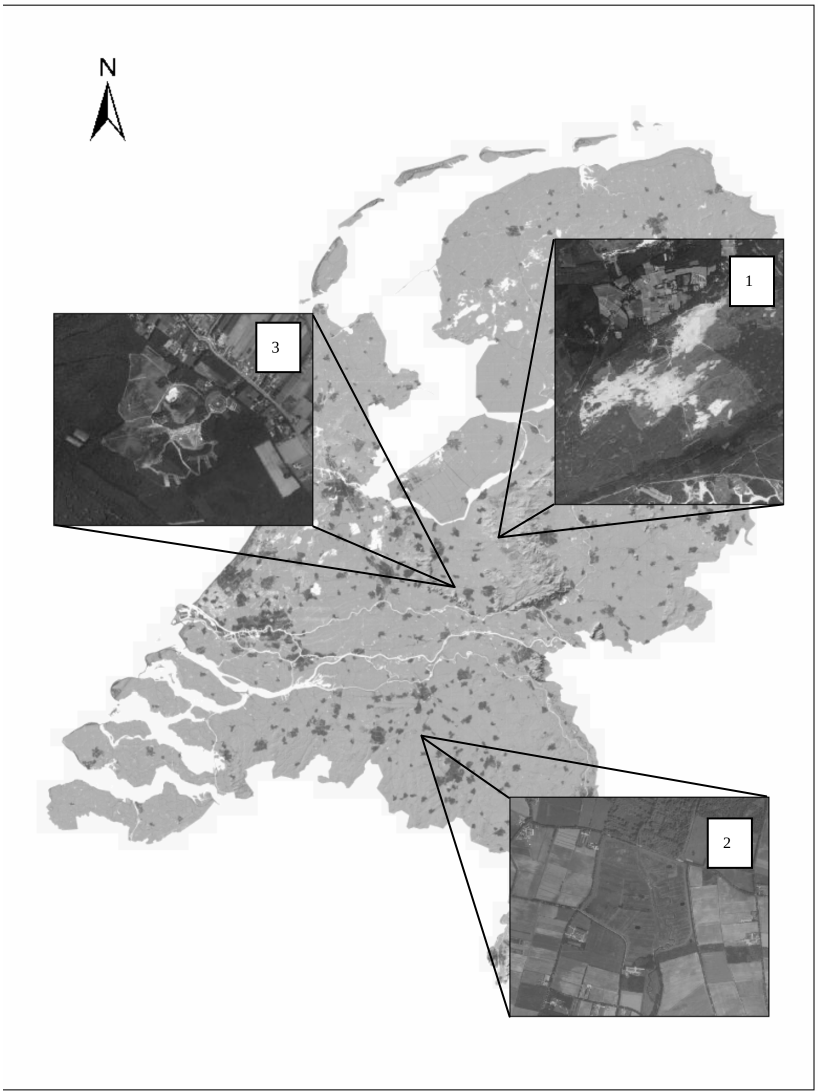


Figure 1.4. Location study sites in the Netherlands: 1 Kootwijkerzand; 2 Beerze Brook valley; 3 Kwintelooijen

The overall goal of this project was to design and evaluate measures that stimulate erosion on locations where this is preferred. Attention was also paid to management aspects such as planning, applicability of the interventions and costs.

In this project three sites in the Netherlands were selected (Figure 1.4.):

1. Wind erosion in inland drift-sands (major case), study site: Kootwijkerzand;
2. Water erosion and sedimentation in and along low land streams on sandy soil (minor case), study site: Beerze brook valley near Boxtel; and
3. Water erosion in a hilly forest landscape (minor case), study site: the former sandpit Kwintelooijen within the Utrechtse Heuvelrug located to the east of Veenendaal.

The following objectives were formulated:

- Describe the role of erosion in a 'natural' landscape and the main controlling factors
- Identify the added value of erosion features to nature and/or recreation.
- Identify and test measures.
- Formulate a management strategy to maintain 'wanted' erosion habitats.

After the first field research period the progress in the wind erosion research appeared to be most promising. Within this research it was possible to develop and test measures in the field, whereas this was almost impossible in the other locations due to Dutch law, burocratic and high recreation pressure (Kwintelooijen case). This study area was therefore selected as major case, as recommended by the PE&RC graduate school, and further worked out as presented in this thesis. The research activities of the two minor cases were restricted to monitoring of erosion activity and was mainly done by students as part of their MSc. thesis. The results of these minor cases were presented at several conferences and recently at the 2005 World conference on ecological restoration in Zaragoza. In 2005 we also organised a mini-symposium entitled 'water-storage and nature development' to discuss the results of research on sedimentation, patterns and composition in the water storage area 'de Logtse baan' in the Beerze brook valley near Boxtel, the Netherlands.

Given this development on the one hand, and the amount of available material on wind erosion at the other hand, it was decided to present only the result of the wind erosion studies in this thesis.

1.3. Outline of the thesis

Studying the role of erosion as a landscape forming process is complex and concerns many different aspects. Describing and modeling the erosion processes, like in a reductionist approach, alone will not do because other factors on different spatial and temporal scales within the studied system can influence these processes: for example legislation, land-ownership or, in case of drift sands, recreation pressure. This study therefore used a research methodology that combines:

- The reductionist's approach for a detailed understanding of underlying processes; and
- Constructivist's approach for the explication of the existence, association, and behavior of the studied systems.

Both research strategies were important in this study where they provided complementary insights. The research contained a variety of methodologies originating from different disciplines. The thesis is compiled from mainly published, accepted and submitted papers in peer reviewed journals and books.

The role of wind erosion in an agricultural landscape is discussed in Part I and the role of wind erosion in a 'natural' landscape in Part II.

Chapter 2 and 3 presents the results of an assessment of on- and off-site effects of wind erosion on European light soils and of the order of magnitude of the damage and costs caused by these effects. Knowing the effect of wind erosion in an agricultural environment it became possible to predict wind erosion damage for different scenarios. Chapter 4 presents the results of a sensitivity analysis using the WEELS model to simulate wind erosion for two alternative climate, two wind break and three land use scenarios separately. Chapter 5 examines the role of policies and farm management practices in controlling the effects of wind erosion on European light sandy soils.

Part II discusses the role of wind erosion in inland drift-sands. Chapter 6 presents an overview of the development of the last active inland drift sands in north-west Europe. First a description is given of the origin and development of inland drift sands in The Netherlands before 1960 (Section 6.2). Section 6.3 describes the rapid decline of the remaining active drift sands in The Netherlands after 1960 and the role of the increased atmospheric nitrogen deposition and the introduction of invasive species in the drift-sand ecotopes in this. Section 6.4 discusses the consequences of these developments for the management of the drift sands and proposes a few topics for further research.

Chapter 7 discusses the results of experiments and observations that were carried out between 2001 and 2005 concerning the extent, the intensity and the role of the natural processes in a drift-sand ecosystem. It focuses on the two dominant processes that displace sediment in the drift-sand landscape: deflation and (wind-driven) splash erosion. It also discusses the impact of the results on management strategies to keep the erosion processes active. Chapter 8 presents the results of an evaluation of four mechanical methods that are currently used to reactivate by vegetation stabilized drift-sand. This chapter focuses on the physical aspects of the measures. Chapter 9 discusses management strategies to maintain the erosion habitats within the drift-sand ecosystem with its unique and rare flora and fauna.

Finally, similarities and differences between the main principles of wind erosion in both landscape types, are discussed in Chapter 10 the synthesis of this thesis. Does wind erosion play a significant role in Northwest Europe landscapes and are we able to manage this process in both, agricultural and natural environments?

PART I

THE ROLE OF WIND EROSION IN AGRICULTURAL LANDSCAPES

Chapter 2

ON-SITE AND OFF-SITE EFFECTS OF WIND EROSION ON EUROPEAN LIGHT SOILS

M. J. P. M. Riksen and J. de Graaff

Published in: *Land Degradation & Development* **12**: 1-11 (2001)

In: Wind Born(e)Landscapes
(M.J.P.M. Riksen) Wageningen, 2006, pp. 17 -31.

2. On-site and off-site effects of wind erosion on European light soils

Michel Riksen and Jan de Graaff

Erosion and Soil and Water Conservation Group, Wageningen University, Nieuwe Kanaal 11, NL-6709 PA Wageningen, The Netherlands

Abstract

In intensively cultivated areas with light soils in Europe, wind erosion can have important on-site and off-site effects. In the framework of the EU research project Wind Erosion on European Light Soils (WEELS), an assessment has been made of these effects and of the order of magnitude of the damage and costs caused by these effects. An analysis is made of the land use and cropping in four selected sites, and farmers have provided information about the damage of wind erosion. This damage consists mainly of crop losses and additional inputs in the case of re-sowing. Detailed information from one of these sites shows that depending on the crop the average annual on-site costs in high-risk areas amount to about €60 per hectare. However, for sugar beet and oilseed rape the costs can be once in five years as much as €500 per hectare. Farmers are generally well aware of the erosion risk and do apply a variety of control measures. With these measures the average annual costs of wind erosion can be reduced significantly.

Key words: wind erosion; light soils; on-site damage; off-site damage; costs; control measures; Europe

2.1. Introduction

European areas with sandy, peaty or loess soil types, under arable land, on large fields without barriers are very vulnerable to wind erosion: about 1,000,000 ha in the western part of Denmark (Prendergast, 1983); 170,000 ha in Sweden (Jönsson, 1985); almost two million ha in North Germany (Schäfer, 1991); 260,000 ha in the United Kingdom (Prendergast, 1983) and 97,000 ha in The Netherlands (Eppink, 1982). The erosion risk within these zones depends on such factors as vegetation cover, soil roughness and soil moisture and this varies throughout the year. The actual field condition determines the wind velocity at which wind erosion starts. The threshold value is low especially in spring when the soil is dry with a fine structure and not well protected by field crops. On those places where the actual wind velocity exceeds the threshold value, wind erosion can cause serious on-site and off-site damage. However, not much is known yet about these economic losses and about the effectiveness and benefits of erosion control measures.

Within the research project Wind Erosion on European Light Soils (WEELS) that started in early 1998 we undertook an economic analysis of alternative climate and land-use scenarios, and looked at policy measures in four representative sites (see Figure 2.1), located in England, Sweden, Germany and The Netherlands where serious wind erosion problems occur. Partners in this EU funded project are University College London (England), Lund University (Sweden), Wageningen University (The Netherlands) and the Institute of Soil Technology (Bremen, Germany).

The occurrence of wind erosion in north western Europe, the erosion process and the assessment of on-site and off-site effects are discussed, followed by an assessment of the risk and actual on-site damage in the four sites. Subsequently some attention is paid to the effectiveness of wind erosion control measures.

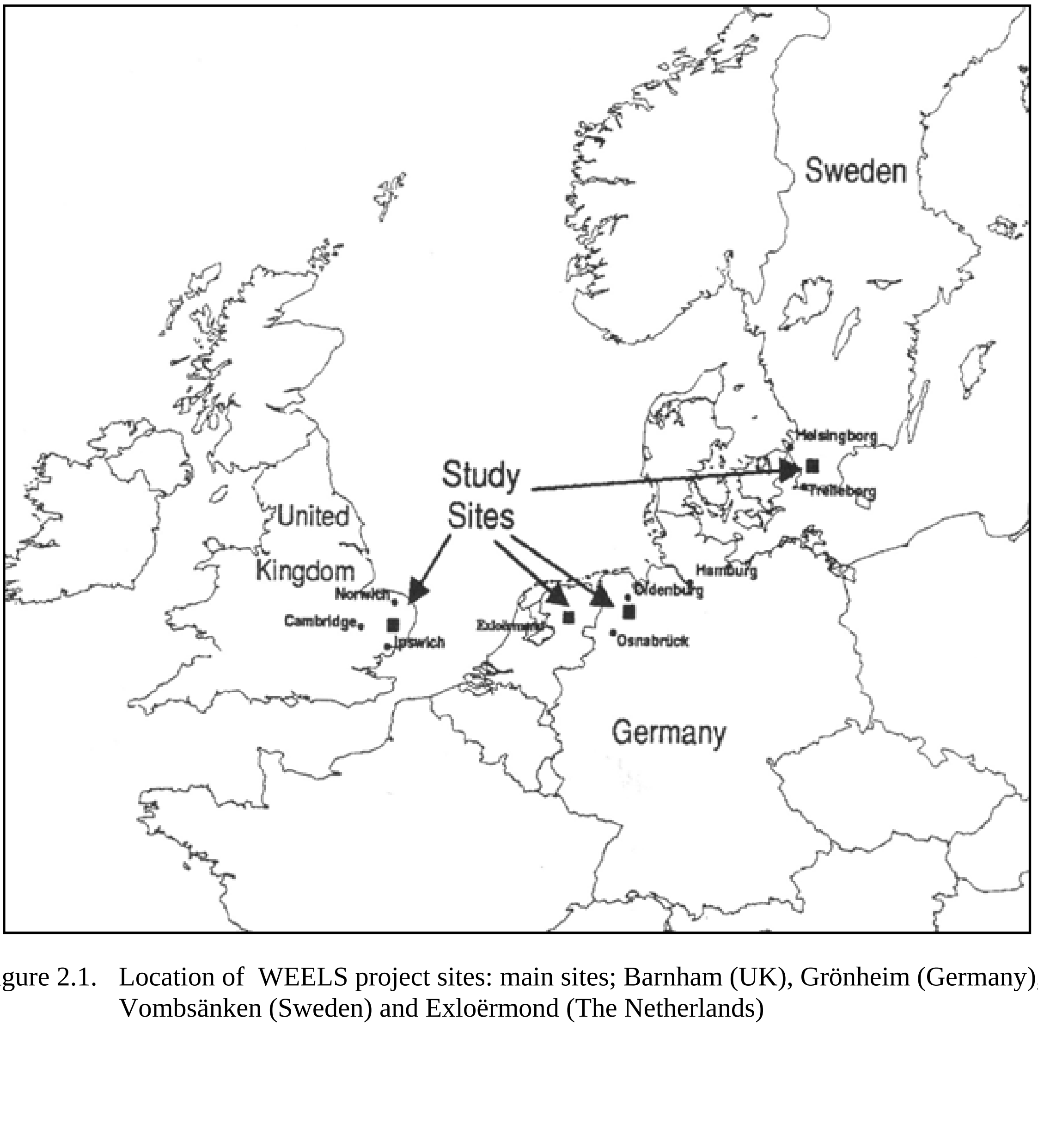


Figure 2.1. Location of WEELS project sites: main sites; Barnham (UK), Grönheim (Germany), Vombsänken (Sweden) and Exloërmond (The Netherlands)

2.2. Wind erosion in north western Europe

Sweden

In Sweden the botanist Von Linné had already recorded in 1749 many cases of erosion damage during a visit to Scania. Population growth in the 18th century forced new lands to be cultivated and led to much deforestation. In sandy soils this resulted in much wind erosion and the development of large dunes behind obstacles such as fences. Such fossil dunes can still be seen in the landscape of Scania. The situation became more severe at the end of the 18th century, but at the beginning of the 19th century large-scale planting of pine forests halted the sand drifts.

In the 1940s, the Swedish Committee on Erosion (1950) saw wind erosion again as a national problem. At that time the area affected by wind erosion was about 35,000 ha, most of which was in Scania. The increase of wind erosion was due to the mechanization of agriculture, the removal of high vegetation in combination with an increasing number of days in the spring (Jönsson, 1992). In the Vomb valley in Scania erosion continued and a second generation of dunes began to form along obstacles. On the borders between fields, sand started to accumulate. The progress of accumulation at a fence within the research site was monitored between 1975 and 1985, in which time the dune had reached a height of 0.5 m.

United Kingdom

The Breckland district in United Kingdom, with its light sandy soils, is known for its wind-erosion hazard. The district covers a large part of southwest Norfolk and northwest Suffolk to an extent of about 243,000 ha. The climate in this region is more continental than elsewhere in Britain, with low rainfall, hot summers and cold winters. The erosion not only affects the farmers, but it can also cause serious off-site damage, especially during the spring.

Wind erosion started after woodland clearances by Neolithic farmers around 3,000 BC, when a lack of tree regeneration on the thin soils resulted the formation of heathland. The extensive open heaths supported huge numbers of sheep and rabbits. In time, the overgrazed heaths were denuded of vegetation resulting in widespread soil erosion, mobile sand dunes and ferocious sand blows. John Evelyn, who visited Euston Hall in 1667, wrote: 'The soil is dry, barren and sandy, which flies in drifts as the wind sits' and 'in which nothing will grow kindly'. The name 'Breckland' was only coined in 1894, with 'Breck' meaning the breaking up of a tract of heathland for cultivation. After a few years of farming this land the soil became too poor and a new plot of heathland was broken up for cultivation and the old parcel was left and regenerated into heathland again (Rush, N., 1998, unpublished). The General Enclosure Act of 1801 started the process of planting windbreaks or shelterbelts, mainly of Scots pine (Rush, N., 1998, unpublished). The Forestry Commission started in 1922 with the reforestation of large areas, also mainly with Scots pine. This all helped to stabilize the thin soils. Much replanting nowadays is with Corsican pine.

Germany

In Lower Saxony in North Germany the increase of the population at the end of the 18th century led to the intensive use of heathland. The burning and cutting and overgrazing by sheep on the heath turned parts of the heathland into blowing sands and sand dunes were formed. Arable farming at that time did not contribute much to wind erosion due to the small field size and the use of high amounts of organic manure (Schwerdtfeger and Schröder, 1976). In the second half of the 19th century the import of cheap wool and the introduction of fertilizers led to a change in land use. Large areas of heathland on poor sandy soils were forested while other parts were turned into intensive arable farmland. A good balance was kept between arable fields and woodland or shelterbelts. Since the 1930s this balance bas been disturbed by the large-scale cultivation of the poor sandy soils and the loss of a considerable part of the groves and hedges. This and the change in cropping from mainly rye to rotations with sugar beet and vegetables caused an increase of wind erosion. After 1945 the need for construction and fuelwood amplified the wind-erosion risk. In the period from 1947 to 1951 wind erosion caused severe crop damage over large areas (Richter, 1965). With the increase of the area under permanent pasture and the planting of new windbreaks in the past 50 years the extent of damage has decreased. Wind erosion is nowadays mainly a problem on large arable fields with crops like sugar beet, potato and maize.

The Netherlands

In the Peat Rec1amation District (Veenkoloniën) in the northeast of The Netherlands, people had already started to reclaim peat on a small scale in the 12th and 13th centuries to satisfy local fuel needs. Systematic exploitation started in the 17th century, when canals were dug to transport the peat and to drain excess water. The remaining peat was covered with the sand from the canals to make the soil suitable for agriculture. Every year small amounts of peat were ploughed through the sandy upper layer to ensure a stable organic matter content. To make the land more fertile, waste from the town of Groningen and animal dung were brought onto the land. These soils had (and in same areas still have) a high content of organic material. The introduction of fertilizers in about 1880 made it easier to turn the cut-over peat soils into profitable agricultural land, but the reduced amount of humus destabilized the soil structure. The organic material therefore contributes little to the forming of stable soil aggregates. These sandy reclaimed cut-over peat soils, being originally aeolian deposits, are very susceptible to wind erosion.

With the establishment of the potato industry in 1840, this became the main crop, followed by sugar beet and wheat. In the last decades the watertable bas been lowered and many canals have been filled to enlarge the fields.

The large fields, the open landscape and the light sandy soil, make the area very susceptible to wind erosion. Present measures to reduce erosion risk are mainly the use of cover crops in spring and spraying the soil with a thin layer of liquid manure.

The four areas have in common intensive deforestation, overgrazing and intensive cultivation that have led in the past to enormous wind erosion. Heath cultivation, afforestation of poor sandy soils, the planting of hedges and other measures to cover the soil have partially diminished the hazard, but large-scale arable farming aggravate the problem. The main erosive factors are:

- the increase of wind force relative to larger open fields and the removal of windbreaking vegetation (Jönsson, 1992);
- increasing erodibility of the soils due to use of heavier machines and chemicals rather than organic fertilizers; and
- cropping changes, such as the increase in the area under sugar beet (Morgan and Rickson, 1990).

2.3. Wind erosion process and assessment of erosion effects

2.3.1 Wind erosion process

When the wind reaches a critical speed (threshold friction velocity) soil particles can start rolling along the surface (creep) and if it gathers enough speed, they will start bouncing off the ground (saltation). A third possible way of particle transport is suspension. Small particles (<100 μm) are lifted into the air and are transported over great distances (Lyles, 1977).

According to Livingstone and Warren (1996) the occurrence of wind erosion can be described as a function of wind energy and time over which it is manifest (erosivity) and the degree to which the surface is susceptible to erosion (erodibility). Erosivity and erodibility together can be expressed in erosion hours and intensity. Once erosion events are known, their effects can be assessed.

2.3.2 Assessment of wind erosion effects

Most erosion damage occurs while the soil is bare and until it has a vegetation cover of at least 30 per cent. The assessment needs are as follows:

(1) Identification of fields with *high potential wind-erosion risk* based on:
  (a) intrinsic soil properties or soil erodibility;
  (b) lack of permanent vegetation cover; and
  (c) lack of wind shelter.
(2) Assessment of *actual wind erosion risk* based on:
  (a) crop rotation, land preparation and erosion control measures; and
  (b) computing erosion hours with computer model.
(3) Assessment of *actual on-site and off-site effects:*
  (a) compare computed erosion hours with field data on actual damage; and
  (b) estimate total cost of wind erosion damage in an area.

2.3.3. On-site and off-site effects of wind erosion

Table 2.1. shows the most common physieal and economic effects. Mechanical action can eause blistering of seedlings and plants, removal of seed or seedlings and burying of seedlings and plants. Blistered and buried plants can either die, due to plant injury or drying out, or will have backward growth and hence a lower production. Seed and seedlings blown away will also reduce production. The storage capacity of plant-available water can be reduced. Furthennore, loss of plant nutrients, organic matter and degradation of soil structure will reduce the soil productivity. Pathogens (e.g. nematodes) and agro-chemicals can be moved by the sand and deposited elsewhere (Orr and Newton, 1971; Pimentel *et al.*, 1995).

Deposition of the transported material can clog up drainage channels, and carries agricultural chemicals into the air. Drifting sand can bury cultivated land and decrease soil fertility. In greenhouse areas dust on the glass surfaces may limit light incidence which reduces plant growth.

Finally, dust can hinder traffic, obstruct respiration and cause other health problems (Chardon, 1999), affect houses and other buildings and increase the need for cleaning (Huszar and Piper, 1986).

Table 2.1. A selection of physical and economic effects of wind erosion

Location of effects	*Physical effects*	*Economic effects*
On-site		
- on the soil	Fine soil and organic material blown away	Decrease of soil fertility and production
	Degradation soil structure	Costs of additional labour for tillage, etc.
	Loss of fertilisers, pesticides	Replacement costs of agro chemicals
- on the crop	Loss of seeds and plants	Replacement costs of plants and seeds
	Damage of stem and leaf	Loss of production
- use of equipment	Damage to machinery	Increased cost of repair and maintenance
	Postponement of operations	Lack of timeliness and loss of production
Off-site		
- adjacent sites	Sedimentation in ditches, hedges and on roads	Costs of labour for cleaning
- at a distance	Eutrophication/damage to nature reserves etc.	Costs of liming, etc.
	Dust in residential areas	Opportunity costs of cleaning
	Dust in machinery	Costs of maintenance and repair

2.4. On-site damage in the selected sites

The four selected sites have a light sandy soil type. Table 2.2 shows the land-use distribution. The Dutch site has the lowest area under forest and pasture, large arable fields, a uniform crop rotation and few obstacles and therefore the highest potential erosion risk.

In a landscape with shelterbelts and wood stands, as in the Gennan site, wind erosion is mainly on-site. Under extreme circumstances, as in Schleswig-Holstein in 1991, wind erosion resulted in so-called black rains. On approximately 50 per cent of the agriculturalland in Lower Saxony, erosion risk is classified as high. About 9 per cent of the total area, 420,000 ha, in 1991 was cultivated with erosion-sensitive crops (Klaasse and de Raadt, 1999).

Table 2.3. shows in which months the most common crops provide a good soil cover in the Dutch site. The bold letters **O** (open land) and **N** (not enough protection) indicates the months with no or little protection by the erop. Since heavy storms most often occur in spring and autumn, most crops provide little protection against wind erosion, except for winter grains and oilseed rape. These latter crops have low gross margins, however. Most sensitive to wind erosion are crops like sugar beet and potatoes that need a relatively long period to reach a 30 per cent vegetation cover. These, however, are the crops with the highest gross margin. Less sensitive to wind erosion are fast-growing crops like maize, spring-sown cereals and peas that reach a 30 per cent cover in a relatively short period.

A crop rotation *potato - sugar beet- potato - cereal*, which is common in the Dutch site (Table 2.3.), is very vulnerable to wind erosion because of the long periods during which the field is without a proper vegetation cover. In the English and the Swedish sites sugar beet, potato and carrots are the most sensitive crops. In the last two sites we found big variations in crop rotation between farms and also between the fields

Table 2.2. Land use and potential wind erosion risk (% of total area) in selected sites (1999)

Site	*Forest*	*Permanent Pasture*	*Arable land*	*Other use*	*Arable land with high potential wind erosion risk*
Vombsänken, Scania (Sweden)	10	28	46	16	23[2]
Barnham, Brecklands (UK)	15	5	72	8	35
Grönheim, Lower Saxony (Ger)	15	9	70	6	19[1]
Exloermond, Veenkoloniën (NL)	0	5	85	10	60[2]

[1]) Source: Klaasse and de Raadt, 1999.
[2]) Rough estimation because not all the farmers in these sites were interviewed

Table 2.3. Soil cover and gross margins of different crops on sandy soils in The Netherlands (1997)

Month / ***Crop***	J	F	M	A	M	J	J	A	S	O	N	D	Gross margin[1] (€.ha^{-1})
Sugar beet	**O**	**O**	**O**p	**O**s	**N**	c	c	c	c	ch	ch	**O**	2177
Potato	**O**	**O**	**O**p	**O**s	**N**	c	c	c	ch	**O**p	**O**	**O**	1661[2]
Winter rye	c	c	c	C	c	c	c	c	**O**p	**O**s**N**	c	c	739
Winter barley	c	c	c	C	c	c	ch	**O**p	**O**s	**ON**	c	c	783
Winter wheat	c	c	c	C	c	c	c	ch	**O**p	**O**	**N**	c	961
Oat	**O**	**O**p	**O**s**N**	C	c	c	c	ch	**O**p	**O**	**O**	**O**	823
Spring barley	**O**	**O**p	**O**s**N**	C	c	c	c	ch	**O**p	**O**	**O**	**O**	942
Spring wheat	**O**	**O**p	**O**s**N**	C	c	c	c	ch	**O**p	**O**	**O**	**O**	840
Peas	**O**	**O**p	**N**	C	c	c	c	ch	**O**p	**O**	**O**	**O**	779
Maize	**O**	**O**	**O**	**O**p	**O**s**N**	c	c	c	ch	**O**p	**O**	**O**	978
Oil seed rape	-	-	-	-	-	-	-h	**O**s**N**	-	-	-	-	942

1) Gross margin is gross value minus product bounded costs without labor costs. 2) Average price potatoes.
O = open land: no crop nor soil cover; **p** = soil preparation; **s** = seed bed preparation, sowing/planting;
N = crop on field but not yet enough protection against wind erosion; c = crop on field, h = harvest period,
(Source: Praktijkonderzoek voor de akkerbouw en de vollegrondsgroenteteelt. Kwantitatieve informatie 1997/1998).

within one farm. In a crop rotation with sugar beet, the crop after sugar beet is almost always a cereal or 'set-aside'. For example, in the Barnham site the percentage distribution of the crop following sugar beet was: 63 per cent winter cereal, 24 per cent spring cereal, 9 per cent set-aside and 3 per cent sugar beet, carrots or parsnips. In the German site, where no sugar beet is cultivated, maize and peas are the most sensitive, especially maize because it is sown relatively late, around the end of April beginning of May (Table 2.4.).

When land preparation takes place just before sowing, the stubble or residues of the former crop can protect the soil just enough to avoid wind erosion. Ploughing of these sandy soils before the winter will result in a loss of soil structure.

Table 2.4. Percentage distribution of arable cropping in the sites (1996 – 1998)

Crop / ***Site***	Potato	Sugar beet	Spring cereals	Winter cereals	Maize	Oilseed rape	Carrots parsnips onions	Pasture, Gr. fallow Set-aside	Pasture for pigs	Other
Vombsänken (S)[1)]	13	9	30	27	0	0	0	16	0	5
Barnham (UK)	3	21	4	41	0	4	6	6	7	8
Grönheim (GER)	1	0	19	44	23	0	0	9	0	4
Exloermond (NL)	46	24	12	12	0	0	0	6	0	0

1) Average land use in the period 1997 - 1999
Source: WEELS survey 1998 – 1999

Table 2.5. Production losses due to wind erosion on two farms in Barnham (UK)

Year	*Fields affected*	*Area (ha) affected*	*% Land affected*	*Production losses (%)*	*Details of losses*
Farm A (with 501 ha in the site)					
1985	1	11	2	1	Spring barley lost
1986	1	16	3	1	Spring barley lost
1987	2	28	6	2	Spring barley lost/resow sugar b.
1988	3	39	8	2	Resow sugar beet/ barley lost
1989	2	31	6	1	Oils. Rape lost/resow sugar beet
1990	3	53	11	2	Resow sugar beet/oils. Rape lost
Average	*2.0*	*30*	*6*	*1.5*	
Farm B (with 275 ha in the site)					
1992	1	22	8	4	Loss sugar beet prod.
1993	0	0	0	0	
1994	2	23	8	5	Loss sugar beet prod.
1995	1	22	8	4	Loss sugar beet prod.
1996	1	14	5	not known	Winter barley affected but recovered
1997	2	24	9	1	Resow. Sugarbeet 2x
Average	*1.2*	*18*	*8*	*About 2*	

Source: WEELS survey in 1999.

The Sugar Beet Research and Education Committee in England (Jaggard, 1995) advises shallow cultivation in the autumn after a cereal crop and to use tined cultivation in spring to keep a mulch of straw and soil on the surface to prevent wind erosion. However, the timing of soil preparation depends on the availability of labour and equipment. Many farmers used to plough in autumn, nowadays most farmers plough in spring, a few weeks before sowing. In the Swedish site some farmers still plough in the autumn because of labour availability.

Effects and damage

In the German, English and Swedish sites loss of topsoil is in general not seen as an extra cost in terms of loss of soil fertility: farmers are more concerned about the blistering effect on the crop and the blowing away of seed or seedlings. In the Dutch and Swedish sites filling ditches was also mentioned. In the Dutch site, in which organic matter content is much higher, loss of this fine organic material is seen as a real problem. Most farmers remember events that had caused serious damage to their crops or when a significant amount of topsoil was blown away. However, only few farmers were able to indicate when, where and how much damage they had. One farmer could give a rough estimate of the total average annual loss on his farm (1,400 ha) of €14,175 or about €10 per ha.

Table 2.5. shows the information on land affected and production losses for two farms with fields in the Barnham site. With 776 ha these two farms together cover about 30 per cent of the total site of 5 x 5 km or 2,500 ha. On average 7 per cent of their land is annually affected by wind erosion, and this led to a loss of about 2 per cent of the total production value of these two farms. Sugar beet fields were the most affected followed by barley fields.

In the past wind erosion caused serious damage nearly every year, but over the last 15 years farmers have adopted new practices. Some avoid risk and always take measures on fields with a high erosion risk. Others only take measures when, and only on those places where, they consider the risk to be high (for example after a long, dry spell).

Using the farmers' information, three general damage classes and their recurrence on a farm level could be distinguished for fields with a high erosion risk without conservation measures. The period before early 1980 is taken as the 'without case'. The frequency of events and associated damage for individual fields can be characterized as follows (see also Table 2.6.):

- *At least every year:* little wind erosion damage; damage less than 5 per cent of the affected fields; no re-sowing.
- *At least every other year:* moderate to serious crop damage; resowing necessary or loss of crop up to 40 per cent of the total crop.
- *At least once in five years:* wind erosion with serious crop damage; more than 40 per cent resowing and/or loss of the crop.

On field level the recurrence depends on the erop. Most damage occurs in sugar beet, carrots, parsnips, spring unions, oilseed rape and spring barley. Table 2.6. gives the costs caused by wind erosion for the most common crops in the Bamham site in the situation without conservation measures. It shows that the yearly damage is very modest, but that the damage that occurs once in five or seven years can be quite high for sugar beet and oilseed rape. In the case of spring barley farmers often do not resow the parts of the fields that are damaged.

2.5. Wind-erosion control measures

2.5.1. Measures

The most common conservation techniques in present farming systems are: cover crops in sugar beet and potato, minimum tillage (planting in the stubble), furrow pressing, spreading manure on top of the soil and adjusting the crop rotation to limit the period in which the field is without vegetation cover. Some of these measures are generally applied in all crops, for example furrow pressing, while others are only applied in specific crops. If a measure is expensive, it is only used in high-value erops and if its effects are proven.

Farmers in the Barnham site who used cover crops in sugar beet stated that the extent of wind erosion with moderate damage has declined from once every one or two years to less than once every three or four years. Severe damage used to occur once every four years and is now less than once in ten years.

Table 2.6. Type of damage and variable costs per ha for high-risk fields in the Barnham site (without measures)

Crop	*Frequency*	*Extent of damage Loss (%)*	*Consequences*	*Variable cost (€.ha^{-1})*[1)]
Sugar beet	Every year	< 5 %	Loss of production = 2 %	40
	Every other year	5 - 40 %	Re-sow 20 %, of which 5 t lost	172[2)]
	Once in 5 years	> 40 %	Re-sow 60 %, of which 5 t lost	515[2)]
Winter Oilseed rape	Every year	< 5 %	Loss of production = 2 %	17
	Once in 4 years	5 - 40 %	Re-sow 20 % + corresp. prod. loss	145[3)]
	Once in 7 years	> 40 %	Re-sow 60 % + corresp. prod. loss	434[3)]
Spring Barley	Every year	< 5 %	Loss of production = 2 %	8
	Once in 5 years	5 - 40 %	Re-sow 20 % or production loss of 20 %	74
	Once in 10 years	> 40 %	Re-sow 60 % or production loss of 60 %	222
Winter Barley	Less than once in 10 years	Plants cut off, but mostly recovered	Loss of production	82[4)]

1) Based on average production level and cost prices of harvest year 1996 (M.C. Murphy, 1998).
2) Depending on time of Re-sowing between 0-260 €.ha^{-1}: When plant population is adequate, sowing during late March and early April produces the maximum yield. Sowing later will show a decline in sugar yield and the land would need to be Re-sown no later than mid-May if costs of additional seed, and perhaps herbicides and pesticides, are to be recovered (Jaggard, 1979).
3) As maximum loss of production is taken here: the difference in crop production of winter sown oilseed rape and spring sown oilseed rape based on figures from Euston farms harvest year 1998.
4) As maximum loss of production is taken here: the difference in crop production of winter barley and spring barley.

Table 2.7. shows the effect of conservation measures on the damage-return period, based on the interviews with the farmers. It was difficult for farmers to give straight answers and the table therefore only presents approximate figures on losses and on return periods; further research is needed.

Table 2.7. Effect of conservation measures on damage return period in the Barnham site

Crop	*Damage*	*Return period*	
		Without conservation	*With conservation*
Sugar beet	Loss of < 5%	Once every year	Once every 2 years
	Loss of 5 – 40% [seed(lings)]	Once every 2 years	Once every 4 years
	Loss of > 40%	Once every 5 years	Once every 10 + years
Winter sown Oilseed rape	Loss of < 5%	Once every year	Once every 2 years
	Loss of 5 – 40% [plants]	Once every 4 years	Once every 7 years
	Loss of > 40%	Once every 7 years	Once every 10 + years
Spring Barley	Loss of < 5%	Once every year	Once every 3 years
	Loss of 5 – 40% [seedlings]	Once every 5 years	Once every 7 years
	Loss of > 40%	Once every 10 years	Once every 10 + years
Winter Barley	Cut off plants, but recover in most cases	Less than once in 10 years	Less than once in 10 yrs

Table 2.8. shows the difference in wind-erosion damage between farming with and without conservation measures. According to the farmers the 'without-case' describes the situation before the 1980s and the 'with-case' the present situation. Some of the measures are related to soil preparation techniques such as furrow pressing and have small additional costs, while other measures are more crop-related such as the use of cover crops in sugar beet.

The area of 410 ha with high erosion risk, which constitutes 16 per cent of the total area in the site, before 1980 caused an estimated average annual damage of about €25,000. After the implementation of conservation measures this was reduced to a total of about €15,000.

2.5.2. Farmers judgement about the measures

From the interviews with the farmers followed that they differ in their perception of erosion and their ideas about certain wind erosion control measures, it is therefore necessary to consider farm type, land ownership, farming style and perceived erosion risk. In Vombsänken farmers were asked to state the advantages, disadvantages and effectiveness of various wind erosion control measures (Table 2.9.; Borstlap, 1999). Furrow pressing is the only measure that is used by all farmers, and it is considered to be moderately to highly effective. Manuring is used by more than half of the farmers, and is considered as highly effective. Other measures that farmers find effective are the reduction of the field length in the prevailing wind direction, sowing in autumn, mixed cropping, shelterbelts, rubber emulsion and deeper drilling of the seed. However, all the measures incur more costs, either in the form of additional inputs or as a reduction in output.

Table 2.8. Average on-site variable costs of wind erosion (Barnham site; 1996)

A: without conservation measures

Crop	*Fields with high erosion risk[1)] in 1996 (ha)*	*Average on-site costs per ha (€.ha^{-1})*	*Average annual on-site costs total high risk area (€)*
Sugar beet	115	175	20,125
Winter sown Oilseed rape	10	113	1,130
Spring Barley	38	43	1,634
Winter Barley	247	8	1,976
Total	**410**	**61**	**24,865**
B: with conservation measures			
Sugar beet	115	98	11,259
Winter sown Oilseed rape	10	54	539
Spring Barley	38	27	1,013
Winter Barley	247	8	1,976
Total	**410**	**36**	**14,787**

1) According to the farmers

Table 2.9. Measures to control wind erosion in the Vombsänken site, Sweden

Measures to reduce wind erosivity	*Advantage*	*Disadvantage*	*Effectiveness according to farmer*	*Presently used by (% of farmers)*
Smaller fields	Reduction wind erosion	Increase input	High	14
Autumn sowing	Short bare period	Climatic conditions limit use	High	29
Plant rows on wind direction	Sheltering effect	Higher labour input	Moderate	29
Mixed cropping	Maximum field coverage, two crops	Difficulties harvest, competition in crop	High	29
Shelterbelts	Very low erosion risk, positive effects on soil properties	Increased input, reduction yield	High	14
Measures to reduce soil erodibility				
Minimum tillage	Improves soil structure	Increased use chemicals	Moderate/high	14
Manure	Improves soil fertility and structure	Extra input	High	57
Rubber emulsion	Works for a long period	High costs	High	0
Watering soil	Can be used during wind erosion event	High water use	Low	0
Furrow pressing	Compacted topsoil	Sometimes extra work movement	Moderate/high	100
Measures to reduce damage				
Change land use	Reduction sensitive fields	Reduction benefits	Moderate	14
Drilling seed deeper	Seeds are not blown away	Reduced production?	High	14

Source: Borstlap, 1999

2.6. Conclusions

In intensively cultivated areas with light soils in Europe, wind erosion can have important on-site and off-site effects. The actual occurrence of wind erosion damage highly depends on: landscape and landuse. Measures to reduce erodibility of a field or reduce the vulnerable period can minimize the occurrence of damage considerably.

Most on-site damage occurs in crops such as sugar beet, oilseed rape, potatoes and maize. Therefore erosion risk is high if a substantial part of an area is grown with these crops. The damage consists mainly of crop losses and additional inputs, in the case of resowing. For sugar beet and oilseed rape the costs can be once in five years as much as €500 per ha. Farmers are generally well aware of the erosion risk. Depending on the contribution of a crop to the net farm income farmers apply certain control measures. With these measures the average annual costs of wind erosion can be reduced considerably. Most measures are taken at cropping level.

Measures such as planting shelterbelts or reducing field size are applied only in profitable cases and where shelter is very beneficial, for example near buildings. For future landscape management, land-use planning and the planning of measures it is essential to quantify the erosion risk more precisely at farm level and for regions. As in Table 2.10, this will show under which conditions what type of measures would be most suitable for the farmer and the community.

Table 2.10. Strategy for planning wind erosion control measures

Level	**Selection criteria**	**Scores on criteria**							
	Soil	*Highly Erodibile soils*							
Land-scape	*Land use*	*Forest*	*Pasture*	*Arable land*					
	Open wind blow			*Short (Small fields, wind barriers)*		*Long (open area, large fields)*			
Field	*Crop rotation*[1)]	-	-	Short	Long	Short		Long	
	Erosion risk:	No	No	Very low	Low	Medium		High	
	Off-site risk:	No	No	Very low	Low	No	Medium	No	High
	Measures preferred:	None	None	None	None	Simple	Simple or crop specific	Crop specific	Wind barriers

1) period without vegetation

Chapter 3

OFF-SITE EFFECTS OF WIND EROSION ON AGRICULTURAL LAND IN NORTHWESTERN EUROPE

M.J.P.M. Riksen

Published in: *Wind Erosion and Dust Dynamics: Observations, Simulations, Modelling* (Eds. D. Goossens and M.J.P.M. Riksen). ESW, Wageningen University, Wageningen, 103-121, (2004).

In: Wind Born(e)Landscapes
(M.J.P.M. Riksen) Wageningen, 2006, pp. 33 -49.

3. Off-site effects of wind erosion on agricultural land in northwestern Europe

Michel Riksen

Erosion and Soil & Water Conservation Group, Department of Environmental Sciences, Wageningen University, Nieuwe Kanaal 11, 6709 PA Wageningen, The Netherlands, Tel: +31 317- 482833, Fax: +31 317-484759, Email: Michel.Riksen@wur.nl

Abstract

In most of Europe wind erosion is not a major problem, but it can cause severe damage in some areas. The off-site effects of wind erosion are quite diverse in space and time and often difficult to quantify. Most off-site effects are related to the fine soil particles that are emitted. This paper gives an overview of the off-site effects of wind erosion and the factors that determine their extent. Most off-site damage is caused by short-term suspended material. A field study in four areas in northwestern Europe with a high wind erosion risk showed that soil and landscape characteristics determine the potential – and land use and farmers the actual – risk for off-site damage. The actual damage in the transport and deposition zone depends on landscape roughness, which determines the size of the area in which off-site effects can be observed. Characteristics such as the number of households and the vulnerability of ecosystems in this area determine the type and extent of the effects.

Keywords: wind erosion, off-site effects, dust, Europe

3.1. Introduction

Wind erosion is a serious problem in many parts of the world. It is worse in arid and semiarid regions. The areas most susceptible to wind erosion on agricultural land include much of North Africa and the Near East; parts of southern, central and eastern Asia; the Siberian Plains; Australia; northwest China; southern South America; and North America (WERU, 2004). In most of Europe wind erosion is not a major problem, but it can cause severe damage in some areas. Some of the problems, such as the creation of dust, occur mainly in the east and the south, where there is a combination of susceptible soils, dry and hot conditions, and particular cultivation practices (Gross and Bärring, 2002).

The effects of wind erosion, on-site and off-site, are quite diverse in space and time and often difficult to quantify. Most studies focus on the on-site effects, and mainly on sediment transport. Although the off-site effects are summarized in many articles, only a few large-scale studies have been carried out on this topic and on the costs of wind erosion, such as those by Huszar and Piper (1986) for New Mexico in the United States, Williams and Young (1999) for South Australia, and Riksen and de Graaff (2001) for northwestern Europe. In these studies, however, little attention is paid to the factors controlling the extent of the off-site effects. The extent of off-site effects and the related costs depend not only on on-site factors controlling wind erosion activity (and resulting in the transport of sand and dust outside the source area), but also on the characteristics of the off-site area affected.

This paper gives a review of possible off-site effects of wind erosion. Next, an analysis of the factors determining the extent of the off-site effects is presented. The study is based on a literature review and on research conducted in areas with a high wind erosion risk located in The Netherlands, England, Sweden and Germany.

3.2. Off-site effects: an overview

The effects of wind erosion on agricultural land are very diverse and show great variety in time and space. Table 3.1. provides an overview of the most common effects. In the erosional zone there is no sharp demarcation between on-site and off-site effects. Both are strongly related to the on-site conditions. On-site effects such as soil degradation caused by the removal of fine particles and organic matter will automatically result in off-site effects in the transport and deposition zones. The composition of the soil surface in the deflation zone thus forms a major factor in determining the extent and type of the off-site effects of wind erosion.

In the literature, the off-site effects are usually related to the finest particles (dust), which are transported in suspension. However, in the area adjacent to the deflation zone fine sand fractions transported in saltation can also cause serious off-site damage (see Figure 3.1.) by filling up ditches, by causing abrasion or sedimentation, which may result in crop damage, or by entering private properties and causing cleaning costs. Off-site effects thus include effects caused by particles in transport and effects caused by deposited particles. In an agricultural setting, each field from which soil particles are evacuated can be seen as a source area. Effects occurring in the source area are still considered on-site. Economically, off-site effects of wind erosion can be defined as those effects (caused by wind erosion) that affect the community.

Off-site effects are often related to the mode of transport of the particles. Three major transport modes appear in aeolian sediment transport:

- Creep (within the field)
- Saltation (short distance)
- Suspension (moderate to large distance)

There is no sharp demarcation line between these three modes of particle transport but rather a gradual transition. The largest particles (>500 µm) roll or slide over the surface without loosing contact with the latter, a process known as surface creep or

Table 3.1. Most common off-site effects of wind erosion

Off-site effect caused by	*Damage*	*Scale of the event*
Accumulation of sand and dust at the field borders or hedges	Burial of soil surface with poor sand; burial of fences; pollution by chemical residues, pathogens, weeds and plant residues	Field
Transport and accumulation in adjacent fields	Crop damage due to abrasion, burial of plants, spread of chemical residues, pathogens and weed seeds	Field
Accumulation of sand and dust in ditches and surface water	Blocking of drainage systems, contamination and increased eutrophication of surface and ground water	Local to regional
Transport and accumulation of sand and dust on roads and real estate	Car accidents due to reduced visibility; blocked roads, dirt in and around buildings	Local to regional
Penetration of dust in machinery	Increased wear of machinery	Field to regional
Penetration of dust and its constituents in lungs	Lung diseases and other respiratory problems	Regional
Absorption of airborne particulates by plants and animals	Affects plant and animal health and poisons the food chain	Regional
Deposition of dust on agricultural and industrial crops	Loss of product quality	Regional
Deposition of dust and chemical residues in nature reserves	Pollution and increased eutrophication	Regional
Change in atmospheric composition (dust load)	Affects climate	Regional to worldwide

surface traction (Pye and Tsoar, 1990). Creep is here considered an on-site process that only has an effect on on-site soil properties.

Smaller particles (between 500 and approximately 50-100 µm) are transported in saltation. Saltating particles jump and bounce over the surface, reaching a maximum height of approximately 1 m, though the main particle mass moves just above the soil surface. When saltating particles fall back to the surface they not only eject other saltation-size grains but also induce surface creep, reptation and surface deformation. They also cause the raising of dust particles, which are transported in suspension. Suspended particles are kept aloft due to the turbulent nature of the airflow. A distinction is made between short-term and long-term suspension, depending on whether the particles stay airborne for only a short time (normally a few hours) or longer (days or weeks). The transition mode between saltation and suspension is known as modified saltation. Trajectories of particles transported in this mode show similarities with typical saltation jumps but are significantly affected by turbulence. No clear particle size boundaries exist between saltation, modified saltation and suspension, although typical saltating particles are

Figure 3.1. Wind erosion patterns on agricultural land seen from the air, near Sjöbo, Scania, Sweden. The effects of the transport of fine sand are not restricted to the field where deflation took place but have clearly crossed field borders and roads. (Photo: Richard Åhman).

normally >100 µm, whereas suspended particles are usually <50 µm. The lack of clear boundaries indicates that certain particles may be moved by different transport modes, depending on particle density, wind speed and the level of turbulence in the airflow (Sterk *et al.*, 2001).

3.2.1. Off-site effects caused by particles transported in saltation

The physical impact of particles in saltation (known as abrasion or sandblasting) may result in serious damage to crops. Damage can even occur during low to moderate winds. Moreover, only short periods of exposure are needed for damage to occur (Armbrust, 1968). Abrasion damages (parts of) the crop skin, which lowers the marketability of the crop, increases the susceptibility of the plants to certain types of stress such as sunburn, increases susceptibility to diseases, and facilitates the penetration of chemicals and pathogens (Armbrust, 1968, 1972, 1984; Downes *et al.*, 1977; Skidmore, 1982; Fryrear, 1986; Grace, 1988). Various types of matter such as chemical residues, pathogens, weed seeds and plant residues originating from the eroded field can be transported with the soil particles to adjacent fields.

When saltating particles fall back to the surface they not only eject other saltation-size grains but also cause the raising of dust particles. The impact of particles is one of the major mechanisms for dust emission, as has been demonstrated by many experiments (e.g. Shao *et al.*, 1993; Rice *et al.*, 1996; Gillette and Chen, 1999).

Obstacles in the landscape such as ditches or hedges will trap most saltating particles (Figure 3.2, left) and a part of the particles transported in modified saltation, whereas most suspended material will remain unaffected. Especially the sedimentation in ditches can lead to increased maintenance cost for the drainage system, as well as to contamination of the water. Sedimentation may also block local roads or cycling paths (Figure 3.2, right).

Generally speaking, particles transported in saltation mainly cause local damage at relatively short distances from the source area. Most of this damage is on-farm. Only during severe events can significant damage be done to the local community.

The distance of transport of suspended soil particles is usually more than a few hundred metres, but can reach thousands of kilometres. The size range of the particles is normally from less than a micron to a few tens of microns at maximum.

3.2.2. Off-site effects caused by particles transported in suspension

Suspended particles leaving agricultural fields during wind erosion events normally have a grain size of below 60 µm (Goossens, 2002).

Particles in suspension can reduce the visibility, pollute the air, and be deposited in uncontaminated areas and waterways where they can affect the local habitat and water quality. They can also cause automobile accidents, settle on houses and other buildings and increase the need for cleaning, foul machinery, and imperil animal and human health (Huszar and Piper, 1986; Skidmore, 1988; Goselink *et al*., 1993; Chardon, 1999; Riksen and de Graaff, 2001; Goossens, 2002; Nordstrom and Hotta, 2004).

Figure 3.2. Local off-site effects. Left: Sedimentation of saltating particles in a ditch and dust crossing a road, Valthermont, The Netherlands (photo provided by Proefboerderij 't Kompas/ Kooijenburg PAV-NNO). Right: Remnants of sediment on a cycling path after a moderate event, Vehrensande, Germany (photo by D. Goossens).

The off-site effects caused by suspended particles can be further classified according to how long the particles stay airborne. Two transport regimes can be distinguished in this context (Goossens, 2002):

- Short-term: the particles settle rather quickly. The effects they cause only occur during the erosion event and relatively close to the source area.
- Long-term: particles smaller than 20 µm may remain suspended for a long time (days or weeks).

With respect to their significance, there are no fundamental differences between the short-term and the long-term effects. For instance, both transport regimes contribute to the spread of pollutants. Effects usually described as short-term have only a short lifetime.

3.2.2.1. Short-term effects

Effects caused by high dust concentrations
Increased atmospheric dust load can reduce visibility and hinder traffic, and even cause traffic accidents. Reduction of the visibility to less than 50 metres has been reported during severe dust storms (Knottnerus, 1985; Skidmore, 1988). Dust also causes considerable nuisance when it penetrates into buildings and machinery, or when it deposits on cars. The effects are most intense close to the source, but may become a regional problem if the entire surface of a large area of agricultural land suffers from wind erosion all at the same time, resulting in a severe dust storm. Dust storms are reported all over the world but they occur most frequently in semi-arid areas with an open landscape, such as the Middle East, northern Africa, Australia, and parts of Asia and North America (Pye, 1987). They are less frequent in Europe, though several particular regions in northwestern Europe are notorious for dust storms, such as the Peat Colonies in the northeastern (ca. 100,000 ha) and mid-southern regions (ca. 6,000 ha) of the Netherlands (Eppink and Spaan, 1989). Stach and Podsiadlowski (1998) reported an increasing need for cleaning, maintenance and replacement due to dust deposition in rural and urban areas in Poland.

Direct and indirect effects on crop production
Deposited dust can also affect the production of agricultural, horticultural and industrial crops. For example, Poesen *et al.* (1996) reported considerable damage by settling dust to floriculture in northern Flanders. Deposition of airborne dust can also cause indirect damage to crops as shown by Eppink and Spaan (1989) in the case of damage in greenhouse horticulture in Drenthe, The Netherlands. Besides the costs caused by unsaleable crops, extra costs due to the delay of harvest, cleaning, and loss of foils were reported by these authors.

Effects caused by the spread of pesticides

Most pesticides used in European agriculture have a relatively short period during which they can be harmful to the surrounding area. The risk of contamination by pesticides depends on the amount of pesticide applied, the physico-chemical characteristics of the pesticide, its mobility, and its persistency (Goselink *et al.*, 1993). Especially the mobility and persistency of the pesticide determine how much of the pesticide is available for spread by wind erosion. The mobility determines the distribution of the pesticide in the soil, whereas the persistency determines its rate of destruction. Together they determine the amount of pesticide left in the erodible surface layer over time.

3.2.2.2. Long-term effects

The dust leaving the land carries organic matter, heavy metals, pesticides, fertilizers, etc. Once they have become part of the atmospheric dust load, these substances can travel over long distances. Most transport occurs within continents or from continents to nearby oceans, but fine dust (fine silt and clay) is carried from one continent to another. The wide range in size and intensity of storms is matched by the amounts of dust they carry and deposit. Dustfall is greatest near the source and diminishes with increasing distance. Estimates of dust quantities produced by a storm vary from 500 to 1,000,000 tons for small storms and from 100 million to 150 million tons for extreme storms (Simonson, 1995). Measurements and estimates of dustfall, expressed in kg ha^{-1}, range from less than one for a single storm to a few thousand for a succession of storms. The off-site effects caused by the dust therefore depend on the distance to the source area, the intensity and frequency of dust storms, and the composition of the airborne dust.

Effects on soil properties

In a review paper, Simonson (1995) reported a variety of effects caused by the accretion of mineral dust in soils on soil development and on soils after their original formation. On sites favoured by the trapping of airborne dust, the texture of the dust dilutes the clay formed by weathering. Simonson also reports that soils in Central Africa benefit from nutrient elements carried to the south from the Sahara. When the source area consists of arable fields with a high nutrient content due to the addition of high quantities of fertilizer and/or manure, as in Europe, eutrophication of vulnerable ecosystems nearby can occur.

Spread of pollutants

In Europe the spread of pollutants from agricultural land is increasingly related to the contamination of the land by atmospheric pollutants such as heavy metals, dioxins, radionuclides, organic pollutants, xenobiotica, etc. Together with the spread of pesticides, they can form a threat to uncontaminated areas. Poesen *et al.* (1996) describe the gradual poisoning of several hundred km^2 in rural northeastern Belgium as a result of the deposition of particles emitted by the wind in heavily polluted upwind areas.

Effects on health

The health problems associated with the increasing atmospheric dust load include eye irritations, skin irritations and diseases, shortness of breath, and other respiratory disorders such as asthma (Chardon, 1999; Williams and Young, 1999; Goossens, 2002; Nordstrom and Hotta, 2004; Van Dingenen *et al*., 2004). The human respiratory tract effectively filters the particles greater than 10 µm, thus preventing them from entering the human body. The efficiency of the filtering decreases with decreasing particle size, however. As yet, there is no indication which physical or chemical PM characteristic is responsible for a specific health problem. However, recent research seems to indicate that PM10 is most associated with respiratory responses and PM2.5 with cardiovascular diseases (Van Dingenen *et al*., 2004). Epidemiological studies show that an increase in PM10 mass concentration by 10 µg m^{-3} results in an increase of 0.5-1.5% in total premature mortality in the case of short-term/episodic exposure, and in an increase of up to 5% in total premature mortality in the case of long-term/life-long exposure (Van Dingenen *et al*., 2004). Rutherford *et al*. (1999) reported a significant increase in respiratory problems immediately after an event when there was a substantial amount of agricultural dust in the air. Williams and Young (1999) defined dangerous events as periods when the concentration of PM10 particles in the air exceeds 150 µg m^{-3} during at least one hour.

3.3. Off-site effects in northwestern Europe

The overview presented above indicates that the off-site effects caused by wind erosion are very diverse. To reduce the off-site effects it is necessary to know their extent, to determine the type of damage they cause, and to identify which factors play a role in their manifestation. Two types of factors can be distinguished:

- Factors related to the source area
- Factors related to the transport zone and the deposition area

These factors will now be discussed for four wind erosion risk areas. The sites, 5 km x 5 km in size, were studied during the WEELS wind erosion project (1998 – 2001). The sites are located in the Ems-Hunte Geest area in the central western part of Lower Saxony, Germany; in the reclaimed cut-over peat soils in east Drenthe, The Netherlands; in the Breckland district of East Anglia, England; and in the Vomb valley in Scania, Sweden.

3.3.1. Factors related to the source area

Besides climate, other factors such as soil and landscape characteristics, which are more or less static, determine the potential wind erosion risk. The *actual* wind erosion risk is determined by the actual state of the fields in the area, a factor which depends mainly on the farm management.

Soil characteristics determine, besides the erodibility, also the potential amount of fine particles that can go into suspension. The silt, clay and organic matter (peat) fractions of the soil form the main source for suspension. Nickling (1994) found greater particle emission in the case of loamy textured soils. On arable land with peaty sand, or on other peaty soils with >35% organic matter, wind erosion is a very frequent (often yearly) phenomenon (Davies, 1983). After oxidation, the organic matter forms a potential source for suspension (Eppink and Spaan, 1989). In the Peat Colonies in the Netherlands, black dust storms occur almost every year. They mainly occur during spring, after many arable fields have been prepared for the main crop. Table 3.2. shows the soil characteristics in the other three research sites. The K-factor (after Neemann, 1991) characterizes the soil's erodibility and represents the strength of the binding agents within the aggregates.

Landscape characteristics such as the openness of the landscape, the presence of barriers (windbreaks), land use and relief influence the wind profile and, thus, the wind force at the soil surface. Upper winds act fairly uniformly over wide areas. Within a particular area, the average wind profile depends on the landscape roughness. This roughness is determined by the height, size, shape and arrangement of the landscape elements, such as trees, forests, houses, vegetation, ridges, surface aggregates, etc. Table 3.3. shows the role of land use in the potential wind erosion risk for the four WEELS sites.

Wind erosion becomes a more local phenomenon when the variation in land use in an area increases. Fewer fields are vulnerable at the same time, and more obstacles will limit the distance over which the eroded particles travel. In areas with many shelterbelts and wood stands, such as the German site, wind erosion is mainly an on-site problem.

Table 3.2. Soil characteristics of wind erosion risk areas in northwestern Europe

Site	*Soil textural classes (USDA)*	*Size distribution (%)*				*Organic matter (%)*	*K-factor*
		2 - 0.6 mm	*0.6 - 0.2 mm*	*0.2 - 0.06 mm*	*< 0.06 mm*		
Grönheim, Germany	Loamy sand	0.7	14.6	65.1	19.6	2.1	0.92
Barnham, England	Sand to loamy sand	1.9	29.1	53.8	14.9	2.7	0.62
Vombsänken, Sweden	Sand to loamy sand	5.1	40.9	40.9	13.9	3.8	0.34
Exloërmond, the Netherlands	Fine sand to loamy fine sand	1.4	12.6	82.8	3.2	1.8	*

Source: Warren, 2001; Stiboka, 1977; Knottnerus, 1985.
* = no data available.

Table 3.3. Land use and potential wind erosion risk (% of total site) in four areas in Northwest Europe

Site	*Forest*	*Permanent Pasture*	*Arable land*	*Other*	*Arable land with high potential wind erosion risk*
Grönheim, Germany	15	9	70	6	19 (1)
Barnham, England	15	5	72	8	35
Vombsänken, Sweden	10	28	46	16	15 – 30 (2)
Exloërmond, the Netherlands	0	5	85	10	50 – 70 (2)

(1) Source: Klaasse and de Raadt, 1999.
(2) Rough estimation, because not all the farmers on these sites were interviewed.

However, under extreme circumstances wind erosion in these areas can result in so-called "black rains", such as occurred in Schleswig-Holstein in 1991 (Text box 3.1.). Although the effect of wind erosion is relatively low at the level of the individual farm, many individual fields in a large area may be affected all at the same time, thus causing a significant rise in the concentration of dust in the atmosphere. On approximately 50% of the agricultural land in Lower Saxony, the erosion risk is classified as high. In 1991 approximately 420,000 ha, which is 9% of the total area, was cropped with erosion-sensitive crops (unpublished data provided by the Institute of Soil Technology Bremen, 1998).

“Ackerkrume in der Luft”

Minister rät Landwirten von Mais und Kartoffeln ab (31.5.88)

Hannover (eb). Die außergewöhnlich trokkene Ostwind-Wetterlage dieses Monats hat bereits zu erheblichen Winderosionen in den beackerten Geestregionen Niedersachsens geführt. Darauf hat Niedersachsens Umweltminister Dr. Werner Remmers hingewiesen. Remmers: "In den vergangenen Tagen konnten dichte Wolken der in Bewegung befindlichen Ackerkrume beobachtet werden."…….

“Wie schwarzer Regen entsteht”

Bremer Institut erforscht Bodenerosion/Mit dem Wind in die Atmosphäre
(29.04.1991)

In Schleswig-Holstein ergoß sich am 16. April schwarzer Regen aus den Wolken, die Menschen waren verunsichert……..

Text box 3.1. Wind erosion in German newspapers

Farm management concerns field size and orientation, crop type, crop rotation, tilling and conservation practices. Timing and the land preparation method can also influence the vulnerability of the soil. When land preparation takes place just before sowing, the stubble (or other residues) of the former crop may protect the soil just enough to avoid wind erosion. Ploughing of sandy soils before the winter nearly always results in a decline of the soil structure.

On the WEELS sites the wind erosion risk was highest in areas with large arable fields characterized by more or less uniform crop rotation, such as the Dutch site. The erosion risk is highest when the soil is bare (especially after tillage and seedbed preparation) and until a certain amount of vegetation cover (generally 30%) has become established. Crops that need a relatively long period to produce a 30% cover, such as sugar beets and potatoes, are most sensitive to wind erosion. Fast-growing crops that produce the 30% cover in a relatively short time, such as maize, spring-sown cereals, oilseed rape and peas, are less sensitive to wind erosion. Winter-sown crops, especially winter cereals, are hardly sensitive at all to wind erosion. The crop rotation and the moment when tillage takes place within the rotation influence the length of the period during which the soil is vulnerable to wind erosion. Table 3.4. shows the main crops grown. And Table 3.5. shows in which months crops provide good soil cover. The months during which there is little or no protection by the crop are printed in bold. The crop rotation pattern *potato - sugar beet - potato - cereal*, which is common on the Dutch site, is extremely vulnerable to wind erosion. On the English and Swedish sites, sugar beets, potatoes and carrots are the most sensitive crops. At both sites significant variations in crop rotation between farms as well as between the fields of a farm were observed. In a crop rotation system involving the sugar beet, the crop after the sugar beet is almost always a cereal or set aside (on the Barnham site, the next crop after the sugar beet was 63% winter cereal, 24% spring cereal, 9% set aside and 3% sugar beets/carrots/parsnips). On the German site, maize and peas are the most sensitive crops - especially maize because this crop is sown rather late, around the end of April or early May (see Table 3.5.).

Table 3.4. Crops grown in the WEELS sites in 1996-1998 (% of arable land) Source: WEELS survey 1998-1999

Site	*Crop*									
	Potato	Sugar beet	Spring cereals	Winter cereals	Maize	Pasture, green fallow, set aside	Oilseed rape	Carrots, parsnips, onions	Temporary pasture for Pigs	Other
Exloërmond (NL)	46	24	12	12	0	6	0	0	0	0
Barnham (UK)	3	21	4	41	0	6	4	6	7	8
Vombsänken (S)[(1)]	13	9	30	27	0	16	0	0	0	5
Grönheim (GER)	1	0	19	44	23	9	0	0	0	4

[(1)]Average land use in the period 1997-1999

Table 3.5. Soil cover by a number of different crops on sandy soils in northwestern Europe

Crop	*Month*											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sugar beet	**O**	**O**	**Op**	**Os**	**N**	X	X	X	X	Xh	Xh	**O**
Potato	**O**	**O**	**Op**	**Os**	**N**	X	X	X	Xh	**Op**	**O**	**O**
Winter rye	X	X	X	X	X	X	X	X	**Op**	**OsN**	X	X
Winter barley	X	X	X	X	X	X	Xh	**Op**	**Os**	**ON**	X	X
Winter wheat	X	X	X	X	X	X	X	Xh	**Op**	**O**	**N**	X
Oat	**O**	**Op**	**OsN**	X	X	X	X	Xh	**Op**	**O**	**O**	**O**
Spring barley	**O**	**Op**	**OsN**	X	X	X	X	Xh	**Op**	**O**	**O**	**O**
Spring wheat	**O**	**Op**	**OsN**	X	X	X	X	Xh	**Op**	**O**	**O**	**O**
Peas	**O**	**Op**	**N**	X	X	X	X	Xh	**Op**	**O**	**O**	**O**
Maize	**O**	**O**	**O**	**Op**	**OsN**	X	X	X	Xh	**Op**	**O**	**O**
Winter oil seed rape	X	X	X	X	X	X	Xh	**OsN**	X	X	X	X

O = no crop on the field, no soil cover; **p** = soil preparation; **s** = seed bed preparation, sowing/planting; X = crop on the field; h = harvest period; **N** = crop on the field but provides no protection against wind erosion. (After Riksen and de Graaff, 2001)

Timing and the land preparation method. As noted earlier, the ploughing of sandy soils before the winter negatively affects the soil structure. The Sugar Beet Research and Education Committee in England (Jaggard, 1995) therefore advises to create a more stable seedbed surface by using a plough and furrow press in late winter or early spring, when the soil is moist. As an alternative they suggest to leave the stubble during the winter and use only a tined cultivation with a flat-lift type cultivator to remove any ruts and pans. In spring, straw is then shallowly incorporated with a powered harrow to keep a protective mulch of straw on the surface. The seeds are directly drilled into this mulch. In the latter case it is necessary to use herbicides to kill the weeds. In practice a variety of techniques is used, such as direct drilling and strip tillage. However, the timing of soil preparation also depends on the availability of labour and equipment. In the past, farmers used to plough in autumn; nowadays most farmers plough in spring, a few weeks before sowing. On the Swedish site some farmers still plough in autumn because of labour availability.

3.3.2. Factors related to the transport and deposition area

The distance over which an airborne particle can travel is affected by the landscape characteristics, as described above. Saltating particles settle within a short distance of the source, ranging from a few metres to a few tens of metres, depending on the surface conditions. They can also be trapped by obstacles such as vegetated field borders, open water or ditches. Most short-term suspended material will also settle relatively close to the source, normally within a few hundred metres. For the finest particles, which are transported in long-term suspension, the deposition pattern is more influenced by the type of wind and the presence of (large) obstacles.

Data from two surveys, in Exloërmond (the Netherlands) and Grönheim (Germany), showed that the social and economic impacts of wind erosion differ for these two regions. In the Netherlands wind erosion significantly affects the farmer's practice (on-site costs), and there is also much off-site damage. On the German site, according to the farmers and other actors interviewed, the impact of wind erosion is limited. Most houses and roads on the German site are protected by windbreaks.

The damage off-site effects cause is also affected by the human activities in the affected area. In 1985, for example, the Extension Service at Assen, Drenthe (The Netherlands) estimated the damage airborne dust caused to greenhouse horticulture at more than € 22,000. This sum includes the costs caused by the loss of foils, extra heating costs, cleaning costs, costs due to unsaleable products, and costs caused by the delay of the harvest.

3.3.3. Magnitude of off-site damage

The magnitude of off-site damage depends on many factors, the most important of which are the availability of erodible fine material and the capability of the wind to transport it to locations where it could cause damage. The first factor mainly depends on the field conditions in the source area, which may be influenced by farm management. The second factor is strongly related to the roughness and the degree of openness of the landscape. An illustration is given in Table 3.6. The average production of dust during an event is relatively low in the German site compared to the Dutch site because the latter area has more unprotected arable land. At the same time, much of the short-term suspended dust on the German site is unable to travel over large distances due to the many windbreaks, whereas on the Dutch site there are hardly any windbreaks. As a consequence, only a few people on the German site suffer from off-site damage and wind erosion is not really seen as a problem. In the Dutch case most people living on the site regular notice wind erosion. Nearly 50% of the persons interviewed saw wind erosion as a problem. People who have spent their whole lifetime in the region, however, generally do not see wind erosion as a problem because they have become too accustomed to the phenomenon.

Table 3.6. Comparison of two sites with high wind erosion risk

Cloppenburg, Germany	*Exloërmond, The Netherlands*
1. Landscape	
Gently undulating, rarely hilly, large variation in land use and in field size and shape, many shelterbelts along roads and around (farm) houses	Very open and flat, uniform land use and field layout (former fen community)
2. Farm types	
Most farmers are livestock breeders (porkers, pigs, poultry, bulls and some dairy cattle). Arable land is mainly used for fodder crops.	Most farmers cultivate arable (contract) crops, producing them for the sugar beet and potato industries. Many of them also have other activities, such as poultry breeding.
3. Land use	
72% Arable land	90% Arable land
9% Pasture	5% Pasture
12% Forest	0% Forest
2% Peat land	5% Other use
5% Other use	
4. Arable land	
>50% cereals (mostly winter cereals)	50% potato
15 – 40 % maize	25% sugar beet
5 – 30 % other crops	25% cereals
5. Wind erosion	
All farmers are familiar with wind erosion but none of them see it as a problem. Only a few farmers report damage.	The arable farmers all have extra costs related to wind erosion damage and/or prevention. Most damage occurs during spring. Almost every year there are 2 or 3 days with dust storms.
Most damage in maize and rye	Most damage in sugar beets, less in potato
6. Off-site damage	
38 % of the persons interviewed are familiar with wind erosion, but off-site damage is negligible. Wind erosion is not seen as a problem.	86% of the persons interviewed are familiar with wind erosion, and 13% experience damage. 50% see wind erosion as a problem.

3.4. Conclusions

The extent of wind erosion-induced off-site damage is relatively small in the northwest European countries, especially when it is compared to the damage caused by the large-scale dust storms that occur in other parts of the world, such as in Northern Africa (Figure 3.3), Southeast Asia (Text box 3.2) and North America (see example http://www.weru.ksu.edu/new_weru/multimedia/multimedia.html). In the northwest European regions with a high wind erosion risk, the extent of the

Figure 3.3. Dust storm in Senegal

Asia's dust storm misery mounts (http://news.bbc.co.uk/1/hi/sci/tech/3585223.stm)

By Alex Kirby, Wednesday, 31 March, 2004, 11:31 GMT 12:31 UK

BBC News Online environment correspondent in Jeju, Korea

Scientists say they believe the dust and sand storms that for centuries have blanketed north-east Asia are becoming more dangerous to people's health.

They think the storms are now combining with airborne pollutants emitted by human activities, and are adding to the region's severe air quality problems.

Similar dust storms from the Sahara have been blamed for spreading illness and destroying Caribbean coral reefs.

The concern has been raised with the United Nations Environment Programme.

Text box 3.2. Asia's dust storms in the BBC News, 31 March 2004 off-site damage is very diverse. Realistic estimates of the off-site damage and its related costs are difficult to make due to:

- the diversity of the on-site and off-site factors and their interaction;
- variations in the extent and intensity of wind erosion events over the years;
- the lack of a complete picture of off-site damage caused by wind erosion events. The damage reported is often related to only a few causes (and sometimes even a single cause), for example, traffic.

To better understand the off-site damage, those effects that have the highest impact on society (in economic, ecological and sociological terms) should first be identified. Next, the extent and the related social, economic and ecological consequences of these effects should be studied.

A risk assessment for off-site damage in a region can also be based on:

- Soil characteristics: percentage of areas with highly erodible soils, characteristics of the material transported.
- Landscape characteristics: openness of the landscape, land-use, percentage of the area where the near-surface winds are high, potential size of the area where off-site effects can be expected.
- Farm practices: field size, crop types, crop rotation, tilling and conservation practices, use of fertilizers and pesticides in the period when the land is not properly protected against wind erosion. From this information the percentage of land not properly protected during the periods of high wind speed can be calculated.
- Population density, number of households in the area under risk, distance to the source, protection by obstacles. This information allows one to estimate the potential risk for cleaning and health problems.Other economic activities sensitive to sediment transport and/or sediment deposition.
- Ecologically valuable objects that are sensitive to sedimentation, to eutrophication, and/or to pesticides.

Chapter 4

IMPACT OF LAND USE AND CLIMATE CHANGE ON WIND EROSION:

Prediction of wind erosion activity for various land use and climate scenarios using the WEELS wind erosion model

J. Böhner, J. Gross and M.J.P.M. Riksen

Published in: *Wind Erosion and Dust Dynamics: Observations, Simulations, Modelling* (Eds. D. Goossens and M.J.P.M. Riksen). ESW, Wageningen University, Wageningen, 103-121, (2004).

In: Wind Born(e)Landscapes
(M.J.P.M. Riksen) Wageningen, 2006, pp. 51 -73.

4. Impact of land use and climate change on wind erosion:

Prediction of wind erosion activity for various land use and climate scenarios using the WEELS wind erosion model

Jurgen Böhner[1], Jens Gross[2] and Michel Riksen[3]

[1]*Department of Geography, Georg-August University of Göttingen, Goldschmidt Str. 5, D-37077 Göttingen, Germany*

[2]*Physical Geography and Landscape Ecology Section, Institute of Geography, University of Hannover, Schneiderberg 50, D-30167 Hannover, Germany*

[3]*Erosion and Soil and Water Conservation Group, Wageningen University, Nieuwe Kanaal 11, NL-6709 PA Wageningen, The Netherlands*

Abstract

Because wind erosion forms a serious degradation process in the agricultural land ecosystems of the North European Quaternary Plains, an evaluation of current and potential future trends is needed to safeguard sustainable land-use practices and management strategies for the future. A sensitivity analysis using the WEELS model to simulate wind erosion was performed for two alternative climate, two windbreak and three land use scenarios separately. The results give spatially extended information on increase and decrease of the erosion risk per month, expressed in terms of projected erosion duration and maximum "Bagnold" sediment transport rates. By combining this information with information on farming practices and actual wind erosion damage for the scenario which represents the actual land use, it is possible to determine for each other scenario if and when additional wind erosion control measures and/or policy measures are desired.

Keywords: wind erosion model, climate changes, land use policies

4.1. Introduction

Although the actual wind erosion risk is relatively low on the European continent, the area under potential wind erosion risk is considerable, involving almost 4 million ha of land (Riksen and de Graaff, 2001). Because wind erosion forms a serious degradation process especially in the agricultural land ecosystems of the North European Quaternary Plains, an evaluation of current and potential future trends is needed to safeguard sustainable land-use practices and management strategies for the future.

History has shown that drastic changes in land use practices can lead to severe soil degradation by wind erosion. In the late Middle Ages the cover sands in

Northern Europe suffered under severe wind erosion due to large-scale deforestation followed by over-grazing, slash and burning and sod cutting. Large drift-sand areas were formed, which were then no longer suitable for agricultural use. The land owners, the farmers and the government only became aware of the problem when it was too late. Although models are a simplification of the real world, they can help decision makers and other stakeholders to interpret the consequences of change and to better anticipate the impact of these changes.

In the European belt of light sandy soils, the actual wind erosion risk is controlled by climate conditions on one hand and land management on the other. The role of these determinants is understood in principle, particularly the effects of associated variations in controlling components such as wind speed, friction velocities, roughness and topsoil moisture. Each determinant can be simulated numerically, either by empirical or physically based modelling approaches.

However, the long-term effect of future land use and climate changes on wind erosion risks is not easy to assess. The wind erosion process presupposes a discrete combination of certain tillage controlled disposition factors (bare or nearly bare topsoil, low surface roughness) and climate controlled factors (friction velocity above a critical threshold, dry topsoil). From a purely statistical point of view, the entire process is best described as a discrete stochastic event, happening in characteristic timescales from minutes to hours. In the process of soil degradation (water erosion, physical soil degradation, etc.) long-term climatic fluctuations and changing land use strategies result in corresponding transient changes in the degradation process.

The long-term estimation of wind erosion risks (e.g. in terms of transport rates or net soil loss) predominantly reflects the frequency of wind erosion events and thus the occurrence of coinciding disposition and controlling factors. The competing and overlapping determinants that control the wind erosion process make it difficult to carry out a proper assessment of potential future wind erosion risks within an overall framework of climate and land use change scenarios. This requires a separate analysis and evaluation of the sensitivity of the modelled process against changing human (land management) and quasi-natural (climate) determinants.

This paper aims to contribute to this discussion by presenting a sensitivity analysis, using the WEELS model to simulate wind erosion for alternative climate and land use scenarios separately. Due to the comprehensive availability of static and dynamic data sets, all simulations were performed in accordance with the example of the Barnham test site, a 5 km x 5 km piece of land near Barnham, Suffolk (UK), which was studied in detail within the framework of the WEELS project (Wind Erosion on European Light Soils). After a brief description of the WEELS model and a geographic characterization of the Barnham test site, the method to be used for determining the scenario definition and for generating the scenarios themselves is discussed. The results of alternative scenario runs, which constitute the numerical basis for the entire sensitivity analyses, were compared and discussed with respect to their economic dimensions.

4.2. Materials and Methods

4.2.1. Model description

The WEELS model was developed within the overall framework of WEELS (1998-2001). Apart from the long-term erosion risk assessments and the simulations of single wind erosion events, one primary objective of the development of the model was to support the impact assessment of changing management strategies in the order and magnitude of wind erosion risks. To ensure proper representation of the temporally highly variable dynamics of erosion processes, the actual erosion risk, expressed by means of the duration of erosive conditions and the corresponding maximum sediment transport rate according to Bagnold's (1966) sediment transport formula, is simulated in hourly resolution. Within the WEELS Project, long-term estimations were performed for the Barnham (UK) test site for the period 1970-1998 and the Grönheim (Germany) test site for the period 1981-1993 in a spatial resolution of 25 m by 25 m, with each modelling domain covering 250 ha (5 km by 5 km). The entire modeling approach consists of two groups of sub-modules (Figure 4.1): The "WIND", "EROSIVITY" and "SOIL MOISTURE" sub-modules combine the factors that contribute to the temporal variations of climatic erosivity, while the "SOIL ERODIBILITY", "SOIL ROUGHNESS" and "LAND USE" modules predict the temporal soil and vegetative cover variables that control soil erodibility.

The entire approach was validated against two sets of data, local knowledge and long-term soil erosion rates, which were estimated according to the ^{137}Cs method (Chappell and Warren, 2002). The first data set consists of wind erosion damage observed by farmers. These events, which were observed on the Barnham test site, were suitably reproduced by the temporally high resolution modelling estimates. Known hot spots of erosion activity within the test site are likewise represented in the modelled erosion parameters. A second, more sophisticated validation and calibration procedure considered calculations of long-term soil erosion rates estimated according to the ^{137}Cs method. The spatial pattern of the simulated long-term maximum transport rates of the Barnham test site (see Figure 4.7, Barnham Reference Run) largely represents the spatial approximation of erosion rates derived by the ^{137}Cs method. However, the WEELS model assumes the surface to be an unlimited source of erodible soil material and thus exceeds the ^{137}Cs measures by a factor of 2.6. More suitable results are likely to be obtained after a case-wise calibration, for example, of crusting effects, though the spatio-temporal disposition of erosion risks is sufficiently approximated. For a more detailed discussion of the WEELS model, including the methods it uses for long-term erosion risk assessment, and its capabilities and limitations, the reader is referred to Böhner *et al*. (2003). In the following, the main modules of the modelling approach are briefly summarized.

4.2.1.1. Climatic erosivity

Spatio-temporal variations of wind speeds are estimated in hourly resolution using the frequently used WasP approach (Mortensen *et al.*, 1993). The input data consist of a time series of wind velocity and wind direction values measured at one or two regional meteorological stations. The influence of the topography is determined on the basis of land use data presented in the form of vectors (meteorological roughness length) and digital terrain models. The output of the wind sub-module consists of a grid map (25 m × 25 m) of Weibull-A and Weibull-K parameters

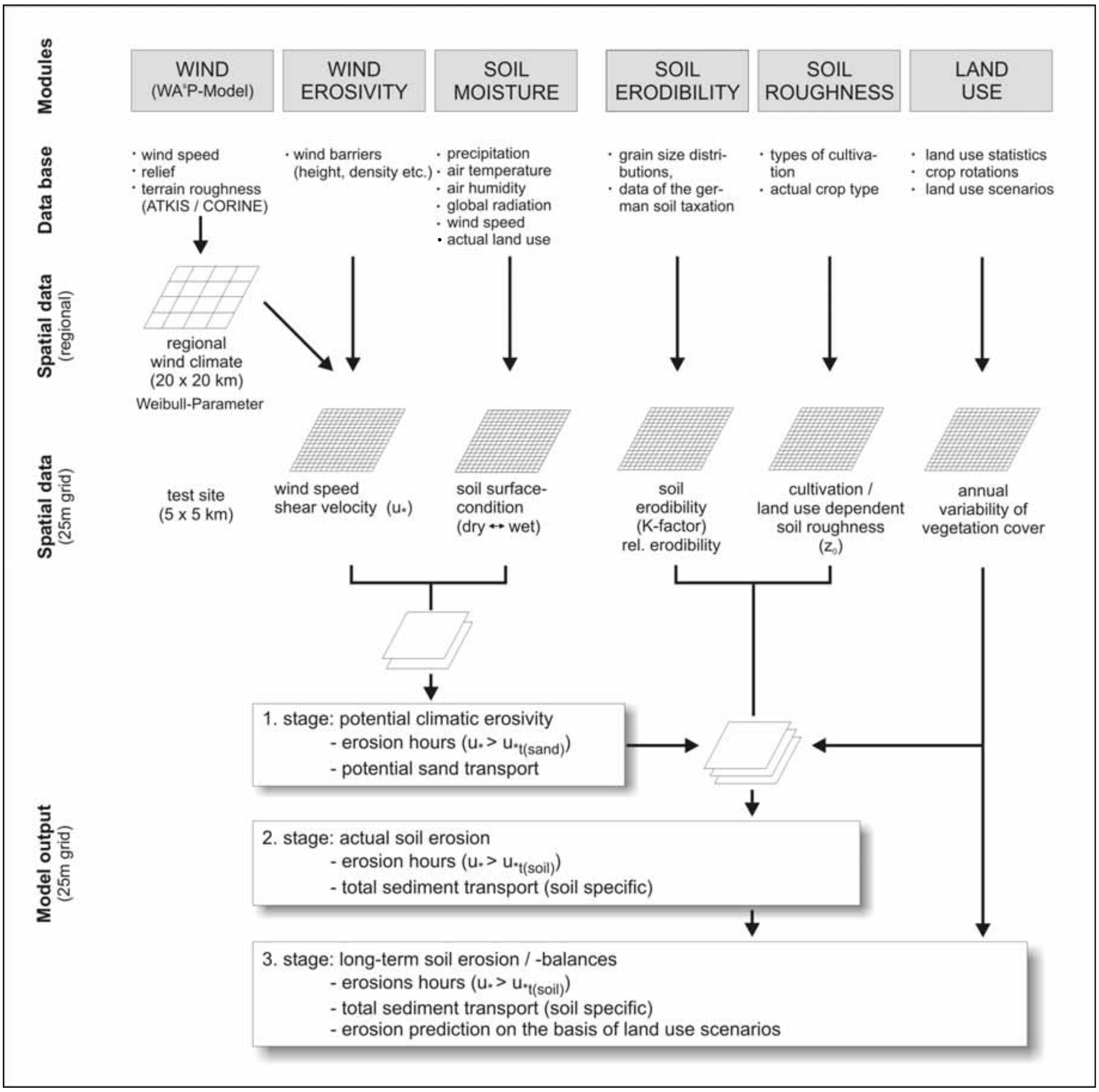


Figure 4.1. Model structure of the WEELS model.

(Troen and Petersen, 1990; Traup and Kruse, 1996), calculated for 10 m above ground level. The soil moisture module uses a simplified soil water balance equation to estimate the water content of the uppermost 0-1 cm of the soil on a daily basis. With respect to the predominantly sandy soils of the test sites, two discrete (wet and dry) soil moisture conditions are predicted. Dry conditions indicate that the uppermost soil layer is below an empirically determined, critical soil water threshold and the soil is susceptible to wind erosion. The outcome of the soil moisture sub-module provides wet/dry topsoil conditions for each grid point.

4.2.1.2. Surface erodibility

The influence of the spatial variations in the soil's pedo-physics is taken into account in the so-called K-factor, a dimensionless value that expresses the topsoil erodibility as a function of soil texture and organic matter content. The basic regression equation of the soil erodibility sub-module, which reduces the maximum sediment transport of standard sandy soils (Bagnold 1966) as a function of K, was derived from wind tunnel experiments conducted for different topsoil classes. Crop cycles and associated spatio-temporal variations in soil cover and surface roughness are considered in the soil roughness sub-module, using temporal phenology functions defined for eight prevalent crop types. A transfer function also allows the derivation of z_0 values from the land use type in combination with the K-factor. The necessary land use data were collected from existing maps or farmers' records. Gaps were filled using the land use sub-module. The random approach yields a land use pattern based on crop statistics and typical crop rotations, and thus enables a definition of land use change.

4.2.1.3. Model output

In its current state of development, the WEELS model yields regular gridded estimates of wind speeds (10 m above ground level) and friction velocities in an hourly resolution, while topsoil moisture (wet or dry topsoil), crop cover and associated roughness lengths are optional outputs, estimated as daily values. The previously mentioned erosion parameters (duration of erosive conditions and the maximum sediment transport rates) each are estimated with and without consideration of topsoil moisture in hourly resolution. In addition, a simplified daily erosion/accumulation balance is inferred from the transport ratio of neighbouring grid cells in a three-by-three grid cells moving window. However, in the scenario modelling applications we concentrate on the duration of erosive conditions and the sediment transport rates, which we assume are suitable integrative parameters for assessing the impact of changes in land use and climate on wind erosion.

4.2.2. Description of the Barnham test site

The test site is located near Barnham in the Breckland District, Suffolk, England (Figure 4.2). The Breckland District covers a large part of Southwest Norfolk and Northwest Suffolk to the extent of approximately 2430 square km. The climate in this region is more continental than elsewhere in Britain, with low rainfall, hot summers and cold winters (Table 4.1). According to the weather data from Broom's Barn, a dry spring (March to May) might be <90 mm of rain (7 years in last 35), and a wet spring might be wetter than 170 mm (5 years in last 35). The extremes were 42 mm (1996) and 244 mm (1983). The region is underlain by chalk, much of which is covered by sandy soils derived from glacio-fluvial deposits, and with some areas of gravel and boulder clay. Consequently the soils can vary from being pure sand to mainly chalk within a few metres. The water holding capacity of these soils is low (about 12%). Most soils in the region are low in fertility and vulnerable to droughts. The wind erodibility of these sandy soils is fairly high due to the high content of particles of 0.10 to 0.15 mm and a lack of soil structure. The topography of the area varies from gently undulating to slightly rolling (75m - 200m above sea level).

Because of its light sandy soils, the Breckland is known for its wind erosion hazard. Wind erosion is a problem for the farmers on-site, but during extreme events it can also cause serious off-site damage, especially in the springtime after a dry spell when the soil is bare or the crops are too small to prevent the soil from blowing away.

The Barnham test site (Figure 4.3) covers 5 km x 5 km and is representative for the Breckland District. The arable fields in the site represent a total of approximately 1,800 ha or 72 per cent of the total site. About 16 per cent of the site is covered with coniferous woodland and some 5 per cent is permanent grassland. The Honington Airfield is situated in the southwest of the test site and covers about 5 per cent of the site (Figure 4.3). As observed at the RAF-Honington

Table 4.1. Average weather, 1965-1995, Higham, Bury St. Edmunds, Suffolk

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RH 09:00 h (%)	90.0	88.3	82.8	77.0	73.3	72.7	74.1	75.4	79.6	86.2	88.2	90.2
Daily air max. (°C)	6.0	6.0	9.0	11.7	15.7	18.9	21.0	21.1	18.3	14.4	9.1	7.0
Daily air min. (°C)	1.0	0.6	2.1	3.7	6.7	9.6	11.7	11.6	10.1	7.5	3.5	2.2
Air mean (°C)	3.5	3.3	5.5	7.7	11.2	14.3	16.3	16.3	14.2	11.0	6.3	4.6
Precipitation (mm)	49.4	33.1	45.7	43.3	51.1	55.3	46.2	54.2	50.1	53.9	58.4	55.8
Wind run (km)	7487	6563	7554	6636	6184	5245	5192	5273	5482	5938	6572	7439
Rain days (>1.0 mm)	11.4	8.7	11.0	10.1	10.3	8.4	8.2	8.5	8.2	8.8	10.6	11.5

Source: IACR-Broom's Barn

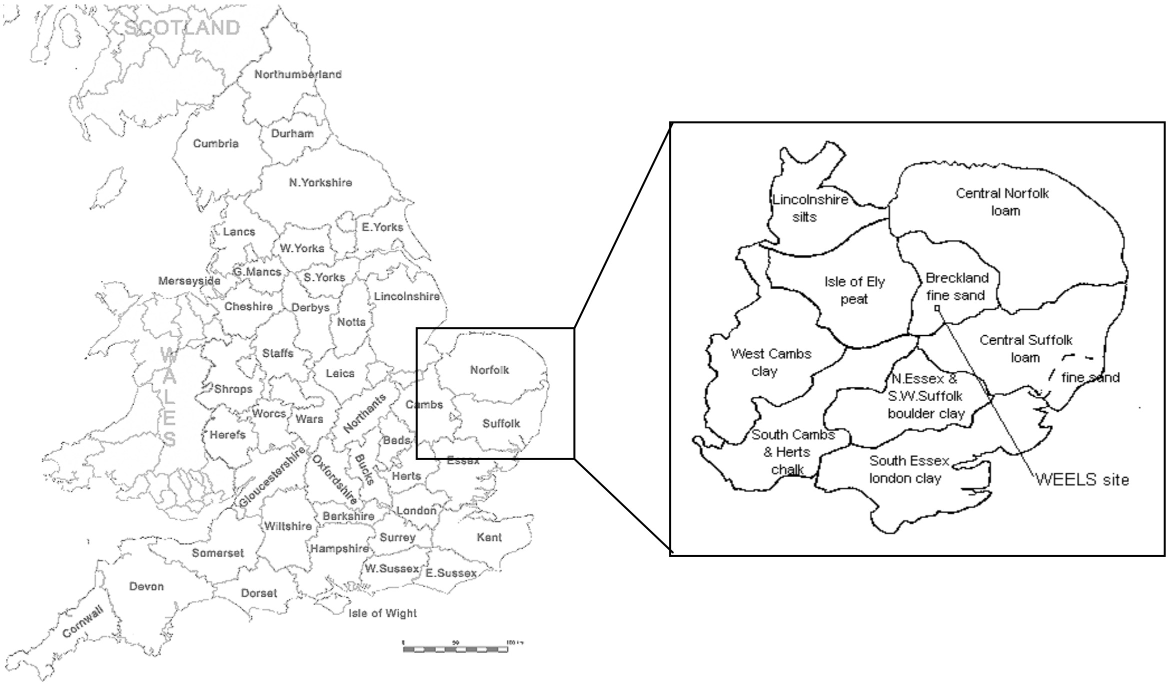


Figure 4.2. Location of the WEELS test site near Barnham, Breckland district, East Anglia, England

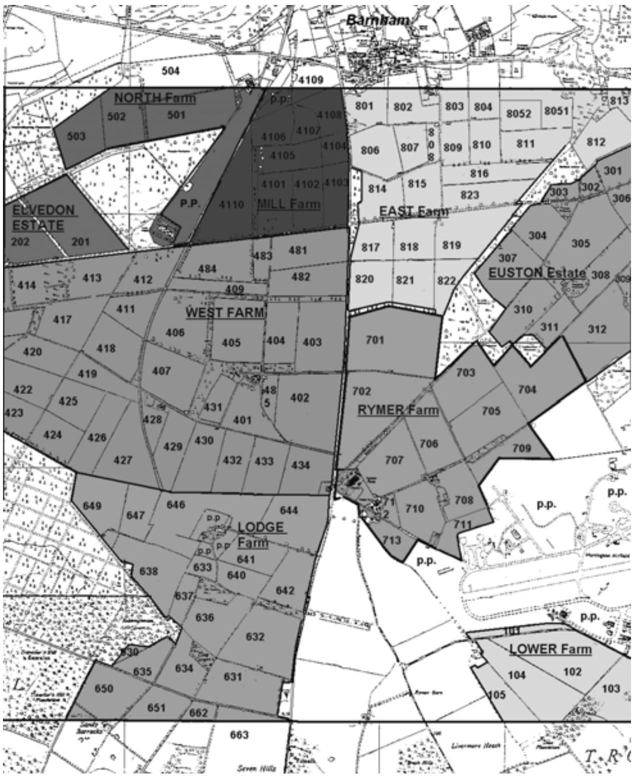


Figure 4.3. The Barnham test site (Based upon Ordnance Survey Mapping, with the permission of The Controller of HMSO.© Crown copyright. ED 2813360001)

meteorological station, the wind climate of the test site is characterized by prevailing southerly to westerly winds, which account for more than 50 per cent (54.96 %) of wind directions and an annual mean wind speed of 4.6 m s^{-1}. The frequent cyclonic activity in winter and spring is mirrored in monthly means of >5 m s^{-1} from December to April, while in the summer months the mean velocity remains below 4 m s^{-1}.

4.2.3. Scenario definition

Though wind erosion is commonly assessed as a complex process, there is a rather simple combination of conditions necessary for wind erosion to take place: firstly, strong winds and a dry top surface, and secondly, a susceptible more or less bare soil surface with low meteorological roughness length. While the first conditions are determined by climate, the latter are controlled by land use management and crop cycles. To a certain extent, management is related to the climate condition itself. However, the inter-annual variations in crop cycles are not as variable as the climate conditions, which are commonly assessed as the main forcing factor for temporal variations. As stressed in the introduction, the discrete stochastic combination of preconditions that are required for wind erosion requires very diverse needs for scenario construction. Based on the assumption that realistic scenarios on climate and land use change are only obtained when the conditions and determinants for wind erosion are properly represented, we decided to base our scenario definition directly on observations and empirical data collected for the area of 5 km x 5 km near Barnham for the period 1970-1998. Although the following approaches thus yield only analogues, the discrete definition of certain time spans within the entire period of observation ensures a realistic assessment of spatio-temporal variations of the major controlling factors.

4.2.3.1. Land use scenario definition

As already pointed out in Böhner *et al.* (2003), market conditions and government policies can lead to abrupt changes in farm type, farm practices and crops grown, and therefore in the crop rotation. Against this background, land use statistics from the Barnham test site were analyzed to identify periods with significant differences in crop types used in the crop rotation. A combination of two different approaches in cluster analysis was chosen: the iterated minimum-distance approach, and the hill-climbing routine (Rubin, 1967). Starting from the time series of crop statistics, cluster centroids are first initiated by fast cluster algorithm and subsequently used as the input for the iterated minimum-distance method. The Forgy approach assigns each year to the cluster based on least-square estimations. The result of the preliminary clustering is forwarded to the hill-climbing algorithm, which continuously establishes new clusters, using least square optimization schemes. The

Table 4.2. Results of cluster analysis – land use scenarios, cluster centroids and periods

Scenario	*Cluster*	*Crop type fraction (%)*							
		P	*SB*	*SC*	*WC*	*WW*	*OR*	*SA*	*PP*
LUS-1	1970-1980	3.03	11.45	15.89	21.79	5.58	0.17	0.00	26.85
LUS-2	1981-1992	5.36	18.82	8.73	18.71	14.53	1.98	0.00	16.07
LUS-3	1993-1998	3.89	15.96	7.24	16.49	14.46	0.71	6.23	20.13
Control run	1970-1998	4.20	15.50	11.17	19.47	11.12	1.00	1.34	21.00

LUS = Land use scenario; *P* = potatoes; *SB* = sugar beet; *SC* = spring cereals; *WC* = winter cereals; *WW* = winter wheat; *OR* = oil seed rape; *SA* = set-aside; *PP* = permanent pasture.

optimal number of clusters is subsequently defined through an iterative algorithm that increases the number of clusters until a local optimum is reached. Based on the so-called elbow criterion, a measure for changing variances by increasing cluster numbers, the first local variance minimum with three clusters was found suitable, differentiating the entire period in three phases of different crop type combinations, each defining a land use change scenario for the subsequently performed sensitivity analyses and scenario model runs (see subsection scenario modelling, results and discussion). The first cluster comprises the period from 1970 to 1980 and is characterized by a comparably high fraction of spring and winter cereals, while the area under vegetables and particularly winter wheat was limited. The second (1981-1992) and third clusters (1993-1998) differ only slightly and are determined by the extent of the area under forage and oil seed rape. Furthermore, only in the latest period (cluster 3) is arable land set aside.

Table 4.2. gives an overview of cluster centroids, each representing crop type fractions of the particular period. The last line denotes the long-term mean values of the entire period, subsequently used as the basic input for the land use model control run. The inter-annual statistics of crop type fractions for the 1970-1998 period of observation are given in Figure 4.4.

Since windbreaks are well known measures for wind erosion protection, the sensitivity analysis also considered two windbreak scenarios to estimate the degree to which windbreaks affect wind erosion. The first simply assumes a nearly complete protection by windbreaks at the south-western to Northwest field boundaries, reflecting the dominance of westerly winds at the Barnham test site. The influence of wind barriers and windbreaks is estimated by applying a reduction factor to the friction velocities in the protected zones. For the long-term erosion risk assessments, three types of windbreaks were defined on the basis of differences in height and porosity. However, for the scenario runs, only the maximum protection type No. 3, defined by a height of 15 m, a porosity of 0.25 and an optical density of 0.75, was considered. In section 3 this windbreak scenario will be compared with the long-term estimation and a model run assuming no windbreaks.

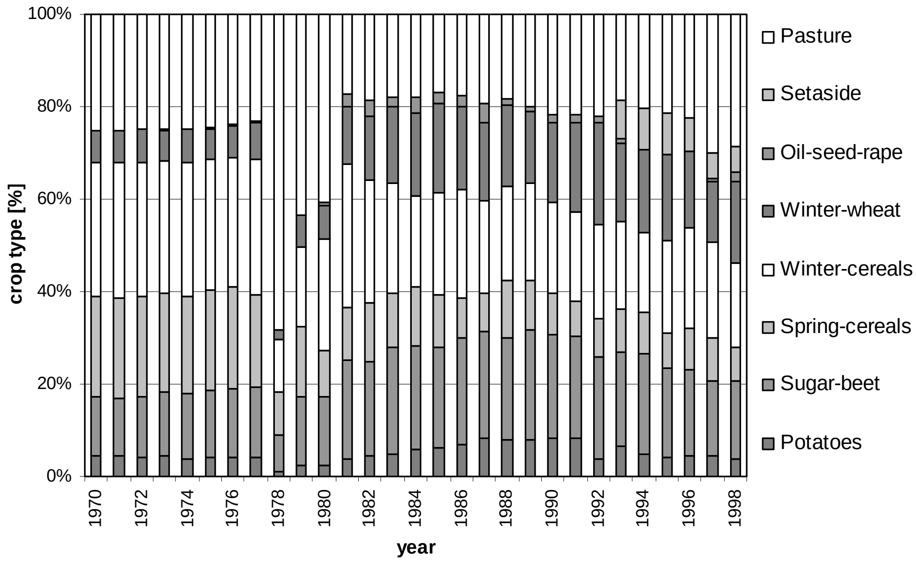


Figure 4.4. Crop statistics for the Barnham test site (1979-1998)

4.2.3.2. Climate change scenario definition

In other degradation processes, changes in the day-to-day variability already mirror a relevant temporal resolution, for example, of precipitation and the associated water-induced soil erosion on bare surfaces. In wind erosion, events are related to gust speeds which may mobilize susceptible soil in characteristic time spans from hours to minutes. The common praxis in climate change scenarios is to use GCM-based model runs (e.g. NCAR/CDEAS-GCM) for perturbed climates and then to nest a weather generator to represent the short-term stochastic variability (see e.g. Gyalistras and Fischlin, 1996). However; in the case of wind erosion it is hardly possible to produce a suitable representation of the climatic impact, due to the extreme temporal variability of wind climates. Against this background, we also based our climate change scenario construction on directly observed data from the RAF Honington observatory, which is situated to the south-east of the test site.
However, to obtain a method that is operational for further GCM-experiments we analyzed a time series of the North Atlantic Oscillation Pattern as a basic parameter for scenario construction. The NAO (North Atlantic Oscillation) has been widely recognized as an important teleconnection pattern influencing climate and weather characteristics in all seasons for the entire north Atlantic, the east of North America and western Europe (Deser and Blackmon, 1993; Kushnir, 1994; Sutton and Allen, 1997). The NAO is designated as a north-south dipole pressure anomaly with one centre located above Greenland and the opposite centre spanning the central latitudes of the North Atlantic between 35°N and 40°N. Positive NAOs constitute phases with high north-south pressure gradients and thus reflect a rather zonal circulation pattern, commonly associated with a strengthening of westerlies. A

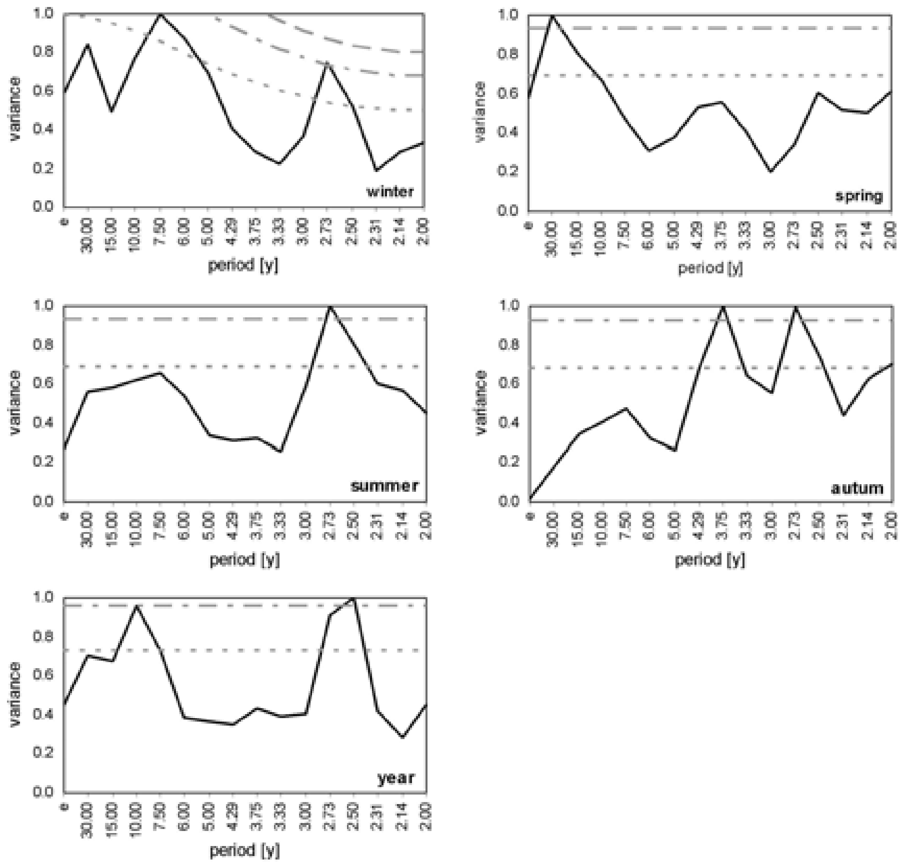


Figure 4.5. Spectral statistics of North Atlantic Oscillation (NAO) in seasons and years

rather meridional circulation pattern with variable wind directions is associated with negative NAO phases. For further teleconnections of the NAO and its influence on temperature and precipitation variations, the reader is referred to Hurrel (1995). From the different NAO estimations, the time series from the climate prediction centre of the United States (National Oceanic and Atmospheric Administration – NOAA) constitutes the most reliable NAO database. They consider pressure pattern anomalies of the entire northern Atlantic region constructed by means of Rotated Principle Component Analysis (RPCA, Barnston and Livezey 1987). Unlike other prominent teleconnection patterns such as the El Nino Southern Oscillation (ENSO), the NAO is not commonly assessed as a periodical phenomenon. Despite this fact, we analyzed the periodicity of the NAO series to obtain an estimate of the scale of minimum period lengths, which is required for further scenario definitions. Starting from the NAO time series of 1951-2000 in a first step, we analyzed the periodicity for seasons and the year using the Autocorrelation Spectral Analysis (Blackmann and Tuckey, 1958). The analysis yields characteristic period lengths based on autocorrelation functions and Fourrier transformations. The statistical significance of the variance pattern is subsequently determined by means of the Chi-square test (Böhner, 1996). The results of the analysis are presented in Figure 4.5.

With the exception of the winter series, a simple white noise (Monte Carlo) random was used to assess the significance of the periodicity. For the winter series, a Markov chain had to be used for significance assessment due to significant autocorrelation. All spectra were normalized by setting the maximum variance value to one. In general, Figure 4.5 reveals a heterogeneous periodicity with low significance in all seasons. However, the variance spectrum of the year series shows a slightly significant secondary maximum for the period length of ten years, which we assume to be a suitable period length for further scenario constructions.

In the second step, on the basis of this period length of ten years we performed t-tests to detect those decades within the entire modelling period (1970-1998) that represent maximum contrasting characteristics of the NAO. Starting from the comparison of 1970-1979 and 1980-1989, 1970-1979 and 1981-1990 and so on, the decades 1976-1985 and 1986-1995 were identified as the most contrasting ones, which for this reason were later considered in the scenario runs. The seasonal variations of the NOA indexes and t-test statistics are summarized in Table 4.3. Apart from June and August, Table 4.3. exhibits generally positive deviations in the NAO with rather negative Oscillation Indexes in the decade 1976-1985 (subsequently termed "Negative NAO") and predominantly positive NOA phases in the decade 1986-1995 (subsequently termed "Positive NAO"). Particularly for January, February, March, May and September, significant or nearly significant differences indicate a strengthening of the large-scale North Atlantic Circulation mode in the second Positive NAO decade.

Despite these distinctly differing large-scale circulation patterns, the changing NAO modes are not so clearly mirrored in the corresponding decadal wind statistics obtained from hourly observations by the RAF Honington meteorological station. Figure 4.6 indicates only small differences between the two decades in the

Table 4.3. Seasonal variations of the North Atlantic Oscillation (NAO) in the periods 1970-1998 (Mean NAO), 1976-1985 (Negative NAO) and 1986-1995 (Positive NAO), and significance of the differences between the periods 1976-1985 and 1986-1995 (t-test probabilities)

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year*
M-NAO	0.12	0.25	0.17	-0.17	-0.02	-0.23	-0.03	0.24	-0.13	-0.06	0.08	-0.04	0.02
N-NAO	-0.17	-0.06	-0.18	-0.08	-0.18	-0.20	-0.24	0.18	-0.39	-0.12	0.11	-0.06	-0.12
P-NAO	0.73	0.44	0.78	0.13	0.35	-0.26	0.17	0.08	0.06	0.09	0.42	-0.03	0.25
difference	0.90	0.50	0.96	0.21	0.53	-0.06	0.41	-0.10	0.45	0.21	0.31	0.03	0.36
t-test (%)	96.9	87.9	98.7	67.3	85.9	55.3	80.1	58.1	84.8	68.2	72.2	52.1	98.1

M-NAO = Mean NAO; N-NAO = Negative NAO; P-NAO = Positive NAO

Table 4.4. Mean wind speeds (m s^{-1}) at RAF Honington Observatory in 1970-1998 (Mean), 1976-1985 (Negative NAO) and 1986-1995 (Positive NAO), and differences in the NAO decades (m s^{-1}). Changes in the distribution of wind speeds (m s^{-1}) in the NAO decades are given as the ratio values

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year*
Mean	5.23	4.98	5.20	4.71	4.33	4.10	3.97	3.93	4.23	4.46	4.77	5.01	4.58
N-NAO	5.45	4.57	5.36	4.68	4.27	4.20	3.94	3.84	4.46	4.38	4.94	5.12	4.60
P-NAO	5.31	5.13	5.46	4.63	4.09	3.83	3.83	3.98	3.94	4.21	4.24	4.72	4.45
difference	-0.14	0.56	0.10	-0.05	-0.18	-0.37	-0.11	0.14	-0.52	-0.17	-0.70	-0.40	-0.15
0 - 2	1.20	0.80	1.13	1.03	0.98	1.29	1.05	0.84	1.40	0.91	1.24	1.51	1.10
2 - 4	1.11	0.96	0.96	1.02	1.16	1.10	1.03	1.04	1.13	1.13	1.27	1.08	1.08
4 - 6	0.91	0.95	0.97	1.06	0.99	0.89	1.01	1.04	0.90	1.05	1.07	0.90	0.98
6 - 8	0.88	0.92	1.01	0.90	0.80	0.81	0.86	0.99	0.77	0.86	0.70	0.75	0.85
8 - 10	0.98	1.34	0.99	0.91	0.89	0.79	1.09	1.22	0.76	0.68	0.62	1.01	0.92
> 10	1.11	2.82	1.18	1.03	0.79	0.42	0.82	1.69	0.48	1.19	0.42	0.99	1.09

N-NAO = Negative NAO (1976-1985); P-NAO = Positive NAO (1986–1995)

distribution of wind directions and wind speed frequencies; furthermore, the negative though small difference in the annual mean wind speed of -0.15 m s^{-1} (Table 4.4.) seems to confirm the conclusions of the WASA Group (1998) and the IPCC (2001) that, so far, there has been no overall consistent evidence for transientlong-term changes in the wind climates of the North Atlantic and adjacent European regions within the instrumental period. Only a monthly separated analysis of the two decades reveals more insight into the differing wind climates of these two decades. This is shown by the ratios (Positive NAO divided by Negative NAO) for the distribution of wind speed frequencies (Table 4.4.) and wind directions (Table 4.5.).

Table 4.5. Changes in the distribution of wind directions from the decade 1976-1985 (Negative NAO) to the decade 1986-1995 (Positive NAO); values denote the ratio of Positive NAO to Negative NAO

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year*
N	0.79	0.68	0.62	0.87	1.05	1.43	0.67	0.73	1.71	1.32	0.98	2.06	1.00
NE	1.04	0.67	0.72	0.91	1.08	1.19	0.95	0.86	2.65	1.84	0.89	1.87	1.06
E	0.83	0.47	0.71	1.04	0.85	1.00	0.84	0.79	1.21	1.45	2.12	0.73	0.90
SE	0.99	0.78	0.99	1.13	0.93	1.09	1.31	0.82	0.94	1.27	1.59	0.48	1.00
S	1.69	1.27	0.89	1.35	0.85	1.02	1.30	1.08	0.69	0.82	0.97	0.79	1.01
SW	1.25	1.73	1.22	1.31	1.28	0.82	1.26	1.17	0.85	0.87	0.80	1.09	1.09
W	0.58	1.14	1.24	0.85	0.92	0.71	0.92	1.17	0.86	0.75	0.93	0.97	0.90
NW	0.88	2.16	1.36	0.78	1.12	1.31	0.82	1.14	1.44	0.95	0.84	1.21	1.10

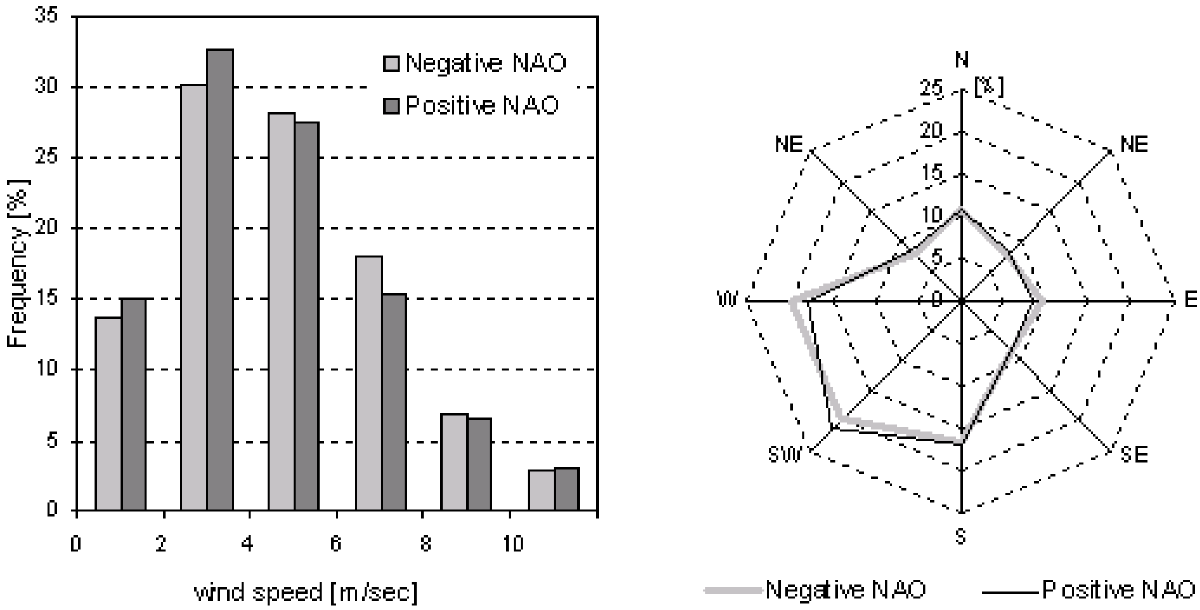


Figure 4.6. Distributions of wind speeds (left) and wind directions (right) at RAF Honington observatory in the decades 1976-1985 (Negative NAO) and 1986-1995 (Positive NAO)

Disregarding the summer months, which are commonly judged not to be that relevant to wind erosion (Warren, 2002), the positive NAO generally tends to decreasing easterlies and south-easterlies throughout the winter and in March and May, while the western components, and particularly the south-western, are strengthened throughout the winter and spring. In contrast, the autumn months are characterized rather by decreasing westerlies and a marked increase of easterlies and north-easterlies (Table 4.5.).

As shown in Table 4.4, the slight reduction of annual mean wind speeds is mainly influenced by the negative deviation of the autumn months, while positive deviations occur in February, March and August. Particularly the gust speeds (>10 $m\ s^{-1}$) show distinct differences, with increases from January to April and a marked maximum magnitude in February. Decreases in gust speeds occur mainly in autumn, with the greatest reduction in September and November. Although these roughly highlighted differences in the wind climates mirror no clear structured climatic change, we assume this to be a realistic representation of the magnitude to which wind climates may change due to variations in the large-scale circulation. Therefore we consider that both decades are suitable databases for the subsequently performed sensitivity analyses and scenario modelling.

There are several aspects that should be taken into consideration when the economic consequences of wind erosion are considered:

- On-farm damage: wind erosion can lead directly to a decline in farm income due to the loss of crops, increasing operating costs, etc. (Riksen and de Graaff, 2001). Indirectly, it can cause a decrease in soil productivity.
- Off-site effects: damage to the community, for example, blocked roads, increased health problems, etc. (Goossens, 2002; Riksen, 2004).

4.2.4. Economic assessment of wind erosion risk

For a proper economic assessment of the different scenarios, the wind erosion related increase or decrease in costs should be taken into consideration. Scenario related costs and income changes should also be taken into account. Examples of such costs are increased maintenance costs for extra windbreaks, and loss of farm income related to the surface area of arable land needed for new windbreaks in the extended windbreak scenario (see also Riksen *et al.*, 2004). In the current stage of development of the scenario study, the gathering of the economic data required per scenario has not yet been completed. Instead, the scenarios have been evaluated only on the basis of the WEELS wind erosion model results (mean, median (Q50%) and 95% quantile (Q95%) duration rates), in combination with information on the actual damage due to wind erosion for the Barnham site (see Riksen and de Graaff, 2001). The major on-farm costs related to wind erosion damage are re-sowing costs and the loss of income due to a reduced crop production. Only a few farmers were able to give detailed information on crop damage and/or loss of crop production in the period 1993-1998 (LUS-3 scenario). For this period, the on-farm average yearly cost caused by wind erosion was estimated at € 67 $ha^{-1}yr^{-1}$. Most of the crop damage occurred in March, April and May, as well as in September, i.e. in the period when most crops are sown and are therefore most susceptible to wind erosion. In the economic evaluation of the scenarios of the on-farm effects, only the WEELS model results of these four months have been used. For all scenarios, the relative wind erosion duration was estimated using the LUS-3 scenario as a standard (e.g. 100%). This ratio was then used to estimate the on-farm costs for each scenario.

Off-site effects are mainly caused by the soil particles that are transported in modified saltation or suspension (Riksen, 2004). For the LUS-3 period (1993-1998), no evidence of structural off-site damage was found. In some individual cases some off-site damage was reported, but the number of stakeholders was too small to give a realistic estimation of the off-site damage for the whole site. The economic assessment will therefore be expressed only as a relative off-site damage risk ratio, corresponding to the transport rates per scenario, and taking the LUS-3 scenario as the standard.

4.3. Results

Sensitivity analyses and scenario runs were performed, recombining land use and climatic data according to the previously defined land use and climate variations. Since the land use scenarios are based on a randomly generated land use pattern, a control run was also performed on the long-term mean crop statistics of the period 1970-1998 to assess the sensitivity and the "virtual" impact of the land use random module in comparison with the long-term estimation (Böhner *et al.*, 2003). To yield a largely consistent and realistic temporal pattern of crop cycles and climate variations, the climate scenarios integrate the unchanged modelling results of the long-term estimations from the periods 1976-1985 (for the Negative NAO scenario) and 1986-1995 (for the Positive NAO scenario), while the land use data from the other years was recombined with the climate data from the designated NAO periods (e.g. for the Negative NOA scenario: land use data from the clusters 1970-1975 and 1986-1998, with climate data from 1980-1985 and 1975-1978). All scenario results are summarized in Tables 4.6 (Erosion Duration) and 4.7 (Maximum Sediment Transport Rate). Each table contains aerial means, medians, standard deviations and the 95% quantile, listed separately for each scenario and each month. All statistics refer to the arable land only, which means that the woodlands, broad roads, farmyards and the RAF Honington airport area are not taken into consideration. In addition, for each scenario the aerial means are given as ratios to the reference estimations of the Barnham model run for the period 1970-1998 (Böhner, 2003). The spatial distribution of the long-term annual means of the maximum sediment transport rates is shown in Figure 4.7. The spatial patterns indicate that most particles will deposit relatively close to the source within the fields, and the net sediment losses will therefore remain relatively low. Depending on the duration and intensity of an event, sediment will also accumulate along the field borders and windbreaks, though most of the on-site economic losses appear to be related to sandblasting and, thus, sediment transport. Figure 4.7 highlights the areas where the risks for economic losses are highest.

Table 4.8 represents the preliminary results of the economic assessment of the scenarios. The assessment is based only on the estimated on-farm costs due to wind erosion and risk ratio for off-site damage for each scenario compared to LUS-3. Changes in costs or income are not taken into account.

Table 4.6. (next page) Long-term aerial statistics of erosion duration (h) at the Barnham test site for different land use and climate scenarios

Barnham = reference run; Mean = mean erosion duration (h); Ratio S/R = ratio of scenario mean and long-term reference mean BRR; Q 50% = median (h); S = standard deviation (h); Q 95% = 95% quantile (h); LUS = land use change scenario; EHS = extended windbreaks; NHS = no windbreaks; N-NAO = Negative NAO; P-NAO = Positive NAO.

Barnham	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	0.098	0.106	0.133	0.063	0.021	0.000	0.005	0.037	0.111	0.041	0.098	0.000	0.714
Ratio S/R	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Q 50%	0.060	0.075	0.087	0.039	0.012	0.000	0.002	0.022	0.068	0.021	0.054	0.000	0.590
S	0.102	0.106	0.130	0.071	0.025	0.001	0.008	0.043	0.123	0.050	0.115	0.000	0.575
Q 95%	0.301	0.319	0.392	0.217	0.075	0.001	0.021	0.127	0.372	0.153	0.345	0.000	1.785
Control	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	0.091	0.107	0.112	0.059	0.024	0.000	0.005	0.036	0.138	0.044	0.096	0.000	0.715
Ratio S/R	0.931	1.006	0.845	0.935	1.186	1.109	1.049	0.991	1.241	1.083	0.980	0.698	1.001
Q 50%	0.061	0.080	0.083	0.036	0.012	0.000	0.002	0.021	0.101	0.022	0.060	0.000	0.616
S	0.099	0.096	0.110	0.068	0.031	0.001	0.008	0.041	0.132	0.056	0.104	0.000	0.548
Q 95%	0.289	0.296	0.332	0.210	0.091	0.002	0.023	0.124	0.400	0.173	0.327	0.000	1.746
LUS-1	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	0.085	0.107	0.088	0.045	0.020	0.000	0.005	0.039	0.140	0.048	0.100	0.000	0.676
Ratio S/R	0.863	1.007	0.661	0.714	0.953	0.652	0.923	1.057	1.261	1.183	1.013	0.698	0.947
Q 50%	0.048	0.075	0.055	0.017	0.007	0.000	0.002	0.024	0.093	0.025	0.060	0.000	0.549
S	0.095	0.103	0.094	0.071	0.028	0.001	0.007	0.044	0.143	0.058	0.112	0.000	0.554
Q 95%	0.264	0.314	0.269	0.220	0.086	0.001	0.021	0.131	0.440	0.172	0.343	0.000	1.742
LUS-2	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	0.088	0.108	0.126	0.075	0.031	0.000	0.005	0.037	0.138	0.047	0.111	0.000	0.766
Ratio S/R	0.895	1.019	0.946	1.187	1.519	1.530	0.983	1.011	1.240	1.147	1.130	0.811	1.074
Q 50%	0.064	0.076	0.095	0.044	0.022	0.000	0.002	0.025	0.081	0.024	0.072	0.000	0.632
S	0.087	0.098	0.120	0.085	0.032	0.001	0.007	0.037	0.152	0.055	0.121	0.000	0.597
Q 95%	0.262	0.301	0.365	0.251	0.089	0.002	0.020	0.110	0.469	0.169	0.376	0.000	1.892
LUS-3	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	0.082	0.087	0.115	0.067	0.027	0.000	0.005	0.033	0.126	0.033	0.088	0.000	0.663
Ratio S/R	0.831	0.822	0.868	1.049	1.336	1.233	0.898	0.895	1.136	0.815	0.891	1.065	0.929
Q 50%	0.045	0.062	0.070	0.030	0.011	0.000	0.002	0.020	0.072	0.017	0.044	0.000	0.512
S	0.094	0.086	0.133	0.099	0.038	0.001	0.007	0.036	0.146	0.043	0.106	0.000	0.583
Q 95%	0.301	0.253	0.403	0.302	0.114	0.002	0.018	0.110	0.467	0.122	0.327	0.000	1.901
NHS	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	0.274	0.356	0.386	0.225	0.091	0.002	0.021	0.146	0.358	0.140	0.292	0.000	2.291
Ratio S/R	2.786	3.357	2.907	3.545	4.450	8.038	3.942	3.975	3.219	3.433	2.972	6.302	3.210
Q 50%	0.251	0.334	0.369	0.202	0.078	0.001	0.017	0.145	0.339	0.118	0.265	0.000	2.320
S	0.169	0.171	0.210	0.155	0.062	0.002	0.015	0.071	0.199	0.094	0.175	0.000	0.765
Q 95%	0.571	0.648	0.765	0.503	0.222	0.006	0.053	0.261	0.710	0.327	0.596	0.001	3.554
EHS	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	0.056	0.061	0.050	0.028	0.019	0.000	0.001	0.016	0.041	0.017	0.044	0.000	0.334
Ratio S/R	0.575	0.574	0.376	0.442	0.911	0.783	0.168	0.441	0.372	0.419	0.449	1.063	0.468
Q 50%	0.031	0.041	0.023	0.010	0.009	0.000	0.000	0.008	0.021	0.007	0.025	0.000	0.261
S	0.066	0.064	0.067	0.041	0.024	0.001	0.002	0.022	0.050	0.028	0.052	0.000	0.296
Q 95%	0.197	0.187	0.193	0.107	0.073	0.001	0.004	0.063	0.150	0.076	0.148	0.000	0.931
P-NAO	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	0.082	0.165	0.255	0.041	0.006	0.000	0.001	0.023	0.046	0.016	0.002	0.000	0.636
Ratio S/R	0.840	1.555	1.918	0.641	0.306	0.195	0.118	0.619	0.412	0.395	0.019	2.414	0.892
Q 50%	0.056	0.131	0.192	0.023	0.003	0.000	0.000	0.012	0.030	0.005	0.000	0.000	0.526
S	0.089	0.150	0.237	0.048	0.009	0.000	0.001	0.028	0.050	0.029	0.004	0.000	0.505
Q 95%	0.252	0.468	0.706	0.135	0.025	0.000	0.003	0.081	0.147	0.072	0.009	0.001	1.621
N-NAO	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	0.169	0.024	0.048	0.045	0.019	0.000	0.002	0.030	0.278	0.026	0.097	0.000	0.738
Ratio S/R	1.721	0.227	0.361	0.710	0.926	0.194	0.435	0.809	2.500	0.648	0.984	0.000	1.035
Q 50%	0.114	0.015	0.030	0.030	0.008	0.000	0.000	0.013	0.203	0.017	0.071	0.000	0.612
S	0.168	0.028	0.056	0.047	0.026	0.000	0.004	0.038	0.275	0.029	0.092	0.000	0.611
Q 95%	0.494	0.081	0.168	0.142	0.077	0.000	0.011	0.110	0.803	0.088	0.275	0.000	1.948

Barnham	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	3.97	3.21	5.33	2.19	0.52	0.00	0.05	1.02	3.38	1.38	3.73	0.00	24.78
Ratio S/R	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Q 50%	1.91	1.98	2.62	0.84	0.20	0.00	0.01	0.46	1.59	0.45	1.46	0.00	18.65
S	4.71	3.82	6.51	3.46	0.76	0.01	0.11	1.38	4.27	2.15	5.52	0.00	22.99
Q 95%	13.87	10.68	19.22	9.76	2.21	0.01	0.29	4.10	12.64	5.99	15.37	0.00	71.00
Control	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	3.69	3.29	4.52	2.13	0.66	0.00	0.06	0.99	4.32	1.51	3.60	0.00	24.78
Ratio S/R	0.928	1.026	0.848	0.975	1.281	1.134	1.095	0.969	1.281	1.093	0.967	0.723	1.000
Q 50%	1.72	2.11	2.40	0.72	0.20	0.00	0.01	0.44	2.71	0.51	1.72	0.00	18.97
S	4.50	3.57	5.98	3.62	1.08	0.01	0.14	1.30	4.73	2.46	4.70	0.00	22.19
Q 95%	13.07	10.48	17.46	9.69	2.78	0.02	0.27	3.77	14.06	6.29	14.49	0.00	71.09
LUS-1	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	3.33	3.30	3.43	1.55	0.53	0.00	0.05	1.10	4.56	1.66	3.66	0.00	23.18
Ratio S/R	0.839	1.028	0.644	0.709	1.020	0.691	0.908	1.079	1.352	1.202	0.982	0.679	0.935
Q 50%	1.23	2.02	1.45	0.19	0.10	0.00	0.01	0.54	2.40	0.61	1.66	0.00	16.44
S	4.43	3.92	4.87	3.45	0.89	0.01	0.09	1.40	5.56	2.39	4.88	0.00	22.22
Q 95%	12.04	11.56	12.79	9.26	2.67	0.01	0.25	4.02	16.05	6.73	14.47	0.00	67.82
LUS-2	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	3.56	3.33	4.76	2.71	0.87	0.00	0.05	1.04	4.34	1.63	4.07	0.00	26.36
Ratio S/R	0.897	1.037	0.894	1.238	1.678	1.890	0.826	1.017	1.286	1.176	1.093	0.858	1.064
Q 50%	1.89	1.97	2.64	1.00	0.48	0.00	0.01	0.59	2.08	0.58	1.97	0.00	19.34
S	4.47	3.60	5.99	4.21	1.02	0.01	0.08	1.21	5.70	2.41	5.30	0.00	24.01
Q 95%	12.36	10.81	18.10	12.25	2.90	0.04	0.20	3.58	15.41	6.80	15.63	0.00	74.48
LUS-3	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	3.41	2.72	4.82	2.51	0.76	0.00	0.05	0.93	4.12	1.12	3.16	0.00	23.59
Ratio S/R	0.858	0.846	0.905	1.147	1.465	1.625	0.904	0.910	1.222	0.807	0.849	1.095	0.952
Q 50%	1.24	1.58	1.92	0.55	0.19	0.00	0.01	0.43	1.86	0.35	1.30	0.00	15.90
S	4.65	3.17	6.97	4.68	1.18	0.01	0.09	1.21	5.85	1.83	4.44	0.00	24.21
Q 95%	14.29	9.53	20.41	15.11	3.34	0.04	0.22	3.55	16.42	4.87	13.44	0.01	77.06
NHS	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	12.52	12.01	17.43	8.59	2.49	0.02	0.25	4.37	11.80	5.18	12.06	0.01	86.71
Ratio S/R	3.152	3.740	3.272	3.926	4.816	9.429	4.477	4.279	3.495	3.745	3.237	7.773	3.500
Q 50%	10.86	10.49	13.84	5.90	1.72	0.00	0.17	4.10	10.17	4.15	9.46	0.00	79.67
S	10.17	7.22	13.52	8.47	2.28	0.04	0.24	2.74	8.21	4.63	9.67	0.01	39.76
Q 95%	32.71	26.10	45.00	26.00	7.55	0.11	0.73	9.23	27.49	14.58	30.73	0.02	156.99
EHS	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	2.28	1.70	1.71	0.87	0.50	0.00	0.01	0.42	1.11	0.50	1.49	0.00	10.60
Ratio S/R	0.574	0.530	0.322	0.396	0.965	0.769	0.228	0.411	0.329	0.360	0.400	1.081	0.428
Q 50%	0.78	0.93	0.56	0.21	0.16	0.00	0.00	0.15	0.43	0.14	0.62	0.00	7.34
S	3.14	2.13	2.88	1.68	0.79	0.01	0.03	0.71	1.64	0.99	2.17	0.00	10.93
Q 95%	8.95	6.17	7.34	3.69	2.28	0.01	0.07	1.84	4.63	2.38	5.84	0.01	32.38
P-NAO	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	3.65	5.13	11.24	1.23	0.11	0.00	0.01	0.47	1.27	0.45	0.03	0.00	23.61
Ratio S/R	0.920	1.599	2.110	0.563	0.222	0.025	0.181	0.457	0.377	0.325	0.009	2.390	0.953
Q 50%	1.77	3.36	6.81	0.57	0.04	0.00	0.00	0.19	0.69	0.09	0.00	0.00	16.82
S	4.77	5.80	12.95	1.59	0.17	0.00	0.02	0.71	1.55	1.02	0.09	0.00	22.13
Q 95%	13.28	15.91	35.36	4.69	0.49	0.00	0.05	1.91	4.41	2.47	0.16	0.01	65.94
N-NAO	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*
Mean	6.94	0.59	1.33	1.17	0.52	0.00	0.05	0.75	9.12	0.73	2.88	0.00	24.08
Ratio S/R	1.748	0.185	0.249	0.534	1.000	0.124	0.920	0.730	2.700	0.530	0.774	0.000	0.972
Q 50%	4.13	0.32	0.65	0.71	0.14	0.00	0.00	0.22	5.51	0.34	1.88	0.00	18.00
S	8.00	0.78	1.92	1.31	0.90	0.00	0.10	1.11	10.27	0.98	3.09	0.00	22.63
Q 95%	22.96	2.14	5.26	4.03	2.34	0.00	0.28	3.21	32.41	2.72	9.12	0.00	69.19

Table 4.7. (previous page) Long-term aerial statistics of maximum sediment transport rates (kg m^{-1}) at the Barnham test site for different land use and climate scenarios

Barnham = reference run; Mean = max sediment transport rates for mean erosion duration (kg m^{-1}); Ratio S/R = ratio of scenario mean and long-term reference mean; Q 50% = median (kg m^{-1}); S = standard deviation (kg m^{-1}); Q 95% = 95% quantile (kg m^{-1}); LUS = land use change scenario; EHS = extended windbreaks; NHS = no windbreaks; N-NAO = Negative NAO; P-NAO = Positive NAO.

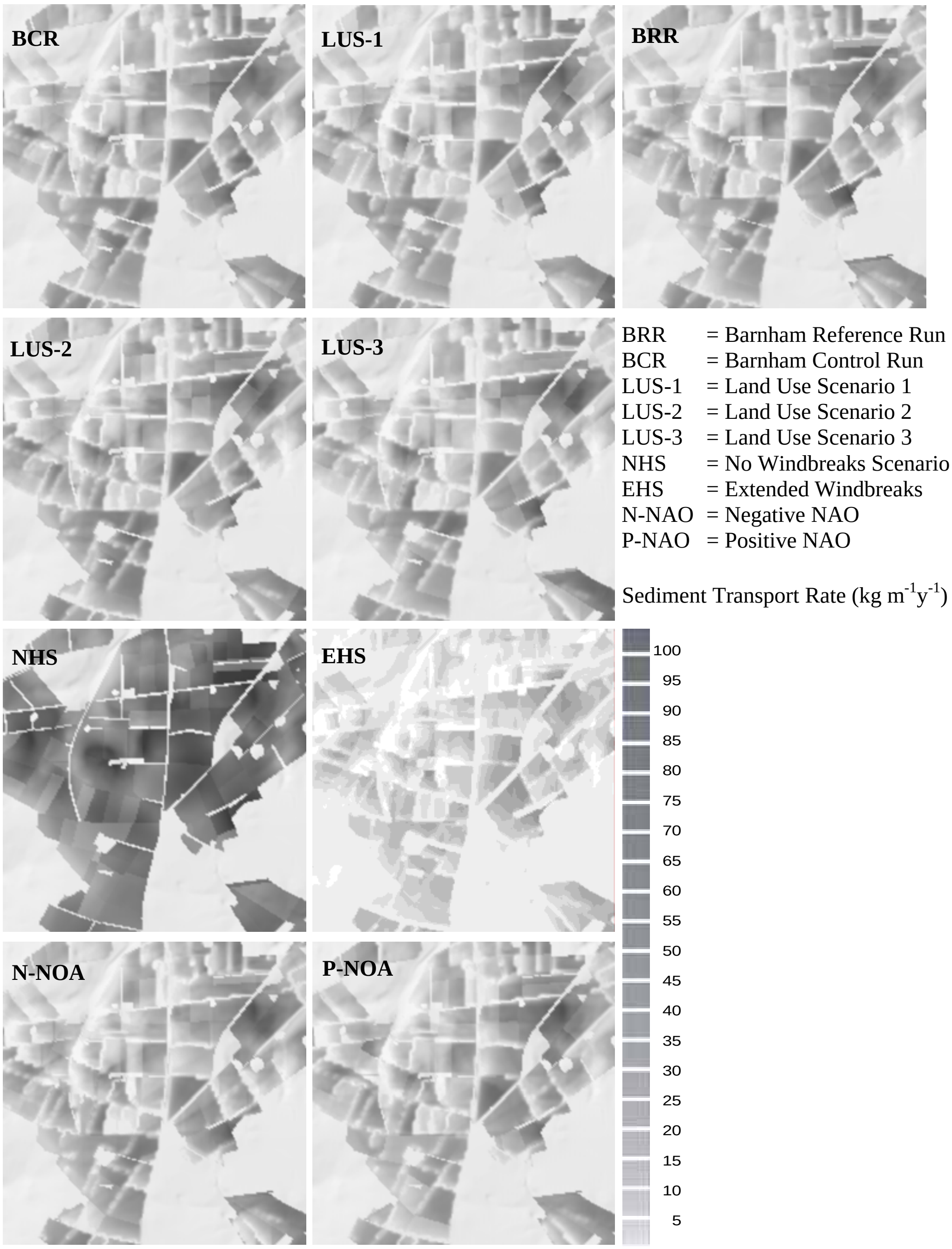


Figure 4.7. Long-term average of the maximum annual sediment transport rate

Table 4.8. Maximum on-site costs (€ $ha^{-1}y^{-1}$) and off-site risk ratio at the Barnham test site for different land use and climate scenarios

Scenario		*Duration (h)*					*On-site costs*	*Transport*	*Off-site damage risk ratio*
		March	*April*	*May*	*Sept*	*Average*	*(€ $ha^{-1}yr^{-1}$)*	*(kg yr^{-1})*	
LUS-1	Mean	0.088	0.045	0.020	0.140	0.073	58.60	23.18	0.98
	Q 50%	0.055	0.017	0.007	0.093	0.043	34.40	16.44	1.03
	Q 95%	0.269	0.220	0.086	0.440	0.254	203.00	67.82	0.88
LUS-2	Mean	0.126	0.075	0.031	0.138	0.093	74.00	26.36	1.12
	Q 50%	0.095	0.044	0.022	0.081	0.061	48.40	19.34	1.22
	Q 95%	0.365	0.251	0.089	0.469	0.294	234.80	74.48	0.97
LUS-3	Mean	0.115	0.067	0.027	0.126	0.084	67.00	23.59	1.00
	Q 50%	0.007	0.030	0.011	0.072	0.030	24.00	15.90	1.00
	Q 95%	0.403	0.302	0.114	0.467	0.322	257.20	77.06	1.00
NHS	Mean	0.386	0.225	0.091	0.358	0.265	212.00	86.71	3.68
	Q 50%	0.369	0.202	0.078	0.339	0.247	197.60	79.67	5.01
	Q 95%	0.765	0.503	0.222	0.710	0.550	440.00	156.99	2.04
EHS	Mean	0.050	0.028	0.019	0.041	0.035	27.60	10.60	0.45
	Q 50%	0.023	0.010	0.009	0.021	0.016	12.60	7.34	0.46
	Q 95%	0.193	0.107	0.073	0.150	0.131	104.60	32.38	0.42
P-NAO	Mean	0.255	0.041	0.006	0.046	0.087	69.60	23.61	1.00
	Q 50%	0.192	0.023	0.003	0.030	0.062	49.60	16.82	1.06
	Q 95%	0.706	0.135	0.025	0.147	0.253	202.60	65.94	0.86
N-NAO	Mean	0.048	0.045	0.019	0.278	0.098	78.00	24.08	1.02
	Q 50%	0.030	0.030	0.008	0.203	0.068	54.20	18.00	1.13
	Q 95%	0.168	0.142	0.077	0.803	0.298	238.00	69.19	0.90

LUS = land use change scenario; EHS = extended windbreaks; NHS = no windbreaks; N-NAO = Negative NAO; P-NAO = Positive NAO; Mean = mean erosion; Q 50% = median; Q 95% = 95% quantile.

4.4. Discussion

The following general aspects of the scenario runs are assumed to be relevant:

- The land use scenarios show no marked changes in the order of magnitude of the wind erosion parameters. Apart from slight differences in the spatial pattern of maximum sediment transport rates (see Figure 4.7), changes in the erosion duration in the sediment transport rates are mainly influenced by seasonal variations. However, relevant changes of erosion parameters such as the increase in the mean September duration of erosional conditions by the factor 1.261 in the land use scenario 1 (LUS-1, Table 4.6) do not essentially differ from the pure randomly induced crop type distributions and resulting changes of erosion parameters in the control run. Nevertheless, land use scenario 2 (LUS-2) yields a higher erosion duration as well as higher transport rates, which can be explained by the increased land area under more vulnerable crops such as sugar beet, potato and oil seed rape, on the one hand, and the decreased land area under permanent pasture, on the other. The on-site costs, though, do not dramatically increase, and these crops will normally produce higher profits. The risk for off-site damage is on average slightly higher for LUS-2 compared to LUS-3, though this factor is assumed not to be relevant for the Barnham site, as the damage was in fact found to be marginal.

- The most marked changes are found in the windbreak scenarios. The extended windbreak scenario is calculated with the total reduction of erosion parameters of more than 50%. Particularly in March, April and September, the extended windbreak scenario reveals a drastic erosion reduction. Instead, the model is run without considering any windbreaks, and consequently it shows a tremendous increase in erosion duration and sediment transport rates. The winter months and the transitional seasons depict the relevance of this well known measure of wind erosion protection, disregarding the high ratio values for the summer months and December. These high ratio values result from the generally low value levels of erosion parameters. The somewhat surprising extreme erosion duration in March and September becomes clear in view of the extreme excess of the Weibul-distributed wind speeds and friction velocities. This causes a marked decrease in erosion duration and transport rates, despite comparatively small increases in wind speed. As a consequence, these two scenarios also formed the two extremes in the economic assessment. The reduction in the extended windbreak scenario, however, will probably not compensate for the extra costs and loss of income caused by the loss of production land (Riksen *et al*. 2004). Instead, the model can be used to find the economic optimum for the density of the windbreak network. If the off-site damage leads to significant costs to the community then this could become an important criterion for increasing the windbreak network. As shown by the scenario without windbreaks, the risk for off-site damage is 3.68 times higher than under the present situation. Although little is known about the relationship between the amount of dust emitted from arable land and off-site costs, we assume that this relationship is probably not linear. Especially health related costs will increase dramatically when the PM_{10} concentration in the air becomes too high. The U.S. Environmental Protection Agency's guidelines stipulate that PM_{10} levels should not exceed 150 µg m^{-3} (24-h interval) or 50 µg m^{-3} (annual average value) (Nordstrom and Hotta, 2004).

- The climate scenarios differ only slightly in terms of the spatial pattern of the annual erosion parameters, though more distinct differences appear in their seasonal analyses. While the negative NAO scenario shows a drastic reduction throughout the spring, and particularly in February, the September values increase due to rising wind speeds, as noted in the previous section. The risk of crop damage for crops sown in August-September will increase by a factor of 2. As a consequence, it could be necessary to change farm practices in this period to reduce this risk. In contrast, the positive NAO scenario shows notable increases in February and March, and the autumn months are drastically reduced. Here crops sown in February-March will need extra protection to reduce the increased wind erosion risk. On the Barnham site it is common practice to sow spring barley as a cover (nursing) crop two weeks ahead of sugar beets in order to protect the sugar beets against wind erosion. The increased risk in February and March will mainly increase the risk of wind erosion damage in the cover crop, and a failing cover crop could increase the risk of damage in the main crop. To avoid this risk it might be necessary to change this practice and switch to using cover crops sown in the winter.

4.5. Conclusions

The scenario runs with the WEELS wind erosion model give insight into the general change in erosion risk per month. With this information, the possible consequences for on-site and off-site damage can be estimated, and from this estimation, additional (policy) measures for controlling wind erosion can be formulated for the region in question.

The land use scenarios show no marked changes in the order of magnitude of the wind erosion parameters. Apart from slight differences in the spatial pattern of maximum sediment transport rates, changes in the erosion duration are mainly influenced by seasonal variations. The most marked changes are shown in the windbreak scenarios. The extended windbreak scenario is calculated with a total reduction of erosion parameters of more than 50%. The climate scenarios differ only slightly in the spatial pattern of annual erosion parameters, though more distinct differences appear in their seasonal analyses.

Due to the complex causal chain of large-scale circulation modes and the related highly dynamic local variations of wind climate, on the one hand, and the hardly predictable development thus far of primary market-controlled management strategies and farming practices, on the other, a reasonable definition of integrated land use and climate change scenarios constitutes a major scientific challenge for the prediction of future wind erosion risks.

Chapter 5

SOIL CONSERVATION POLICY MEASURES TO CONTROL WIND EROSION IN NORTHWESTERN EUROPE

M.J.P.M. Riksen, F. Brouwer and J. de Graaff

Published in: *Catena* **52,** 309-326, (2003)

In: Wind Born(e)Landscapes
(M.J.P.M. Riksen) Wageningen, 2006, pp.75 -93.

5. Soil conservation policy measures to control wind erosion in northwestern Europe

Michel Riksen[1] , Floor Brouwer[2] and Jan de Graaff [1]

[1] *Erosion and Soil & Water Conservation Group, Department of Environmental Sciences, Wageningen University, Nieuwe Kanaal 11, 6709 PA Wageningen, The Netherlands*

[2] *Agricultural Economics Research Institute (LEI), P.O. Box 29703, 2502 LS Den Haag, The Netherlands*

Abstract

Wind erosion is not as significant or widespread a problem in Europe as in dryer parts of the world, but it can cause major damage in small areas. The hazard is greatest in the lowlands of northwestern Europe with more than 3 million ha at high-potential wind erosion risk. Crop damage and off-site damage have prompted farmers and policymakers to pay more attention to wind erosion control. A great variety of measures have been developed in the last decades. Most farmers, however, only use measures to protect their high value crops. In existing policies little attention is paid to the off-site effects and long-term effects of wind erosion. There are no direct policy measures at a European level to control soil erosion, and few measures exist in individual Member States. Agricultural or environmental EC policies offer different policy tools to approach the wind erosion problems related to agricultural practices. Tools like subsidies for the re-afforestation of arable land can help regional policy makers with the implementation of wind erosion control measures. A case study concerning the 'Code of Good Agricultural Practice' shows that regional differences result in different control measures that fits best given the physical, social and economic context. The formulation of the practical details of such Code should therefor remain a task of the local or regional government. The main objectives of a Code of Good Agricultural Practice could be formulated at national or European level.

Keywords: Wind erosion; Soil conservation; Good Agricultural Practice, Policy; Northwest Europe

5.1. Introduction

Water erosion is one of the most important agriculturally related environmental problems in Europe, especially in the Mediterranean countries. Wind erosion is not as significant or widespread a problem in Europe, but it can cause major damage in small areas. The hazard is greatest in the lowlands of northwestern Europe, in places such as Lower Saxony (about 2 million ha of land), The Netherlands (97,000 ha), western Denmark (about 1 million ha), southern Sweden (170,000 ha) and south-eastern and eastern England (260,000 ha) (Riksen and De Graaff, 2001). A recent study showed that wind erosion is also frequently occurring in north-eastern Spain (Sterk *et al*., 1999), but compared with water erosion, wind erosion is a minor problem in southern Europe.

On-site effects of wind erosion are damage to crops, loss of fertile topsoil and loss of soil structure resulting in yield reduction and the need for additional inputs, and the long-term degradation of the soil. The off-site costs are mainly the result of dust penetration into residential areas and into machinery. The relationship between on-site and off-site effects is difficult to quantify. Huszar and Piper (1986) in New Mexico found the off-farm effects to exceed the on-farm effects. Except from press releases about severe wind erosion events, little is known about off-site costs in Europe. Uncertainty remains regarding long-term effects (including health effects).

Unfavorable management practices like growing susceptible crops on large fields, intensive tillage or soil desinfection practices, can contribute to the problem. Figure 5.1 shows serious soil degradation due to wind and water erosion on arable land near Sjöbo, Sweden. In the Mediterranean, conservation tillage (through minimum tillage or no tillage farming) has recently contributed to reduced erosion. In Northwest Europe several changes in agricultural practices over the past decades have increased the hazard of wind erosion (Riksen and de Graaff, 2001). Prominent among these are: the intensification of production, including the increase in the size of fields, the intensive use of machinery and the grubbing-up of hedges and hedgerows. The size of agricultural holdings has doubled in developed agriculture since the 1970s, increasing from 9 to 18 ha (FAOstat website: http://www.fao.org/). Increases in crop damage and in off-site damage have prompted farmers and policymakers to pay more attention to wind erosion control.

Figure 5.1. Wind erosion has led to the degradation of some of the farmland in the research area. Vomb, Sweden, May 1999

A great variety of measures have been applied: more careful tillage and crop rotation; physical control measures, such as hedges and shelterbelts; and agronomic measures, such as cover crops. Most farmers, however, only use measures to protect their main crop. Little attention is paid to the off-site effects or the long-term effect of wind erosion in existing policy.

This paper examines the role of policies and farm management practices in controlling the effects of wind erosion on European light sandy soils. The study reported is part of the European Union funded project: 'Wind Erosion on European Light Soils (WEELS)'. The main objectives of this particular study were:

- To trace existing public policy measures in several Member States (including national measures in northern Germany and The Netherlands), that are intended to control wind erosion directly or indirectly (section 5.2).
- To evaluate policy measures, which can abate the harmful effects of wind erosion and contribute to the mitigation of its on- and off-site effects. The criteria applied to these measures are their efficiency and effectiveness (costs relative to the ability to control wind erosion) (section 5.3).
- To evaluate the efforts taken by the stakeholders involved in their attempt to control wind erosion (section 5.3).

The study consists of a literature research and interviews with policy makers. Most of this information was available within the WEELS project.

5.2. Policy measures to control wind erosion in the EU

In the EU land users have to deal with many regulations that originate from policies at different levels: EU level, national level, regional level and local level. Some of these regulations or policies directly aim at the control of erosion. Other regulations can have an indirect influence on the extent of erosion, both positive and negative. There is also a distinction in the degree of legal obligation.

Current policy measures for soil conservation in general are identified in this section and their relevance to the control of wind erosion is explored. Most existing measures are mandatory requirements under national and regional policies. Compensatory payments are offered in some member states in the context of the agri-environmental measures and forestry measures. It is arguable, nonetheless, whether those public funds should be used to reward farmers in return for measures taken to control wind erosion.

5.2.1. Direct policy measures to control wind erosion

In this study we looked for direct policy measures to control wind erosion at the different policy levels in the EU; at EU, national and regional level.

5.2.1.1. EU level

Although the main objectives of the EU’s Fifth Environmental Action Programme 'Towards Sustainability' are to ' … maintain the overall quality of life; to maintain continuing access to natural resources; to avoid lasting environmental damage; to consider as sustainable a development which meets the needs of the present without compromising the ability of future generations to meet their overall needs', no specific reference is made in European legislation to the control of wind erosion. There are no direct policy measures at European level to control wind or water erosion on agricultural land.

5.2.1.2. Individual Member States

In some individual member States direct policy measures to control wind erosion exist. These measures can be subdivided in:

- Mandatory measures to which land users are legally bound to act according to these regulations.
- Exemptions to mandatory measures that do forbid certain practises in normal situations, but allow these as wind erosion control measure.
- Voluntary measures to control wind erosion.

5.2.1.3. Mandatory measures to control erosion problems

This kind of measures only exists in a few Member States e.g. in Germany and The Netherlands. In Germany the national Soil Protection act forms the base for more detailed regulations at federal level depending on the extent of erosion problems in these federal states. Whereas in The Netherlands the regulations are directly related to regions where farm practices can lead to serious wind erosion.

<u>Mandatory measures at national level</u>
Mandatory measures apply to farmers in Germany in the context of the implementation of soil conservation. Measures need to be taken under the Soil Protection Act (Bundes Bodenschutzgesetz 17-03-1998 [BGBI. I S. 502]) to reduce or to prevent erosion problems. General objectives for good agricultural practice are developed at the national level by a committee of scientists, extension officers, policy makers and farmers. "Good Agricultural Practice" means that farmers are compelled to take precautionary measures to preserve soil fertility and the capacity of the soil as natural resource. The agricultural extension service does instruct farmers about the principles of Good Agricultural Practice. In cases of off-site damage due to erosion on farmland, the farmer can be penalised if he can be shown not to have farmed according to the Good Agricultural Practice Code. On the other hand compensatory payments are offered where constraints need to be met that go beyond what is legally required.

Table 5.1. List of measures of which at least one should be applied on arable fields after harvesting in the areas pointed out by the Dutch government

	Type of measure
a	Grow a green manure
b	Break up the soil to create a rough soil surface
c	Apply a layer of cellulose
d	Apply a layer of compost
e	Apply a layer of straw

Regional directives

Directives to combat wind erosion in The Netherlands are restricted to particular regions. In these regions it is forbidden on arable land to create a situation in which wind erosion can occur. Farmers are therefore obliged to take at least one measure from a prescribed list of measures (Table 5.1). For example farmers in the so-called Veenkoloniën are only obliged to take measures on desinfected land. Desinfection of the topsoil often takes place after a potato crop resulting in a very smooth highly erodible bare field. These directives became valid in July 2001.

5.2.1.4. Exemption from mandatory measures

In some cases farmers need to be exempted from general mandatory measures to legalize certain wind erosion control measures like in the following case found in The Netherlands. In general mandatory measures apply to farmers who use animal manure. They need to work manure in the soil soon after application. In order to reduce damage from wind erosion, Dutch farmers in Veenkoloniën and Texel are exempted from such restrictions. The exempted areas are those that are the most vulnerable to wind erosion. In these regions, the application of animal manure as a surface protection layer (Figure 5.2) is permitted during the spring period, but only when farmers depend on a rotation with 50% (starch) potatoes. The main reason for this exemption is that other measures are too expensive for this low profitable crop.

The high concentration of livestock production in The Netherlands and the excessive amounts of livestock manure offer incentives to increase livestock production in regions which originally mainly focussed on arable production. This is observed to some extent, allowing farmers to dispose of excess amounts of manure at lower costs than would be the case in regions with a high concentration of livestock production. This trend is also observed in the Veenkoloniën region (Table 5.2). After the introduction of fertilisers, this region was mainly specialised in arable production. This caused a dramatic drop in soil organic matter content and has thus increased the erodibility of these soils. At present the supply of livestock

Figure 5.2. Prevention of wind erosion by spraying liquid Cattle manure (15 tonnes/ha) on top of the soil is still allowed in the Dutch reclaimed peat soils (Photo: Proefboerderij 't Kompas/Kooijenburg PVA-NNO, the Netherlands)

manure in this area has increased again. The application of livestock manure is permitted in this region during the cropping season, increasing the options to dispose of excess amounts of livestock manure. The period of the year to apply livestock manure has been extended by national legislation to soils which are vulnerable to erosion.

The changes have also increased the viability of farming in that region, reducing the risks of farm abandonment. Farm abandonment is likely to result in increased wind erosion due to unfavorable management of the land. Without a proper management these low fertile soils might not generate a sufficient vegetation cover to prevent wind erosion.

Table 5.2. Arable and livestock production in the Veenkoloniën, 1985, 1990, 1995 and 1999 and relative change over these periods

Feature	*1985*	*1990*	*1995*	*1999*	*relative change (%)*	
					1985-1999	1995-1999
Arable crops (ha)	72,675	72,755	68,833	70,094	- 4	+ 2
Arable farms	2681	2299	1923	1859	- 44	- 3
Starch potatoes (ha)	32,804	32,308	30,573	27,476	- 19	- 10
Cattle (number)	51,819	45,571	42,101	50,918	- 2	+ 21
Holdings with cattle	992	752	599	658	- 51	- 10
Pigs (number)	83,203	98,055	107,713	152,424	+ 83	+ 42
Poultry (number)	1,766,335	1,686,690	2,691,731	3,965,080	+ 124	+ 47

Source: LEI (Agricultural Economic research Institute in The Netherlands)

5.2.1.5. Voluntary measures

Voluntary measures are intended to guide farmers in their attempts to avoid long-term soil and environmental damage. This advise is provided at different levels like at crop level where farmers are advised by the industry to which they deliver their products, or regional level by the regional extension service.

In Britain soil conservation practices are covered in the Codes of Good Agricultural Practice. The Soil Code is designed to guide farmers in their attempt to prevent the harmful effects of farming practices on soils (MAFF, 1998). The Soil Code contains a list of relevant measures to be adopted, including a set of 'best practices'. Farmers, however, are not legally bound to manage their farm according to this Code. Several examples of relevant measures from the Code are discussed in section 5.3.3.

5.2.1.6. Grants for wind erosion control

In some cases farmers gets grants for the implementation of wind erosion control measures. In Denmark the main policy is to establish a dense shelterbelt network in regions at high wind erosion risk. Farmers can participate on voluntary basis. Despite the high investment costs, planting shelterbelts is a big success in Denmark resulting in the planting of 900 km of shelterbelts per year (Als, 1989). Farmers receive a grant of 50% in connection with soil preparation, plants, planting and maintenance for 3 years if the hedges form part of a regional shelterbelt project.

5.2.2. Policy measures that indirectly influence wind erosion

Agricultural and environmental policy measures can have an indirect positive or negative effect on the extent of wind erosion. In this section we look at two examples of compensatory measures that could be of value for the control of wind erosion. That agricultural policy measures can have a negative side effect is illustrated by an example how Set Aside in Sweden led to further soil degradation. Also the mandatory measures apply to farmers who use animal manure as described in section 5.2.1.2 can been seen as an example of a policy measure that had an indirect negative impact on erosion control.

5.2.2.1. Compensatory measures

The provision of incentives for environmental purposes is a relative new policy instrument in the EU. Compensatory payments are offered under EU Regulation 2078/92 and EU Regulation 2080/92, and these can indirectly contribute towards the control of wind erosion.

The provision of compensatory measures under EU Regulation 2078/92

Regulation 2078/92, which became operational in 1993, aims to 'encourage farmers to make undertakings regarding farming methods compatible with the requirements of environmental protection and maintenance of the countryside, and thereby to contribute to balancing the market; whereas the measures must compensate farmers for any income losses caused by reductions in output and/or increases in costs and for the part they play in improving the environment'.

Some of these measures might be used to counter wind erosion. The measures must be linked to agricultural activities that provide environmental benefits. Several objectives are eligible for funding (CEC, 1992):

1. Substantial reduction in the use of agrochemicals, or the maintenance of reductions already achieved; or the introduction or continuation of organic farming;
2. Changing to more extensive forms of production or maintaining extensive production methods introduced in the past;
3. Reducing stock density of sheep and/or cattle;
4. Using farm practices compatible with the requirements of protection of the environment and natural resources, as well as the maintenance of the countryside and the landscape;
5. Upkeep of abandoned farmlands or woodlands;
6. Long-term set-aside (20 years) with a view to use for environmentally sound purposes, in particular, for the establishment of biotope reserves or national parks or for the protection of hydrological systems;
7. Managing land for public access and/or leisure.

Farmers are paid on a voluntary and contractual basis for the provision of environmental services that are defined in the programmes. Approximately 17% of the agricultural land in the EU is subject to management agreements under Regulation 2078/92, covering some 22 million ha (Table 5.3). The coverage differs considerably by country.

Policy makers could make use of these funds in regions with wind erosion problems due to agricultural activities. Farmers could get compensated for using farm practices e.g. wind erosion control measures, compatible with the requirements of protection of the environment and natural resources, as well as the maintenance of the countryside and the landscape (objective 4).

An investigation of the MEKA (Programm zur Marktentlastungs und Kulturlandschaftsausgleich) programme in Baden-Württemberg showed that these measures under 2078/92 have reduced wind and water erosion by some 3%. The key measures included transformations to organic farming and measures to extensify the production of arable crops and of grassland and environmental-friendly farming practices. The payments did not exceed 280 € per hectare. The annual payments on average amounted to about 1,500 € per holding (Wilson, 1995).

Table 5.3. Take-up of aid schemes under Regulation 2078/92 at mid-1997 for some EC member states

Member State	Total number of 2078 contracts	No. of contracts as % of total farms	No. of contracts as % of all	Total area Under contract	Proportion of total UAA under contract
	N	%	%	Ha	%
Belgium	1,242	1.7	0.1	17,000	1.2
Finland	91,509	a)	6.8	2,000,000	91.2
Germany	554,836	a)	41.2	6,353,000	37.0
Greece	1,839	0.2	0.1	12,000	0.3
Luxembourg	1,922	60.0	0.1	97,000	76.9
Netherlands	5,854	5.1	0.4	31,000	1.5
Spain	29,599	2.3	2.1	532,000	2.1
Sweden	68,969	77.6	5.1	1,561,000	51.0
United Kingdom	21,482	9.16	1.6	1,322,000	8.1
Total all EC member states	1,345,119	18.3	100	22,628,000	16.5

a) Impossible to determine with any accuracy as many farms hold multiple contracts.
Source: Buller (2000)
UAA = utilisable agricultural areas

Some of the main areas of interest in the agri-environmental programmes in the WEELS countries (Sweden, Germany, UK and The Netherlands) are presented in Table 5.4. A more detailed investigation into the effects of each individual measure on wind erosion is needed. This enables policymakers to select only those measures that have a positive effect on wind erosion control in regions with a high wind erosion risk.

The provision of compensatory measures under EU Regulation 2080/92

In addition to the agri-environment measures under Regulation 2078/92, measures for the afforestation of agricultural land were also introduced in 1992 with the reform of the Common Agricultural Policy. Member states have to establish a national framework for both regulations, defined for and possibly differentiated between regions.

Table 5.4. Emphasis given to the agri-environmental programmes in the 4 WEELS Countries

Country	*Key areas of the programmes involved*
Germany	Programmes in Lower Saxony focus on extensive grassland and the transition to organic farming
Netherlands	Management agreements (e.g. limiting grazing and mowing) to reduce the decline in plant species diversity and the conservation of valuable grasslands
Sweden	Focus on landscape issues (e.g. open natural landscapes, forest areas and semi-natural grasslands)
United Kingdom	The principal programmes are in Environmentally Sensitive Areas, where farming practices could change ecology, landscape or heritage

Regulation 2080/92, which concerns forestry on agricultural holdings, is considered important with regard to land use and environmental protection. Member States may grant support for afforestation to farmers, to any other individual or forestry association. The support may be granted to meet:

- costs of planting;
- costs of maintenance over a period of (the first) five years;
- income losses in agriculture because of afforestation; and
- investments in woodland improvements, such as the provision of shelterbelts, fire-breaks, waterpoints and forest roads, and the improvement of woodland under cork oak.

The most beneficial effects on the environment are observed with well-managed short- rotation forest trees.

Afforestation of agricultural land can take place in two schemes:

1. Afforestation of agricultural land on a temporary basis. This applies to agricultural land, which is part of a set-aside scheme. For example about 1500 ha of agricultural land is currently used to grow forests in The Netherlands. The scheme has been adopted in the Veenkoloniën region. Although no precise figures are available, the uptake in this region is a few hundred hectares, primarily by farmers who were considering to give up farming. Contracts for afforestation (mainly with poplars) are for a period of between 15 and 30 years. After the contracts ends the land can still be used for agricultural purposes.
2. Afforestation of agricultural land on a permanent basis. In The Netherlands, this so-called SBL regulation ('Stimulering bosaanleg op landbouwgronden), is also used as part of Regulation 2080/92 (see above). The programme, submitted by The Netherlands for approval by the European Commission, includes a total of about 9,200 ha of land to be afforested. Between 1993 and 1996, around 6.500 ha of land has been afforested under this scheme generally on arable land. Elsewhere in the EU more than 60% of land afforested under Regulation 2080/92, used to be permanent grassland.

Afforestation in areas prone to wind erosion have more effect on reducing the erosion risk on arable land than on grass land. Afforestation programmes generally offer favourable options to farmers with marginal land, because they are always searching for other production opportunities to bring in additional income (European Commission, 1997). This was for example observed in the Vomb valley, Sweden, where farmland was not longer cultivated, but planted with fuel wood or used as set aside. The fuel wood provides a good soil protection, whereas the set aside in this region does not reduced the erosion risk due to the lack of the development of a sufficient vegetation cover on these poor sandy soils.

Table 5.5. Uptake of programmes under Regulation 2080

Feature	*Germany*	*Netherlands*	*UK*
Area afforested (ha)	18,611	6,499	61,597
Share of utilised agricultural area (%)	0.1	0.3	0.4
Number of beneficiaries	15636	386	10452
Share of broadleaves and mixed plantations (%)	91	95	67

Table 5.5 summarises the uptake of programmes under this scheme for Germany, The Netherlands and The United Kingdom. A small amount of resources were agreed under this scheme for the period 1993-97 in Sweden, but no further information was available.

5.3. Discussion: What role can the EU play to combat wind erosion in member states

Section 5.2 showed many different approaches, existing and potential, on which a wind erosion policy can be based. The main question here is what role the EU can play in the future to combat wind erosion on agricultural land in the member states. Is there a need for general EU policy measures for wind erosion control or should the EC support regional policies by providing supporting tools? This section discusses the approaches currently available to the EU on their applicability to support wind erosion control in the member states. It also discusses the role of the EC in the formulation of a Code of Good Agricultural Practice (GAP).

5.3.1. Approaches to reckon with the external effects of farming practices in agricultural and environmental policies

Successful implementation of wind erosion control policy measures depend on how effectively these policy instruments can be linked to the external effects of farming practices and soil conservation measures. As part of Agenda 2000, three approaches are currently available to the EU to consider the external effects of farming practices, including their effects on the conservation of soils:

- First, general mandatory environmental requirements to meet legal obligations. The application of minimum environmental conditions in agriculture implies that all farmers must comply with them. As shown above, some Member States of the EU already apply mandatory measures to conserve their soils.
- Second, environmental conditions could be attached to support payments under the present CAP (Common Agricultural Policy) in the EU. This is commonly called "cross-compliance". A few member states have put environmental conditions on support payments.

- Third, support for agri-environmental schemes and the provision of environmental conditions to support measures for farmers. This would deliver environmental ‘services’ on a voluntary basis. An additional payment could be provided if an extra effort were to be made, but this must go beyond the requirements (applicable to cross-compliance) laid down in a Code of Good Agricultural Practice. In this option, farmers would be eligible for compensatory payments on a voluntary and contractual basis for the provision of environmental services that are defined in the programme.

5.3.2. Integrated Rural Development

The Agenda 2000 reform of the Common Agricultural Policy (CAP) in 1999 formulated a transition from the CAP to Integrated Rural Development. However, the agreement made at the EU Summit in March 1999 was significantly less ambitious than what was originally proposed by the Commission (Lowe and Brouwer, 2000). Current measures include a Rural Development Regulation (Regulation 1257/1999) which is aimed to:

- Support a viable and sustainable agriculture and forestry sector as part of the rural economy;
- Develop the territorial, economic and social conditions which are considered to be necessary for maintaining the rural population;
- Maintain and improve the environment, the countryside and the natural heritage of rural areas.

Regulation 1257/1999 has formulated several objectives for rural development policy, including the maintenance and promotion of low-input farming systems and the preservation and promotion of high-value wildlife and a sustainable agriculture that respects environmental requirements. It builds on the wide diversity of production systems, which currently exist in Europe and are vital to maintaining the multi-functional nature of agriculture.

Some policy measures now need to be reviewed by the EC in the context of Rural Development Regulation to abate harmful effects of wind erosion and mitigate their on-farm and off-farm effects. Criteria that require consideration are:

- To what extent regionally targeted problems are addressed?
- Are all relevant stakeholders involved?
- What are the costs involved of measures proposed, either for the farming community or the public sector?

This review should answer the question if these policy measures sufficiently reduce wind erosion damage and how the uptake is of these policy measures in the different regions at risk in Europe.

5.3.3. Good Agricultural Practice

In order to arrive at a more clear formulation of the conditions that have to be fulfilled to qualify for payments, a proper definition of the term "Good Agricultural Practice (GAP)" is essential. GAP is the benchmark. The requirements that GAP has to meet can be defined as "farm management that ties in with the existing legal framework". Penalties would be imposed on the parts of the income-support for farms that do not meet the requirements of GAP. The penalty would be either a reduction in or possibly even the withdrawal of income support. Difficulties would remain with the provision of compensatory payments conditional on meeting certain environmental requirements. The costs involved in putting such conditions on compensatory payments might be high relative to their efficiency, with high costs required in control and monitoring and in the risk of fraud.

The linkage of environmental and conservation conditions to income support must tie in, wherever possible, with the conservation and environmental standards demanded by society. For that reason, the measures will have to be appropriate and geared to specific nationally and regionally distinctive environmental features. Moreover, the standards that are laid down for the Code of Good Agricultural Practice must be tightened. Similar developments in GAP would also have implications for agri-environmental policy. With the tightening of the standards of environmental quality, measures that are currently eligible for income support may well apply as conditions for income support in the context of market and price control policy.

Several considerations for the formulation of a better Code of Good Agricultural Practice to control wind erosion are presented in the next section, including the objectives and requirements with regard to wind erosion control, as well as the role of the EU.

5.3.3.1. Objectives

Wind erosion mostly affects sandy and peaty soils when they have little or no vegetation cover, especially between March and June. Good Agricultural Practice should therefore be focused on the protection of the soil during this vulnerable period. General objectives should be:

1) Sustainability: sustainable use of the means of production by avoiding crop damage, by preventing that the rate of erosion exceeds that of soil formation and by restoring the fertility of degraded soils;
2) Minimal off-site damage: public and private property and public health should be protected against harmful effects.

Good Agricultural Practice should therefore result in the use of additional measures in cases where the general agricultural practices do not meet these objectives. These objectives could be accomplished through a single measure or a combination of measures. There is no standard procedure to prevent wind erosion at field level.

The effectiveness of measures at field level does not only depend on soil type. Other factors of importance include types of crops grown, and crop rotations applied. Measures like an artificial protection layer or straw mulching can work for high value crops like flower bulbs, but are too expensive for crops like sugar beet or fodder maize. To fill in the practical details of the GAP is not longer a task for the EU, but for local governments in co-operation with the stakeholders. Several steps need to be taken into account in the selection of measures:

1. assessment of the potential wind erosion risk based on climate, soil type and land use (forest, land with permanent vegetation cover or arable land);
2. assessment of potential risk for off-site damage;
3. assessment of actual wind erosion risk based on crop rotation, crop type, field size and farm-management practices;
4. selection of measures that best fit within existing land use and farm-management practices based on their effects and extra costs. Measures should fit within the farmer's capacity or capability (labour, finance);
5. if there are no suitable measures that fit within existing practices to reduce the wind erosion risk to an acceptable level, additional incentives, like subsidies for planting shelterbelts or changing land use, will be needed.

This procedure can be applied at farm level as well as at regional level. Consensus between the stakeholders involved (landowners, land users, scientists and local or regional policy makers) could result in a Code of Good Agricultural Practice for wind erosion control. This Code should describe:

1. the agreed management practices for fields classified as having a high potential wind erosion risk;
2. who is responsible;
3. regulation for compensatory payments;
4. penalties in case of wind erosion damage due to mismanagement.

The EU could support the GAP by delivering the tools e.g. compensatory payments or penalties on income support, necessary to stimulate farmers to farm according this Code. Two types of measures might be applied on fields with high wind erosion risk:

- measures with a temporary effect used to minimize the erosion risk in those periods of a crop rotation when there is little or no protection;
- measures with a more permanent character which lower the risk of wind erosion.

Table 5.6. presents a selection of measures, which are commonly used in northern Europe. On locations with a high risk for off-site damage due to wind erosion, for example along main roads or near to domestic houses, measures that offer a more permanent protection should be used.

Table 5.6. List of most common measures to minimise wind erosion risk in Northern Europe

Type of measures	*Measures*	*Remarks*
Measures that minimize actual risk (short term effect)	- Autumn sown varieties	Need to be sown before the end of October to develop a sufficient cover
	- Mixed cropping	After the main crop is harvested, second crop remains on the field
	- Nursing or cover crop	More herbicides needed
	- Straw planting	Unsuitable on light sandy soils
	- Organic protection layer (e.g. liquid manure; sewage sludge; sugar beet factory lime)	Use depends on availability, and regulations on the use of these products.
	- Synthetic stabilizers	Unsuitable on peat soils
	- Time of cultivation	Depends on availability of labor and equipment
	- Cultivation practice (e.g. minimum tillage; plough and press)	Not suitable for all crop or soil types
Measures that lower the potential risk (long term effect)	- Smaller fields	Increase in operational time and costs
	- Change of arable land to permanent pasture or woodland	Loss of agricultural production and farm income
	- Marling (increasing the clay content to 8 - 10%)	Suitable material should be available close-by
	- Wind barriers	High investment costs, and loss of production land. Takes several years before it provides full protection. Protection from the shelter reduces with distance.

Source: WEELS survey 1998 - 2000; Jaggard, 1995; MAFF,1998; Borstlap, 1999

5.3.3.2. Costs and benefits of Good Agricultural Practice

The costs of Good Agricultural Practice depend not only on the type of measure but also on the economic value of the main crop and the price of land. The latter is especially the case for measures like strip cropping or shelterbelts.

According to Piper (1989) the benefits of Good Agricultural Practice can be defined as the total damage without erosion control practices minus the damage with the practices. The net benefits are then the benefits minus the costs of the wind erosion control measures. Although little is known about actual costs of wind erosion damage, it is likely that the off-site costs exceed the on-site costs. Piper and Huszar (1989) estimated that the annual off-site household costs in New Mexico ranged from € 227 million to € 407 million, while Davis and Condra (1989) estimated that the annual on-site costs in New Mexico were only € 8.7 million. The WEELS survey showed that within a region the off-site costs varied considerably. In the Molbergen community in Lower Saxony, Germany the off-site damage is negligible according to the stakeholders interviewed. In the nearby village Garrel, however, roads have to be cleaned nearly every year.

Little is known of the effects of dust on human health and the spread of diseases. Dust emitted during wind erosion also causes significant off-site damage from deposition in adjacent ecosystems. Chemical substances, which are often contained in the fine particle fraction, contaminate surface- and ground -waters and cause eutrophication. This process is becoming increasingly important in the North-European economies, which are characterised by:

1) the use of large amounts of fertilisers, manure and pesticides, and
2) increasing contamination of arable soils by the atmospheric deposit of various pollutants (heavy metals, dioxins, radionuclides, nitrogen, organic pollutants, xenobiotica, etc).

The spread of pollutants in the fine particles derived from the wind erosion of contaminated arable land has not yet been fully quantified, but must be considered important. Fine soil particle emissions may also play an important role in the spread of plant and animal diseases (Bout 1987; Pimentel *et al*. 1995) such as foot and mouth disease. Fine soil particle emissions can cause also lung and other respiratory problems (Knottnerus, 1985; Van Nijf, 1987; Pope *et al*., 1999). Given the knowledge that the dust can travel over long distances, these off-site effect is not a local or regional problem, but concerns whole Europe. More research is therefor needed at European level.

The benefits in case of Good Agricultural Practice are therefore difficult to quantify. Table 5.7 shows the benefits of different erosion control measures for a sugar beet crop based on a survey in the region around Barnham, England. It also shows the benefits for different levels of off-site costs respectively: zero, 10 times on-site costs and 20 times on-site costs.

5.3.3.3. The adoption of Good Agricultural Practice

A study by the OECD (1998) showed that farmers take decisions that improve the environment if they:

- are provided the right incentives,
- are made aware of the environmental costs and benefits of their activities,
- are motivated, and
- have enough resources.

Table 5.7. Benefits of Good Agricultural Practice (GAP) for three different levels off-site costs (€/ha)

	Production costs[1)]	On-site costs due to wind erosion[2)]	Net benefits of GAP in case off-site costs=0	Net benefits of GAP for off-site costs=10 times on-site costs	Net benefits of GAP for off-site costs=20 times on-site costs
Without case: sugar beet	586	175			
With case: sugar beet with cover crop	666	50	45	1170	2420
With case: sugar beet with plough and press	586	98	77	770	1540
With case: sugar beet with Vinamul layer	800	50	-89	1036	2286

1) WEELS survey1998 - 2000, Barnham site
2) These measures never give a 100% protection. These figures are a rough estimation based on information from farmers (WEELS survey1998 - 2000, Barnham site) and literature.

The adoption of Good Agricultural Practice by farmers depends on their perception of the problem. In the case of wind erosion this differs considerably between farmers and depends on:

- the value of the crops they grow: damage in crops like sugar beet and potato leads to higher extra costs than in crops like barley or fodder maize;
- the way they look at soil fertility: the loss of soil fertility is often not noticed, because it can be masked with fertilisers, and few farmers see it as a problem (WEELS, 1999);
- land ownership: most farmers are not willing to undertake large investments on land they do not own. In Sweden it was found that some degraded fields were leased and only used as 'set-aside'. No measures were taken to improve the soil or to stop further degradation;
- off-site effects and the actors involved: the extent of dust storms and the way this affects the local community determines whether farmers feel obliged to the community to avoid wind erosion.

The most appropriate technology is the one that best fits the farming system. For the purpose of adoption, it is imperative, before recommending a course of action, to examine its consequences for the farming system, for its socio-cultural compatibility, the labour input, and the costs of innovations (Lamers, 1998).

5.3.3.4. Monitoring

When additional payments, penalties or cross compliance is part of the Code of Good Agricultural Practice, one should also agree on how the implementation of control measures should be monitored. Monitoring can be linked to funds farmers receive. As in the USA, farmers who receive funds from the government must implement a soil conservation plan for fields that are vulnerable to erosion. In several States they also need to have a plan to prevent damage to off-site properties. The disadvantage of this is that farmers who do not claim these funds can not be penalised for not farming according the code of Good Agricultural Practice.

Monitoring can also be based on the potential wind erosion risk map. Fields classified as high potential wind erosion risk could be monitored by obtaining soil coverage and crop type using remote sensing techniques.

5.4. Conclusions

- Regionally targeted efforts taken by local authorities could stimulate farmers to take measures to control wind erosion and reduce both on-farm and off-farm effects. Compensatory payments could be introduced for measures taken beyond legal requirements. These would compensate farmers for any loss of income. Some Member States have already good experiences with offering compensatory payments to farmers who operate in groundwater protection zones. For example in the groundwater protection zones near Grönheim, Lower Saxony, Germany farmers have for the last few years been able to get compensatory payments for growing catch crops. Most farmers now grow them.
- Further consideration should be given to the establishment of voluntary agreements between the main actors involved in wind erosion problems at local level (farmers, extension service and local communities). Experience might be gained from the land care groups that have been established in Australia and New Zealand to promote more sustainable land management practices. Such arrangements, with voluntary participation, could develop awareness among farmers, identify options for change, guide implementation strategies and attract resources for their implementation.
- Several tools are required for the proper implementation of Codes of Good Agricultural Practice. These include the provision of wind-erosion risk maps; mapping of the vulnerability of off-site damage; and regulations for the management of arable land in erosion-risk classes. In Lower Saxony, this approach has reached the stage of defining these management regulations by a committee formed of scientists, policy makers and farmers' organisations.
- In case of off-site effects of wind erosion the source remains often difficult to identify, and individual farmers can not be held responsible. This complicates the monitoring of measures taken by the farming community and of the benefits of controlling wind erosion. The difficulties of linking measures taken by farmers to the occurrence of wind erosion hamper the application of cross compliance because it constitutes of environmental conditions for direct payments. Proper monitoring of wind erosion would be essential if a link were to be established between the measures taken out the provision of payments to compensate farmers for their foregone income.

PART II

THE ROLE OF WIND EROSION IN NATURAL LANDSCAPES

Chapter 6

WILL WE LOSE THE LAST ACTIVE INLAND DRIFT SANDS OF WESTERN EUROPE?

The origin and development of the inland drift-sand ecotype in The Netherlands

M. Riksen, R. Ketner-Oostra, C. van Turnhout, M. Nijssen,
D. Goossens, P.D. Jungerius and W. Spaan

In press: *Landscape ecology*

In: Wind Born(e)Landscapes
(M.J.P.M. Riksen) Wageningen, 2005, pp. 99 -122.

6. Will we lose the last active inland drift sands of Western Europe?

The origin and development of the inland drift-sand ecotype in The Netherlands

M. Riksen[1], R. Ketner-Oostra[2], C. van Turnhout[3,4], M. Nijssen[5], D. Goossens[6,7], P.D. Jungerius[8] and W. Spaan[1]

[1] *Erosion and Soil & Water Conservation group, Department of Environmental Science, Wageningen University, Nieuwe Kanaal 11, 6709 PA Wageningen, The Netherlands.*
[2] *Nature Conservation & Plant Ecology group, Department of Environmental Sciences, Wageningen University, Bornsesteeg 69, 6708 PD Wageningen, The Netherlands.*
[3] *SOVON, Dutch Centre for Field Ornithology, Rijksstraatweg 178, 6573 DG Beek-Ubbergen, The Netherlands.*
[4] *Department of environmental Studies/ Department Animal Ecology, Radboud University Nijmegen, P.O. box 9010, 6500 GL Nijmegen, The Netherlands.*
[5] *Stichting Bargerveen/ Department Animal Ecology, Radboud University Nijmegen, P.O. box 9010, 6500 GL Nijmegen, The Netherlands.*
[6] *Physical and Regional Geography Research Group, Catholic University Leuven, Redingenstraat 16 bis, B-3000 Leuven, Belgium.*
[7] *Laboratoire Interuniversitaire des Systèmes Atmosphériques, Université de Paris 12, 61 Av. du Général de Gaulle, 94010 Créteil, France.*
[8] *Geomorphology & Landscape (G&L), Oude Bennekomseweg 31, 6717 LM Ede, The Netherlands.*

Abstract

In The Netherlands the total active drift sand area has been declining rapidly during the last 50 years. To preserve the in-land drift sands, it is necessary to understand its origin and development and the role of human activity in this semi-natural ecotype. The objective of this literature review is to describe the development of the drift-sand ecotopes, to explain the rapid decline of the active drift sands, and to develop a management strategy for the remaining active drift sands.

Drift-sand landscapes are relatively young landscapes of Holocene age. They often occur as oval-shaped cells with a length of 1.5 to over 6 km in the direction of the prevailing wind. These cells presumably represent reactivated deposits of Younger Cover Sands. Large-scale erosion events in combination with human activity suppressed the development of vegetation. After the change in land use in the first half of the twentieth century in which most of the drift sands were re-afforested, the vegetation succession started to show a progressive development. In this stage inland drift-sand ecotopes developed in most of the remaining drift sands with all forms of the typical succession stages from bare sand to forest. The rate at which this development took place mainly depended on the geomorphological development stage of the area, the area size and human activity. Since the 1960s the increased nitrogen deposition has accelerated the vegetation succession, not only resulting in a further decline of the drift sands, but also in a loss of the fragile balance between the different ecotopes and loss of its typical habitants like the Tree Grayling and Tawny Pipit.

Most drift-sand vegetation and fauna need the presence of bare sand nearby and a certain level of erosion activity to survive. To preserve the drift-sand ecotype, it is therefore recommended to keep the area affected by erosion sufficiently large (process management). In the meantime one should also ‘maintain’ or increase the wind force in the drift-sand area by suppressing the growth of high vegetation and removing trees, which form a wind barrier. In areas which are less suitable for reactivation, one could restore the mosaic vegetation by removing the vegetation on a limited scale (pattern management). More research is needed to develop a more balanced management strategy and to develop a management tool for the managers of inland drift sands. Also the role of the increased nitrogen deposition in the regeneration process needs further investigation in order to find an effective way to suppress its effect. The development of management strategies for the Dutch inland drift sands might be of great value to drift-sand areas in Western Europe where nature conservationists start to show more interest in the restoration of former drift-sand areas.

Key words: Drift-sand ecotype, Wind erosion, Nature conservation, The Netherlands.

6.1. Introduction

In today's Europe, the interest in the inland drift-sand landscape is on the rise. The inland drift sands are appreciated for their unique landscape, their cultural/historical value and their unique flora and fauna. They are also appreciated for recreational purposes. Inland drift sands, also known as drift sands, form a separate group within aeolian forms and deposits and can be defined as (Koster, 2005): aeolian deposits, irrespective of their form as sheets or dunes, resulting from reactivation of sandy deposits by human impact during the late Holocene. In this they differ from other aeolian forms such as coastal dunes or coastal drift sands, river dunes or cover sands.

The extent of drift sands in northwest Europe alone has been estimated at 3000-4000 km^2 (Castel *et al*., 1989), but outside The Netherlands, active drift-sand landscapes have almost completely disappeared. With this landscape, several Red-list species such as the Tawny Pipit (*Anthus campestris*) become extinct, along with various lichens (Bal *et al*., 2001). In The Netherlands several active drift-sand areas have been saved from the large re-forestation projects and officially turned into nature reserves. However without a certain level of erosion activity, these "active" drift sands evolve in a forest.

To preserve these drift sands simply by buying them and turning them into a protected area is therefore not enough. All kinds of negative external influences may influence their existence. For the preservation of the present biodiversity or the re-entry of lost species, the natural differentiating processes should first be restored.

This new nature approach is focused on management of systems (processes). The question is whether the inland drifts-sand ecotype can be preserved in a sustainable way by this approach. In some cases large scale reactivation of drift-sand areas by removing all the vegetation including the topsoil has led to a loss of the for drift sands characteristic dunes. To be able to manage these drift sands in a more sustainable way it is necessary to know how they have been developed. What are the stages in the development of the present drift-sand ecotype, and what are today's main bottlenecks? For a better management of the remaining active drift-sand areas and reactivation strategies, a more multi-disciplinary process-oriented approach is needed.

This paper presents an overview of the development of the inland drift sands in The Netherlands. First a description is given of the origin and development of inland drift sands in The Netherlands before 1960 (Section 6.2). Section 6.3 describes the rapid decline of the remaining active drift sands in The Netherlands after 1960 and the role of the increased atmospheric nitrogen deposition and the introduction of invasive species in the drift-sand ecotopes in this.

Section 6.4 discusses the consequences of these developments for the management of the drift sands and proposes a few topics for further research.

6.2. Origin and development of inland drift-sand ecotopes in The Netherlands

6.2.1. Late glacial dune fields and cover sands

Drift sands are mainly derived from late-Pleistocene sands. In Europe during parts of the Last Glacial, cold desert-like conditions prevailed. Extensive aeolian deposits were formed in the ‘European Sand Belt’ (Koster, 1978; Castel *et al*., 1989) which extends from the Northwest and central European lowlands, to the Polish-Russian border and beyond. Small areas with similar deposits are found in England most of them in East Anglia (Castel *et al*., 1989; Riksen and de Graaff, 2001). Koster (2005) recognizes various types of aeolian forms and deposits, based on a combination of geomorphology, sediment and depositional environment. Most important are the *cover sands* and *dune fields* (mainly river dunes).

From west to east across the European lowlands the proportion of cover sands to dune fields changes; cover sands are found mainly in the western part whereas dune fields predominate in the east (Koster, 2005). Within the cover sand region, a distinction is made between the almost level ‘Older Cover Sand’, which occasionally contains loamy laminae, and the undulating to rolling ‘Younger Cover Sand’ in which loam is absent (Pannekoek, 1956). The more pronounced relief of the younger sands is attributed to the trapping of sand in the vegetation, which followed the warming-up of the climate at the transition from the Pleistocene to the Holocene. Cover sands are commonly fine-grained with a modal grain size between 105 and 210 μm (Koster, 2005).

During the Holocene, the aeolian sands were gradually covered with forests. A brown forest soil developed in the upper part of the sands. Starting with the settlement of farmers in the Neolithic Age, about 5000 years ago, the forests were destroyed and replaced by heath land. The soil profile changed to a heath podzol.

6.2.2. Drift sands

Drift-sand landscapes are relative young landscapes of Holocene age. Several theories on the initiation of the sand drifts have been proposed. The most popular theories attribute drift- sands to agricultural practices, roads and cattle/sheep drifts or in some cases to the falling water table (Slicher van Bath, 1977). Heidinga (1984) found indications that the formation of the first drift sands coincides with periods of extreme droughts and heavy winds during the 10^{th} century AD, and that the drift sands developed on bare arable fields. Their main expansion however, took place after 1150 AD (Koster, 2005) after large-scale deforestation by men changing the landscape from a nearly closed to an open landscape with mainly heath land.

The communal heath lands were used for heath cutting to manure the arable fields. Heather sods together with sheep dung was used to manure the arable fields. For one ha of arable land a sod digging area of about 3 to 7 ha was needed. The great need for heather sods sometimes created large bare sandy surfaces, vulnerable to wind erosion.

Apart from sod digging, this agricultural practice needed a large area of heath land for grazing. Grazing and burning the heath lands also contributed significantly to the development of drift sands by keeping the landscape open and making the topsoil vulnerable to wind erosion.

Another theory links the drift sands with roads and cattle/sheep drifts, which in the loose sands were always unstable and often had to be shifted as Tesch *et al.* (1926) described for the Veluwe. This theory is more popular in Germany, because heath cutting for agricultural purposes was not practiced east of Schleswig Holstein (Pape, 1970). One of the few examples in The Netherlands is the recently discovered road of Late Bronze Age/Early Iron Age across the heath in SE North Brabant near the Belgian border (Van den Ancker and Jungerius, 2003).

Although deforestation, agricultural practices, roads and cattle/sheep drifts may have triggered their formation and maintained their activity, recent research by Koomen *et al.* (2004) points to a geomorphological control of the drift sands. They often occur as oval-shaped cells with a length of 1.5 to over 6 km in the direction of the prevailing south-westerly wind. These cells presumably represent reactivated deposits of the Younger Cover Sands, which are more sensitive to wind erosion than the Older Cover Sands due to their stronger relief and low loam content (Koomen *et al*., 2004). The structure within the cells shows a fairly regular pattern. At the south-west end the original cover sand morphology is replaced by a deflation plain in the cover sand, dotted with isolated nabkhas (dunes of drift sand formed around plants). Towards the north-east the deflation plain expands due to the gradual erosion of the nabkhas and the formation of vegetated parabolic dunes. This part is still active in the large sand drift areas of the Netherlands. Scattered remnant knobs, so-called "forts", testify to the former pattern of these nabkhas. The wind accumulates the drift sand in a wide zone around the deflation plain. Here parabolic dunes can develop due to erosion at the windward side of the deposits in combination with deposition at the lee side of the erosion dune. The lithology and morphogenesis of the inland drift sands is well described by Castel *et al*. (1989).

Koomen *et al*. (2004) found that all these occurrences have in common that they hardly show any change in outline in the 200 years that reliable topographic maps are available. The main period of aeolian activity as the dominant landscape differentiating process apparently took place earlier.

Once the wind got a grip on the bare sand these spots easily expanded during extreme erosion events, causing the deposition of large quantities of poor cover sand in the surrounding vegetation. Locations where the vegetation died or was completely covered by the sand also became vulnerable to wind erosion. Hereafter the interaction between large scale wind erosion activity, vegetation development and human activity played a more dominant role in their further development. The number of documents between 1532 and 1855 in which the government speaks about the problems caused by wind erosion or measures to control the drift sands as listed by Tesch *et al*, 1926, indicate periods of relative low erosion activity followed by periods with increased wind erosion damage. It seems that only severe storms of high intensity and duration can generate sufficient sediment transport into the vegetated zones adjacent to the bare sand. Under the given land use in combination the openness of the landscape, the large area bare sand and an extreme micro-climate, the erosion risk remained high. In this situation the first vegetation development was easily suppressed during the periods with high erosion activity as schematically presented by Figure 6.1.

This development changed with the major land use changes, which started in the second half of the 19th century. With the introduction of fertilizers, the collapse of the wool industry and the increased demand for wood for the mine industry it became interesting for the Dutch government to invest in the afforestation of the drift sands. Additionally this would reduce the off-site damage on community properties, e.g. farm land, settlements and roads, caused during the extreme wind erosion events. Earlier attempts to control the drift sands had no or little effect due to a lack of economical benefit by the government nor financial benefits for the local farmers.

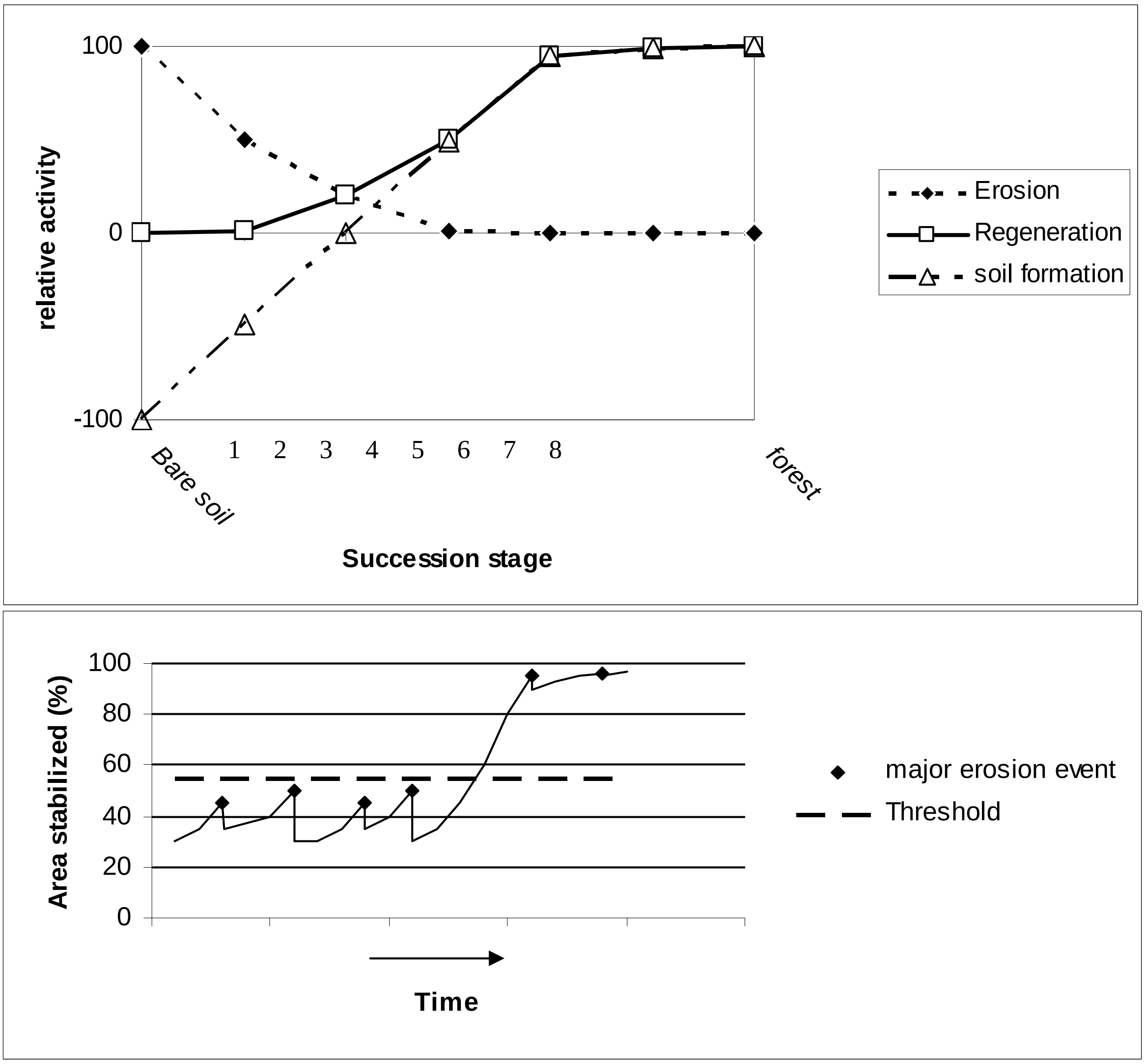


Figure 6.1. Schematically representation of the interaction between soil degradation caused by wind erosion and regeneration by vegetation development on drift sands. Top: Relation succession stage and relative activity of the different processes; Bottom: Role of wind erosion at landscape level: When the area covered with vegetation exceeds the threshold the effect of the extreme wind erosion events will become too small to have a significant influence on the landscape development.

In the Netherlands, about 60 km^2 of the original drift-sand area still existed in the mid-1960s (Bakker *et al.* 2003). These 60 km^2 have been saved for their unique landscape value, or for recreation or military use, like Aekingerzand in Drenthe, Kootwijkerzand and Harskamperzand at the Veluwe, and the Loonse en Drunense Duinen in North Brabant. Figure 2 shows the largest remaining active drift-sand areas in the Netherlands.

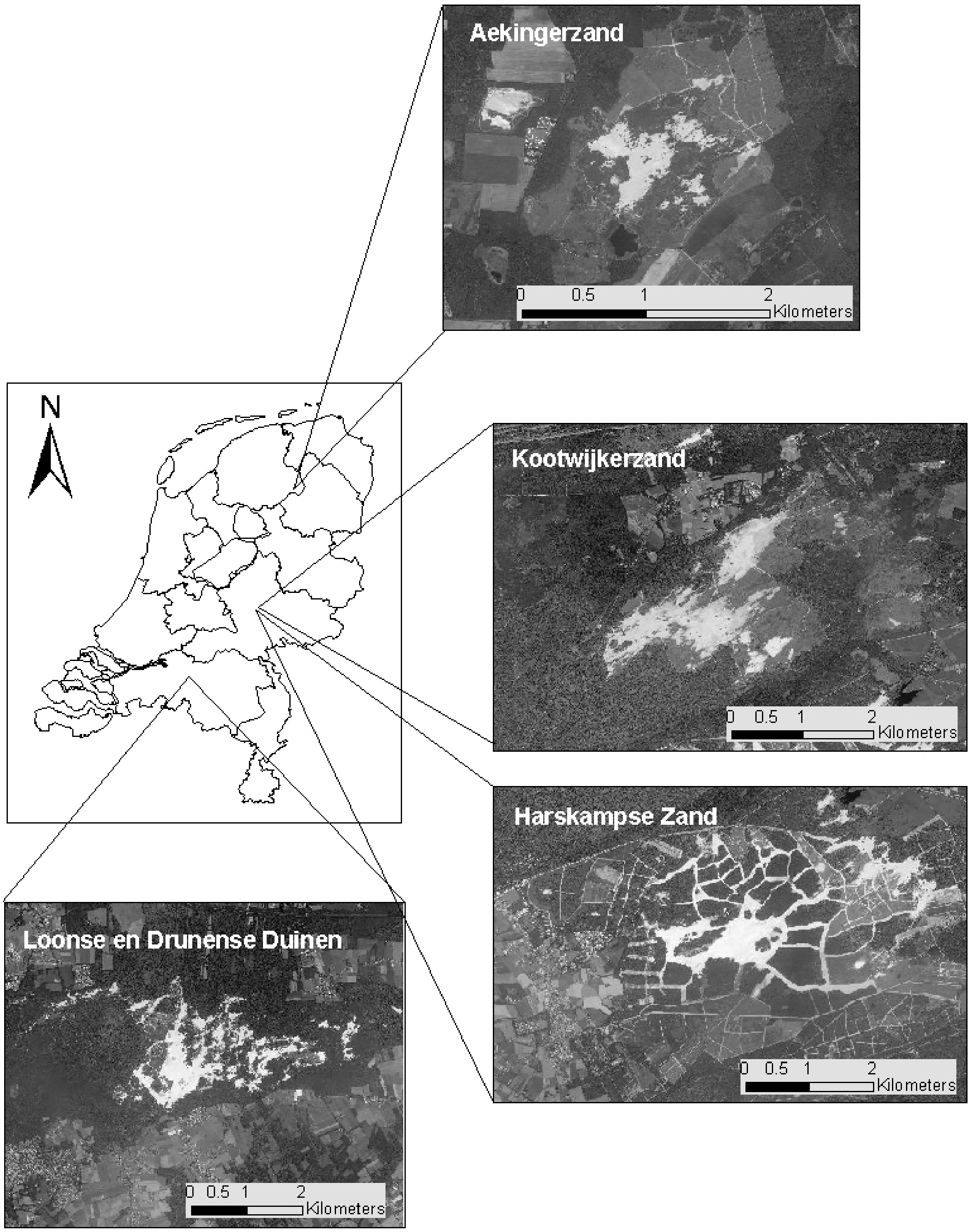


Figure 6.2. Major active drift-sand areas in The Netherlands (aerial photograph: © Eurosense, 2003)

6.2.3. Effects of the land use changes on the further development of the drift sands

The land use change, which took place in the period between 1850 and 1960, had a major effect on the development of the remaining active drift sands. These effects were a direct corollary of:

1. The afforestation; and
2. The change in human activity in the remaining drift-sand areas: activities that disturbed the vegetation growth and/or the soil surface.

6.2.3.1. The effects of re-forestation

Since the late 19th century most drift-sand areas in The Netherlands were reforested successfully mainly with an exotic pine species like Scottish pine (*Pinus sylvestris*), as in the Veluwe, Brabant and Drenthe (Tesch *et al*., 1926; Schimmel, 1975; Castel *et al*., 1989).

As a result the remaining drift-sand areas are small compared to the size they had before re-forestation as illustrated by Figure 6.3. for Kootwijkerzand. The re-forestation has changed the landscape from open into closed or half-open. This reduced the average wind velocities in these landscapes, thereby diminishing the wind's erosive force. As a consequence wind activity in the zones close to the forest is low, and regeneration is not seriously hampered. In these zones vegetation and algae develop rapidly and inhibit wind erosion. The seed of *Pinus sylvestris* (Scottish pine) will easily geminate and survive. These seedlings grow fast and can form a closed forest within a few decades. Schimmel (1975) found for the drift-sand area Harskamperzand (Veluwe, The Netherlands) that between 1950 and 1973 the area under vegetation had increased by 70%, with mainly *P. sylvestris*.

With the forestation of large parts of the drift-sand areas and their surrounding regions, the remaining active areas became spatially fixed and could no longer develop in line with the drift-sand structure as described in Section 6.2.2. Wind erosion was thus reduced to a local process, and the fine sand could no longer be transported over long distances. Drift sand that is trapped in the forest's borders is usually no longer available for subsequent wind erosion because of the sheltering effect caused by the forest. In the deflation zone, on the other hand, the increase in coarse material at the surface can form a non-erodible desert pavement, or due to the lowering of the surface the ground water table (or another non-erodible geological layer) may be reached so that wind erosion no longer occurs. Furthermore, the forest at the border of the drift-sand areas inhibits the formation of new sources for deflation. Under these conditions wind erosion activity is low, and the natural regeneration of these soils can take place in more or less undisturbed conditions.

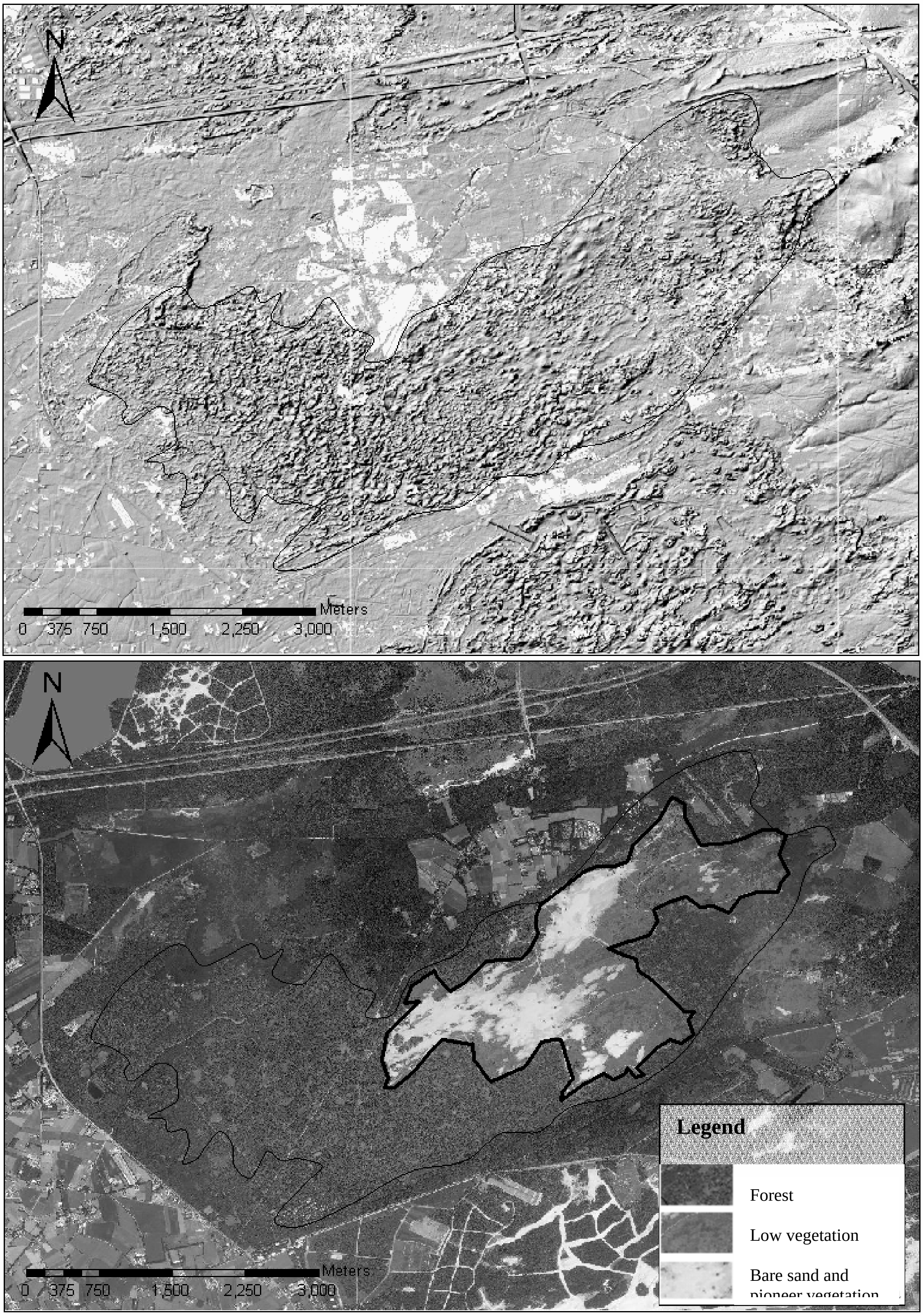


Figure 6.3 Top original size drift-sand area Kootwijkerzand based on relief shaded model (Source: AGI-ITC Rijkswaterstaat, 2004); down: Remaining active drift-sand area Kootwijkerzand in 2003 (aerial photograph: © Eurosense, 2003)

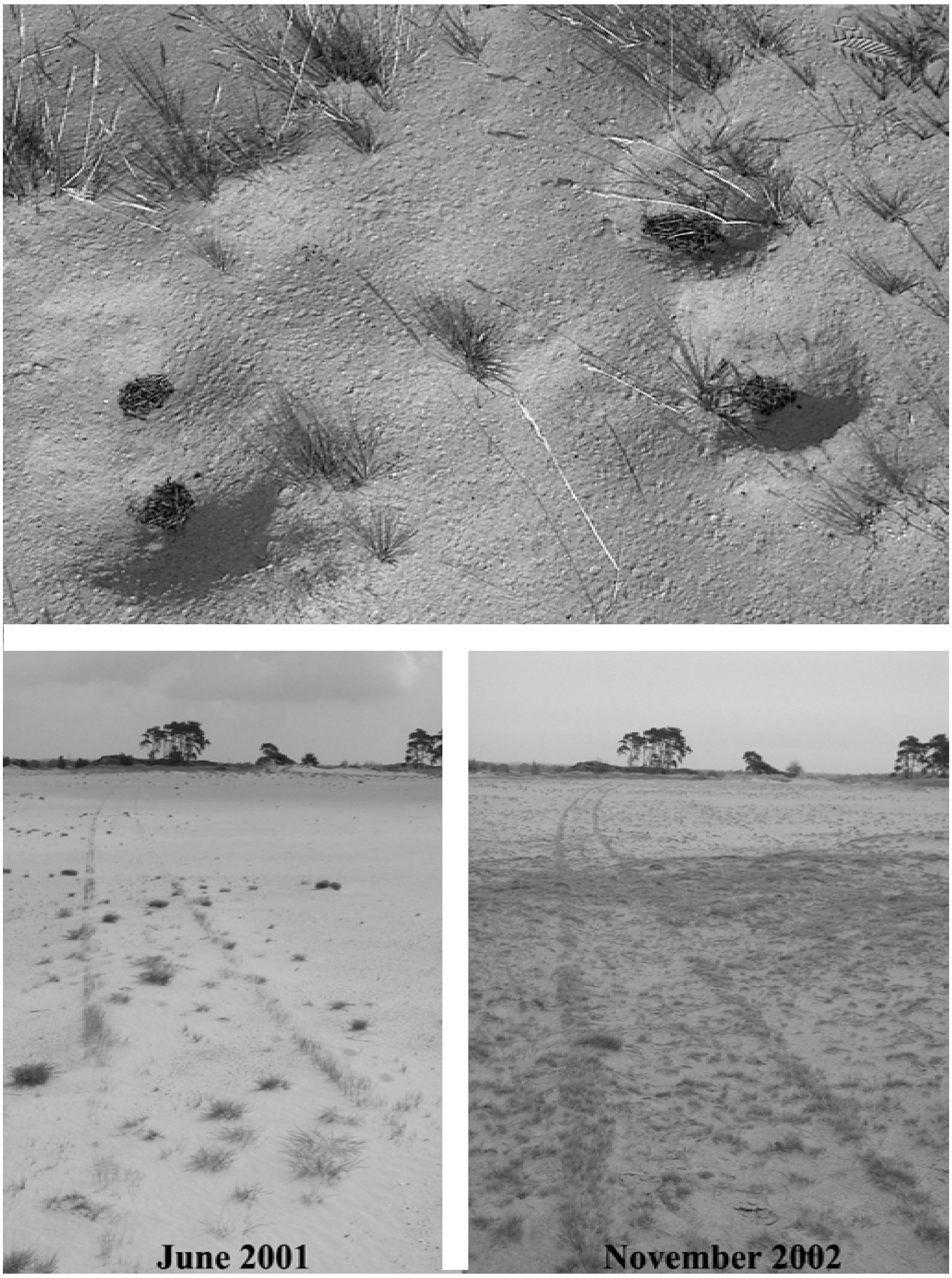


Figure 6.4. Effect of footprints and tracks on vegetation development. Top: Organic material trapped in footprints. Down left: Vegetation developed in car tracks have formed a vegetated ridges. Down right: 17 month later: Rapid vegetation development due to lack of erosion activity

Sandblasting, burying and blowing out of vegetation no longer take place at a sufficiently large scale and a sufficiently short time interval. No new dunes are formed in the zones of deposition due to the lack of a sufficient amount of sand transport.

2.3.2. Change in land-use

The abolition of communal land use in the 19th century (Van den Bergh, 2004) was an important intervention in the drift-sand areas of the Veluwe (central Netherlands).The large-scale communal landscape was reclaimed and transformed into many small “private” plots, each bordered by hedges to delimit property and to control cattle (Staring, 1862). Together with the introduction of fertilizers and the collapse of the wool industry at the end of the nineteenth century agricultural practices like intensive grazing, burning heath lands and collecting heather sods to manure the arable fields, slowly disappeared. As a consequence no new highly erodible hotspots could develop from where new deflation plains could grow into larger drift-sand areas, and sheep and cattle flocks no longer crossed the drift-sand areas.

New types of land use, particularly recreation and military use came instead. Land-use types as recreation and military use may positively or negatively affect the development of drift sands, depending on their frequency and intensity. Only intensive tread will keep the vegetation away. Extensive use will result in footmarks or tracks which trap organic matter and seeds. On these spots new vegetation develops and reduce the erosion activity (see Figure 6.4). A disadvantage of intensive tread by recreation or military activity is the disturbance it will cause for the fauna, especially during the breeding season.

Table 6.1. Number of higher plants, mosses and lichens in eight succession phases (vegetation type 1-8) of drift sand vegetation at the Kootwijkerzand in 1993 (after: Ketner-Oostra and Huijsman, 1998; Masselink, 1994; Ketner-Oostra, 1994)

Vegetation type	**Description**	**Number of**			**Vegetation cover (%)***
		Higher plants	**Mosses**	**Lichens**	
0	No vegetation	0	0	0	0
1	Patches of pioneer grasses	5	0	0	< 5
2	Fixation of bare sand by *Corynephorus. canescens* and green algae	2	1	0	50 – 80
3	Fixation as in type 2, and also by mosses	5	1	0	40 – 75
4	Moss carpets, partly covered by algae (*Gloeocystis polydermatica*)	5	2	0	70 - 100
5	Dying moss carpets through ageing and effects of covering by algae	7	5	11	70 - 100
6	Lichen growth on partly dead moss carpets	7	2	20	90 - 100
7	Species-rich lichen vegetation, including reindeer lichens	9	7	18	90 - 100
8	Mosaic vegetation of driftsand vegetation with heath (*Calluna vulgaris*) including *Juniperus communis*	11	5	21	90 - 100

* The actual vegetation cover varies between the different seasons.

6.2.4 The development of the drift-sand ecotopes

Due to these changes in land use, which led in most cases to a reduction of soil degradation caused by the disturbance by wind erosion and /or human activity, natural regeneration process became the more dominant process in the remaining open drift sands. As result a clear distinction can be made in the present Dutch drift-sand areas between zones of a different vegetation composition. In general eight types (Table 6.1), which represent the succession stages from bare sand to the development of forest, can be distinguished. The presence of all these stages seems to be of importance for the typical drift-sand fauna.

6.2.4.1. Natural succession

The bare (moving) sand is generally very poor in organic matter and nutrients. If the parent material at the soil surface consists of cover sand the organic matter content is negligibly small. The organic matter content for Dutch drift sand is approximately 0.3 % (Table 6.2).

The early pioneer species are adjusted to growing in moving sand, like *Ammophila arenaria* and *Festuca rubra* ssp. *commuta*, both extending with an underground rhizome system. The maritime species *A. arenaria* has been introduced in inland sand dunes for retaining blowing sands in the past (Tesch *et al.*, 1926; Van Embden and Verwey, 1968). A species as *Carex arenaria* is adapted to extend with creeping underground rhizomes producing shoots at intermediate distances over an open sand surface.

Table 6.2. Description of the soil for the different drift-sand succession stages (Source: Ketner-Oostra and Riksen, 2005)

Succession stage	**Description**	**Soil profile**	**OM 0 – 5 cm (%)**	**pH KCl 0 – 2 cm**
0	No vegetation	C	0.30	4.7
1	Patches of pioneer grasses	C	0.30	4.7
2	Fixation of bare sand by *Corynephorus. canescens* and green algae	C	0.34	4.6
3	Fixation as in type 2, and also by mosses	C	0.58	4.5
4	Moss carpets, partly covered by algae (*Gloeocystis polydermatica*)	AC	0.79	4.0
5	Dying moss carpets through ageing and effects of covering by algae	AC	0.88	3.5
6	Lichen growth on partly dead moss carpets	AC	1.37	3.5
7	Species-rich lichen vegetation, including reindeer lichens	AC	1.64	3.5
8	Mosaic vegetation of driftsand vegetation with heath (*Calluna vulgaris*) including *Juniperus communis*	A(B)C	5.25	3.2

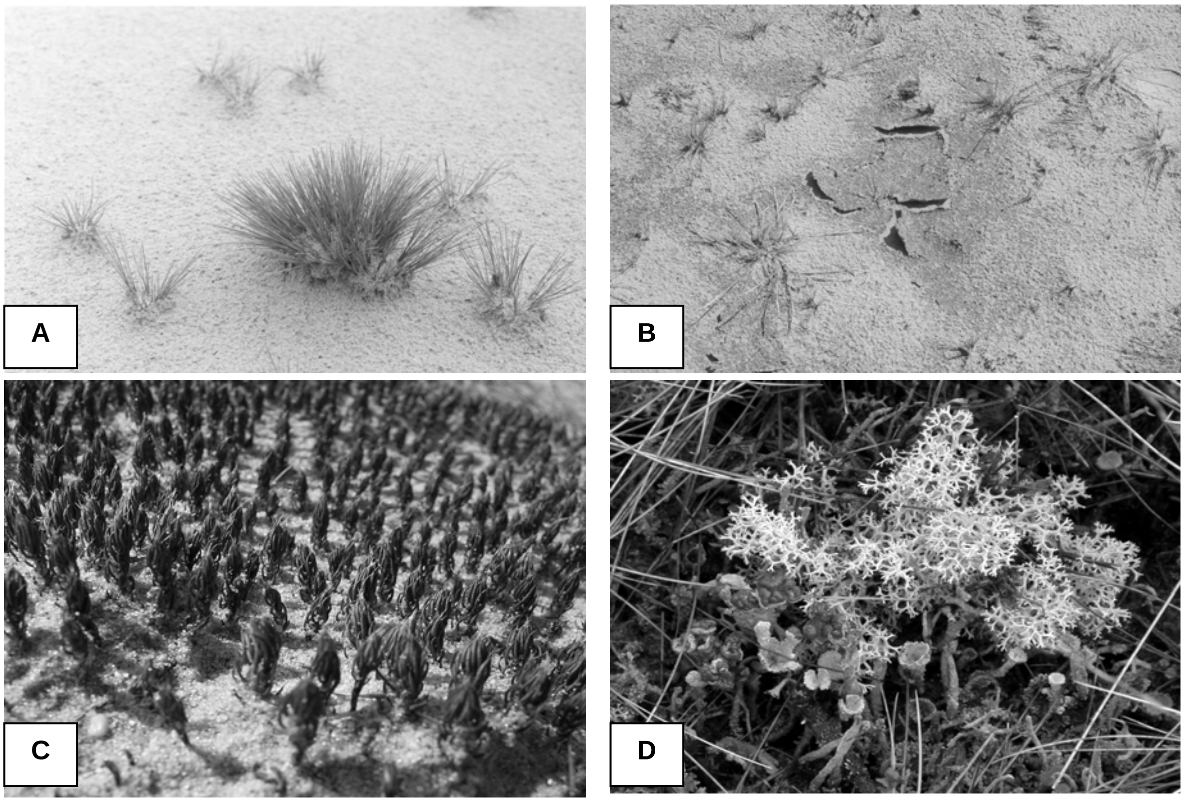


Figure 6.5. Drift-sand vegetation; A. Gray hairgrass (*Corynephorus canescens*) (Photo: M. Riksen); B. Algae crust (Photo: M. Riksen); C. The pioneer moss *Polytrichum piliferum* (Photo: M. Riksen); D. *Cladonia coccifera* and *Cladina portentosa* (Photo: A .Aptroot)

The settlement of the pioneer grass *Corynephorus canescens* (Figure 6.5A) depends on its spread by wind. Seed and organic material is often found in higher concentrations behind small obstacles, in foot prints or in tracks. Most seeds therefore geminate in the deposition zone behind or between the existing vegetation. Successfulness of the germination of these grass seeds probably mainly depends on the weather conditions. In a period with dry and windy conditions it only geminates very locally whereas in periods with rainy conditions it geminates in a more widespread, uniform pattern. Under the latter conditions the algae present in the top soil show an increased growth and may develop a crust (Figure 6.5B). It is believed that the formation of such biotic crusts enables the successful germination of pioneer vegetation like *C. canescens* and the winter annuel *Spergularia morisonii*. Weeda (1985) claims that humus should be present in the latter case. *Pinus* seeds might germinate in bare or nearly bare sand, but generally do not survive a dry season. In Table 6.1 these first pioneering plants are summarized under Type 1.

Soil formation in the first succession stage is limited. The acidity of the parent soil material (e.g. drift sand or cover sand) in the un-vegetated zone and in the top soil of this first vegetation type remains at pH.KCl 4.6 and remained largely

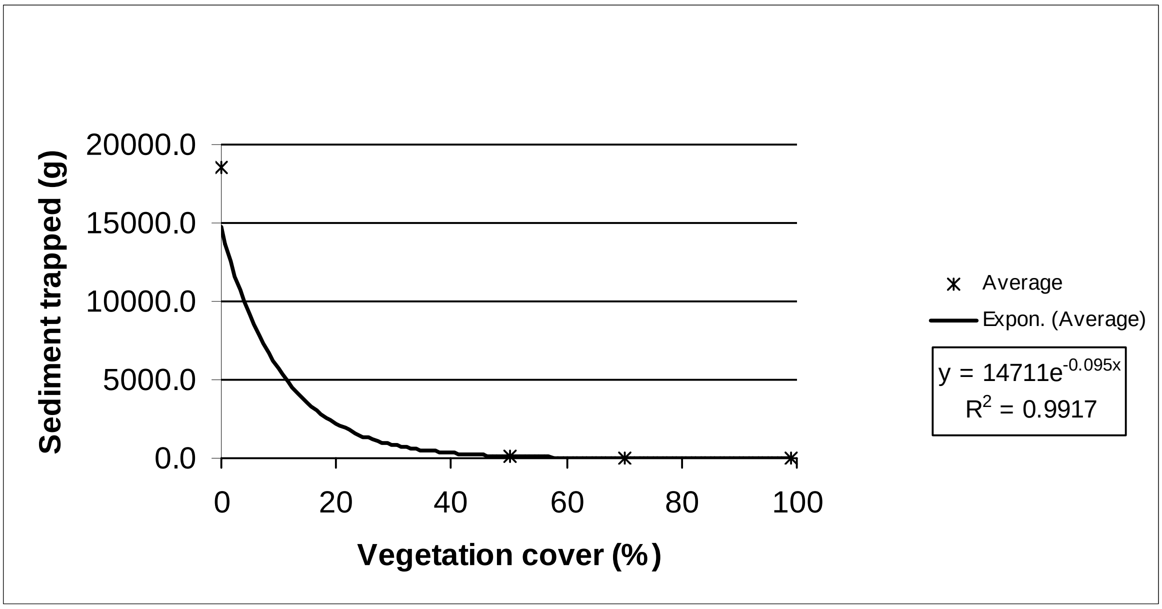


Figure 6.6. Relation vertical accumulation flux and vegetation cover (after: Ketner-Oostra and Riksen, 2005)

unchanged over the last ten years (Ketner-Oostra, 1994ab, 2003). With an increasing soil cover the vegetation reduces the sand transport and thus the regular deposition of nutrient-poor sand as shown in Figure 6.6. The organic matter content in the topsoil will slowly increase, which creates favourable conditions for species that cannot bear the poor conditions and/or the high sediment deposition rates found near an active deflation/transport zone.

As more sand is stabilized plaques of green algae might develop between the tussocks of *C. canescens*, followed by protonemata of mosses. In this early stage with still significant sediment transport (Figure 6.5) the pioneer moss *Polytrichum piliferum* (Figure 6.5C) is found. This species expands through perennial underground rhizomes. Individual shoots may live for several years continuing forming annual segments. A mat of *P. piliferum* may consist of circular colonies up to 1 m in diameter, being clones (Hobbs and Pritchard 1987; During 1990). In the top two centimetres of sand inside this *C. canescens* vegetation dominated by *P. piliferum* (Type 3 in Table 6.1) some humus has formed resulting in a small decrease of the pH.KCl (see Table 6.2).

After one to three years spore capsules might be formed as part of the life cycle of the dioecous *P. piliferum*. This mostly occurs in a fine maze over the moss carpet, in which not all plants sporulate (Hobbs and Pritchard, 1987). After sporulating these moss plants might die. The mucous containing algae *Gloeocystis polydermatic* intensifies this process by the covering of the moss layers. During rain the algae absorb nearly all the water until they have formed a more or less impermeable layer over which the surplus of rain is discharged that might otherwise be available for development of the new shoots from the rhizomes (Type 4 in Table 6.1).

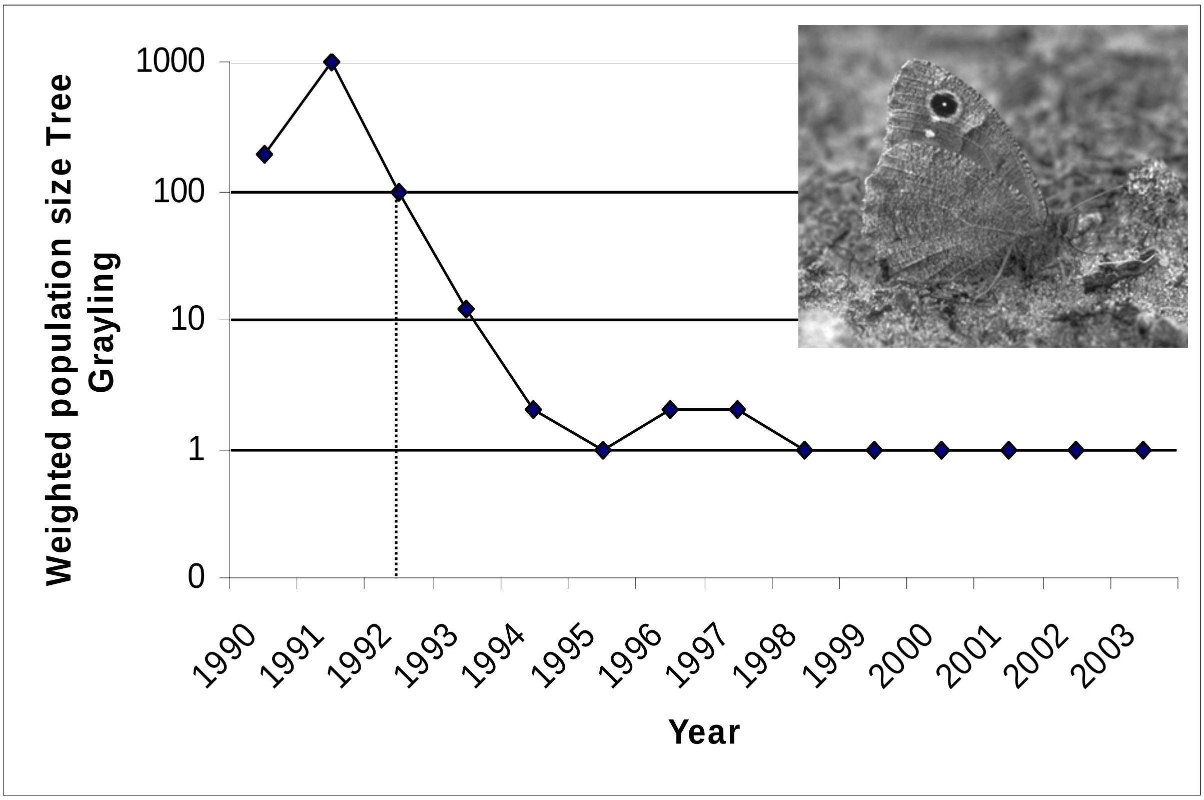
On the carpet of partly dead mosses lichens will start to colonize (Table 6.1, type 5). These are mostly common humicolous species such as *Cladonia coccifera* (Figure 6.5D), *C. macilenta, C. glauca* and *C. floerkeana*. But also more rare species might develop such as the Red List species (Aptroot *et al*., 1998) *C. zopfii, C. crispata* and *Stereocaulon aculeatum*. In Type 6 this has added up to 22 species (Ketner-Oostra, 1994ab). Real pioneer species like *Cetraria aculeata* and *Cladonia foliacea* can also be found, species mentioned so far behaving as secondary pioneers on dead moss (Van der Meulen *et al*., 1987, Biermann and Daniëls, 1997). In Type 5-6, clear acidification has taken place as shown in Table 6.2. With the lowering of the pH the efficiency of the N-mineralization will increase resulting in a higher biomass production (Bakker *et al*., 2003).

At the drift-sand area Kootwijkerzand near Kootwijk, The Netherlands, the climax in lichen-richness is reached when aero-hygrophylous reindeer lichens (Figure 6.5D) have settled in, like *Cladina portentosa* (Figure 6.5D) and *C. arbuscula* s.l. (Type 7). This type consists of more grasses, like *Festuca ovina* s.l. and *Agrostis vinealis*, the latter when there is clearly more soil moisture available in flat gravel-rich locations where cover sand is surfacing (Ketner-Oostra 2003). The acidity is as low as in the former type but even detectable in the 10 - 30 cm layer (see Table 6.2). In this grass and herb-rich vegetation *Calluna vulgaris* might germinate and form a mosaic with the moss and lichen-rich grass vegetation (Type 8 in Table 6.1). Gradually a dry heath will develop, mainly with *Calluna vulgaris*. This succession from initial species-poor grey hairgrass vegetation (Type 1) into lichen-rich final phases (Type 8) might take 10 - 12 years, while they might stay for years more or less without succession until the age of 20 years (Daniëls and Krüger, 1996). However, little is known about the influence on the succession of the location in the drift-sand landscape. On a former deflation plain the succession will probably take longer than on stabilised drift-sand deposits or in the zone close to the forest due to the lower nutrient content.

2.4.2 Drift-sand fauna

With the development of the typical drift-sand vegetation as described above, a selective number of fauna species has settle down. The composition and distribution of the characteristic fauna communities of the Dutch inland drift sands is closely related to the extreme conditions in this landscape. Relatively few fauna species can cope with these extreme conditions. Therefore inland drift sands accommodate a species poor, but very characteristic fauna community. This community is however under severe ecological pressure, though only little is known about the exact mechanisms underlying the decline of characteristic species.

Most characteristic fauna species belong to the insects (*Insecta*), especially wasps and ants (*Aculeata*; *Hymenoptera*) and beetles (*Coleoptera*) (Mörzer and Westhoff, 1951). Only three species are known to be restricted to inland drift sands in The Netherlands: Tawny Pipit (Aves: *Anthus campestris*), Tree Grayling



The year 1992 is 100

Figure 6.7. Relative abundance of Tree Grayling in The Netherlands since 1990 (data Dutch Butterfly Foundation; photo by Kars Veling, 1992, Dutch Butterfly Foundation)

(Lepidoptera: *Hipparchia statilinus*) and Giant Earwig (Dermaptera: *Labidura riparia*). The Red-Listed Tawny Pipit has recently reached the point of extinction. From the 250-350breeding pairs present in the period 1940-1960, only 21-23 were left in 2000 (Van Turnhout, 2005). In 2003 only one territory was occupied. Populations of the Red-Listed Tree Grayling have also declined rapidly in the last three decades (Figure 6.7). This butterfly species now only occurs in three areas in the central part of The Netherlands. The Tawny Earwig is probably found on many, but not all, inland drift sands and on these places it seems not to be threatened yet.

Many other fauna species of inland drift sands are also found in coastal dunes, dry heath lands or dry calcareous grasslands. Species which are found mainly, but not solely, in drift sands are the Grey Spider Wasp (*Pompilus cinereus*) and its parasite *Ceropales maculata*. Many other species of digging wasps (Specidae), wasps (Apidae) and spider wasps (Pompilidae) find their optimum habitat in inland drift sands. Other interesting insect species are the ant species *Myrmica specioides*, *Lasius psammophyllus* and *Formica lusatica*, Snow Scorpion Fly *(Boreus hymealis*), Spotted Ant-lion (*Euroleon nostras*), the Red-Listed Blue-winged

Grasshopper (*Oedipoda caerulescens*), the ground beetles *Amara infima*, *Cymindis macularis* and *Harpalus neglectus*, the tiger beetle *Cycindela maritima* and the Red-Listed butterflies Silver-spotted Skipper *(Hesperia comma)* and Grayling (*Hipparchia semele)* (Bakker *et al.*, 2003). Furthermore inland drift sands and the surrounding dry heaths and forests accommodate significant parts of the Dutch populations of some Red-Listed breeding birds: European Nightjar (*Caprimulgus europeus*), Northern Wheatear (*Oenanthe oenanthe*), Wryneck (*Jynx torquilla*) and Great Grey Shrike (*Lanius excubitor*), which has almost disappeared from The Netherlands. European Thicknee (*Burhinus oedicnemus*) probably used to breed in small numbers on inland drift sands until a few decades ago, but reliable records of confirmed breeding are lacking (SOVON, 2002).

Due to physiological adaptations or life cycle adjustments, most characteristic fauna species are resistant against or dependent on extreme climatic conditions, mainly high or fluctuating temperatures and drought, and low nutrient availability. Examples of physiological adaptations are metallic colours and long hair as a response to heat (Almquist, 1971) and slow growth and a long larval period as a response to the use of low nutritious food such as Tree Grayling and its host plant *Corynephorus canescens*. Furthermore several behavioural adaptations occur, such as burrowing in bare sand by different *Harpalus* species and Tawny Earwig, and hiding under fallen branches or trees during daytime (probably many species). Because of low nutrient availability there is a high specialisation rate of feeding guilds. Most species are parasites or carnivorous. However in carabid beetles some very characteristic species have developed the faculty to feed (partly) on plants, especially seeds of grasses and the herb *Spergularia rubra*. Many aculeate species feeding on nectar or pollen are small and find enough food on *Spergularia rubra* and shrubs of *Rhamnus-species* in adjacent woodlands. Species that occur on the most dynamic places of drift sands are characterized by high mobility, a short life cycle and one or several generations per year. Species of fixed dunes generally have a low dispersal power and a life cycle of more than one year.

Many fauna species depend on two or more ecotope types within the inland dune landscape to fulfil their needs and complete their life cycle. Tree Grayling for instance needs stands of *Calluna vulgaris* to facilitate its nectar demand during its mature stage and vital stands of the pioneer grass *Corynephorus canescens* during its larva stage.

Because of the dependence on extreme conditions many characteristic species have a southern and/or eastern distribution in Europe and occur on the Northwest border of their range in The Netherlands such as Tawny Pipit, Tree Grayling, Blue-winged Grasshopper. Their reproduction surplus in general is probably low and strongly depends on weather conditions. Local extinction of populations may be significant in years with low temperatures and/or high precipitation, especially in small and isolated areas.

6.3. The rapid decline of the active drift sands after 1960: causes and consequences

Since the 1960s the remaining inland drift-sand areas have shown a rapid decline in size. From the 60 km^2 that remained in The Netherlands after the major period of reforestation, only 40 km^2 were left around 1980 (Bakker *et al.*, 2003). Bakker *et al*. (2003, pp. 103-105) estimated the total area of *active* drift sand less then 1.5 km^2. Figure 8 shows the rapid extension of the vegetation at the drift-sand area Kootwijkerzand between 1964 and 2004.

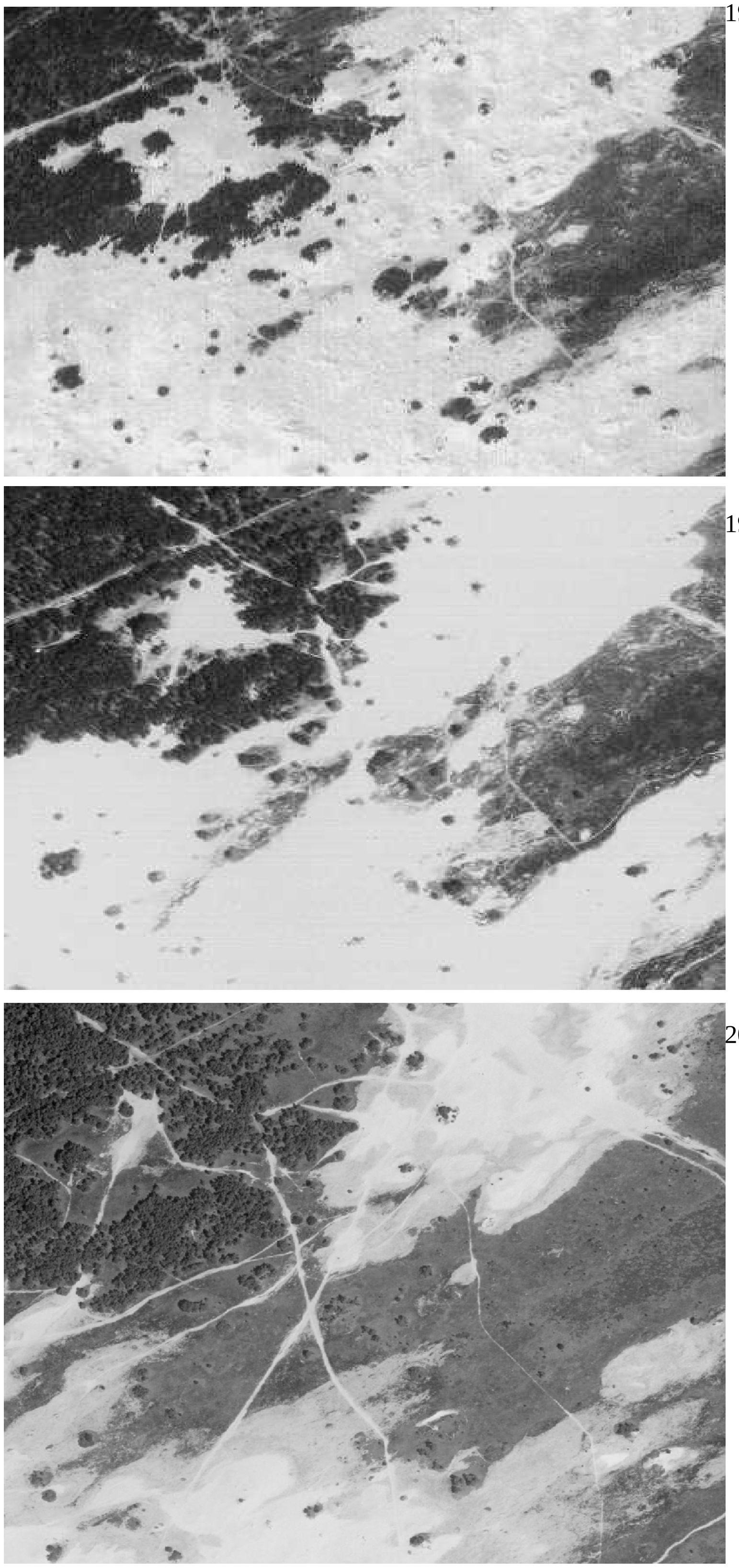
Besides the ongoing decline due to natural regeneration on the one hand and a lack of erosion activity and human activity on the other, the regeneration seems to have changed in speed as well as in pattern after 1960 due to external factors:

- eutrophication by relatively high atmospheric nitrogen deposition; and
- invasive (exotic) species.

6.3.1. Atmospheric nitrogen deposition

In The Netherlands, the increase in atmospheric N-deposition led to an increase in biomass production and, consequently, a more rapid succession. The nitrogen mainly originates from animal husbandry and the bio-industry. Although the deposition reduced from 3000 mol ha^{-1} y^{-1} in 1990 to 2350 mol ha^{-1} y^{-1} in 2001 (Buijsman, 2004), in and near areas with high livestock concentrations the N-deposition is still high with values above 3500 mol ha^{-1} y^{-1} (Buijsman, 2004). In combination with sufficient available moisture nitrogen can stimulate the growth of algae. On locations with moderate or little wind erosion activity the algae can form a few millimetre thick crust, which effectively stops erosion (Pluis, 1994). For this reason this problem is often observed in the smaller drift-sand areas and in zones in the wind shadow of obstacles, but also in zones covered by more then 30% grey hair grass, where the wind erosion activity is relatively low. The atmospheric N-deposition also accelerated the succession in the drift sand vegetation. The algae not only form a non-erodible crust but also fixate the nitrogen that normally would have been leached out. Another algae that has accelerated the succession since the 1980s is the mucous containing algae *Gloeocystis polydermatic*, the development of which boomed due to the increase in aerial N-deposition. This has intensified the covering of the moss layers by this algae.

Eutrophication also enhance the invasion of *P. sylvestris*, especially in the zone along the forests.



1963

1984

2003

Figure 6.8. Development of vegetation at Kootwijkerzand, The Netherlands in the period 1963 – 2003. (Source aerial photographs: Topografische Dienst Emmen; © Eurosense, 2003)

6.3.2 Invasive (exotic) species

Another external factor is the introduction of invasive species by human (activities). These species can overtake the place of local species in the succession. The most important exotic species that influences the succession of inland drift sands in The Netherlands is the moss *Campylopus introflexus*, which originates from South America. Since the 1980s this neophytic moss has invaded the inland sand dunes (Van der Meulen *et al*. 1987; Masselink, 1994). It disperses very actively by stem tops or leaflets. This life strategy (During, 1979) made it suitable to invade large areas of partly degenerating *P. piliferum*, but also humus containing sandy areas that have low dynamics. But *C. introflexus* is not adapted to blown-in sand like *P. piliferum* and will wither or die when it is covered by sand.

On oligotrophic sites inside the Dutch Veluwe district *C. introflexus* probably takes advantage from the high aerial nitrogen deposition (Londo, 2002). Apart from the aggressive growth of *C. introflexus*, grass encroachment by *F. ovina* s.l. and/or *A. vinealis* is also observed. This does not lead to an increase of the mosaic drift-sand vegetation with heather (which is so important for several fauna elements), however. It was also found that the germination of *Calluna vulgaris* seeds is strongly inhibited by thick moss carpets of *C. introflexus* (Equihua and Usher, 1993).

6.3.3. Effects of the decline of active drift sands on fauna

Many characteristic fauna species of inland drift sands have shown a long-term decrease in both numbers and distribution (Bakker *et al*., 2003). Initially, it was assumed that this was caused by the decline in the total area of active drift sands in The Netherlands due to the re-forestation and because the remaining drift sands had become too small and fragmented. Typical species such as Tawny Pipit and Tree Grayling require a relatively large habitat within a site to sustain viable populations, and it is clear that only few such sites are left.

Since the sixties, as a result of atmospheric deposition, nitrophilic grasses such as *Festuca ovina*, *Deschampsia flexuosa* and *Agrostis vinealis* and the moss *Campylopus introflexus* have become dominant. Low, open vegetations with a dry microclimate, and large temperature fluctuations between day and night, have been replaced by high, closed vegetations with a constant cool and relatively moist microclimate (Biermann and Daniëls, 1997). These changes in the vegetation of drift sands are enhanced by the decrease of Rabbit populations due to viral diseases, as a result of which grazing pressure on grasses is low (Bakker *et al*., 2003). The above described developments will have contributed to the decline of characteristic fauna species, but the exact mechanisms remain largely unknown.

Here we present some hypotheses for the causes of the decline of Blue-winged Grasshopper, Tree Grayling and Tawny Pipit.

For the Blue-winged Grasshopper the decrease in the amount of bare sand may have reduced the possibilities for display and oviposition. Furthermore, a higher vegetation enhances the extinction of sun light near the soil surface, resulting in lower temperatures in the top layer of the soil. As a result of this, the time needed for the development of grasshopper eggs increases, leaving not enough time to complete the year cycle before winter arrives (Kleukers *et al.*, 1997). For some grasshopper species a cooler microclimate also increases the development time of juveniles (Schaedler and Witsack, 1999).

Adults of Tree Grayling will be adversely affected by a decrease of both bare sand and lichen abundance, because they use these ecotopes for warming up. For the related species Grayling *H. semele*, it was demonstrated that egg-laying females use dark lichen species (*Cladonia sp.*) not only for warming up in early morning, but also during the rest of the day for resting, because the butterflies are best camouflaged here (Shreeve, 1990). At some sites the disappearance of *Calluna vulgaris* through grass encroachment will have resulted in food shortage for Tree Graylings. However, caterpillars are believed to be more sensitive to habitat changes than adults. First of all, the infection rate of caterpillars by pathogens may increase when microclimate levels out, resulting in a decrease of winter survival. This was demonstrated once again by the Grayling (Bink, 1992). Furthermore, eutrophication reduces the nutritional value of the food plant *Corynephorus canescens*. Finally, the caterpillars pupate in bare sand, a process which takes 21-46 days (Bink, 1992). Grass and moss encroachment reduce the amount of bare sand, which causes a third possible bottle-neck for Tree Grayling caterpillars.

Many other characteristic invertebrate species of inland drift sands face comparable problems as described for Blue-winged Grasshopper and Tree Grayling (Bakker *et al.*, 2003). Indeed in *Campylopus*-dominated vegetations, grasshoppers and probably many other invertebrate species, appear to be rare (Nijssen *et al.*, 2001) and a shift occurs from day-active to night-active carabid and spider species (Vogels, 2004). This will have seriously affected the food supply for the insectivorous Tawny Pipit, which is the most probable cause for the observed decrease in breeding success of this species (Bijlsma *et al.*, 2001, Van Turnhout, 2005). Furthermore, disturbance by recreation will have been another important cause for the decline of the Tawny Pipit in The Netherlands. Bijlsma (1978) showed a correlation between the local extinction of the Tawny Pipit and the accessibility of the site to the public. As many other ground breeders, Tawny Pipits are very shy when they have young in the nest. Young may starve or nests abandoned when people are constantly around, as is the case in many of the Dutch drift sands nowadays. Besides, Tawny Pipits have only one clutch a year and breed relatively late in the season, when recreation pressure is high. This makes them very susceptible to disturbance (Bijlsma, 1990).

6.4. Discussion and conclusions

The decline of active inland drift sand in northern Europe is explained by various factors. The landscape differentiating processes are not longer functioning according to the geomorphological structure of the original drift-sand area. The major change in land use that took place at the begin of the 20th century can be seen as its main cause. Wind erosion activity in the remaining drift-sand areas is tempered by the reduced size of the potential erodible area on the one hand, and the reduced wind force on the other. In most cases the lack of erosion activity is not compensated for by human activity, e.g. recreation, military use. Only in areas with regular intensive human activity the pioneer vegetation and algae crust is suppressed effectively.

Other factors, such as increased N-deposition, accelerate the regeneration process. Also, in many drift-sand areas the establishment of exotic plant species has significantly disturbed the balance between degradation and regeneration. Invasive species like Scots pine and the neophytic moss *Campylopus introflexus* spread more rapidly, causing a higher biomass production and a more rapid soil formation, resulting in a more rapid evolution of the succession towards a closed forest. This development causes increasing landscape roughness and therefore a further reduction of the area with maximum wind erosion activity. Only severe storms of high intensity and duration can generate sufficient sediment transport into the vegetated zones to set succession back. If the area of bare sand becomes too small, sand transport during these severe storms also becomes too small and the influence on the regeneration process will be minimal. Most pioneer vegetation needs to be regularly covered with a small amount of driftsand to remain vital. For the typical drift-sand fauna the combination of bare sand with a vital transition zone and other ecotopes seems to be crucial to survive. In the present drift sands the distance between the bare sand including the transition zone with other ecotopes has become too large so that for fauna necessary connection between the different ecotopes seem to be lost. However at this stage too little is known about the role of the different drift-sand ecotopes and their connections for the different fauna species. There is also a lack of knowledge about the effect of algae on the regeneration process, and about the direct effect of these algae on the fauna.

In general one can conclude that, under present condition, wind erosion no longer acts as a large-scale landscape differentiation process as was the case during the development stage of the drift-sand areas, but has become a local process. Without proper management the erosion activity will further decline and will no longer influence the regeneration as schematically represented in Figure 6.1.

The best way to reactivate inland drift sands is to restore the natural processes by removing the forests and the A-horizont at the upwind side of the active areas. The main problems faced here are the high costs of such measures, legislation, the presence of infrastructural works or private property in the area, and the risk the measures would bring to community interests.

In most situations the stakeholders prefer to preserve the drift sand in the present setting. In this setting it is recommendable to keep the area with erosion activity sufficiently large by taking management measures in the first succession stages. A good balance between the area with bare sand and the area covered with a pioneer vegetation can be achieved by relatively simple and cheap tilling measures. These measures should be taken on a regular base to destroy the algae crust and the other vegetation, and keep the active areas connected to guarantee a sufficiently large potential sediment transport. To support the characteristic fauna it is important that the area with the first succession stages is not treated at once but phased, and/or to leave small areas untreated.

In the meantime the wind force in the drift-sand area should be ‘maintained’ or improved by suppressing the growth of high standing vegetation and removing trees that shelter the sands from the wind.

In the remaining area the effect of the high nitrogen deposition on vegetation development and soil formation should be counteracted by pattern-based management, by small scale removing of the unwanted vegetation including the top soil.

Chapter 7

THE ROLE OF WIND AND SPLASH EROSION IN DRIFT-SAND LANDSCAPES IN THE NETHERLANDS

Michel Riksen and Dirk Goossens

Submited: *Geomorphology*

In: Wind Born(e)Landscapes
(M.J.P.M. Riksen) Wageningen, 2006, pp. 125 -145 .

7. The role of Wind and Splash Erosion in Inland Drift-Sand areas in the Netherlands

M.J.P.M. Riksen[1], D. Goossens[1,2,3]

[1] *Erosion and Soil & Water Conservation Group, Department of Environmental Sciences, Wageningen University, Nieuwe Kanaal 11, NL-6709 PA Wageningen, The Netherlands*

[2] *Physical and Regional Geography Research Group, Katholieke Universiteit Leuven, Redingenstraat 16 bis, B-3000 Leuven, Belgium*

[3] *Laboratoire Interuniversitaire des Systèmes Atmosphériques, Université Paris 12, 61 av. du Général de Gaulle, F-94010 Créteil, France*

Abstract

European drift-sand areas reached their maximum size in the 19th century. From late 19th century until mid20th century, most drift-sand areas in Europe were successfully reforested. Today, drift-sand formation can still be studied in the Netherlands. However, due to the change in land-use, their limited size, eutrophication and colonisation by invasive exotics the area occupied by active drift sand is rapidly declining and with this its unique fauna and vegetation. Between 2001 and 2005 experiments and observations were carried out at the inland drift sand area Kootwijkerzand (central Netherlands) to know more about the extent, the intensity and the role of wind and splash erosion in a drift-sand ecosystem. Measurements were made of the horizontal sediment flux, the vertical accumulation flux, the raising and lowering of the surface, the organic matter content of the topsoil, the saltation activity and the weather conditions. An attempt was also made to evaluate the effect of various measures to re-activate erosion.

Without sufficient erosion, the scattered drift-sand vegetation will rapidly change into a closed, grass-dominated vegetation. The role of erosion in the drift-sand ecosystem is therefore crucial: erosion slows down the succession rate as it causes the regular deposition of nutrient-poor sediment, and it facilitates the regular renewal of the vegetation by creating new locations with extremely poor conditions (blown-outs).

On bare deflation plains wind erosion is the dominant process. Here the transport generated by splash drift can be of the same magnitude as during a moderate wind erosion event, but splash drift events are less frequent and also shorter than wind erosion events. They normally represent less than 10 percent of the total sediment transport. In the scattered drift-sand vegetation areas, on the other hand, splash erosion and splash drift dominate. Here the organic matter content of the transported (and later deposited) sediment is equal to the organic matter content of the parent soil, showing that splash (drift) has been the main transport mechanism. Biological crust developed in these areas may later reduce the influence of splash. .

Large transport rates are needed to reactivate wind erosion in the vegetated areas. Under the present conditions the erosion activity in most drift-sand areas is small. Heavy wind erosion is only observed after extreme storms. Without human interventions, many drift-sand areas, with their characteristic flora and fauna, will disappear and turn into forest. It is especially the zones immediately downwind of still active deflation zones where measures to increase the erosion activity in the first succession stages should be undertaken. In areas completely stabilized by vegetation, the best locations for creating new spots with high wind erosion activity are the upper terrain parts that contain a sufficiently thick layer of drift or cover sand.

Key words: Drift-sand landscape; Wind Erosion; Splash Erosion; Nature development; The Netherlands

7.1. Introduction

The European inland drift-sand landscapes (Figure 1), which owe their existence to the reactivation of late-glacial cover sands and river dunes, are mainly located in the western part of the European sand belt (Koster, 2005). Most West European drift-sand areas have been re-afforested mainly with pine trees in the first half of the twentieth century. In the Netherlands, some active remnants of this landscape type still exist. However, due to the change in land-use, their limited size, eutrophication and colonisation by invasive exotics (Riksen *et al.*, in press) the area occupied by active drift sand is rapidly declining (Ketner-Oostra and Huijsman, 1998; Bakker *et al*, 2003; Jungerius 2003). Human intervention is urgently needed to preserve these last drift sand areas and the typical fauna and vegetation they house. So far most measures were taken *ad hoc*, but they did not always lead to satisfying results (Ketner-Oostra and Huijsman, 1998; Bakker *et al.*, 2003). For a more efficient management of the drift-sands in the future, more knowledge is needed about the landscape differentiating processes, the factors controlling these processes, and their extent and role in today's drift-sand landscapes.

Figure 7.1. Inland drift-sand landscape; the largest active remnant in western Europe Kootwijkerzand, the Veluwe, the Netherlands

The Literature often refers to the positive effects wind erosion exerts on the characteristic vegetation in these areas (Ketner-Oostra and Huijsman, 1998). In practice, however, wind erosion affects the vegetated surfaces in drift-sand areas only in the first few metres adjacent to the open sand, unless the event is extremely strong and/or its duration is sufficiently long. The role of splash drift in transporting sand further into the vegetation is usually disregarded.

In 2001 a research project was started by the Erosion and Soil & Water Conservation (ESW) group, Wageningen University in cooperation with the Dutch State Forestry Service (SBB) at the inland drift-sand area Kootwijkerzand in the Netherlands. The main research question was how to keep and/or increase the active area drift sand. Between 2001 and 2005 experiments and observations were carried out to know more about the extent, the intensity and the role of the natural processes in a drift-sand ecosystem. In addition, the project aimed to evaluate the effect of various measures to re-activate erosion.

This paper discusses the results of the experiments. It focuses on the two dominant processes that displace sediment in the drift-sand landscape: wind erosion and (wind-driven) splash erosion. It also discusses the impact of the results on management strategies to keep the erosion processes active.

7.2. Situation and methodology

7.2.1. Study site

The drift-sand area Kootwijkerzand (Figure 2) near the village of Kootwijk (52.12° N, 5.45° E) is located on the Veluwe, a region in the centre of the Netherlands. It is characterised by isolated dunes and by blown-out plains. At Kootwijkerzand, a number of buttes occur in addition to the dunes and the blown-out areas. These buttes are several hundred m^2 in size and up to 10 m high. Their summit is usually covered by pine trees or by shrubs, protecting them from severe wind erosion.

The main soil type in the region is an (albic) arenosol composed of fine, well-sorted and well-rounded quartz sands and without a clear A1 horizon. The drift-sand, which is mainly of local origin, is light yellow-greyish in colour. It is characterised by a relatively loose packing (Koster *et al.*, 1993).

Vegetation at Kootwijkerzand is variable in space, depending on the stage of succession (Table 1). In 2003, 18% of the area consisted of bare sand, whereas 15% was covered by forest and 67% was in one of the intermediate stages of succession (Riksen and Sweeris, 2003).

The area classified as drift-sand is approximately 700 ha in size and is surrounded mainly by pine forest (Figure 2). In 1928 the government decided to take approximately 600 ha of the drift-sand out of the re-forestation scheme and turn it into a national nature reserve. However no active management took place until approximately 1960. Today the area classified as true drift-sand comprises

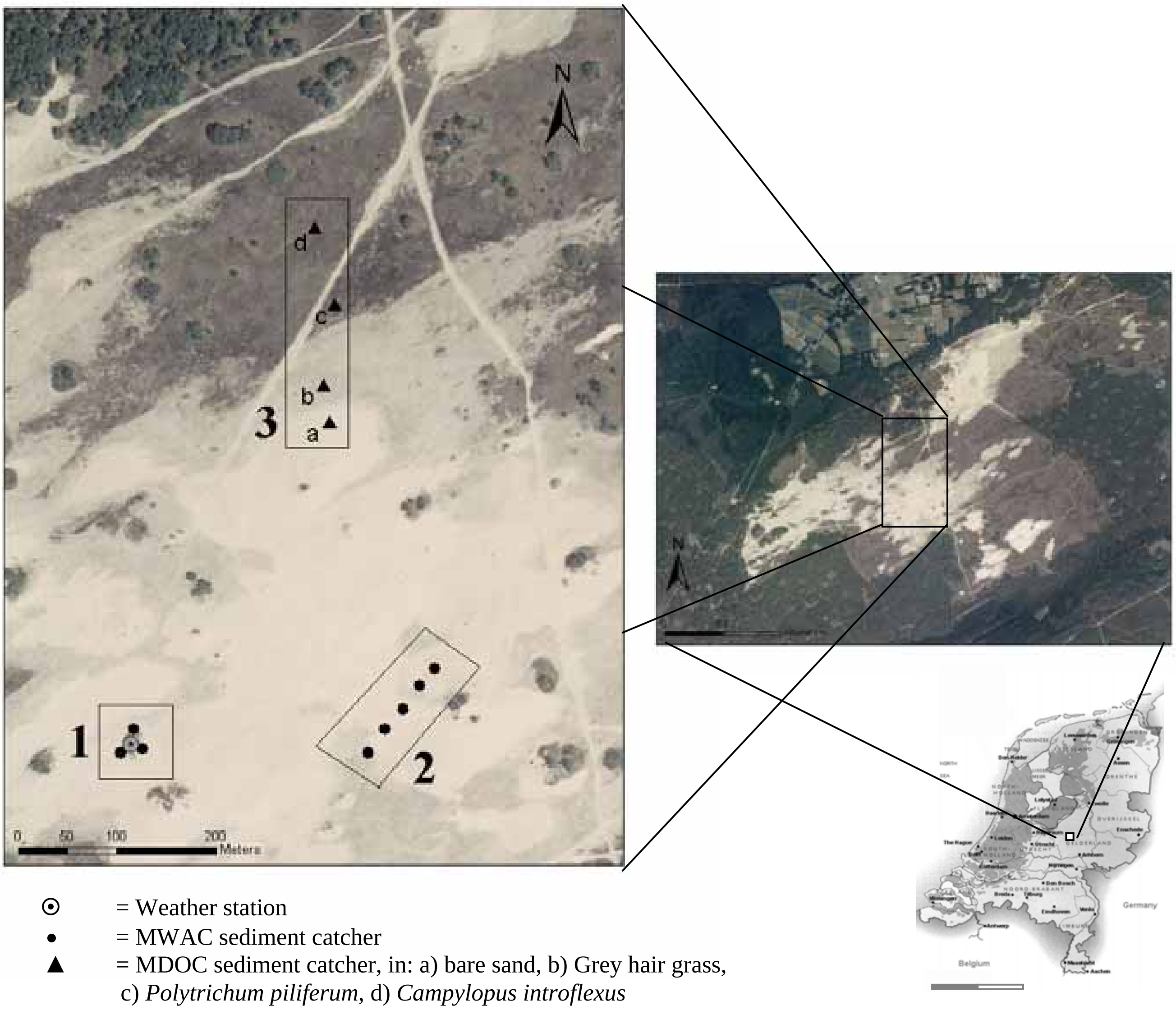


Figure 7.2 Inland drift-sand area Kootwijkerzand, the Netherlands. Location of the experiments and measuring devices for the erosion research which took place between 2001 and 2005 (aerial photograph: © Eurosense, 2003)

approximately 300-350 ha, but the surface of bare sand is rapidly diminishing. The main objective of the SBB is to maintain about 300 - 400 ha as an active drift-sand area.

7.2.2. Changes in vegetation

The changes in the vegetation were studied by analysing aerial photographs of 1963, 1984 and 2000. Five categories were distinguished:

1. Bare sand (vegetation cover < 5%),
2. Scattered low vegetation (5 – 70% vegetation cover),
3. Almost closed vegetation (70 – 100% vegetation cover),
4. Closed vegetation with scattered shrubs and small trees (100% vegetation cover),
5. Closed forest (100 % vegetation cover).

The categories one and two represent the areas with erosion activity. In the almost closed vegetation (category 3) sand transport by wind and/or splash is negligibly small.

7.2.3. Field experiments and equipment used

Vertical accumulation flux in different drift-sand vegetation types

In the different succession stages (Figure 7.2, location 3) the role of wind erosion and splash (drift) was estimated by measuring the *vertical accumulation flux*. The vertical accumulation flux was measured by means of MDCO catchers (Figure 7.3B). As we expected that the deposition in the vegetation would be very low, the MDCO seemed to be the most suitable device for this experiment. Compared to other sediment traps the MDCO is able to measure small deposition rates. A description of the catcher can be found in a paper by Goossens *et al.* (2001). In the Kootwijkerzand experiment the catchers consisted of a rectangular plastic tray 0.525 m long, 0.315 m wide and 0.1 m high, with a filter at the top. The filter consisted of two layers of marbles, 16 mm in diameter, which were stored in a sieve container (mesh diameter of the sieve openings: 5 mm). Sand settles on and between the marbles and is washed down into the plastic tray. The MDCO was installed with the marbles level with the surface.

Four MDOC catchers were installed: the first in bare sand, the second at approximately 20 meter from the bare sand, in a *Corynephorus canescens* vegetation, the third at 90 meter distance, in a pioneer moss (*Polytrichum piliferum*) vegetation, and the fourth at a 200-meter distance, in a closed moss carpet of *Campylopus introflexus*. At each location the vegetation cover percentage was determined at the start and the end of the experiment. The horizontal accumulation flux was measured at a two-week interval. At the end of each interval the erosion features in the zones near the catchers were also described.

The vertical accumulation fluxes were calculated by measuring the amount of sediment caught by the catchers and dividing these over the surface area of the catcher (0.165 m^2) and the total sampling time. The fluxes measured are proportional (but not equal) to the real vertical accumulation flux because of the restricted efficiency of the catcher. For relative comparisons, such as in this study, this does not lead to serious distortions. Apart from the mass, the organic matter content of the collected sediment was also determined by heating the sediment in a pyrolytic oven to 600 °C (Leser, 1977) and measuring the weight loss during the burning process.

Table 7.1. Vegetation and main soil characteristics of drift-sand vegetation succession stages

Succession stage	**Development**	**Composition of the vegetation**	**Vegetation cover**	**Soil profile**	**OM top soil**	**pH KCl**
		(main species)	(%)		0 - 5 cm (%)	0 -5 cm
0	Bare sand, no vegetation development	No vegetation	0	C	0.3	4.7
1	Colonisation of drifting sand with pioneer grasses mainly Corynephorus canescens	Patches of pioneer grasses: C. canescens, Ammophila arenaria, Festuca rubra sp. commutate and Carex arenaria	< 5	C	0.3	4.7
2	Stabilization by algae and C. canescens	Mix of C. canescens and green algae	50 - 80*	C	0.34	4.6
3	Colonisation by the moss Polytrichum piliferum	Mix of pioneer grasses, algae crust and P. piliferum and Spergularia morisonii	40 - 75*	C	0.58	4.5
4	Dying moss because of algae development and decay and development of lichens on partly dead moss and/or colonisation by Campylopus introflexus#	Carpet of P. piliferum covered by algae and lichens, and patches of C. canescens	70 - 100*	AC	0.79	3.5
5	Further decay of moss carpet and colonisation by Festuca ovina and/or Agrostis vinealis and Calluna vulgaris	Mix of C. canescens, mosses, grasses, lichens and C. vulgaris	90 - 100	AC	0.88	3.5
6	Further colonisation by F. ovina and/or A. vinealis, C. vulgaris and seedlings of some trees (Juniperus communis, Pinus sylvestris and deciduous trees)	Mosaic vegetation of grass, mosses, lichen and C. vulgaris with seedlings of some trees	100	AC	1.37	3.5
7	Development into a closed forest	Forest with grasses, mosses and some heather	100	A(B)C	-	-

The moss C. introflexus is an exotic moss species that has invaded inland drift-sands since the 1980s

*) Source: Ketner-Oostra, 1994

-) no data available

(Typology after: Masselink, 1994; Ketner-Oostra and Huijsman, 1998)

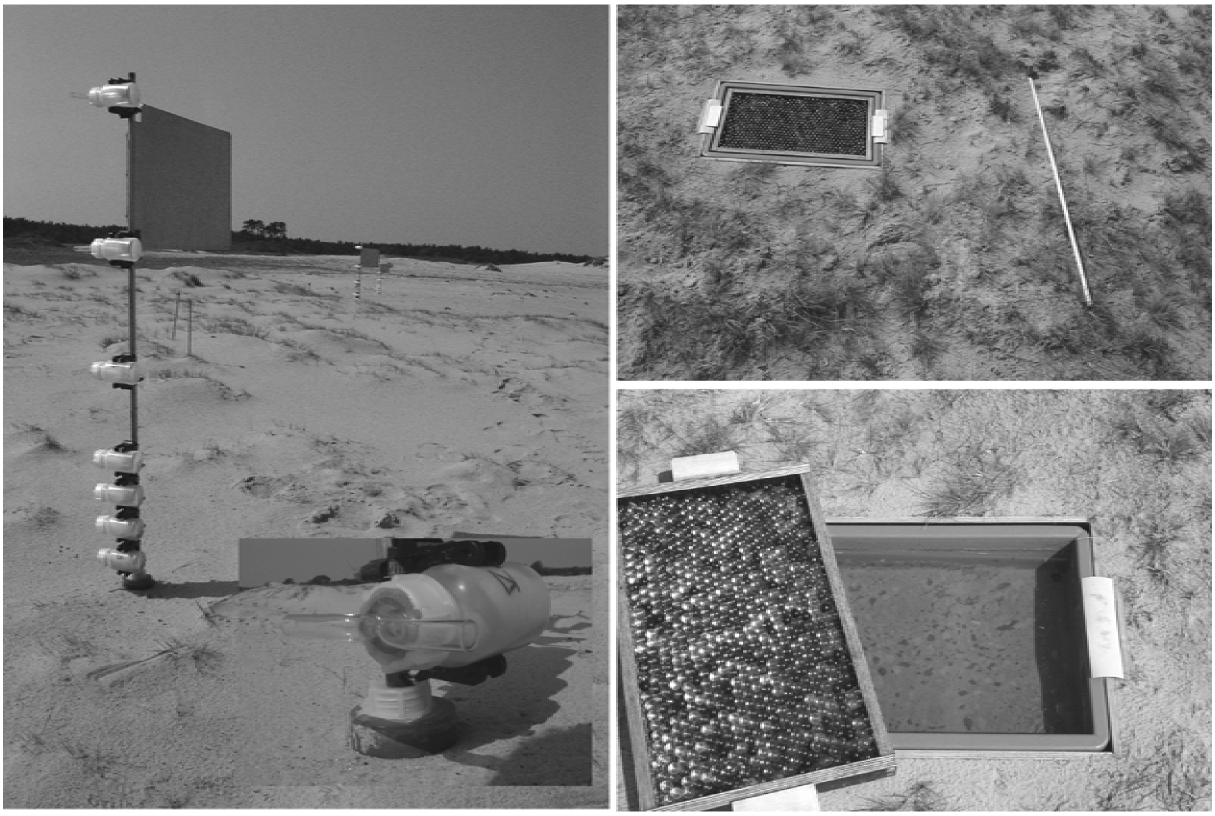


Figure 7.3. Right: MDCO sediment catcher; Left: MWAC Catcher

Horizontal sediment flux and erosion and accumulation on a nearly flat deflation plain and a dune

The erosion activity on an active dune (Figure 7.2, location 1) was compared to the erosion on a nearly flat deflation plain (Figure 7.2, location 2). Erosion activity was measured by studying the horizontal sediment transport rate and the raising (or lowering) of the surface. Horizontal sediment transport was measured with Modified Wilson and Cooke (MWAC) catchers. Seven MWAC catchers (bottles) were installed to vertical masts of 1 m height (Figure 7.3A). The technical description and the calibration of the catchers are described by Goossens *et al.* (2000). The bottles used at Kootwijkerzand were 9.4 cm long and 4.8 cm in diameter. For sand with a grain size similar to that at Kootwijkerzand the efficiency of the catchers is between 109 and 119% compared to true isokinetic sampling, independent from the wind velocity (Goossens *et al.*, 2000). All measured fluxes were corrected accordingly. The MWAC catchers were installed at the following heights at each mast (values refer to the centre of the inlet tubes): 0.05, 0.12, 0.19, 0.26, 0.45, 0.70 and 1.0 m. The exact values were checked at the start and the end of each measuring period, and any increase or decrease (due to erosion or accumulation near the masts) was taken into consideration when calculating the horizontal sediment fluxes. These fluxes were calculated by measuring the amount of sediment caught by the catchers and dividing these over the surface area of the catcher inlet (0.44 cm^2) and the total sampling time. The total horizontal sediment flux at each mast was then calculated by vertically integrating the flux values for the first 1 m above the surface. Since more than 99% of the airborne sediment at Kootwijkerzand consists of sand (diameter > 63 µm), the amount of sediment transported outside these first 1 m is negligibly small (Riksen and Goossens, 2005).

The raising (due to aeolian accumulation) or lowering (due to aeolian erosion) of the surface was measured with erosion pins (De Ploey and Gabriëls, 1980). The pins were 0.5 m long and had a diameter of 5 mm. All pins were checked weekly. They were read with a precision of 1 mm.

On the dune three MWAC catchers were installed halfway the slopes: the first on the dune's southwest slope, the second on the northeast slope and the third on the northwest slope. Erosion pins were installed in a transect along the prevailing wind direction at (a) ⅓ of the slope, (b) half-way the slope and (c) on top of the dune. In the deflation plain, five MWAC catchers were installed along a transect in line with the prevailing (SW ↔ NE) wind directions starting on a *C. canescens* vegetated border (southwest) and ending in a northeast border (also with *C. canescens)*. The total length of the bare area was approximately 75 m. Also, erosion pins were installed along this transect.

Saltation activity and horizontal sediment flux during a rain shower

Comparisons were made of the sediment transport rates caused by splash drift and sediment transport rates caused by wind erosion (Figure 7.2, location 1). During a rain shower, the horizontal sediment transport was measured with saltiphones and MWAC catchers. For this experiment rain and saltation data were stored as 10-second totals. Sediment transport by splash was measured with 26 MWAC catchers in the direct vicinity of the saltiphones. The results of this experiment are preliminary as for the moment only a single event could be measured.

Weather conditions and saltation activity

To register the weather conditions during the field experiments, a meteorological station was installed at location 1 (Figure 7.2). The following parameters were measured: wind speed at 2 m height), wind direction at 2 m, air temperature, relative air humidity and precipitation. Wind speed was measured with cup anemometers and precipitation with a tipping bucket (resolution of 0.2 mm rain). The tipping bucket was installed at 2 m above ground level to avoid sand blowing in the bucket. Wind, temperature and humidity were stored as 10-min averages.

The saltation activity was recorded simultaneously with the registration of the weather conditions. Three saltiphones (Spaan and van den Abeele, 1991) were installed at a height of 0.1 m above the surface. The impacting particles cause a high-frequency signal in contrast to water droplets and wind, which cause lower frequency sounds (Lima *et al.*, 1992). The saltiphone data were stored as the total number of recorded impacts (counts) within a 10-minute span.

7.3. Results

7.3.1. Changes in the vegetation cover

Figure 7.4 shows a decline of the area of bare sand with 25 per cent in the period between 1963 and 2000. Approximately 40 per cent of this area now shows scattered vegetation, and the other 60 per cent has become completely stabilised with closed vegetation. The area occupied by forest remained more or less unchanged due to the regular removal of the pine seedlings in the drift-sand vegetation.

7.3.2. Effect of vegetation on the vertical accumulation flux and the role of wind and splash erosion

Table 7.2 shows the two weekly total vertical sediment flux at the different drift sand succession stages (location 3) caused by wind and splash erosion. For wind erosion as well as for splash drift, vegetation cover is the dominant factor controlling the erosion process. An exponential relationship exists between the vegetation cover and the vertical accumulation flux.

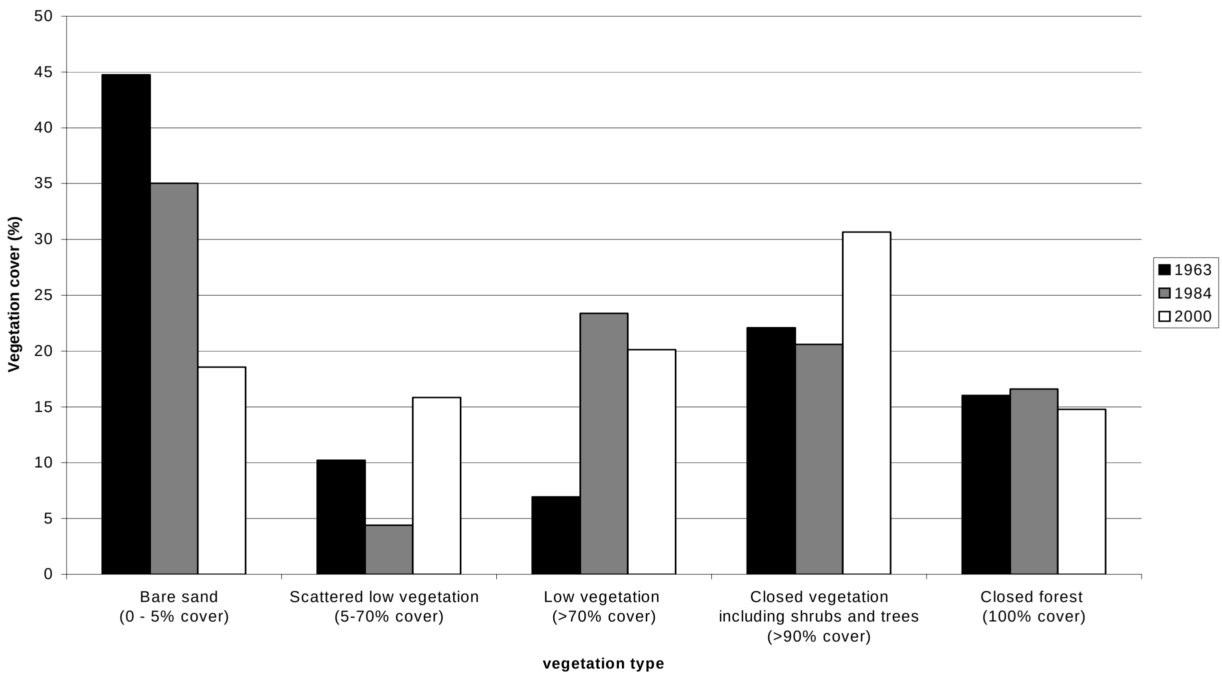


Figure 7.4. Change in vegetation between 1963, 1984 and 2000 at Kootwijkerzand, the Netherlands

Table 7.2. Relation vertical accumulation flux (g m^{-2}) with wind and rain for different drift-sand vegetation succession stages at Kootwijkerzand, the Netherlands in the period 15 May – 16 October 2003

Period	Vertical accumulation flux (g m^{-2}) in vegetation type (vegetation cover %): Sand (0)	Grey hairgrass (50)	Pioneer moss (70)	Moss carpet (99)	Rain-fall (mm)	Average wind speed per mm rain (m sec^{-1})	For wind weighted rainfall [1]	Saltation[2] (counts)
15 May - 29 May 03	51,638	496	111	12	63	1.7	107.44	1,058,456
29 May -12 June 03	129,963	736	208	7	23	3.9	90.48	973,896
12 June - 26 June 03	250,899	170	47	2	7	6.1	45.14	4,896,911
26 June - 10 July 03	157,190	685	190	16	22	4.5	99	424,687
10 July - 24 July 03	217,647	1,016	311	9	20	3.7	73.26	2,573,150
24 July - 7 Aug. 03	38,985	309	96	2	14	2.9	39.44	860,323
7 Aug. - 21Aug. 03	44,145	24	8	1	2	2.6	4.16	823,491
21 Aug. - 4 Sep. 03	10,352	165	59	22	23	3.1	71.92	1,284,852
4 Sep. - 18 Sep. 03	2,874	287	109	3	19	2.4	46.56	273,355
18 Sep. - 2 0kt. 03	141,176	151	99	2	21	3.4	70.04	922,433
2 Okt. - 16 Okt. 03	144,922	1,005	466	11	59	5.1	299.88	1,884,321
Weekly Average (kg m^{-2})	54.081	0.229	0.077	0.004				
Average organic matter content (%)	0.28	0.82	2.39	21.24				

Vegetation type	Correlation coefficient (R^2): Vertical accumulation flux – Rainfall	Vertical accumulation flux - weighted rainfall	Vertical accumulation flux – Saltation[1]
Bare Sand	0,01	0.05	0,52
Grey hairgrass	0,28	0.47	0,00
Pioneer moss	0,32	0.73	0,01
Moss carpet	0,20	0.14	0,03

1) For wind weighted rainfall: The detachment of soil particles by raindrops increases with the wind. In this case the rainfall is weighted by a factor equal to the computed Average wind speed per mm rain.
2) Saltation recorded with the saltiphones is mainly caused by wind.

The data were further analysed to check the relation between the vertical accumulation flux and the erosive agents (wind and rain splash). The correlation coefficients in Table 7.2 show that on bare sand the wind is the dominant agent causing transport. In the partly vegetated zone rain drop impact becomes more important. In the almost closed vegetation with *C. introflexus*, no relation between the vertical accumulation flux and the erosive agents exists.

Observations in the field confirm this picture. There is a clear distinction between the erosion features present in the different vegetation succession zones. Typical wind erosion features such as ripples (Figure 7.5A) and shadow dunes (ephemeral small dunes formed behind a clump of grass, see Figure 7.5B) are common in the zones with only a few individual grass tussocks and in the transition zone with scattered vegetation with a cover of less than 30% (Figure 7.5D). In this transition zone sedimentation is also a common feature.

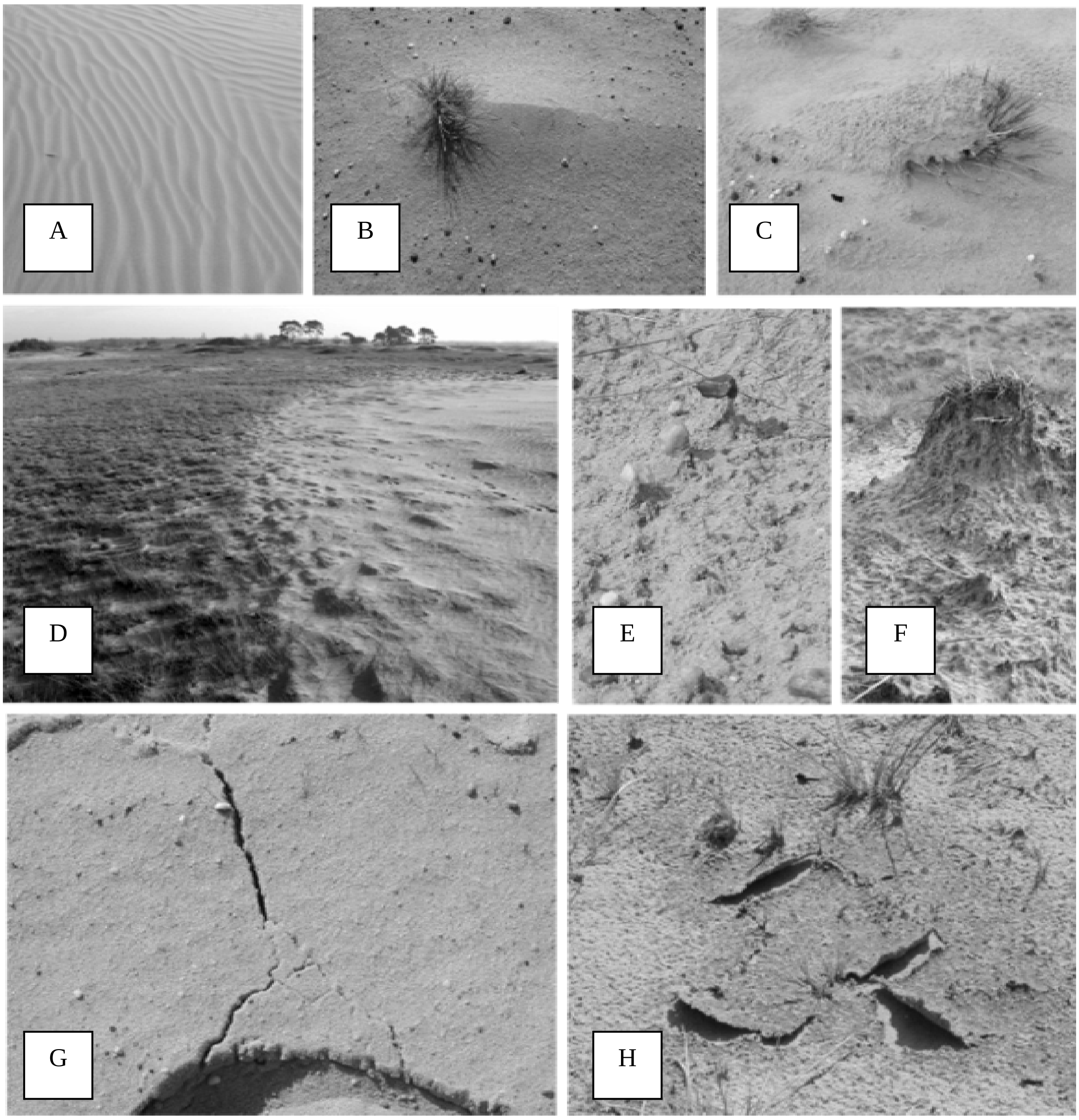


Figure 7.5. A Ripples; B Accumulation of sediment behind a grass tussock by wind erosion; C Accumulation of sediment in front and on a grass tussock by splash drift; D transition zone between bare sand and first succession stage; E Splash pedestals; F splash pattern between scattered vegetation; G Structural crust; H Biological crust

During splash drift events, sediment is deposited in front of the grass tussocks (Figure 7.5C). In the deflation plain and the transition zone a seal may be formed during rain storms. After the seal has dried, a weak structural crust is formed (Figure 7.5G). This crust easily breaks up during the next wind erosion event.

Where the vegetation cover has been significantly reduced due to the burial by sediment, erosion features can be observed, especially at the head of the vegetated parabolic dunes. The width of the transition zones highly varies through space and time. These zones are rather broad (up to approximately 50 m) in the direction of the most erosive winds, but very narrow (< 10 m) parallel to these winds (Figure 7.5D).

Table 7.3. Erosion and accumulation (mm) on a deflation plain and a dune at Kootwijkerzand, The Netherlands, 2003

	location									
	Deflation plain					Dune				
week	Vegetated border	SW border	Centre	NE border	vegetated border	SW (1/3) slope	SW (2/3) slope	Top dune	NE (2/3) slope	NE (1/3) slope
8	-1	1	-3	-2	-4		38	4	-44	
9	0	-4	-3	-1	-1		0	-2	8	
10	-1	1	3	1	0	0	-15	-6	-1	2
11	-1	9	-3	-3		-13	-64	7		48
12	1	-8	-1	-2	-4	2	32	0	-35	-16
13	1	0	0	2	-2	-1	6	2	-25	0
14	0	3	-1	0	5	-4	-34	1	-3	7
15	-2	-13	-2	-5	-17	-9	-16	-22	-49	17
16	1	7	-3	0	-2	21	163	16	-28	-22
17	2	8		1	-4	47	98	-77	-95	-6
18	0	17	-4	-5	28	-1	-2	15	29	1
19	1	4	4	4	-3	-5	-109	5	34	3
20	1	1	-1	-4	5	0	-13	1	16	4
21	1	4	0	3	3	-3	-4	2	2	3
22	0	-2	-1	-1	0	1	-3	-1	-6	-4
Sum	*03*	*28*	*-15*	*-3*	*4*	*35*	*59*	*-55*	*-197*	*-8*
Stand. dev.	*1*	*7*	*2*	*4*	*10*	*15*	*64*	*22*	*35*	*24*

- = erosion

Splash pedestals caused by raindrop impacts (Figure 8.5E and F) are common features in the zone with *C. canescens* and the pioneer moss *P. piliferum*. Drift-sand pioneer vegetation traps the water drops and the sediment very efficiently. The accumulation of sediment in and on the vegetation amplifies the effect of splash erosion. Under extreme storms, pedestals with dome shaped tops are formed. The relationship (Table 8.2) between the vertical accumulation flux and the wind speed-weighted rainfall is strongest in the zones with *C. canescens* and the moss *P. piliferum*.

The soil cover percentage in the vegetation zone with *C. introflexus* is almost always 100%. Here erosion is negligible, and no erosion features are observed.

7.3.3. The slope effect on the horizontal sediment transport flux and erosion an accumulation rates

The erosion activity on an active dune (Figure 7.2, location 1) was compared to the erosion on a deflation plain (Figure 7.2, location 2) by measuring the raising and lowering of the surface with erosion pins and by studying the horizontal sediment transport rates with MWAC catchers. Table 7.3 shows the changes in level of the

Table 7.4. Horizontal transport flux, on a erosion dune and a deflation plain at Kootwijkerzand

	Horizontal transport flux					
Period	***11 May -27 May 04***		***27 May - 10 June 04***		***10 June - 25 June 04***	
Duration wind erosion activity[1)]	***45 h***		***21 h***		***70 h***	
Location	**($g\ cm^{-1}$)**	**($g\ cm^{-1}\ s^{-1}$)**	**($g\ cm^{-1}$)**	**($g\ cm^{-1}\ s^{-1}$)**	**($g\ cm^{-1}$)**	**($g\ cm^{-1}\ s^{-1}$)**
Deflation plain: North east side	520	$3.2\ 10^{-3}$	1.1	$1.5\ 10^{-5}$	82.3	$0.3\ 10^{-3}$
Deflation plain: Centre	692	$4.3\ 10^{-3}$	3.6	$4.8\ 10^{-5}$	109.5	$0.4\ 10^{-3}$
Deflation plain: South west side	18	$0.1\ 10^{-3}$	0.1	$0.1\ 10^{-5}$	1.8	$0.0\ 10^{-3}$
Dune: North-east slope	2477	$15.3\ 10^{-3}$	21.5	$28.4\ 10^{-5}$	212.3	$0.8\ 10^{-3}$
Dune: South slope	342	$2.1\ 10^{-3}$	2.4	$3.2\ 10^{-5}$	313.9	$1.2\ 10^{-3}$
Dune: West slope	2765	$17.1\ 10^{-3}$	13.5	$17.9\ 10^{-5}$	414.5	$1.6\ 10^{-3}$

1) Duration wind erosion activity based on saltiphone data

surface 1) along the dune, and 2) along a transect on the deflation plain. The spatial differences, in the erosion and accumulation patterns, on the deflation plain are caused by the vegetation and the wind direction. For the dune, topography is the dominant factor determining the rates of deflation, transport and deposition.

Table 7.4 shows the horizontal sediment transport flux for three periods with a prevailing south-westerly wind. On the deflation plain the horizontal sediment transport flux is low at the south-west border. Because the wind has not yet reached its maximum transport capacity, net erosion is observed at this location. The horizontal sediment transport flux is highest near the centre of the deflation plain: here deflation and deposition are more or less equal (Table 7.4). In the north-east, the transport capacity of the wind has diminished due to the increase in vegetation marking the onset of the accumulation zone. The average sediment transport rate was 5 to 8 times higher on the dune than on the plain.

7.3.4 Saltation activity and horizontal sediment transport by splash drift

Analysis of saltiphone data collected earlier at Kootwijkerzand showed that, in addition to aeolian transport, the saltiphone also records splash-induced transport. The distinction between the two processes is easily recognisable in the data output. Grain transport by wind always results in a high impact rate on the microphone, usually of the order of a few tens of impacts per second. Grain transport by splash is characterised by a significantly lower impact rate, in the order of 0.5 - 2 impacts per second, depending on the rainfall characteristics and the wind speed. The two types of impact are clearly recognisable in the data since no transition exists between the two types of signals.

Figure 7.6 shows saltiphone and rain data recorded on bare dune sand during a rainy day (3 July 2003) at Kootwijkerzand. No wind erosion occurred on that day because of the wet soil surface. Rainfall amounts and saltiphone counts were recorded during an 8-h time interval, running from 10:30h local time until 18:30h

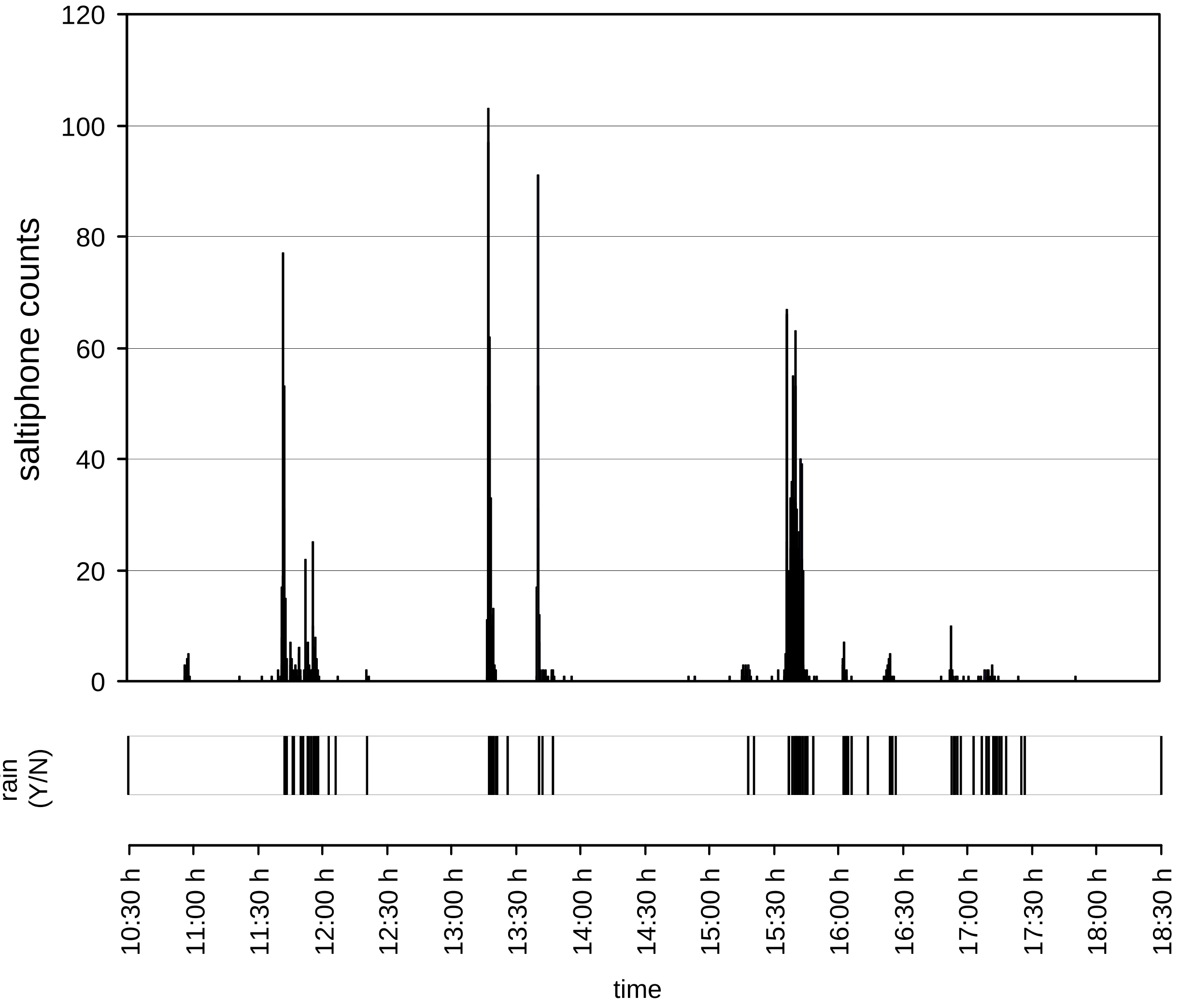


Figure 7.6. Rainfall and saltiphone data for the 3 July 2003 splash erosion experiment at Kootwijkerzand, the Netherlands

local time. During one rain shower between 16:23h and 17:26h local time, the sediment transport by splash was measured with 26 MWAC catchers in the direct vicinity of the saltiphones. Figure 7.6 shows theclose-to-perfect agreement between the periods of rain and the periods of splash-induced sediment transport as recorded by the saltiphone. The number of impacts recorded during the 63-minute period was 67. The corresponding horizontal sediment transport (between 0 and 1 m in height) in the downwind direction, as measured by the MWAC catchers, was 1.30 g cm^{-1}. The effective rain time during the 63-minute period was 610 s; the horizontal sediment flux in the downwind direction due to splash was thus 2.13 10^{-3} g cm^{-1} s^{-1}. Extrapolating these data to the 8-hour long experimental period, during which 2501 counts were recorded by the saltiphone and 16.8 mm rain were registered by the tipping bucket, the horizontal sediment transport by splash (in the downwind direction) was 48.5 g cm^{-1}.

7.4. Discussion

7.4.1. The role of erosion processes in the drift-sand ecology

The drift-sand pioneer vegetation is adapted to extreme conditions: nutrient-poor soils with a low water-holding capacity and a microclimate characterized by a strong difference between the night and day temperatures. Without sufficient erosion the scattered drift-sand vegetation will rapidly change into a closed, grass-dominated vegetation as shown by the analysis of the aerial photographs (Figure 7.4). In the Netherlands the regeneration process is accelerated by the high level of N-deposition and the invasion by exotic plant species (Riksen *et al.*, in press). The rapid colonisation by vegetation has also been documented for other drift-sand areas in the Netherlands (Schimmel, 1975). The colonisation strongly reduces the impact of erosion on the landscape; it also results in the disappearance of many pioneer plants.

Erosion processes play a double role in the drift-sand ecology:

- erosion slows down the succession rate due to the regular deposition of nutrient-poor sediment in the vegetation
- it creates new locations of extremely poor environmental conditions (blown-outs), which are the best areas for an optimal development of the typical drift-sand vegetation (Ketner-Oostra and Riksen, 2005).

Several studies have shown that the pioneer *C. canescens* profits from aeolian sedimentation by showing a strong rejuvenation (Ketner-Oostra and Riksen, 2005). Regular deposition of sediment is also beneficial for the moss *P. piliferum*. Algae, on the contrary, more or less disappear when new sand is deposited (Pluis, 1993).

7.4.2. The role of splash drift in the drift-sand landscape

The strong correlation between the vertical deposition flux and rainfall in the scattered pioneer vegetation (R^2 between 0.4 and 0.7) points to a dominant role of splash and splash drift in these zones. Another observation is that the organic matter content of the sediment in the catchers (Table 7.2) corresponds with the organic matter content of the soil surface in the direct surroundings of the catchers. This also points to the dominant role of splash and splash drift in the scattered vegetation, for the organic matter content of the accumulated sediment would significantly differ from that of the surrounding soil surface if detachment and transport of the soil material had been caused by wind alone (recall that wind-blown sand contains much less organic matter than the parent material, see Govers *et al*., 2004).

The dominant role of splash transport in scattered vegetation has already been recognized by van Asch (1983) for scattered herb and shrub vegetation in Calabria, Italy. He found that splash transport accounts for 30 to 95 per cent of the total transport of material by erosion in this vegetation type.

7.4.3. The role of wind erosion in the drift-sand landscape

The vertical accumulation flux on the bare sand (Table 7.2) showed a correlation with the registered saltation activity. The scattered pioneer vegetation is only affected by wind erosion in a 5 to 50 meter wide zone adjacent to the deflation plains. In this zone deposition of the windborne sediment is the main aeolian process. Only when the vegetation has become buried by the sand, wind erosion will occur in this zone. This mainly happens after severe storms. The renewed erosion is important to maintain the area under bare sand with potentially high sediment transport rates, for the renewal of the first succession stage, and may also have a positive effect on the vegetation adjacent to the reactivated zone.

7.4.4. Stability and instability in the drift-sand system

In terms of stability two major zones can be distinguished in a drift-sand ecosystem:

- *stable areas*: areas in which the dynamic state (phase in the succession) does not significantly change in the short or medium term;
- *unstable areas*: the dynamics state may easily change from highly active (much erosion) to merely inactive (no erosion) or vice versa.

Deflation plains and vegetation-covered surfaces represent the first type. The high intensity and the continuous character of the wind erosion guarantees that no vegetation develops on the deflation plains. Degradation of the soil surface is the dominant process in these areas. As long as there is a sufficient amount of erodible material and the wind regime does not alter, erosion will continue and the dynamic state of the area remains unchanged.

In areas where the soil is completely covered by vegetation, no erosion can take place, and the area will thus remain inactive unless the vegetation is partly or completely destroyed by human interventions. In the drift-sand landscape of Kootwijkerzand the vegetation-covered land becomes stable from succession stage 4 (see Table 7.1). Further development of the vegetation and soil formation are the dominant processes in these areas.

In most drift-sand areas a transition zone can be noticed between the spots of bare sand and succession stage 4 (Table 7.1). Here, erosion is highly variable in space and time (Table 7.2). These zones can change from active to inactive and vice versa in relatively short time intervals, eventually less than a year. They belong to the most unstable zones in the drift-sand ecosystem and require special attention in the management of these areas.

At Kootwijkerzand, the average weekly vertical accumulation flux measured on bare sand was 235 times higher then in a scattered vegetation with 50 per cent vegetation cover. It also showed a correlation with the registered wind erosion (saltation) activity. Wind erosion in drift-sand areas is therefore mainly controlled by vegetation. Castel (1986) found similar results in a study based on simulations with a wind erosion model using the terrain characteristics (vegetation and relief) of another drift-sand area Hulshorsterzand located on the Veluwe, the Netherlands.

7.4.5. The role of surface crusts on sediment transport

Two main types of surface crusts occur in drift-sand areas: physical (structural) crusts and biological crusts. Structural crusts mainly occur on bare drift-sand and in the first succession stage. They are very weak and easily break up (Figure 7.5G). Biological crusts (Figure 7.5H), on the other hand, can form a non-erosive layer and consist of algae. The algae are present in the bare soil as well as in the first four succession stages (Table 7.1). Pluis (1993) found that only low amounts of algae occur on active drift-sands throughout the year; therefore their effect on wind erosion is limited. However, strong algal crusts may develop when the erosion activity is low. These crusts primarily develop under conditions of high moisture and are normally 1-6 mm thick. Their rate of development increases once the surface has been more or less protected by pioneer vegetation, often *C. canescens*.

Once a crust has developed, it protects the soil from erosion (Van den Ancker *et al.*, 1985). Crusts developed near the bare drift-sand zones may become covered by blown-in sediment, leading to a retardation in their subsequent development. Further away from the active zones the loose soil material on the crust is mainly (re)moved by rain splash or by overland flow. Crusts also accelerate the natural succession due to their biomass production (eutrophication). They also reduce the transport of sediment by splash (drift).

7.4.6. Consequences for the management of drift-sand areas

This study showed that the drift-sand landscape and ecosystem are the result of the interaction between erosion and vegetation development. If one of these processes becomes dominant, some of the characteristic drift-sand features will disappear from the landscape. For example, in a completely vegetated drift-sand area no new wind erosion features will form and the drift-sand pioneer vegetation, which only survives due to the regular deposition of fresh sediment, will disappear. A complete removal of the vegetation, on the other hand, results in high erosion activity in the period shortly after the removal. In addition, the sediment transported by the wind is no longer stopped by the vegetation inside the drift-sand area but only at its border. Flattening of previously stabilized dunes after large-scale removal of the vegetation has already been observed at Hulshorsterzand, the Netherlands (Bakker *et al.*, 2003). Maintaining a minimum percentage of active drift-sand is the best strategy to preserve the typical drift-sand landscape and ecology for the future. The transition zones (succession stages 1 - 3) are the best locations to take measures, especially those immediately downwind of the still active deflation zones. In areas completely stabilized by vegetation the best locations for creating new spots with high wind erosion activity are the upper terrain parts that contain a sufficiently thick layer of drift or cover sand. Removing the vegetation in such areas has been successfully used in the past to reactivate deflation plains (Bakker *et al*., 2003).

7.5. Conclusions

To preserve the inland drift-sand ecotype and its characteristic geomorphological features for the future, it is necessary to understand the landscape characteristics and the landscape differentiating processes occurring in it. Active inland drift-sands are characterised by their:

- Relief: blow-outs or deflation plains, plateau dunes, drift-sand dunes and ridges.
- Distinct stages in the natural succession, with typical pioneers like *C. canescens*, *S. morisonii*, *P. piliferum*, lichen like *Cladonia* sp., and *Cladina* sp.
- High dynamics: the landscape is changing constantly in time and space due to the high intensity of the landscape differentiating processes: soil erosion (wind erosion, splash drift erosion, water erosion and mass movement), and regeneration (starting by the colonisation of the bare drift-sand surfaces by pioneer vegetation, followed by the natural succession of the vegetation into forest).

7.5.1. The role of erosion processes in the inland drift-sand ecotype

- Splash drift events can generate sediment transport rates of the same magnitude as moderate wind erosion events. On bare sand, however, their contribution to the sediment transport is negligible compared to the transport generated by the wind alone.
- Pioneer vegetation clearly profits from the regular sedimentation of drift-sand. In the zone next to the deflation area, sedimentation is dominated by wind. The sedimentation rates are generally high, as shown in Table 7.2. Only the pioneer grass *C. canescens* can survive under these conditions.
- The deposition rates decrease exponentially with the increase of the vegetation cover.
- In the scattered vegetation, splash (drift) is the dominant mechanism generating sediment transport. Occasionally, during extreme wind erosion events, sedimentation by wind may also take place in these zones.

- The development of an algal crust between the scattered vegetation probably reduces the sediment transport by splash drift, because it reduces the availability of loose material at the soil surface for detachment. More research is needed to elucidate the influence of these algae on the vegetation's succession, and to develop measures to reduce the effect of biological crust without disturbing the remaining vegetation.

7.5.2. Status of the drift-sand area

- In the areas with no vegetation wind erosion is the dominant process responsible for over 90 percent of the total sediment transport. In many cases however, the size of these zones within the total drift-sand area is nowadays limited. Large-scale dune formation and development thus hardly take place due to the limited sand transport. In addition, most of the vegetated areas in the drift-sand system are not controlled or influenced by wind erosion at all.
- Wind erosion activity occurs throughout the year. However, most transport occurs during the few extreme storms per year. Only these extreme storms can generate sufficient transport to reactivate wind erosion activity in the transition zone. Without these events with high transport rates, the sediment from the deflation plain is deposited in the vegetation within a few meters from the deflation plain and is often no longer available for the wind erosion process.
- The general trend is an ongoing decline of the area of bare sand indicating that under present condition the wind erosion activity is too small and human intervention is needed.

7.5.3. Consequences for the management of the inland drift-sand ecotype

To date, much emphasis has been placed on the preservation of the European drift-sand ecosystems because of their typical mosaic vegetation and rare fauna species. A balance between the active areas prone to wind erosion and the much more stable vegetated areas is needed to preserve the drift-sand ecosystem as well as the characteristic geomorphological landscape elements in it. The preservation of these elements is only possible when sufficient sand is transported within the ecosystem To guarantee sufficient sand transport the following boundary conditions should be met:

1. Scale: A sufficiently large active erosion area;
2. The presence of a sufficient amount of erodible material: drift sand or cover sand;
3. Optimal wind force: no obstacles reducing the wind speed should appear in or near the active area.

Process management, management focused on the increase of the erosion activity, is needed if the active areas within the drift-sand ecosystem becomes too small or show little erosion activity.

On locations where the wind erosion activity has stopped due to the absence of erodible material (blown-outs), process management is no longer an option. Here vegetation pattern management is the only alternative to preserve the drift-sand vegetation.

On locations where there is a sufficient reserve of erodible sand, but little wind activity, the process management consist of the optimisation of the wind field first before applying tillage measures that make soil particles available for the wind.

To increase the chance of success of process management the following aspects should also be considered in the selection of most suitable locations to reactivate and reactivation techniques:

- The positive effect of short slopes, also known as the knoll effect (USDA, 1979), on erosion. On short slopes the wind force is increased at the wind ward slope leading to higher erosion rates than on a horizontal surface;
- The presence of a water table near the surface (< 0.7 m): in some drift-sand areas impermeable soil layers occur near the soil surface leading to a more or less constant wet soil surface;
- Soil formation: a sufficiently developed soil (at the surface or as a buried profile) provides conditions in which seeds can successfully germinate. The rate of soil formation therefore determines if, and how deep, the topsoil can be removed without seriously harming the ecosystem.

Acknowledgements

This study was carried out as part of the research project "Making use of Wind and Water Erosion Processes in Dutch Landscape Development", of the Erosion and Soil & Water Conservation Group of Wageningen University, and was funded by the Dr. Ir. Cornelis Lely Foundation, the C.T. de Wit Graduate School of Product Ecology and Resource Management (Wageningen University). The field experiments were realised in co-operation with the Dutch Forestry Foundation (Staatsbosbeheer) in the persons of Eric Kleinlebbink, Wim Huijsman, Aalt Boonen, Hans Snel, Gerrit Holtslag, Alfred Harmsen, Jan Bijker and Peter Mulder, who provided the experimental terrain and assisted with the preparation of the experimental plots. Special thanks are expressed to Huiberdien Sweeris and Piet Peters for their assistance during the field measurements and the laboratory work, and Rita Ketner-Oostra for sharing expertise on drift-sand vegetation. Special thanks to Pim Jungerius and Wim Spaan for their comments and advises.

Chapter 8

TILLAGE TECHNIQUES TO REACTIVATE AEOLIAN EROSION ON INLAND DRIFT-SAND

Michel Riksen and Dirk Goossens

Published in: *Soil & Tillage Research* **83**: 218-236 (2005)

In: Wind Born(e)Landscapes
(M.J.P.M. Riksen) Wageningen, 2006, pp. 147 -175 .

8. Tillage techniques to reactivate aeolian erosion on inland drift-Sand

M.J.P.M. Riksen[1] and D. Goossens[1,2]

[1] *Erosion and Soil & Water Conservation Group, Department of Environmental Sciences, Wageningen University, Nieuwe Kanaal 11, NL-6709 PA Wageningen, Netherlands*

[2] *Laboratory for Experimental Geomorphology, Katholieke Universiteit Leuven, Redingenstraat 16 bis, B-3000 Leuven, Belgium*

Abstract

The inland drift-sand areas in northern Europe are characterised by a rapid decline in both aeolian activity and areal size. Many former drift-sand surfaces have become immobilised by natural or man-induced processes, such as conversion into forest or other terrain for agricultural, economic or societal purposes. The sharp reduction of these areas automatically implies the disappearance in Western Europe of a unique landscape with a high natural and cultural-historic value. Therefore, it is necessary to investigate how drift-sand areas can be preserved, how the balance between the active areas and those colonised with drift-sand vegetation can be kept under control, and how introducing techniques that reactivate, or benefit, the aeolian processes can counteract irreversible immobilisation by subsequent colonisation. Four such techniques (rotary cultivator, beach sand cleaner, disk harrow and excavator) were evaluated during an 8-month experiment on drift-sand stabilised by grey hairgrass and algae crusts at Kootwijkerzand, Netherlands. The effect of the techniques was measured using five key-parameters: the raising and lowering of the surface due to aeolian activity, the horizontal sediment transport flux, the vertical sediment accumulation flux, changes in the grain size of the top layer due to aeolian processes, and changes in the organic matter content of the topsoil. The effect of each technique on soil compaction, surface roughness and the amount of plant residue left on the field is also discussed. The highest aeolian activity (horizontal and vertical flux, surface lowering) was observed on test fields treated with the beach sand cleaner and the rotary cultivator. The changes in grain size and organic matter content of the top layer were also highest in these fields. Of the four techniques tested, the beach sand cleaner and the rotary cultivator are thus the most recommendable methods to reactivate drift sand stabilised by grey hairgrass and algae crusts. The disk harrow and the excavator may also lead to a reactivation, but they are less effective and therefore less recommendable.

Key words: Wind erosion; Drift sand; Nature conservation; Tillage; Reactivation; Veluwe

8.1. Introduction

Nearly all contemporary inland drift sand in Europe is the remains of degraded areas that date from the late Middle Ages (Slicher van Bath, 1960). In the north-European sand belt, which extends from Belgium and The Netherlands through Germany, Denmark and Poland into the Baltic states, local resedimentation by wind of the original Pleistocene deposits occurred on a large scale from the beginning of the Neolithic up to the present (Koster *et al*., 1993). The intensive land use since the late Middle Ages resulted in a high wind activity on these soils. Large areas turned into drift sand without, or with only very little, vegetation. These inland drift-sand areas are scattered throughout northern Belgium (200-300 km^2), The Netherlands (approximately 800-950 km^2), Northwest Germany (1400-2000 km^2) and Denmark (450-550 km^2) in many relatively small patches. Similar deposits are found in England, particularly East Anglia (Koster *et al*., 1993), and in Poland. Since the late 19th century most drift-sand areas were reforested successfully as in the Brecklands in east England (Riksen and de Graaff, 2001), the Antwerp and Limburg Campine area in Belgium (Vanhecke *et al*., 1981), Vomb in Sweden (Riksen and de Graaff, 2001), and the Veluwe in The Netherlands (Tesch *et al*., 1926; Schimmel, 1975; Koster *et al*., 1993).

In The Netherlands, about 60 km^2 of the original drift-sand area still existed in the mid-1960s (Bakker *et al*. 2003, Jungerius 2003). These 60 km^2 have been preserved for their unique landscape value. Their vegetation forms patches of distinct stages in the natural succession. Typical pioneers are *Corynephorus canescens* (grey hair grass), *Spergula morisonii*, *Polytrichum piliferum*, lichens like *Cladonia* sp., and *Cladina* sp. (reindeer moss). The combination of open land and these vegetated patches forms the habitat for rare insects, birds and lizards. The areas also have an historic cultural value. At Kootwijkerzand (central Netherlands), for example, remnants were found of pottery from different ages (Roman, Karyolitic and early Middle Ages). At the same location an early Middle Age settlement was discovered with farmhouses, sheds, roads, fences and different arable parcels which are now all covered by drift sand (Schimmel, 1975). The active drift-sand areas are also unique for their geomorphic processes, and are also appreciated for recreation.

The inland drift-sand areas of northern Europe have shown a rapid decline in size during the last few decades. From the 60 km^2 that remained in The Netherlands after the major period of reforestation, only 40 km^2 were left around 1980 (Jungerius, 2003). Schimmel (1975), who used historical data and aerial photographs, calculated the reduction in drift-sand area on the Veluwe (central Netherlands) from 145 km^2 in the second half of the 19th century to 21.6 km^2 in 1968 and only 10 km^2 in 1975.

The decline of active inland drift sand in northern Europe is explained by various factors:

1. *Changes in land use*. Up to the early 19th century, the need for large amounts of heath-land to fertilise the arable fields, overgrazing by sheep and the progressive lowering of the groundwater table due to deforestation and land reclamation accelerated the transformation of land into drift sand (Schimmel, 1975; Slicher van Bath, 1977; Koster *et al*., 1993). With the introduction of fertilisers, the collapse of the wool industry, the increasing industrialisation and also because of political decisions, many heath-lands and drift-sand areas were converted into forest. Because of the reforestation, the size of many drift-sand areas dropped below the critical level required to generate wind erosion at the landscape level. The landscape changed from open into closed or half open, hereby increasing roughness and reducing the fetch and the local wind speed. Also, many drift-sand areas were no longer able to "travel" along the prevailing erosive wind direction. Wind erosion was (and is) thus reduced to a local process. Under these conditions, the equilibrium between erosion and regeneration disappears: natural regeneration of the soil is taking place at an increasing speed whereas no new active drift-sand is created.
2. *Import of nutrients*. The natural regeneration of the European drift-sand areas has been considerably accelerated by the airborne import of nutrients. Especially the increased deposition of nitrogen in an ecosystem where nitrogen normally constitutes one of the limiting factors (Ketner-Oostra and Huijsman, 1998) accelerated the succession.
3. *Introduction of exotic plant species*. Exotic species introduced into the drift-sand areas affect the balance between degradation and regeneration. Typical examples are the pine tree and the moss *Campylopus introflexus*, which are characterised by a more rapid spread and/or a higher biomass production than the indigenous species. This results in a more rapid soil formation and, thus, in a more rapid evolution toward a closed forest.

An active and adequate management, focusing on a restoration of the degradation-regeneration balance, is needed if European inland drift-sand areas are to be preserved for future generations. Until 1990, measures were mainly taken ad-hoc (Bakker *et al*., 2003). They usually focused on removing vegetation or retarding its development, but did not, or not fully, take into account the physical process of wind erosion. This puts severe constraints on their efficiency, as optimum results will only be achieved when wind erosion, as a physical process, is sufficiently stimulated by these measures.

The objective of this paper is to evaluate several tillage methods that are currently used to reactivate stabilised drift-sand. Thus far, little is known about the effect of these methods on soil erodibility. Field experiments were therefore carried out at Kootwijkerzand, the largest contemporary inland drift-sand area in Western Europe. Besides their effect on aeolian reactivation, the tillage methods were also evaluated with respect to some of their ecological consequences on the drift-sand ecosystem. A more management-oriented study was also performed on their practical applicability in the field and on their economic cost, but the results of these latter evaluations will be reported elsewhere. This paper focuses on the physical aspects of the study.

8.2. Site description

The Kootwijkerzand nature reserve is located on the Veluwe, in the centre of The Netherlands, near the village of Kootwijk (52.12 N, 5.45 E). It is about 700 ha in size and consists of heath-land and drift-sand surrounded mainly by pine forest (Figure 8.1).

8.2.1. Physical characteristics

The foundation of the late Pleistocene deposits at Kootwijkerzand is of glacial origin (ground moraine) and dates from the Riss/Saale. During the Würm/Weichsel, winds deposited large quantities of cover sand all over the central Netherlands. This cover sand became prone to wind erosion at many places during the Holocene, and large areas changed into drift-sand areas. This drift sand has been described as the formation of Kootwijk (Stiboka, 1979).

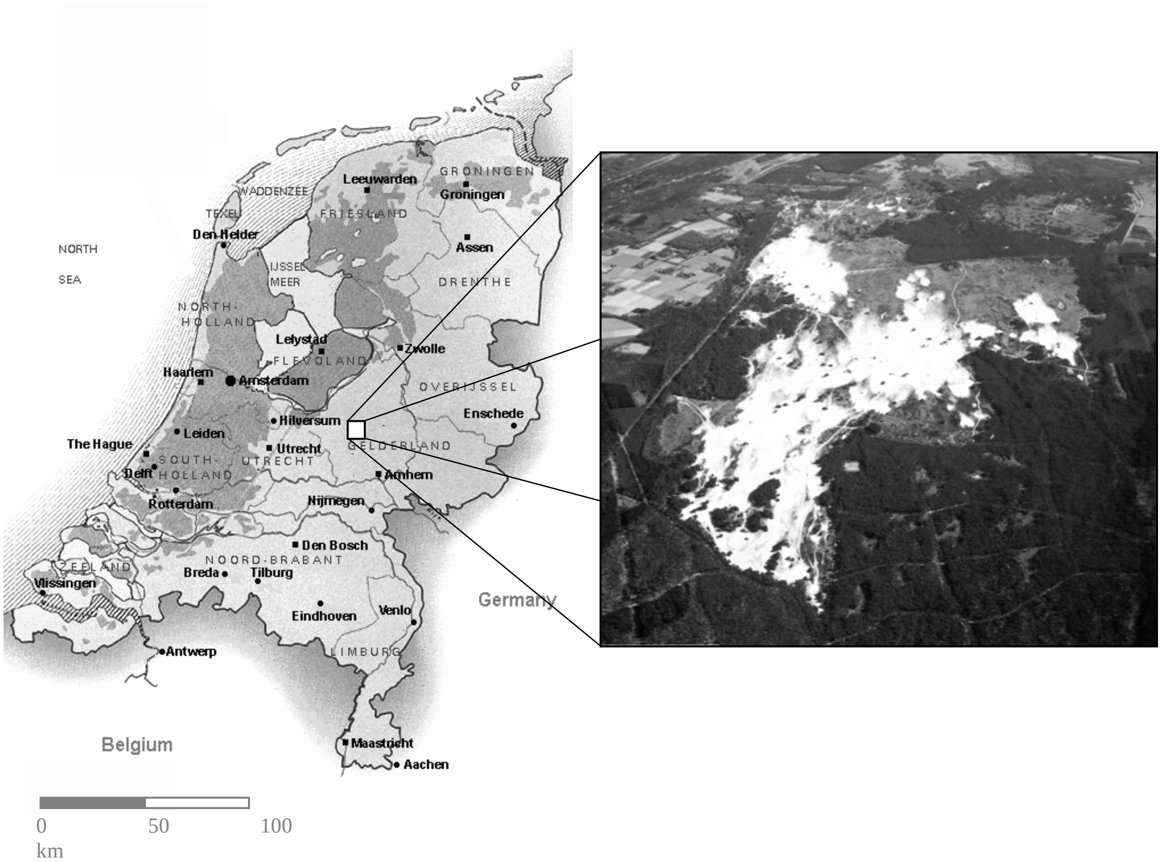


Figure 8.1. The Kootwijk drift-sand area (photograph: AEROFOTO Brouwer-Brummen)

Table 8.1. Stages of succession of the vegetation at Kootwijk drift-sand area, The Netherlands

Succession stage	Description
1	bare drift sand (may contain a few individual grasses)
2	algae and grey hair grass
3	algae and mosses
4	mosses and lichens
5	grasses, mosses, lichens and heather
6	grasses, mosses, lichens, heather and trees
7	forest

The Pleistocene cover sand occurs as large, often irregular ridges or as gently undulating plains. The drift-sand, by contrast, is characterised by isolated dunes and by blown-out plains. The dunes vary from 4 to up to 20 m in height. At Kootwijkerzand, a number of buttes occur in addition to the dunes and the blown-out plains. These buttes are several hundred m^2 in size and up to 10 m high. Their summit is usually covered by pine trees or by shrubs, protecting them from severe wind erosion.

The main soil type in the region is an (albic) arenosol composed of fine, well-sorted and well-rounded quartz sand and without a clear A1 horizon. The drift-sand, which is mainly of local origin, is light yellow-greyish in colour. It is characterised by a relatively loose grain packing (Koster *et al*., 1993).

Vegetation at Kootwijkerzand is variable in space, depending on the stage of succession (Table 8.1). In 2003, 18 % of the area consisted of bare sand, whereas 15 % was covered by forest and 67 % was in one of the intermediate stages of succession (Riksen, 2003).

8.2.2. Management history of Kootwijkerzand

In The Netherlands the ecological and social significance of inland drift-sand landscapes had already been recognised in the early twentieth century. Even during the afforestation programme of the Veluwe, which started around 1900, policy makers changed the initial plans and around 1925 they decided that about 700 ha of drift-sand and heath-land near Kootwijk had to be taken out of the programme and turned into a nature reserve. Over the next 30 years, until 1960, there was no active management strategy to preserve the drift-sand. Hence, no measures were taken to keep the drift-sand area open, and this resulted in a rapid decline of the area of active sand. Especially along the pine-planted borders the seedlings transformed the land into forest. Since 1960, measures have been taken to stop the continuing colonisation of drift sand by pine. These measures consisted of cutting the forest (especially near the borders of the active areas) and removing litter (Ketner-Oostra and Huijsman, 1998). They were not very successfully however: aerial photographs taken in 1963, 1984 and 2000 showed that, despite these efforts, the active areas still decreased by another 20% over this 40-year period, mainly due to colonisation by algae, grasses and mosses. Sufficient transport of sand is necessary to stop further colonisation of the open sand by vegetation and to slow down or reverse vegetation development in adjacent areas. So far, little attention has been paid to practices that could keep the remaining open areas sufficiently large and active. Application of specific techniques with a rapid and direct effect on-site, such as those evaluated in this study, is thus required.

8.3. Test of tillage techniques

Four tillage techniques were evaluated to investigate their potential for reactivating aeolian erosion on stabilised drift-sand areas. The following contains a description of the equipment used in this experiment:

Technique 1: rotary cultivator
The rotary cultivator used has a tilling depth of 0.20 m (Figure 8.2A). L-shaped knifes rotate with a high speed, cutting up the vegetation and mixing the top layer. The treatment leaves a smooth, loosely packed surface. The cultivator can till approximately 0.17 ha per hour.

Technique 2: beach sand cleaner
This machine, also known as the "sod sieving machine", is shown in Figure 8.2B. The machine scrapes a layer approximately 0.1 m in thickness from the topsoil and puts it on a conveyor belt consisting of lamella 0.008 m distant from each other. The conveyor belt moves under an adjustable slope (during the test approximately 30 degrees) over a camshaft and acts as a sieve. Sand falls through the open space on a second identical conveyor belt. Plant residue left on the conveyor belts is dropped into a container at the rear of the machine. The cleaned sand is then dropped to the field surface. The result of the operation is a smooth, loosely packed topsoil devoid of any plant residue.

Under dry conditions the beach sand cleaner can till between 0.05 and 0.075 ha per hour, but this drops with increasing soil moisture. It also depends on the amount of biomass that has to be removed due to the limited size of the container.

Technique 3: disk harrow
The disk harrow has a tilling depth of 0.20 m (Figure 8.2C). The harrow consists of two rows of 9 disks each. The disks are 0.65 m in diameter and are spaced at a distance of 0.2 m. They stand 30 degrees oblique to the direction of advancement. The operation results in a rough top layer with clods several cm in size, and with a relatively high amount of vegetation left. The disk harrow used can till approximately 0.5 ha per hour.

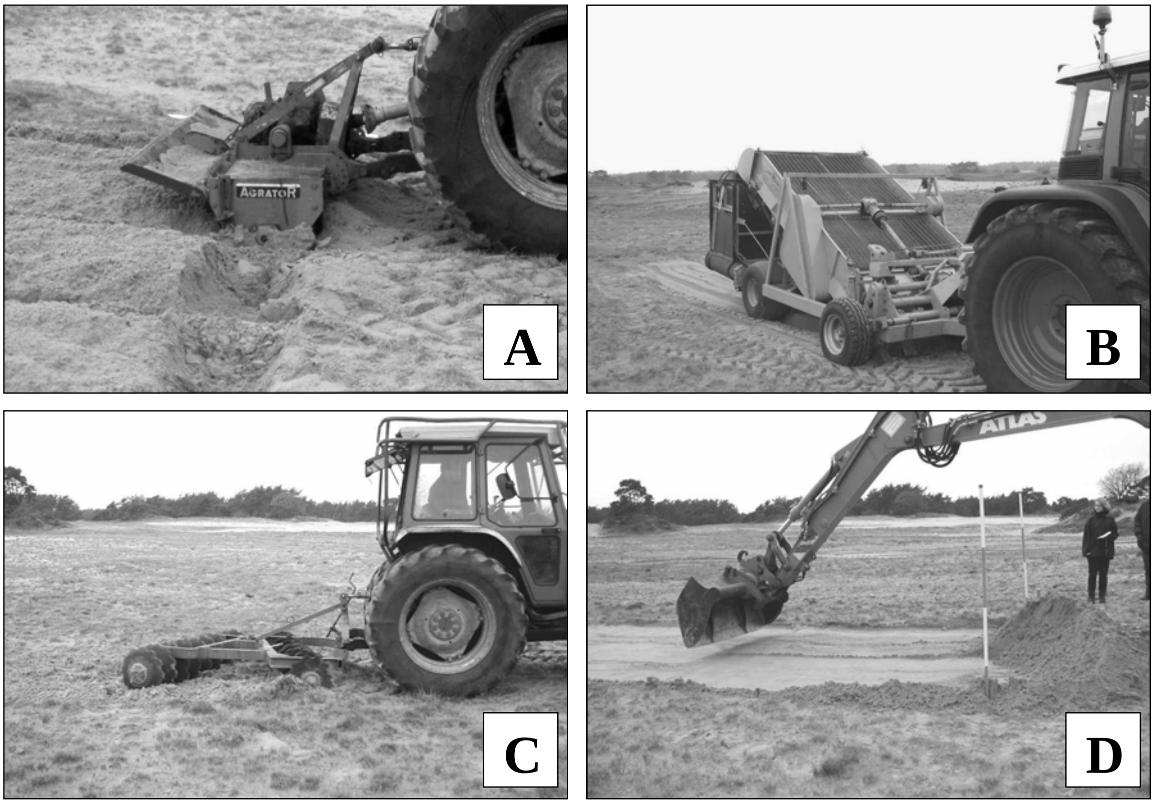


Figure 8.2. (A) rotary cultivator; (B) beach sand cleaner; (C) disk harrow; (D) excavator

Technique 4: excavator

The excavator is used to remove the upper 0.05-0.10 m of the topsoil including all vegetation (see Figure 8.2D). The speed of the operation depends on the type and size of the machine. The excavator used in the experiment treated approximately 0.1 ha per hour. The result of the operation is a flat, slightly compacted sand surface devoid of any vegetation.

8.4. Methodology and instrumentation

A careful examination was made of the entire Kootwijkerzand area to find a place with an appropriate topography, vegetation cover and accessibility. To exclude topographic effects, a fairly flat, open terrain was selected well away from dunes and buttes. The vegetation consisted of scattered clumps of grey hair grass (*Coryneplorus canescens*) with, in between, an initial development of algae crusts and some *Polytrichum piliferum* moss. Within the test area, five experimental plots were installed (Figure 8.3). Plot No. 1 was prepared with the rotary cultivator, plot No. 2 with the beach sand cleaner, plot No. 4 with the disk harrow, and plot No. 5 with the excavator. Plot No. 3, located in the middle of the experimental area, was left untreated as a control area.

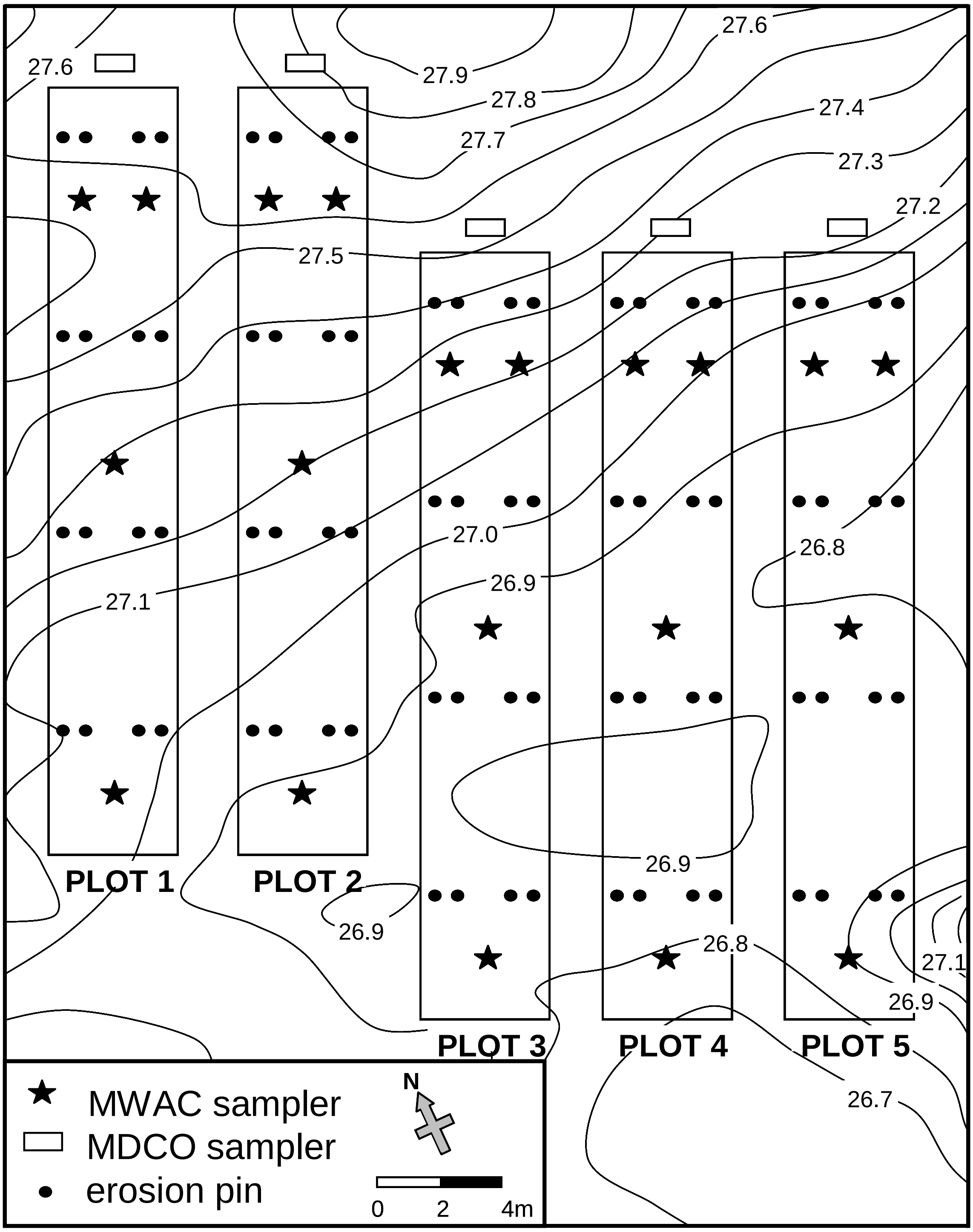


Figure 8.3. Experimental layout, Kootwijk drift sand

All plots were 30 m long and 4 m wide. They were oriented SW-NE, corresponding to the two major directions of wind erosion in the Kootwijkerzand area (see section 8.5). An untreated non-erodible strip 2 m in width separated the test plots. Due to

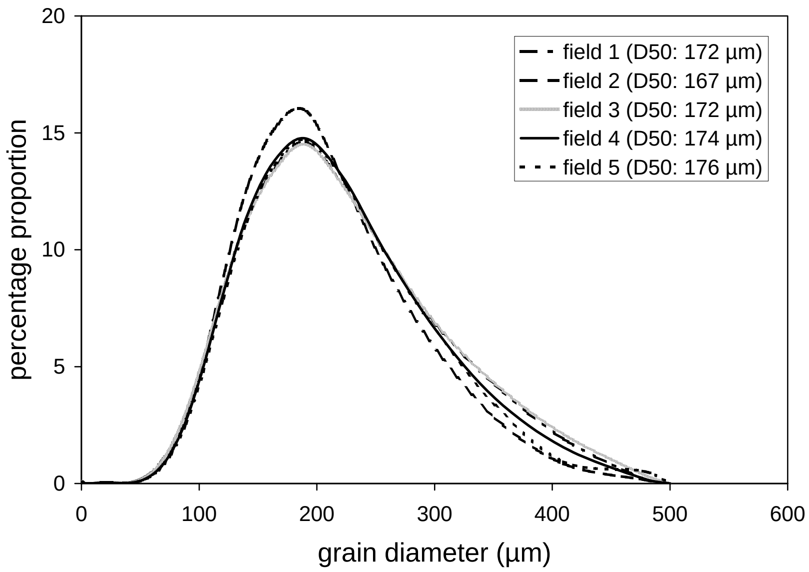


Figure 8.4. Grain size distribution of the top 5 cm of the experimental plots, Kootwijk drift sand

the limited size of the experimental area (a gently undulating topography surrounded the region) no wider strips could be installed between the plots. To ensure identical topographic conditions the experimental plots No. 3, 4 and 5 were installed approximately 6 m more to the SW compared to the plots No. 1 and 2.

Grain size distribution was determined for the upper 5 cm for each plot. The plot samples were composed of 20 randomly taken sub-samples. Each sample was first dried and sieved at 2 mm to exclude possible vegetation residue, and then the fraction > 0.5 mm was determined by sieving at 0.5 mm. Material passing the 0.5 mm sieve was then analysed with a Malvern Mastersizer (type: S). The organic matter content of the samples was very low and varied from 0.28 % for the plot treated with the excavator to 0.46 % for the untreated plot. As the samples showed nearly no aggregation, all analyses were done in water (not in air). Figure 8.4 shows that the grain size distribution below 0.5 mm is almost identical at all plots. The median grain diameter is always between 167 and 176 µm, and the proportion of silt and clay is negligibly small (< 1%). All plots also contain a small (< 5%) fraction of coarse sand grains between 0.5 and 2 mm in size.

The following key-parameters were measured on the experimental plots (see also Figure 8.3):

Meteorological parameters

A meteorological station was installed SW of the test plots. The following parameters were measured: wind speed (at 1 and 2 m height), wind direction (at 2 m), air temperature, relative humidity and precipitation. Wind speed was measured with cup anemometers and precipitation with a tipping bucket (at 2 m above ground level). To record the periods of wind erosion, 3 saltiphones (Spaan and van den

Abeele, 1991) were installed as well, at a height of 10 cm above the surface. Wind, temperature and humidity were stored as 10-min averages whereas the saltiphone data were stored as the total number of counts in 10 minutes.

Horizontal sediment flux

Horizontal sediment transport (caused by wind erosion on the plots) was measured with Modified Wilson and Cooke (MWAC) catchers (Figure 8.5A). Four vertical masts with seven MWAC catchers were installed on each plot. The technical description and calibration of the catchers are given in a paper by Goossens and Offer (2000). The bottles used at Kootwijkerzand were 9.4 cm long and 4.8 cm in diameter. For the wind erosion events investigated, the efficiency of the catchers for sand having a grain size similar to that at Kootwijkerzand was between 109 and 119 % compared to true isokinetic sampling (Goossens *et al*. 2000, Figure 10). Goossens *et al.* (2000) found that this efficiency was independent of the wind velocity in the range between 6 and 15 m/s. All measured fluxes were corrected accordingly. The MWAC catchers were installed at the following height at each mast (values refer to the centre of the inlet tubes): 5, 12, 19, 26, 45, 70 and 100 cm. The exact values were checked every week, and any increase or decrease (due to erosion or accumulation near the masts) was taken into consideration when calculating the horizontal sediment fluxes. These fluxes were calculated by measuring the amount of sediment caught by the catchers and dividing these over the surface area of the catcher inlet (0.44 cm^2) and the total sampling time (usually 168 h, or 7 days). The total horizontal sediment flux at each mast was then calculated by vertically integrating the flux values for the first 100 cm above the surface. Since more than 99 % of the airborne sediment at Kootwijkerzand consists of sand (diameter > 63 µm), the amount of sediment transported above these first 100 cm is negligibly small.

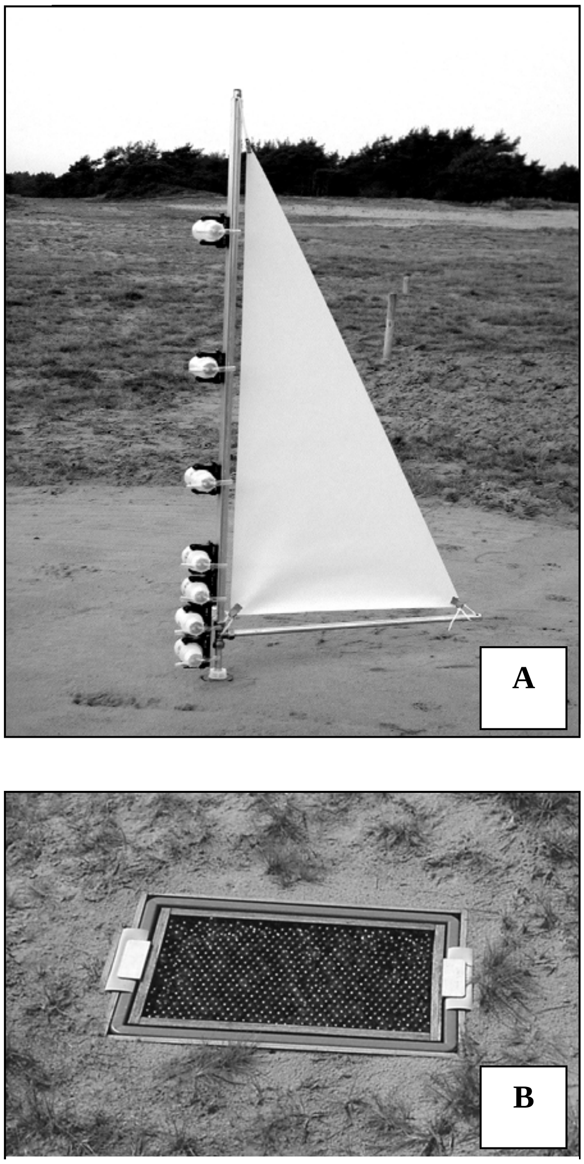


Figure 8.5: (A) mast with MWAC catchers; (B) MDCO catcher

Vertical accumulation flux

The vertical accumulation flux was measured by means of MDCO catchers installed near the NE border (i.e., downwind with respect to the dominant erosion winds) of the experimental plots. A description of the catcher can be found in a paper by Goossens *et al* (2001). In the Kootwijkerzand experiment the catchers consisted of a rectangular plastic tray 52.5 cm long, 31.5 cm wide and 10.0 cm high, with a marble filter at the top (Figure 8.5B). The filter consisted of two layers of marbles, 1.6 cm in diameter, which were stored in a sieve container on top of the plastic tray (mesh diameter of the sieve openings: 0.5 cm). Sand settles on and between the marbles and is collected in the plastic tray. The tray is buried in the soil until the marbles are level with the surface of the experimental plots. The vertical accumulation fluxes were calculated by measuring the amount of sediment caught by the catchers and dividing these over the surface area of the catcher (0.165 m^2) and the total sampling time (usually 168 h, or 7 days). The fluxes measured by the catcher are proportional (but not equal) to the real vertical accumulation fluxes because of the restricted efficiency of the catcher. For relative comparisons, such as in this study, this does not lead to serious distortions.

Raising and lowering of the surface

The raising (due to aeolian accumulation) or lowering (due to aeolian erosion) of the surface in each experimental plot was measured with erosion pins (De Ploey and Gabriëls, 1980). Four NW-SE transects, of four erosion pins each, were installed on each plot (Figure 3). The pins were 50 cm long and had a diameter of 5 mm. All pins were checked weekly. They were read with a precision of 1 mm (0.5 mm when this appeared to be necessary). Because of the highly permeable sand, no runoff occurred on the plots, even during the heaviest rains. This ensures that all changes in surface elevation measured by the erosion pins were caused by aeolian activity only. Periods with no wind erosion activity in the first three months showed that the effect of other processes that may cause a change in surface elevation, such as (wind driven) splash erosion, consolidation or compaction, was minimal.

Changes in grain size

It is well known that wind erosion, especially in sand areas, leads to a coarsening of the topsoil due to the progressive evacuation of the fine material (Govers *et al*., 2004). The changes in grain size that occur in the top layer of the test plots thus provide information on the efficiency of the tillage techniques tested. Samples were therefore taken at the start (November 2002) and the end (August 2003) of the experiment. Three samples were taken from each plot: one near the SW border, one in the centre, and one near the NE border. Each sample was composed of at least 5 sub-samples. Only the first upper cm of the topsoil was sampled.

Grain size distribution was determined by first sieving the samples at 1 mm to exclude possible vegetation residue, and then analysing the samples with the

Malvern Mastersizer. As the samples showed nearly no aggregation, all analyses were done in water (not in air).

Changes in organic matter

Sediment released by wind usually contains more organic matter than the parent soil, which becomes gradually more impoverished when no new organic matter is provided, either *in situ* or by external supply (Zenchelsky *et al*., 1976). The more frequent and the more intense a field is affected by wind erosion, the slower the recuperation of the organic matter content to its original value will take place. With this in mind samples were taken from the top 1 cm of each test plot in November 2002 and again in August 2003. All the samples were composed of at least 5 sub-samples, which were mixed into one average sample. Only the central area of the plots was sampled.

The organic matter content of each sample was determined by heating the sediment in a pyrolytic oven to 600 °C (see Leser, 1977) and measuring the loss of organic matter during the burning process.

Effect on vegetation cover, surface roughness and bulk density

Estimates were made of these three parameters to assess how they are affected by the tillage operations tested in this study. Bulk density of the top 5 cm of the soil was measured on 16 randomised positions on each plot by taking *in situ* samples with 5-cm high pF-rings of 100 cc. The samples were weighed after having been dried for 24 h at 105 °C. Vegetation cover was measured in two 1m x 1m squares in each plot, one near the south-western and the other near the north-eastern plot border. A grid with 100 cells 0.1m x 0.1m in size was used on each square. The area covered by grey hair grass, plant residue, algae and mosses was estimated for each cell. Vegetation was measured twice: immediately after tilling (November 2002) and at the end of the experiment (August 2003). Surface roughness, finally, was described shortly after tilling and monitored by visual inspection at regular intervals during the experiment

8.5. Results

8.5.1 Meteorology and wind erosion episodes during the experiment

All experimental plots were tilled in November 2002. After preparation of the logistics and installation of the equipment, the experiment started on 3 December 2002. It ran until 31 July 2003. Originally the experiment was planned to continue for at least one year, but the site suffered severely from vandalism during the last two months and it was therefore decided to terminate the measurements after eight months.

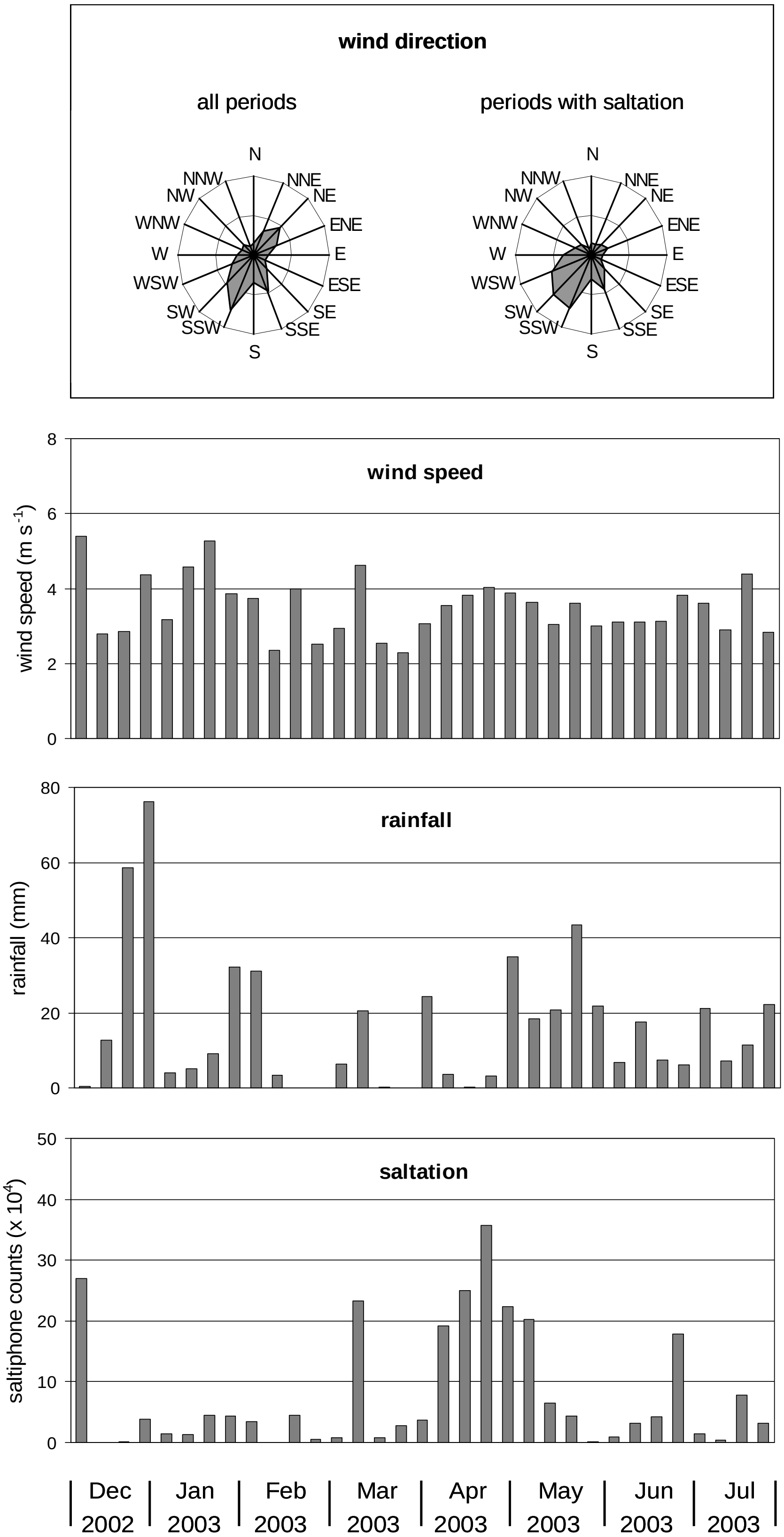


Figure 8.6. Distribution of wind direction (at 2 m) and weekly averaged wind speed (at 2 m), precipitation (at 2 m) and aeolian saltation activity (at 10 cm) at Kootwijk drift-sand area, December 2002 - August 2003

Figure 8.6 summarises the meteorological conditions during the experiment. The upper figure depicts the compass card at Kootwijkerzand for two cases: the complete compass card (all periods included) and the compass card during saltation activity only. At Kootwijkerzand the wind usually blows from the SW and NE directions, but the winds that generate saltation predominantly come from the SW. Therefore, at Kootwijkerzand, wind-eroded sediment is generally transported from the SW to the NE, and the organisation of the five test plots was based on this experience.

There was much variety as to the wind speed during the experiment (see Figure 6). Wind velocity was generally high in January 2003 and in April-May 2003, but there were many other weeks of high wind speed. Rainfall was extremely high in the second half of December 2002, with 135 mm rain in less than two weeks. It was also high at the end of January and in early February 2003, during the last week of April 2003, and in May 2003. There was little rainfall in February and March 2003. Episodes of wind erosion occurred all year, but by far the highest erosion was observed in April and early May 2003. Nearly 50% of all saltation occurred during 10 windstorms in these five weeks. There were only six days with heavy wind erosion outside this period: 7, 8 and 10 December 2002, 8 March 2003, and 20 and 23 June 2003. Thus, apart from the isolated storms, wind erosion at Kootwijkerzand is heavily concentrated in the middle of spring (measurements made between July 2002 and December 2002 indicated no heavy wind erosion in this period, apart from 2 isolated cases in October 2002).

8.5.2. Horizontal sediment flux

The intensity of aeolian activity on the test plots is best described by the (airborne) horizontal sediment flux, which was measured by the MWAC catchers. Figure 8.7A shows the average (in space and time) vertically integrated horizontal sediment flux over each of the five test plots during the experiment. Most atmospheric transport occurred over plot No. 2 (beach sand cleaner), followed by plot No. 1 (rotary cultivator) and plot No. 5 (excavator). Aeolian transport over plot No. 4 (disk harrow) was smaller than over the untreated reference plot No. 3. This is probably due to the rather large clods and the vegetation residue that were produced during harrowing. The clods increased the aerodynamic roughness of the topsoil and reduced the wind speed close to the surface (Chepil *et al.*, 1964; Riksen *et al.*, 2003). Repeated visual inspections showed that the roughness on plot No. 4 did not substantially change with time during the experiment.

The effect of the fetch on the transport flux is illustrated in Figure 8.8. In general, fluxes were low near the SW border of the plots and increased in the NE direction. The figure also shows that the dominance of plot No. 2 becomes only apparent at sufficiently long fetches.

Figure 8.9 depicts the relative efficiency of the four tillage techniques as a function of time. The diagrams indicate the difference, in horizontal sediment flux,

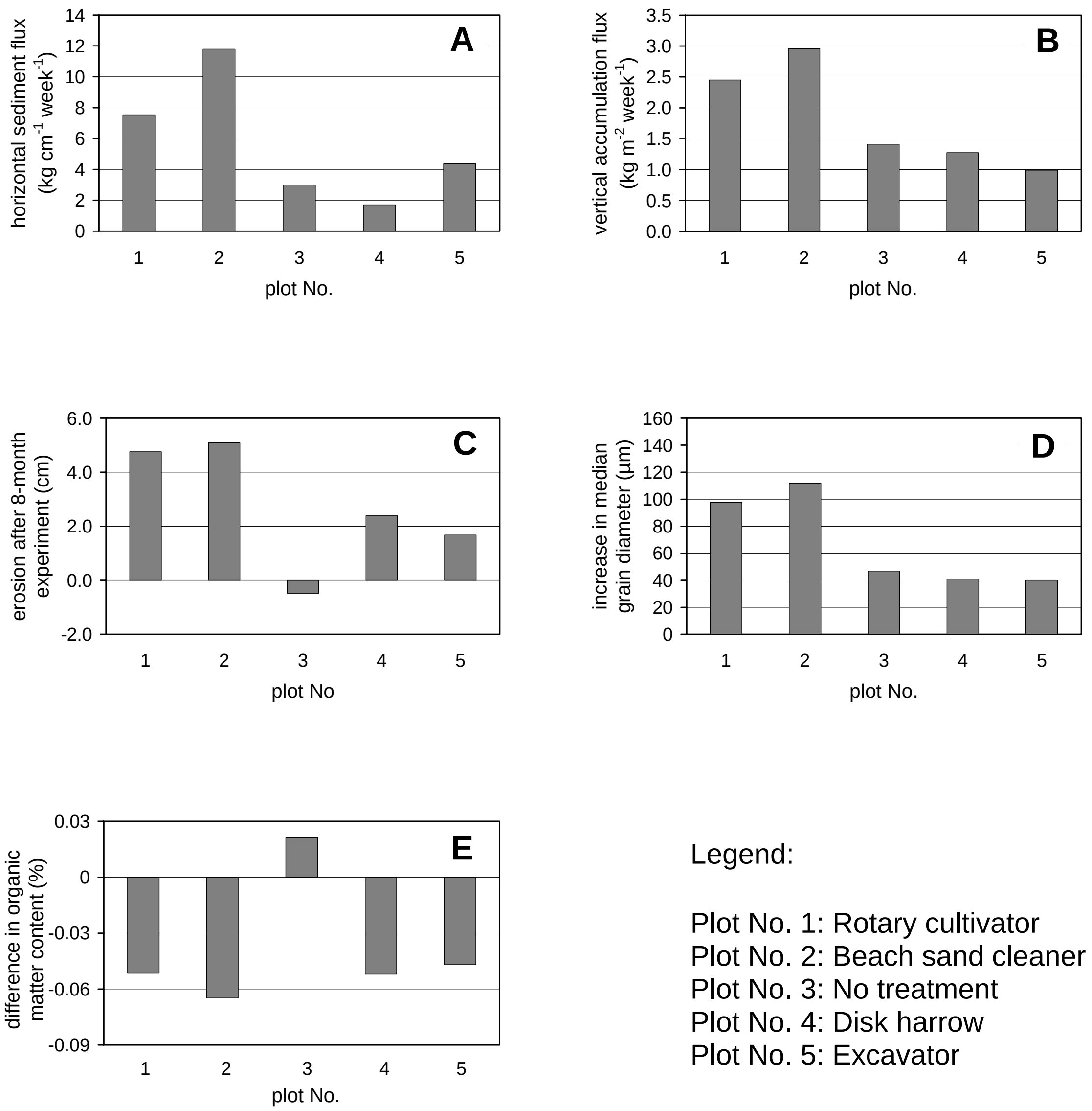


Figure 8.7. Effect of the tillage techniques on the aeolian reactivation of the drift sands (average data for each plot). (A) horizontal sediment flux; (B) vertical accumulation flux; (C) erosion measured by the erosion pins; (D) changes in median grain diameter of the top layer (upper 1 cm); (E) changes in organic matter content of the top layer (upper 1 cm). Kootwijk drift-sand area, December 2002 - August 2003.

with the untreated plot No. 3 after normalisation of the data. At the start of the experiment the differences between the plots were small. A significant increase was observed for the plots No. 1 and 2 after approximately two months, continuing during about three subsequent months. Then the differences relative to the untreated plot No. 3 gradually diminished. These trends also occurred on the plots No. 4 and 5, but here the differences with plot No. 3 were very small and the smoothed curves do not substantially differ from a horizontal line (see Figure 8.9).

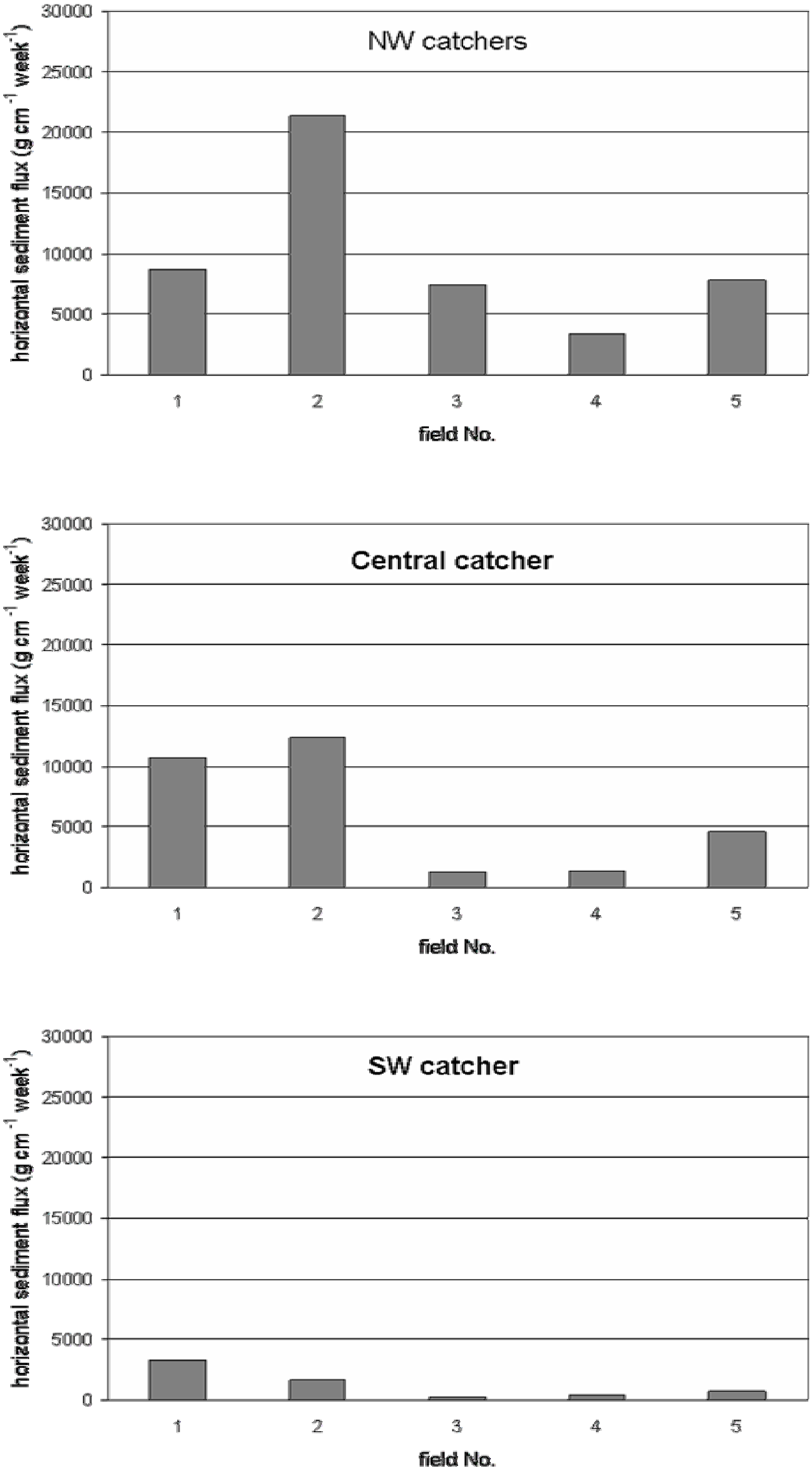


Figure 8.8. Distribution of weekly average horizontal sediment flux over the five experimental plots. Lower figure: SW catcher; Central figure: central catcher; Upper figure: average of NE catchers. Kootwijk drift-sand area, December 2002 - August 2003

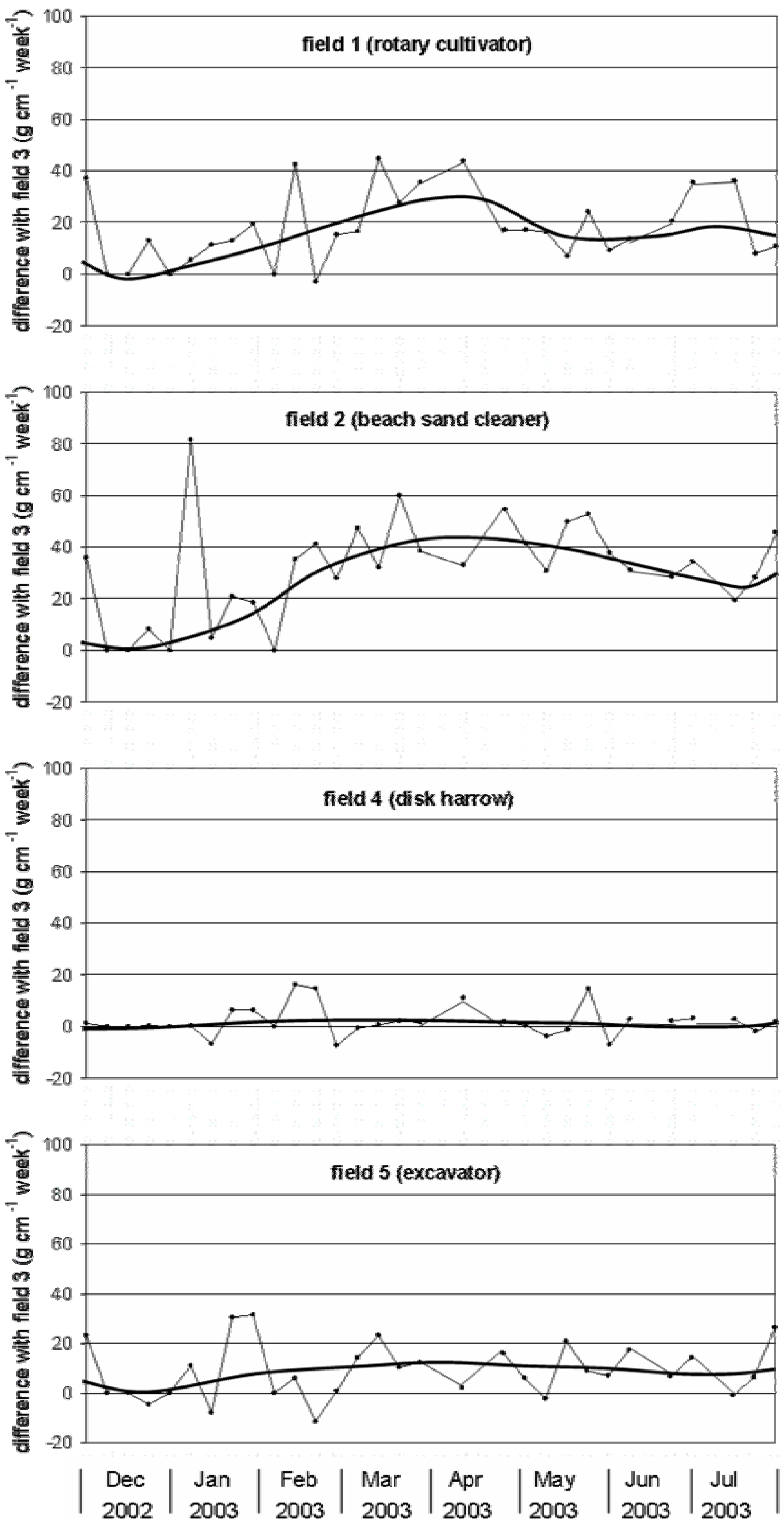


Figure 8.9. Temporal evolution of the difference in horizontal sediment flux with untreated plot No. 3. A smoothed line has been added to the curves for clarity. Kootwijk drift-sand area, December 2002 - August 2003

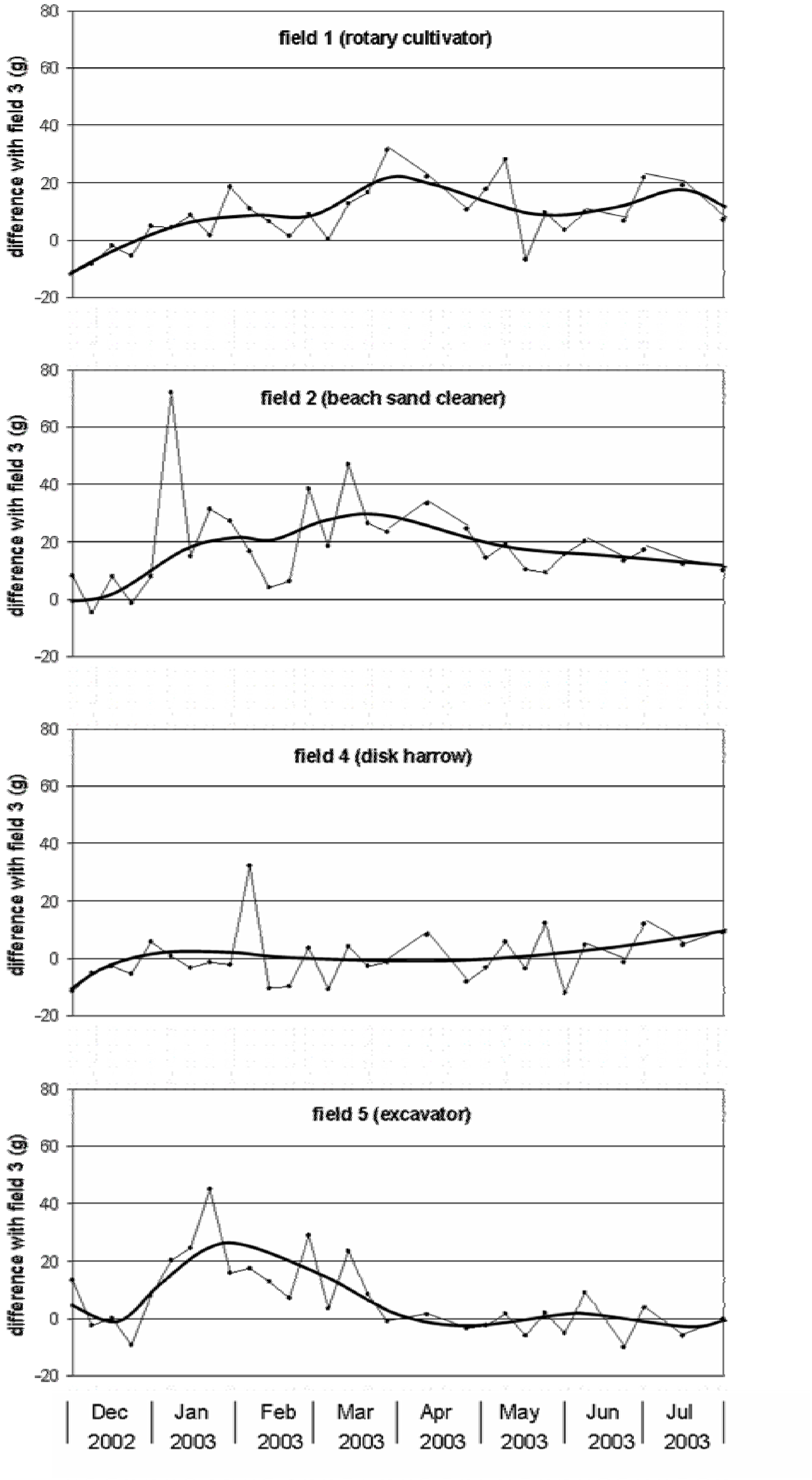


Figure 8.10. Temporal evolution of the difference in vertical accumulation flux with untreated plot No. 3. Kootwijk drift-sand area, December 2002 - August 2003

8.5.3. Vertical accumulation flux

The results of the MDCO measurements, which give an indication of the vertical accumulation flux near the downwind border of the plots, resemble those of the MWAC catchers. Highest vertical accumulation fluxes were observed on plot No. 2 (beach sand cleaner) and also, but less, on plot No. 1 (rotary cultivator) whereas plot No. 4 (disk harrow) showed a lower accumulation flux when compared to the untreated reference plot No. 3 (Figure 8.7B). Unlike Figure 8.7A, the lowest accumulation flux was observed on plot No. 5 (excavator).

The temporal evolution of the relative efficiency of the tillage techniques in terms of vertical accumulation flux (Figure 8.10) is similar to that shown in Figure 8.9, except for plot No. 5, where a local but prominent increase was observed between one and four months after the start of the measurements. After four months, the differences with the untreated plot No. 3 again became negligibly small.

8.5.4. Raising and lowering of the surface

The results of the erosion pins, which depict the raising or lowering of the test plots' surface due to accumulation or erosion, are identical to those of the MDCO measurements in Figure 8.7B, except that a (very small) accumulation was observed on the untreated plot No. 3 (Figure 8.7C). Figure 8.11 shows that there was nearly no accumulation on the SW half of this plot: almost all accumulation occurred on the NE half. The accumulation was due to some inflow of sand from plot No. 2 during a few episodes of NW wind. Figure 8.11 also shows that the effects caused by the different tillage techniques are already prominent near the upwind (SW) border of the plots. Near the NE border, the accumulation on plot No. 2 was smaller than expected (see Figure 8.11, and compare to the other three transects in the figure).

The progressive lowering of the surface on the plots is shown in Figure 8.12. Plot No. 1 (rotary cultivator) deflated more than plot No. 2 (beach sand cleaner) during the first six months of the experiment, but then plot No. 2 showed the highest erosion. All curves also show a slight trend towards stabilisation after approximately seven months, although a perfect stabilisation is not expected to occur before the first algae crusts start colonising the plots.

8.5.5. Changes in grain size

The textural changes that occurred in the top 1 cm of the test plots during the experiment are displayed in Figure 7D. The increase in median diameter was chosen as an experimental parameter in the figure. The effects (in terms of aeolian reactivation) caused by the four tillage techniques are identical to those shown in the Figures 8.7B (MDCO catchers) and 13 (erosion pins) and, with the exception of

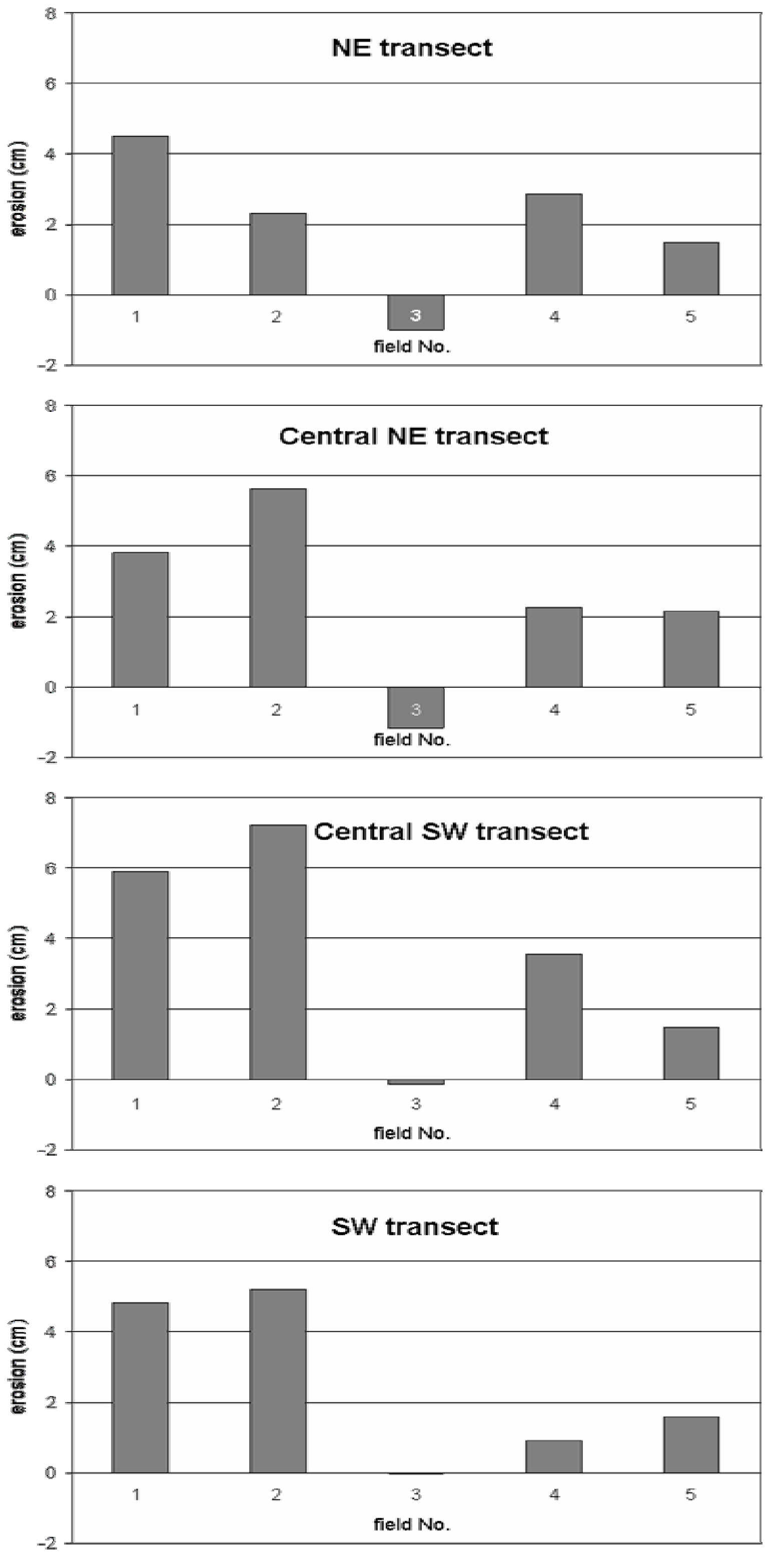


Figure 8.11. Distribution of erosion (measured by erosion pins) over the five experimental plots. Lower figure: SW transect; Central lower figure: central SW transect; Central upper figure: central NE transect; Upper figure: NE transect. Kootwijk drift-sand area, December 2002 - August 2003

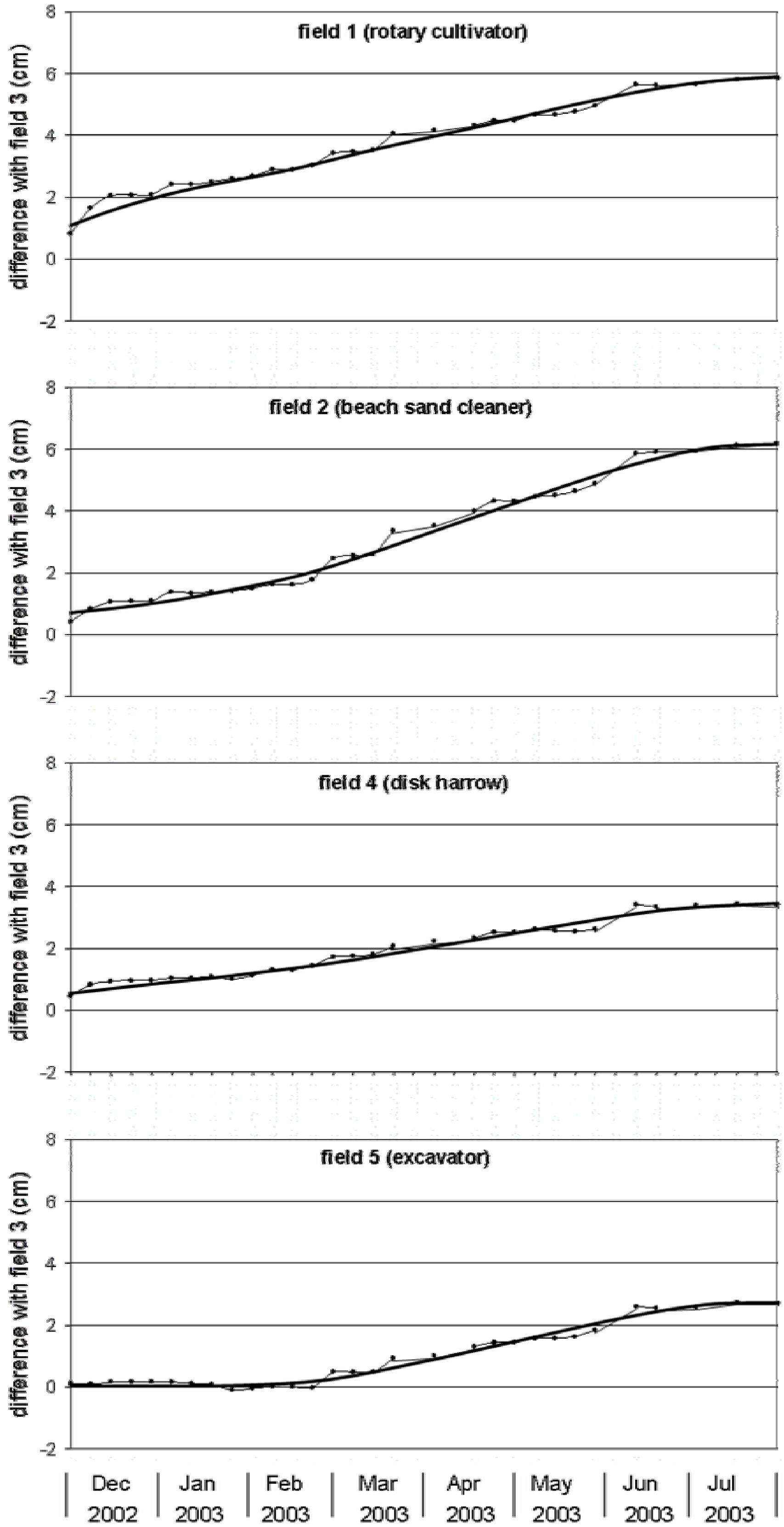


Figure. 8.12. Temporal evolution of the difference in surface lowering (erosion) with untreated plot No. 3. Kootwijk drift-sand area, December 2002 - August 2003

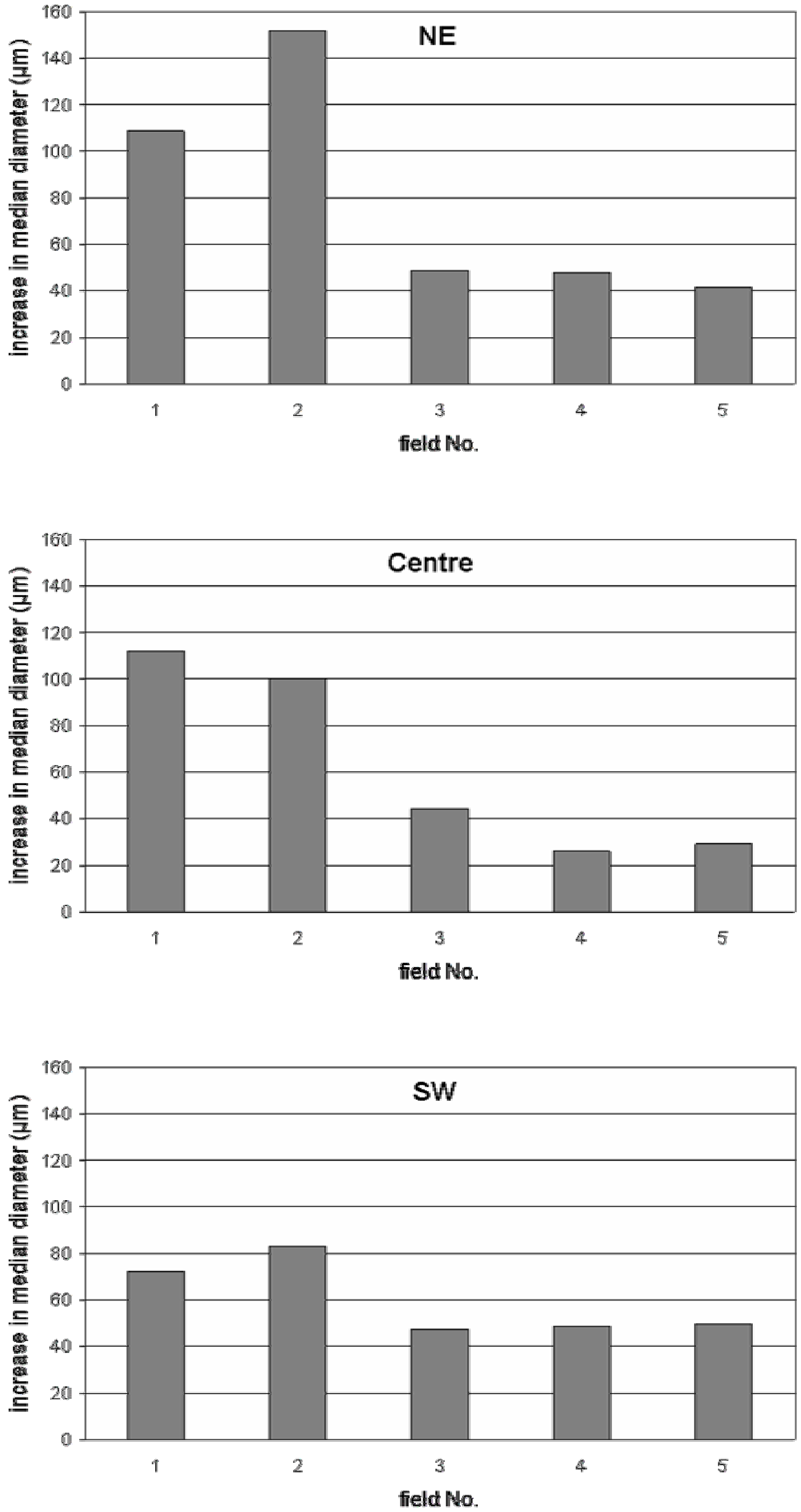


Figure 8.13. Changes in median grain diameter of the top layer (upper 1 cm). Lower figure: SW part of the plots; Central figure: central part of the plots; Upper figure: NE part of the plots. Kootwijk drift-sand area, December 2002 - August 2003

plot No. 5, with those shown in Figure 8.7A (MWAC catchers). Figure 8.13 also shows that the difference in textural coarsening between the plots is rather small near the SW plot border. Near the centre, and especially near the NE plot border the differences between the highly erosive plots No. 1 and 2 and the much less erosive plots No. 3, 4 and 5 become apparent.

8.5.6. Changes in organic matter

The organic matter content in the top 1 cm varied from 0.28 % (plot No. 5) to 0.46% (plot No. 3) just after tillage in November 2002 and from 0.24 % to 0.48 % in August 2003. Figure 7E shows the changes in organic matter content in the top 1 cm of the surface during the experiment. Except for the reference plot No. 3, all plots experienced a loss of soil organic matter. The loss in soil organic matter was highest on plot No. 2, almost equal on plots No. 1 and 4, and lowest on plot No. 5. These results closely resemble those that were measured by the erosion pins (Figure 8.7C), and are also comparable to those obtained by the MDCO catchers (Figure 8.7B) and by the grain size analysis (Figure 8.7D).

8.5.7. Effects on vegetation cover, surface roughness and bulk density

Table 8.2 shows the effect of the tillage techniques on the vegetation cover immediately after tillage. The second survey, at the end of the experiment, did not show significant differences and is thus not shown in the table. The excavator, the rotary cultivator and the beach sand cleaner were very effective in removing the vegetation from the top layer (although some residue remained on the fields treated

Table 8.2. Surface conditions after tillage, Kootwijk drift-sand area, The Netherlands

	Tilling technique				
Parameter	**Rotary cultivator**	**Beach sand cleaner**	**Disk harrow**	**Excavator**	**Control**
Vegetation cover (% of total surface)					
Grey hair grass	0	0	0	0	16
Algae (crust)	0	0	0	0	1
Polytrichum moss	0	0	0	0	Traces
Plant residue	4	2	11	0	0
Surface roughness	Smooth uniform surface	Smooth uniform surface	Irregular surface consisting of clods with an average height of 6 cm	Smooth uniform surface	Irregularities formed by small vegetated mounds
Bulk density (g cm^{-3})	1.55	1.56	1.55	1.60	1.59

by the rotary cultivator and the beach sand cleaner). The disk harrow is much less efficient: the reduction in vegetation cover was only 30 %. The disk harrow also produced a rough, cloddy surface whereas the other techniques created a smooth and uniform top layer. Only minor changes were observed in the roughness characteristics of the plots during the experiment. On the plots No. 1 and 2, the wheel tracks generated during tillage had already disappeared after the first 2-3 wind erosion events, leaving behind a flat, uniform surface. Bulk density of the upper 5 cm of the soil was almost identical for the rotary cultivator, the beach sand cleaner and the disk harrow. These techniques stir the soil and create a loosely packed surface layer compared to untreated soil. The excavator, on the other hand, produced a more compact top layer.

8.6. Discussion

Five parameters (changes in surface level of the topsoil, horizontal transport flux, vertical accumulation flux, textural changes, and changes in organic matter content) were used in this study to determine the efficiency of the tillage techniques with respect to aeolian reactivation. Although these parameters do not measure the same physical properties they provide comparable information, and also lead to comparable conclusions. Most efficient is the beach sand cleaner (plot No. 2), followed by the rotary cultivator (plot No. 1) and the excavator (plot No. 5). Tilling the soil with a disk harrow (plot No. 4), on the other hand, does not appear to be very effective for reactivating wind erosion. Although it leads to net erosion (Figure 8.7C), it may mobilise less sand than an untreated surface does (see Figures. 8.7A and 8.7B). As already suggested in a previous section, the clods created during harrowing hamper the soil from being eroded because of the increased surface roughness they create.

Although the five parameters lead to similar conclusions, it is interesting to reflect on the specific information each parameter provides. The horizontal sediment flux (measured by the MWAC catchers), for example, describes the transport of the eroded sediment, but only for the saltation fraction (recall that at Kootwijkerzand the suspended fraction is negligibly small). The MWAC catchers do not record surface transport by creep. Figure 8.8 shows clearly how the saltation flux increases with the wind fetch. This is what could be expected, since the air becomes progressively more saturated with sediment during its way over the eroding plot surface. The increase of the saltation flux will continue until saturation has been reached (phase of steady state saltation). Figure 8.8 also shows that the differences between, for example, the two heavily eroding plots No. 1 and 2 are relatively high. The patterns shown by the erosion pins (Figure 8.11) and the textural changes (Figure 8.13) are different compared to the saltation pattern: the differences between the experimental plots (or tillage techniques) are already prominent near the SW (= upwind) border of the plots, and they do not really intensify with an increasing fetch. A long fetch is thus not required to attain dynamic equilibrium for these parameters. Unlike the MWAC catchers, which only measure the airborne transport, the data provided by the erosion pins and the textural changes in the top layer are also affected by surface transport (creep) and reptation (in the near-surface air layer). In addition, erosion pins only depict the net (final) result of aeolian activity (erosion or accretion, resulting into surface lowering or raising), independently of the intensity of the aeolian processes. It is well known that sediment transport in agricultural fields is highest at locations where erosion zones change into accretion zones, although the net soil loss in these areas is close to zero (see Goossens and Gross, 2002 for some examples). The vertical accumulation flux, which was measured with the MDCO collectors, is also affected by creep and reptation. This may explain why the MDCO results parallel those of the erosion pins and texture. The changes in organic matter, finally, should predominantly be related to the intensity of the emission since most blowing sediment is richer in organic matter compared to the eroding parent soil (Zenchelsky *et al.*, 1976). Recuperation of organic matter via accumulating sediment is unlikely because it are especially the coarse particles that accumulate. The highest percentage proportions of organic matter in airborne sediment appear in the fine particle fractions, which remain airborne.

Although the parameters adopted to evaluate the effect of the tillage techniques lead to a consistent picture, minor differences may thus be observed in the results depending on the parameter selected.

Apart from its direct effect on the aeolian dynamics, the final assessment of a tillage technique depends on various additional factors. One of these is the state in which the substratum is left after tillage. Several aspects should be taken into account here. First, there are great differences in the degree of compaction of the top layer between the plots. Tilling the soil with a beach sand cleaner, a rotary cultivator or a disk harrow leads to a loosely packed, uncompacted topsoil whereas tilling with an excavator results in a top layer that is even more compact than untreated soil (see Table 8.2). This difference in compaction has consequences for the mobility of the particles, both with respect to their erosion and to their transport. But compaction also affects the water-holding capacity of a soil and, hence, the moisture content of the top layer. The very loosely packed substrata of plots No. 1 (rotary cultivator) and 2 (beach sand cleaner) dry very rapidly, even during low winds, and they are already vulnerable to wind erosion a few hours after the last rainfall. The compacted substratum of plot No. 5 (excavator), on the contrary, stays wet longer and is thus longer protected against wind erosion. It is well known that compaction is used by farmers as a technique to reduce the risk of wind erosion, for instance, by compacting the soil with a Cambridge press after ploughing (Riksen *et al.*, 2003). Soil moisture is also important with respect to the recolonisation of a surface, especially shortly after tillage, when the first pioneers (algae) enter the plots.

Another important point is the roughness of the top layer. Tilling the soil with a disk harrow creates clods several cm in diameter, producing a rather rough surface structure. The roughness not only reduces the wind speed in the lowermost air layers, thereby reducing the driving force for wind erosion, but also creates traps (between the clods) for the airborne particles eroded more upwind. Leaving the surface in clods is a popular technique to prevent wind erosion (Riksen *et al*., 2003; Warren and Bärring, 2003). The absence of roughness elements on the plots treated with the rotary cultivator and the beach sand cleaner results in a much more favourable environment for wind erosion on these plots. This is also true for the excavator-treated surface, but here compaction plays a significant role as discussed earlier.

A third factor that should be taken into account is plant residue. Tilling the surface with a beach sand cleaner, which removes the residue from the treated area, or with a rotary cultivator, which cuts the vegetation and mixes it with the top 20 cm of the soil, results in an almost clean topsoil devoid of residue (see Table 8.2). The same is true when an excavator is used to remove the upper parts of the soil. During disk harrowing, on the other hand, the cut vegetation stays largely on the field (Table 8.2). This may lead to a more rapid restoration of the vegetative cover after tillage compared to the other plots, which have to be freshly colonised.

Apart from the vegetation, the fauna in the tilled plots is also affected by the tillage operations. This is especially true for those species that live in the top 10-20 cm of the soil. Removing this layer (for example, by the excavator) seriously affects the faunal life in the surface layer of the drift-sand. However, the global effect of the removal can only be assessed if the tilling is applied on a sufficiently large scale, which was not the case in the experiment reported here. Therefore, further research is needed to determine the effects tillage techniques exert on animal life in the treated soil. Large-scale research is also required to evaluate off-site effects like the deposition of blown sand in vegetation adjacent to the treated site. Finally, for a complete assessment it is also necessary to evaluate several non-physical factors, such as the applicability of each technique and its financial cost.

8.7. Conclusions

This study evaluated four tillage techniques for reactivating aeolian erosion in drift-sand areas colonised with grey hair grass, algae crusts and *Polytrichum* moss. Their effect on soil erodibility was measured by considering five key-parameters: the raising and lowering of the surface due to aeolian sediment removal or deposition, the horizontal sediment transport flux, the vertical sediment accumulation flux, changes in the grain size of the top layer due to aeolian activity, and changes in the organic matter content of the top soil. Several additional effects of the tillage techniques, such as their impact on soil compaction, on surface roughness, and on the amount of plant residue left on the field, were also discussed.

The techniques significantly differ in their efficiency to reactivate aeolian drift-sand. An overview is presented in Table 8.3. The physically most effective method is the beach sand cleaner, followed by the rotary cultivator, the excavator

Table 8.3. Evaluation of the tilling techniques, Kootwijk drift-sand area, The Netherlands

Assessment criterion	Tilling technique			
	Rotary cultivator	**Beach sand cleaner**	**Disk harrow**	**Excavator**
Aeolian dynamics				
Soil loss	++	++	+	+
Sediment transport	+	++	-	++
Loss of organic matter	+	++	+	o
Surface conditions				
Compaction	++	++	+	-
Surface roughness	++	++	-	++
Texture	++	++	o	o
Plant residue	++	++	o	++
Total physical assessment	+	++	-	o

++: highly positive score for this criterion; +: positive score for this criterion; o: neutral score for this criterion; –: negative score for this criterion. All topics are evaluated in the context of aeolian (re)activation.

and the disk harrow. The first two methods show a highly positive score (++ in Table 8.3) for nearly all key-parameters investigated, although the sediment transport intensity and the loss of organic matter in the upper soil layer are somewhat lower for the rotary cultivator compared to the beach sand cleaner. The excavator and the disk harrow score considerably lower, especially the disk harrow, which does not show much difference with an untreated field for several of the key-parameters considered.

With respect to the aeolian reactivation of drift-sand stabilised by grey hair grass and algae, surface roughness and compaction of the topsoil are the key factors immediately after tilling. Any choice of techniques for increasing the erodibility of stabilised drift-sand should therefore not only be based on the ability of the techniques to remove or disturb the vegetation, but also on the impact they exert on surface roughness and compaction. In later stages of the succession, other criteria (like the amount of organic matter and/or seed remaining in the top soil) may become more dominant.

Acknowledgements

This study was carried out as part of the research project "Making use of wind and water erosion processes in Dutch landscape development" carried out by the Erosion and Soil & Water Conservation Group of Wageningen University, and was funded by the Dr. Ir. Cornelis Lely Foundation, the C.T. de Wit graduate school of

Product Ecology and Resource Management (Wageningen University), and OBN (Overlevingsplan Bos en Natuur – Survival Plan for Nature) of the Dutch Ministry of Agriculture, Nature and Food Quality. The field experiments were realised in co-operation with the Dutch Forestry Foundation (Staatsbosbeheer), who provided the experimental terrain and assisted with the preparation of the experimental plots. Special thanks are expressed to Huiberdien Sweeris and Piet Peters for their assistance during the field measurements and the laboratory work. We also thank Jasper and Chiel for their help in removing the instrumentation from the field after completion of the measurements.

Chapter 9

THE ANSWER IS BLOWING IN THE WIND:
How to use wind erosion to restore and maintain the inland drift-sand ecotype?

Michel Riksen, Wim Spaan and Leo Stroosnijder

To be published in: Nature Conservation

In: Wind Born(e)Landscapes
(M.J.P.M. Riksen) Wageningen, 2006, pp. 177 -200.

9. The answer is blowing in the wind

How to use wind erosion to restore and maintain the inland drift-sand ecotype?

Michel Riksen, Wim Spaan and Leo Stroosnijder

Erosion and Soil & Water Conservation Group, Department of Environmental Sciences, Wageningen University, Nieuwe Kanaal 11, NL-6709 PA Wageningen, the Netherlands

Abstract

Dutch inland drift-sands are of great value to nature and houses several red-listed species unique for Europe. The inland drift-sand landscape consists of three different intertwined wind erosion zones. Together they form the conditions where mosaic vegetation in different development stages can thrive. Under present environmental conditions these drift-sands stabilize and tend to disappear. In 2002 only 1,500 ha could still be classified as active drift-sands. In the 1990s mechanical measures were introduced to disturb the regeneration process and to restore wind erosion activity. Restoration works mainly consist of large-scale sod cutting (*plaggen*) and clearing trees. It is questionable whether such large-scale restoration approach will lead to the preferred landscape in which all characteristic species will return. There is a lack of a management strategy to maintain the drift-sands after restoration. This paper presents a new management concept based on wind erosion processes. The concept is a result of a research project carried out in the period 2001 to 2005 at the inland drift-sand area Kootwijkerzand in the Netherlands. Characteristics and development of the wind erosion processes and their control factors from the active deflation zone through a transition zone into the stabilized vegetated zone are discussed. The main objective of our new management strategy is to maintain optimum field conditions for erosion in a way and scale that it can act as a landscape differentiating process. This process management strategy consists of: (1) an overall management plan for a period of 10-15 years and (2) a short term (1 – 3 years) maintenance plan to keep the erosion potential in the selected deflation zones sufficient high. Details of our general management strategy such as the potential of drift-sand areas, the alternative measures to be undertaken, economic and social considerations and the monitoring and evaluation of our process management approach are elaborated in separate sections. Process management with scheduled maintenance will result in a more stable drift-sand habitat in which the typical drift-sand vegetation and fauna species are better able to survive. In other words, the answer to the question ‘How to use wind erosion to restore and maintain the inland drift-sand ecotype?’ is blowing in the wind if we maintain the optimum conditions for wind erosion.

Keywords: Inland drift-sands; Landscape restoration; Wind erosion; Process management; Mechanical measures; the Netherlands

9.1. Introduction

Inland drift-sands form a unique group within aeolian landforms in Northwest Europe. They result from the reactivation of sandy deposits by human activities during the late Holocene (Koster, 2005). In the Netherlands they are mainly found in southern, central and north-eastern Netherlands as shown in Figure 9.1.

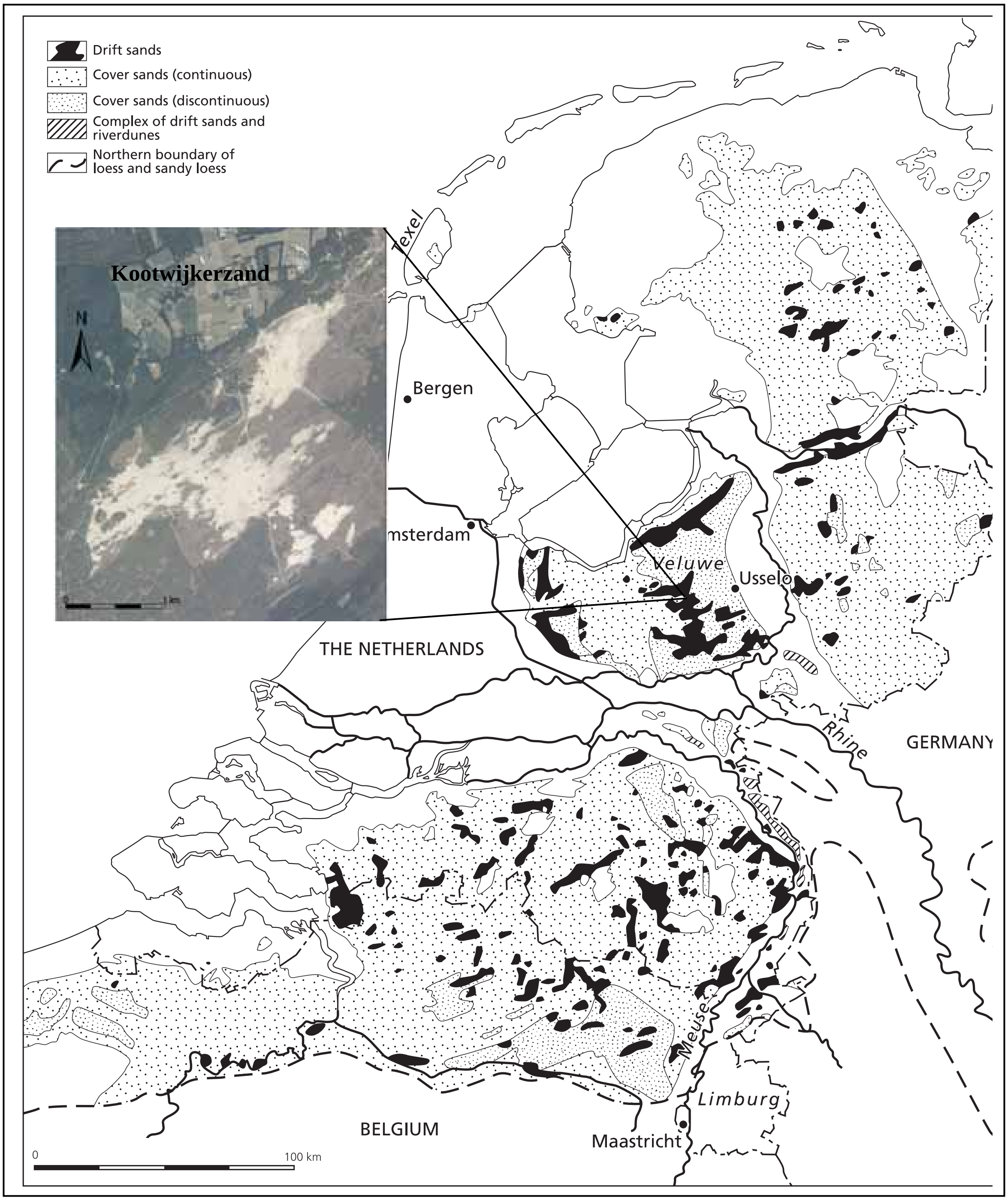


Figure 9.1. Areal distribution of drift sands in the Netherlands and Belgium (Koster, 2005), inset aerial photograph: Kootwijkerzand, the largest still active drift sand area of Netherlands (aerial photograph © Eurosense 2003)

The inland drift-sand landscape consist of three different intertwined wind erosion zones. Together they form the conditions where a mosaic vegetation in different development stages can thrive. This variation in the landscape features and in vegetation is essential for the rare drift-sand flora and fauna.

This habitat type is rapidly disappearing due to a lack of wind erosion activity (Riksen *et al*., 2004; Riksen *et al.*, 2006) and the stabilisation of the bare drift-sand by algae and vegetation. The general trend nowadays is the rapid regeneration of the drift-sands into forest which would mean the complete loss of the drift-sand habitat type in Western Europe.

Therefore, much emphasis is put nowadays on the preservation of the drift-sand ecosystem. In the Netherlands several active drift-sand areas are designated Natura 2000 area, under habitat type 2330: open grassland with *Corynephorus* grass and Agrostis grasses on land dunes. However, to date, there exists no general management strategy for active drift-sand areas. Current management interventions concentrate on the restoration of degraded ecosystems. Restoration works mainly consist of large-scale sod cutting (*plaggen*) and clearing trees. So far little attention is paid to the monitoring and evaluation of the effects of such measures and there is no general management strategy to maintain the drift-sands after restoration. It is unsure if such large-scale restoration approach will lead to the preferred landscape in which all characteristic species will return.

In 1986 Castel already pointed out the need of a more integrated (small-scale) management approach in which both are managed: erosion activity (process management) and vulnerable habitats (pattern management). Based recent research, Ketner-Oostra and Riksen (2005) came to the same conclusion. A more intensive management is needed to preserve the remaining active drift-sand areas and drift-sand flora and fauna.

In 2001 the Erosion and Soil and Water Conservation (ESW) group of Wageningen University, the Netherlands started a research project in co-operation with the State Forestry Service (SBB). First an analysis was made of the main causes of the rapid decline of drift-sand areas with wind erosion activity (section 9.2; Riksen *et al.*, 2006). From 2002 onward several field experiments took place at the inland drift-sand area Kootwijkerzand (see Figure 9.1), the Netherlands. These provided knowledge about the extent, the intensity, and the role of erosion processes in the drift-sand ecosystem (sections 9.3 & 9.4; Riksen and Goossens, 2006).

Simultaneously an inventory was made of the commonly used mechanical techniques to restore wind erosion activity (section 9.5). The research at Kootwijkerzand further focused on how, when and where erosion could be successfully stimulated and maintained (process management). Four different tillage techniques - rotary cultivator, beach-sand cleaner also known as sod-sieving machine, disk harrow and excavator - were tested (section 9.8).

The findings of these studies are used to develop a concept for wind erosion process management (section 9.6). Management scenarios depend on the size of the drift-size complex (section 9.7). In many cases drastic measures are needed first to restore the situation (section 9.8). However to restore the situation of before the forestation would improve the open wind fetch enormously but would be in most cases impossible due to the local infrastructure, high costs, resistance of the local community and the Dutch forestry law (section 9.9). Section 9.10 describes the required monitoring and evaluation part of the proposed management strategy. This paper is concluded by providing the answer to the question posed in the title.

9.2. Drift-sand development in the Netherlands

Since the origin of the drift-sands, mainly late Middle Ages, their extent, the importance of wind erosion and its impact on the landscape has drastically changed. From their origin until the present we can distinguish 4 main periods (Figure 9.2.). The first period covers their origin and rapid extension. The second period represents the period in which the drift-sand area more or less reached its maximum size.

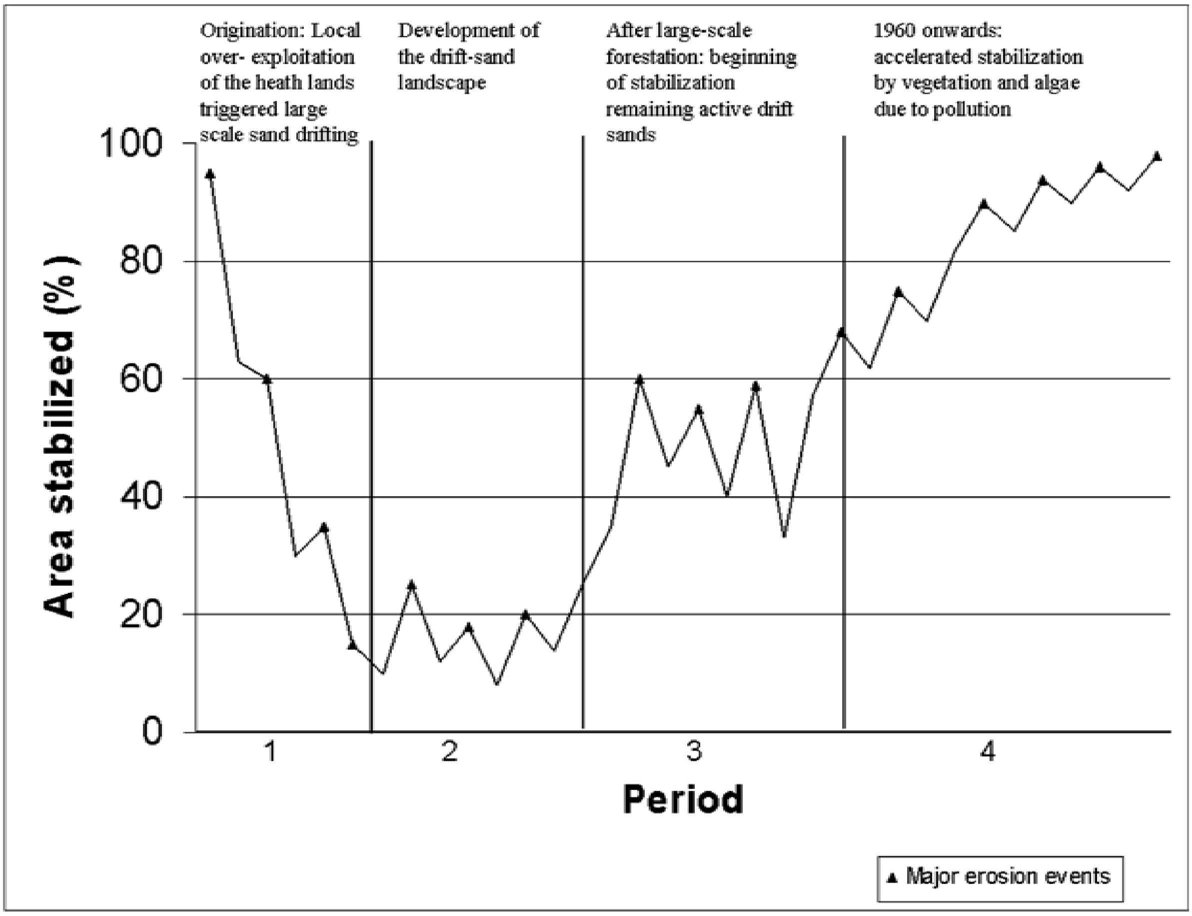


Figure 9.2. Schematic presentation of the development stages of inland drift sand areas and the role of major wind erosion events in the Netherlands

In this period large scale wind erosion activity formed the landscape within and at the direct border of active drift-sands. The typical drift-sand relief developed into deflation zones, rest dunes (plateau-dunes), anchored dunes or drift-sand dunes (topographically anchored dunes and nabkhas), vegetated parabolic dunes and bordering dune ridges. The development of these structures coincides with high sand mobility. Old photographs of the drift-sands often show little vegetation development. Vegetation development was controlled by extreme sand storms with high deflation and accumulation rates.

In the first half of the twentieth century large-scale forestation of most of the drift-sand areas in the Netherlands occurred (Figure 9.2.: period 3). After that most remaining drift-sand areas showed a rapid regeneration of areas within the wind-shade of these new forests unless they were intensively used for recreation or military exercises. Intensive recreation and military exercises compensate the lack of sand mobility by breaking crusts at the soil surface and disturbing vegetation development.

From 1960 onwards the remaining active areas also declined rapidly (Figure 9.2: period 4). On the one hand the sand mobility was too low and on the other hand vegetation growth was stimulated mainly by increased nitrogen deposition and fast growing exotic plant species like *Campylopus introflexus* (Riksen *et al.*, 2006).

The general trend nowadays is the rapid regeneration of the drift-sands into forest which would mean the complete loss of the drift-sand habitat type in Western Europe.

9.3 The three wind erosion zones

Wind erosion comprises the entrainment (deflation), transport (mainly saltation) and deposition (accumulation) of soil material. The main effects (functions) of these processes in a drift-sand ecosystem are (Riksen and Goossens, 2006): (1) Slowing down the vegetation succession, (2) the creation of new sites of extremely poor environmental conditions for the development of typical drift-sand vegetation and fauna and (3) the creation of relief. Hence, wind erosion processes act as landscape differentiating processes causing a spatial differentiation in conditions for flora and fauna.

Once favourable conditions for vegetation development have been created an important feedback mechanism starts. Because vegetation has a direct influence on wind erosion. Vegetation reduces soil loss by wind in three ways (Wolfe and Nickling, 1993): it protects the soil against the erosive force of the wind; it reduces the force of the wind near the ground by extracting momentum from the wind at a height above the surface; and it traps soil particles in transport. The effect of vegetation on the flow above the surface depends on the size, shape, spacing and arrangement of the vegetation elements and plant litter (Cooke *et* al., 1993; Wolfe and Nickling, 1993; Hesp, 2002).

Field measurements at the drift-sand area Kootwijkerzand of the erosion activity in areas with a different vegetation cover showed a exponential decrease with an increase in vegetation cover (Ketner-Oostra and Riksen, 2005). Hesp (1989) studied the relation between wind erosion activity and density of plant cover on coastal dunes. Plants 1m apart acted independently; closer than 0.60 m (equals a vegetation cover between 5 and 8 percent), they encourage deposition.

The characteristics and development of the wind erosion processes and their control factors from active deflation zone through transition zone into stabilized vegetated (former deflation zones) are discussed below.

The deflation zone

In this paper we define a deflation zone by its average vegetation cover which should be lower than 5 %. In this zone with drift-sand or cover sand at the surface mainly entrainment and transport of sediment takes place. The deflation zone is the source area of wind blown material. It has a soil profile containing a C-horizon of fine textured cover sand with a modal grain size between 105 and 210 µm (Koster, 2005) or drift-sand with a modal grain size between 150 and 420 µm (Bakker *et al.*, 2003). These sands are poor in nutrients and organic matter and no structure (Table 9.1; stage 0 and 1). In general this zone is fairly flat but in some cases bare slopes or dunes also function as a deflation area.

Table 9.1. Vegetation and main soil characteristics of drift-sand vegetation succession stages

Main landscape forming process	Stage	Description	Soil characteristics			Vegetation cover (%)
			Soil profile	OM 0 – 5 cm (%)	pH KCl 0 – 2 cm	
Deflation	**0**	No vegetation	C	0.30	4.7	0
	1	Patches of pioneer grasses	C	0.30	4.7	< 5
Accumulation and regeneration	**2**	*Corynephorus. canescens* and green algae	C	0.34	4.6	5 – 80
	3	*Corynephorus. canescens* and green algae and *Polytrichum piliferum*	C	0.58	4.5	40 – 75
Regeneration	**4**	Moss carpets, partly covered by algae (*Gloeocystis polydermatica*)	AC	0.79	4.0	70 - 100
	5	Dying moss carpets through ageing and effects of covering by algae	AC	0.88	3.5	70 - 100
	6	Lichen growth on partly dead moss carpets	AC	1.37	3.5	90 - 100
	7	Species-rich lichen vegetation, including reindeer lichens	AC	1.64	3.5	90 - 100
	8	Mosaic vegetation of drift-sand vegetation with heath (*Calluna vulgaris*) including *Juniperus communis*	A(B)C	5.25	3.2	90 - 100
	9	Development of pine forest	A(B)C	5.25	3.2	90 - 100

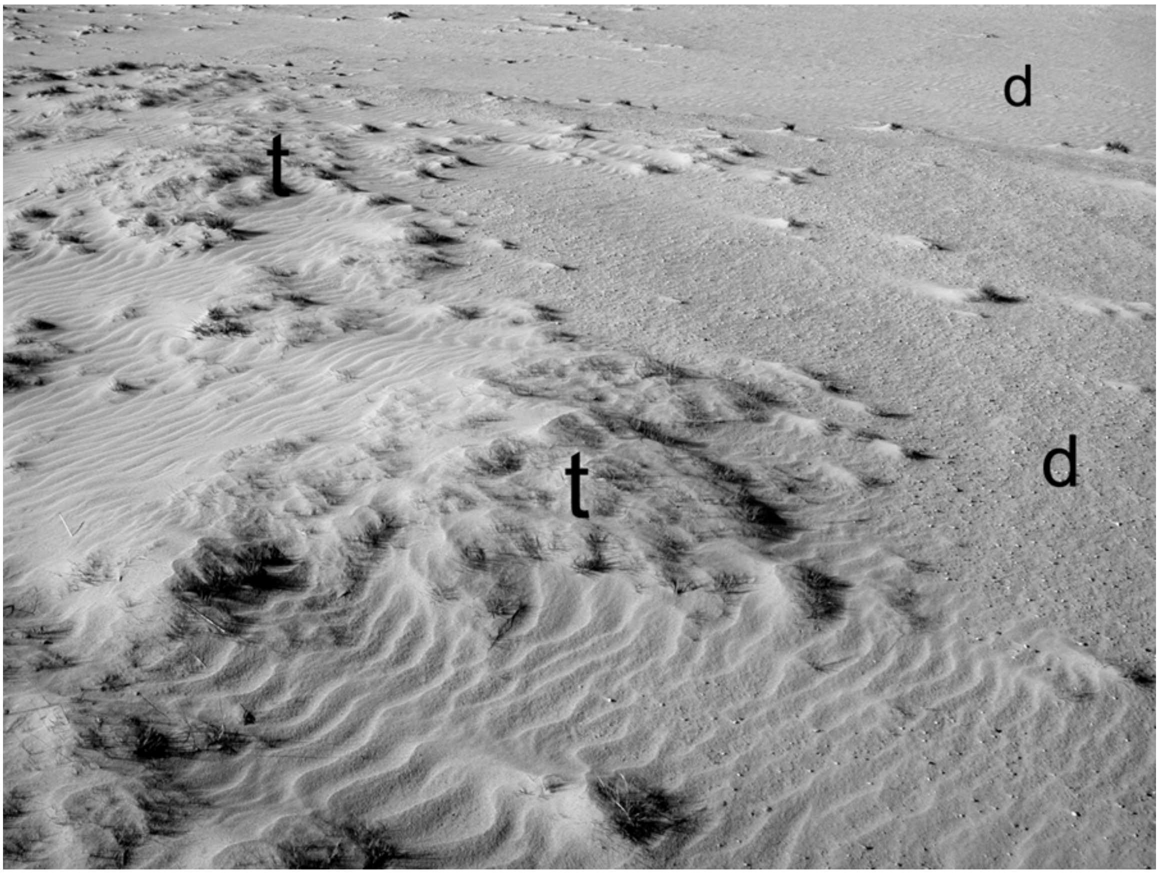


Figure 9.3. Ephemeral accumulation patterns behind vegetation in the deflation zone (d) and more complex transport and accumulation patterns in the transition zone (t)

The actual wind erosion in this zone is mainly influenced by the soil moisture content in the surface layer. This moisture content determines the threshold value of the wind speed at which wind erosion takes place.

Widely spaced single grass tussocks influence the flow mainly locally. A wake region, in which the wind velocity is less than the surrounding region, develops downwind of a tussock. In case of sediment transport this reduction in wind velocity results in the deposition of sediment in this wake zone (Figure 9.3.). With a decrease in spacing between these singe vegetation elements the area where the wind velocity near the surface reaches its original velocity at the surface also reduces. In this case complex patterns of accumulation in combination with deflation and transport may be noticed.

The transition zone

This zone (Figure 9.3.) coincides with vegetation stage 2 (see Table 9.1). In this zone mainly deposition takes place. In drift-sand areas with high sand mobility this results in dune formation (dunes anchored by obstacles: echo dunes, climbing dunes and lee dunes; and anchored by plants: nabkhas, vegetated parabolic dunes).

If a deflation zone is partly stabilized by algae and pioneer grasses, the scarcely vegetated zone between the active parts of the deflation zone is here defined as a transition zone.

A further decrease of spacing between the vegetation elements finally results in a skimming flow over the surface. In this case the roughness length, the thickness of the layer above the surface where the wind velocity is zero (z_0), is displaced upwards. Here entrainment of soil particles no longer occurs. In general this point is reached at a vegetation cover above 30 – 40 %. Field experiments at an inland drift area by Ketner-Oostra and Riksen (2005) showed that the sediment transport by wind erosion or splash erosion decreases exponentially with the increase of vegetation cover and is negligible at a vegetation cover > 40%. Buckley (1987) found in a wind tunnel study similar figures for small dune plants 0.10 m high and 0.12 m across. Depending on the wind velocity he found no transport above a plant cover of respectively 37 % ($v=10 m.s^{-1}$) and 43 % ($v=15 m.s^{-1}$). At this point the transition zone has reached the status of a vegetation stabilized zone in which regeneration of the soil dominates and sediment transport is related to splash drift only (Riksen and Goossens, 2006).

The regeneration zone

This is the stabilized vegetated zone in which the regeneration process is dominant with little or no erosion activity. The vegetation zone starts more or less with the vegetation succession stage 4 (Table 9.1). From this point the regeneration process is no longer controlled by wind erosion and gradually results in the development of a mosaic vegetation of drift-sand vegetation with heath (*Calluna vulgaris*) (Table 9.1: stage 8).

9.4. The unique mosaic pattern of the inland-drift-sand ecotype

The three zones together form the unique mosaic pattern of ecotopes (see also Figure 9.4.) providing a habitat for the characteristic drift-sand flora and fauna.

Drift sand fauna

The composition and distribution of the characteristic fauna communities of the Dutch inland drift-sands is closely related to the extreme conditions in this landscape. Species that occur on the most dynamic places of drift-sands are characterized by high mobility, a short life cycle and one or several generations per year. Many fauna species depend on two or more ecotope types within the inland dune landscape to fulfil their needs and complete their life cycle.

Typical species such as Tawny Pipit and Tree Grayling require a relatively large habitat within a site to sustain viable populations (Riksen *et al.*, 2006). In the Netherlands the Tawny Pipit prefers the transition zone between active drift-sand and densely vegetated stabilized sand, in particular sparse vegetated areas with pioneer vegetation such as *Corynephorus canescens* and *Polytrichum*

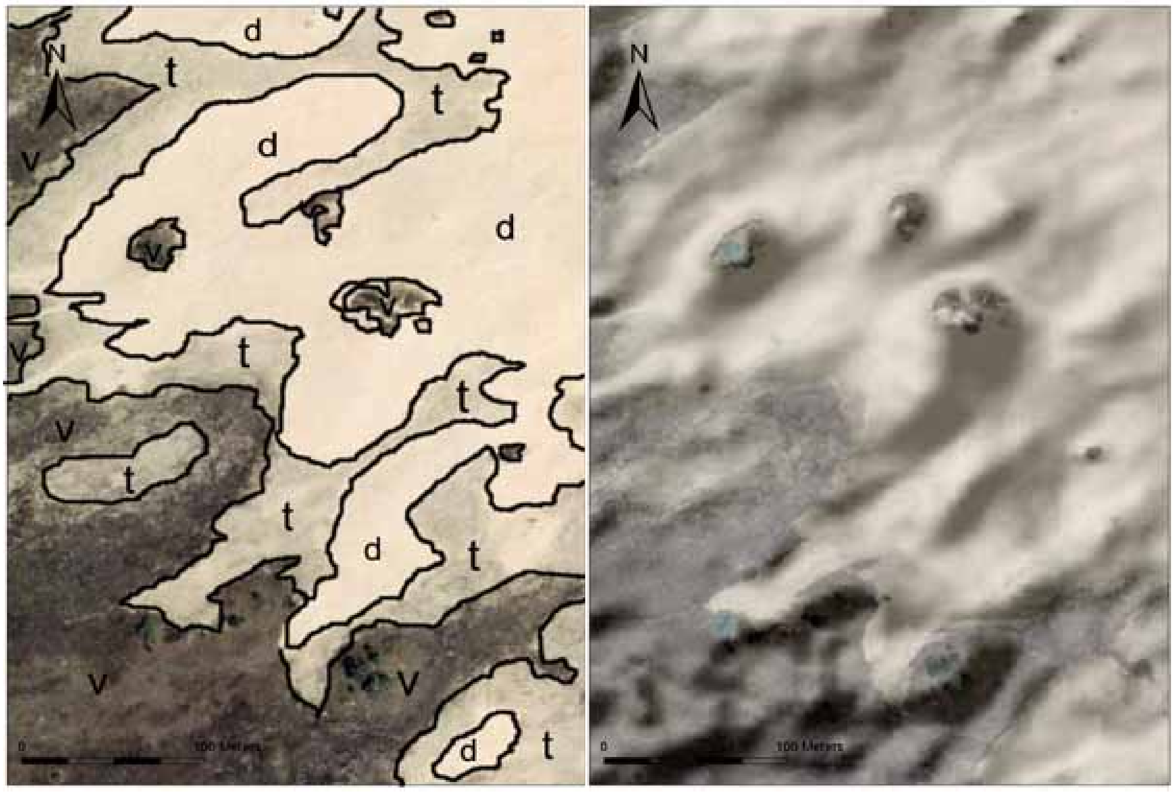


Figure 9.4. Analysis of terrain characteristics in GIS: left relation vegetation cover and erosion d= deflation zone, t= transition zone, v= vegetated stable zone (aerial photographs: © Eurosense 2003); right: relation vegetation and drift-sand relief, (Relief shaded map: Data source: AGI-ITC Rijkswaterstaat, 2004)

piliferum with a ratio between bare sand and stabilized sand of 1:4 (Bijlsma 1978, Bijlsma 1990, Omvlee and Waanders 1992). The presence of relief elements is also important as outlook for territorial behavior and forage. Only areas with a zone open drift-sand vegetation of at least 50 ha seems to be suitable for the successful settlement of the Tawny Pipit. The strong decrease of the area bare sand in many drift-sand areas and the rapid change of the pioneer vegetation into *Campylopus*-dominated vegetations will have seriously affected the food supply for the insectivorous Tawny Pipit (Van Turnhout, 2005; Riksen *et al.*, 2006).

Also the male of the Tree Grayling seems to use the crest of small dunes as outlook to defense its territory and spot females. Tree Grayling also needs stands of *Calluna vulgaris* to facilitate its nectar demand during its mature stage and vital stands of the pioneer grass *Corynephorus canescens* during its larva stage. Adults of Tree Grayling will be adversely affected by a decrease of both bare sand and lichen abundance, because they use these ecotopes for warming up. It is believed that for a healthy population of the Tree Grayling at least 100 ha drift-sand area is needed (Peet and Soerink, 2002; Geraedts, 1986).

Drift sand vegetation

With regular erosion activity in the **deflation zone** the conditions remain poor and vegetation and algae will not develop. In the **transition zone** the vegetation consists of pioneer species which are adapted to the extreme conditions such as the high mobility of sand, the low water-holding capacity, extreme micro-climate and low nutrient content of the soil. Pioneer species like *Ammophila arenaria* and *Festuca rubra* ssp. *commuta* are adjusted to growing in moving sand. The settlement of the most common pioneer grass *Corynephorus canescens* depends on its spread by wind. Soil formation in the first succession stage is limited. The organic matter content in the topsoil increases slowly, which create favourable conditions for species that cannot bear the poor conditions and/or the high sediment deposition rates found near an active deflation/transport zone.

As more sand is stabilized, plaques of green algae might develop between the tussocks of *C. canescens*, followed by protonemata of mosses. In this early stage with still significant sediment transport the pioneer moss *Polytrichum piliferum* is found. In the top two centimetres of sand inside this *C. canescens* vegetation dominated by *P. piliferum* (Table 9.1: stage 3) some humus has formed resulting in a small decrease of the pH.KCl. The vegetation cover in this zone shows a strong fluctuation which is related to the extent of sediment accumulation. Sometimes it happens that parts of this zone change back into a deflation zone, but the long-term trend is for these zones to turn into a **regeneration zone**. The rate at which vegetation stage zero can change into stage 2 mainly depends on weather conditions. At Kootwijkerzand, Ketner-Oostra and Riksen (2005) noted the complete stabilisation of a deflation zone by algae/ *C. canescens* vegetation within 1.5 year.

A surface crust may be formed in periods with little or no sand mobility. A firm algae crust may be formed especially in wet periods. Their role in the fixation of dune sand and drift-sand in the Netherlands was first discussed by Van den Ancker *et al.* (1985) and Pluis (1990, 1994). Algae strongly reduce the erodibility, as shown by Van den Ancker *et al.* (1985). During dry periods with high sand mobility these algae don't get the chance to reach maturity and form an non-erodible crust. As the deflation zone becomes smaller and sand mobility limited, this algae crust may result in the complete or partly stabilisation of the deflation zone in which the pioneer vegetation is able to develop. Small isolated deflation zones are therefore more prone to rapid stabilisation by algae. The high N-deposition rates in the Netherlands is probably one of the main causes for the rapid development of these algae crusts in the inland drift-sands.

This succession from initial species-poor grey hairgrass vegetation (stage 1) into the lichen-rich final phase (stage 8) might take 10 - 12 years, while they might remain more or less without succession for about 20 years (Daniels and Krüger 1996). However with the gradual formation of an A-horizon the seed of *Pinus sylvestris* (Scottish pine) will germinate and survive more easily. These seedlings grow fast and can form a closed forest (Table 9.1, stage 9) within a few decades.

This process of stabilization of deflation zones by the development of vegetation and algae crust forms the point of departure in the concept of process management (Section 9.6).

9.5. Current management interventions in drift-sand areas

Current management interventions indrift-sand areas concentrate on the restoration of degraded ecosystems. The restoration works mainly consist of large-scale sod cutting (*plaggen*) and clearing trees and in some cases cutting a part of the adjacent forest. Only some characteristic trees are maintained (Figure 9.5).

Figure 9.5. Large scale sod cutting at Beekhuizerzand, the Netherlands. Left: Large scale plaggen of the topsoil over an area of approximately 40 ha in 2003. Right: Situation October 2005 (Photographs: G. Koopmans)

Restoration of drift-sands is often very expensive and radical for flora and fauna. Large-scale restoration works are not without risk. Specific vegetation and fauna may be lost and also characteristic relief elements. Dunes formed around vegetation, trees or shrubs as shown in Figure 9.4, may erode away and be even completely lost when the related vegetation, tree or shrub is removed.

During intensive storms with high deflation and transport rates most of the sediment will end in so-called '*randwallen*' in the forest border or vegetated parabolic dunes and often not longer available for the wind erosion process. Little is known about the long-term effect of these developments on the target vegetation and fauna. It seems that most typical drift-sand fauna species highly depend on a habitat in which the different landscape elements are sufficient represented such as bare sand, small dunes, transition zones with a open grassland with *Corynephorus* grass. It is unsure if the large-scale restoration approach will lead to the preferred landscape in which all characteristic species will return.

9.6. Principles of a new management strategy for drift-sand areas

For the preservation of the present biodiversity or the re-entry of lost species in the remaining drift-sand areas, the landscape differentiating processes should first be restored. The main objective of our new management strategy is to maintain optimum field conditions for erosion in a way and scale that it can act as a landscape differentiating process. This process management strategy consists of: (1) an overall management plan or strategy for a period of 10 to 15 years (Figure 6: outer circle) and (2) a short term (1 – 3 years) maintenance plan to keep the erosion potential in the selected deflation zones sufficient high (Figure 9.6.: inner circle).

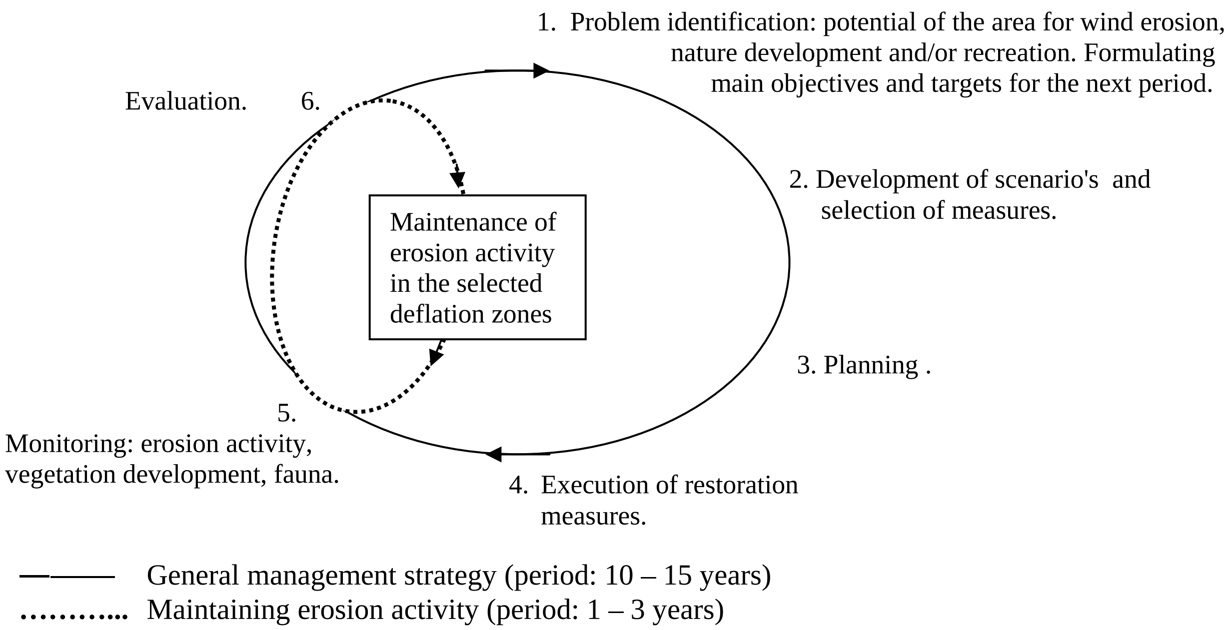


Figure 9.6. Different steps in process management

The overall management strategy takes place at landscape level. The first step includes the problem identification and formulation of the mid- or long-term objectives. These objectives can be translated into scenarios (Figure 9.6.: step 2) each containing a set of measures in which the drift-sand area is divided into zones according the preferred function e.g. recreation versus nature development. Each zone is then subdivided according to its potential into stable zones with mainly vegetation development (regeneration) and zones under influence of wind erosion (degradation). In the next step (Figure 9.6.: step 3) a detailed plan and time schedule for the selected restoration works is made for the selected scenario. After the execution (Figure 6: step 4) of the restoration measures two types of monitoring (figure 9.6.: step 5) should take place: (1) a general monitoring program focused on the general development and quality of the drift-sand area (once every year) based on the main objectives and targets and (2) a special monitoring program for the actual erosion in the deflation zones (once every 1 to 3 year) to actualize the maintenance schedule.

Maintenance (Figure 9.6: inner cycle) is planned for a period varying from 1 to 3 years and is based on the evaluation of the actual erosion. An overall evaluation takes place after 10 – 15 year (Figure 9.6: step 6) which serves as input for the next process management cycle.

Problem identification

Each drift-sand area is unique in terms of geomorphological development stage, size, vegetation development and main use (nature, recreation, military use or a combination). For each drift-sand a study is needed to identify the potentials of the area to function as a drift-sand ecosystem with wind erosion activity as one of the main controlling processes. The first step in the problem identification is a study of digitised aerial photographs (1m resolution) of the area, using GIS tools. From the aerial photographs the following data can be obtained: (1) total size of the drift-sand area and its location in the landscape; (2) obstacles (trees) and (3) the deflation, transition and vegetated zones. These three parameters give a first indication of the present performance of the area as an active drift-sand and the potential role of wind erosion in the future.

An additional field survey is needed to obtain the necessary data which is not visible on the aerial photograph or DEM. This field survey should give insight in the soil (profile), water table and in the presence and quality of the various drift-sand ecotopes and their specific vegetation and fauna species.

Based on the problem identification the main objectives of the management formulated for a 10 to 15 year period can be set. These main objectives or targets contain: the size of the area appointed as drift-sand; its main functions e.g. nature, recreation or military use; the percentage of the area with wind erosion activity; and the preferred vegetation an fauna (target species).

The deflation, transition and vegetated zones can be mapped on aerial photographs as shown in Figure 9.4. The activity/stability ratio can be estimated as the ratio between the by vegetation stabilized area on the one hand and the area controlled by wind erosion activity (deflation and transition zone)on the other hand. This ratio gives a rough indication of the actual role of wind erosion in a drift-sand area. The wind erosion potential in drift-sand areas with a activity/stability ratio above 1.5 here classified as low, between 1.5 and 0.7 moderate and below 0.7 as high. A gradual increase of the ratio in successive years, points to the stabilisation of the drift-sand area and measures are needed to prevent further stabilisation.

Management scenarios and selection of measures

Based on the general targets and available means one or more detailed plans are worked out into management scenarios. For the selection of measures and suitable locations a comparison of present situation with the situation on old aerial photographs (before 1960) can be helpful. A combination of a transparent map of the vegetation cover and a relief shaded map (Figure 9.4 right) gives a good overview of the dune elements and their relation with their environment such as vegetation, trees or other dunes, and which wind direction(s) played a dominant role during their formation. This information can be used to identify potential locations to restore wind erosion activity. Mapping the sheltering effect of forest and groups of trees for the prevailing wind directions can be helpful to select locations where and how the wind field can be improved.

Each scenario should include: a map of the present situation e.g. vegetation succession stages; a map with the selected measures; description of soil (soil profile, organic matter content in the topsoil, vegetation and fauna especially the presence of target species in and adjacent to the locations where measures are planned; and a description of the measures their advantages and disadvantages and costs. After the scenarios are discussed with the actors involved, a final plan including a detailed planning and instructions for execution is worked out.

The implementation of the measures may be spread over several years depending on the scale and the type of measures planned. If the measures also include improvement of the wind field then this should be implemented first. To prevent damage such as deep tracks, the final plan should also indicate the work direction, transport routes and depots for the removed topsoil.

Details of our general management strategy are elaborated in the following sections. In (9.7) the potential of drift-sand areas, in (9.8) the alternative measures to be undertaken, in (9.9) economic and social considerations and in (9.10) the importance of monitoring and evaluation of our process management approach.

9.7. The potential of a drift-sand area

It is assumed that the minimal size of a drift-sand/heath-land landscape should at least cover an area of 500 ha (Farjon *et al.*, 1994) to function as a complete drift-sand ecosystem in which all the various drift-sand ecotopes are represented. In smaller drift-sand areas not all the drift-sand ecotopes might be present or their size might be too limited to provide a habitat large enough to sustain viable populations of typical drift-sand fauna species. Small drift-sand areas in general need a more intensive management to preserve the ecotopes that are related to mobile sand. Small drift-sands are therefore more suitable for recreational purposes. High recreation pressure can help prevent crust formation and vegetation development in the deflation zones. This way, the open character of the drift-sand landscape and its poor conditions can be preserved despite the low wind erosion activity.

Large drift-sand areas are more suitable as a nature reserve. Here one should be careful with combining recreation and nature. Disturbance by recreation is probably one of the main causes of the decline of the Tawny Pipit in the Netherlands. Bijlsma (1978) showed a correlation between the local extinction of the Tawny Pipit and the accessibility of the site to the public.

Process management in small drift-sand units (< 100 ha)
In small drift-sand areas wind erosion cannot fully function as a landscape differentiating process. The limited space is not suitable to generate and maintain the necessary high sand mobility. After large scale restoration by sod cutting, there is also a risk that most of the mobile sand is deposited in the forest border and no longer available for the wind erosion process.

The main goal of process management is therefore to keep the area of bare sand large enough to provide a habitat for drift-sand pioneer vegetation and insects. The advice in this case is to maintain deflation/transition zones varying 2 to 5 ha in size, in the central part of the drift-sand area. Together they may cover approximately 60% of the total area. One can gradually shift the deflation zone by reactivating the adjacent transition zone. The erosion activity can be further improved by removing the trees that cause a reduction of the wind velocity in the deflation zone.

If one opt for nature development as main priority (despite their low potential), the recreation pressure should remain low. In this case high recreation pressure leads to the loss of quality of the drift-sand vegetation and fauna.

Process management in medium sized drift-sand areas (100-500 ha)
In medium sized drift-sand areas it is possible to increase the role of wind erosion by creating and maintaining larger deflation/transition zones of 5 to 10 ha each in the central part of the drift-sand area, together covering approximately 60% of the total area. In this case the role of process management is still focused on maintaining the drift-sand ecotypes only. The landscape differentiating effect on the development of drift-sand relief is still limited.

Process management in large drift-sand areas (> 500 ha)
In large drift-sand areas it becomes possible to connect deflation zones in the central part of the drift-sand area so they can form one large active centre which can generate high sand mobility. High sand transports during extreme events can lead to locally high deposition and dune formation. Together with the transition zone they may cover between 40- 60% of the total drift-sand area.

9.8. Measures to maintain or increase wind erosion activity

Obstacles influence the local wind profile in its direct surrounding. The strongest influence of an obstacle with a height H on the wind near the ground reach an average down-wind distance of 10H till 15H (Wieringa and Rijkoort, 1983; Morgan, 1995) for trees and 7.5xH for a shrub (Leenders et al., in press). Wind tunnel studies showed that in this zone the soil is protected for open wind velocities up to approximately 12 $m.s^{-1}$ (Woodruff and Zingg, 1952). With GIS tools it is possible to mark this so-called wake area for the prevailing wind direction(s). Although erosion is still possible in this zone the duration and average transport rate will be significantly lower compared to areas with no wind reduction. By mapping the zones subject to wind reduction it becomes possible to give a rough indication of the role of wind erosion for the whole drift-sand area by estimating the wind reduction ratio e.g. the area wind reduction by trees divided by the area with no wind reduction. In drift-sands surrounded by a forest the wind reduction can be considerably.

This wind reduction ratio gives an indication for the management level needed to keep the drift-sand area active. For drift-sands with a wind reduction ratio > 1 the management level to prevent stabilisation is high, for a ratio between 1 and 0.5 moderate and for a ratio below 0.5 the necessary management intensity will be relatively low. Mapping the wind reduction zones can also of use to predict the effect of removing trees.

Measures for the restoration or maintenance of wind erosion activity should focus on the zones with high potential wind erosion activity and the parameters that control the actual wind erosion activity. The erosion potential depends on wind erosivity on the one hand and soil erodibility on the other hand. The spatial differences in erodibility and wind velocities determine if a location acts as a deflation, transport or accumulation zone. This differs with the wind direction.

The erodibility of the surface soil material in drift-sand areas only depends on texture as the soils have a very week or no structure. The organic matter content in the topsoil of the drift-sand area is in general too low (OM < 1.5%) to have an effect on the forming of stable aggregates. Organic matter in drift-sands mainly influence the soil fertility and shows a strong relation to the vegetation development.

The actual wind erosion depends on soil moisture, vegetation and surface crusts. Especially the effect of a sparse plant cover on aeolian sand transport seems to be a critical factor in the morphology, evolution and distribution of aeolian dunes (Buckley, 1987).

Based on the actual situation, the main objectives and the available budget different scenario's can be formulated each with a different set of measures. One can chose between the enlargement of the present deflation plains and the creation of new deflation zones, or between measures to improve the wind erosivity and mechanical measures to compensate the lack of wind. In practice a scenario consists of a combination of different types of measures in a complimentary way. There are three types of measures to maintain or increase wind erosion activity: (1) measures to prevent sand stabilisation, (2) measures to re-activate stabilized sand and (3) measures to maintain or improve the wind erosivity.

Measures to prevent sand stabilisation

Most sediment transport occurs during a few extreme erosion events per year (Bakker et al., 2003; Ketner-Oostra and Riksen, 2005). If the duration between two storms is long enough and the growing conditions good, a pioneer vegetation and /or algae crust may develop and protect the sand grains against the erosive winds. In the first stage of stabilisation of a deflation zone, the vegetation development and/or formation of an algae crust can be effectively treated with a rotary cultivator

(Riksen and Goossens, 2005). Main pre-conditions are that the C_1-horizon should consist of cover sand and/or drift-sand, and at least 0.40 m thick to avoid mixing up different soil layers by the measures. There should be no direct influence of the ground water table. Working depth depends on the type of vegetation: 0.10 m in case of *Corynephorus canescens* and algae crust, 0.25 m in case of species such as *Carex arenaria* which is adapted to extend with creeping underground rhizomes.

Measures to re-activate stabilized sand

The best method to re-activate wind erosion in a stabilised zone depends on the development stage, e.g. vegetation cover and type, soil type and soil formation, of the selected area. The vegetation succession stage gives an good indication what kind of measures are needed to restore wind erosion activity in a stabilised deflation zone (Table 9.2.). The succession stage 0 and 1 represent the preferred condition after execution of the measures. The work depth depends on the type of vegetation and the thickness of the A-horizon. The main purpose of these mechanical measures is the first place to remove the protective vegetation. In the succession stages 4 to 9 the measure should also reduce the risk of rapid re-establishing of the vegetation by removing the fertile top-soil and seed bank.

Measures to maintain or improve the wind erosivity

Entrainment of soil particles only occurs when the wind velocity near the soil surface exceeds the threshold wind velocity. The sand discharge rate or horizontal transport rate (flux) also depend on the wind velocity. Obstacles reduce the period in which the wind velocity (friction velocity) exceeds the threshold velocity (erosion hours), and also reduce the average horizontal transport rates. Measures to increase the soil erodibility are therefore less effective in areas where the wind is obstructed by obstacles.

Table 9.2. Process management: measures needed to improve the erodibility per inland drift-sand vegetation succession stage

Measures to support the role of wind erosion	Work depth (m)	Veg. stage	Soil characteristics						Vegetation cover (%)	
			Soil profile		OM 0 – 5 cm (%)		pH KCl 0 – 2 cm			
			Before	Target	Before	Target	Before	Target	Before	Target
Rotary cultivator or Beach-sand cleaner	0.25	2	C	C	0.34	< 0.3	4.6	4.7	5 – 80	< 5
Beach-sand cleaner or Rotary cultivator	0.25	3	C	C	0.58	< 0.4	4.5	4.7	40 – 75	< 5
Sod cutting	0.05	4	AC	C	0.79	< 0.4	4.0	4.7	70 - 100	< 5
Sod cutting		5	AC	C	0.88	< 0.4	3.5	4.7	70 - 100	< 5
Sod cutting	↕	6	AC	C	1.37	< 0.4	3.5	4.7	90 - 100	< 5
Sod cutting		7	AC	C	1.64	< 0.4	3.5	4.7	90 - 100	< 5
Sod cutting	0.10	8	A(B)C	C	5.25	< 0.4	3.2	4.7	90 - 100	< 5
Remove forest Sod cutting	0.10-0.20	9	A(B)C	C	-	< 0.4	-	4.7	-	< 5

On locations where there is a sufficient supply of erodible sand, but little wind activity, the process management consist first of the optimization of the wind field if possible. To improve wind activity in an area one can remove the trees and shrubs causing a wind reduction in the deflation zone. In practice all trees and shrubs at the wind-ward side of the prevailing wind direction within a range of approximately 150 to 200 m from the deflation zone. To stimulate transport in a preferred direction one can decide to clear the trees at the wind-ward side of the deflation plain for this direction only.

In case it is not possible to improve the wind field, and it is preferred to keep the area bare anyway, more frequently tillage is needed to compensate the lack of erosive winds and sand mobility.

9.9. Costs and applicability of the measures

Most common used mechanical measures were tested by Riksen and Goossens (2005) on there effect on the soil erodibility as listed in Table 3. In their final assessment also the costs and applicability were taken into account (Ketner-Oostra and Riksen, 2005).

Table 9.3. Evaluation of tillage techniques on their ability to reactivate wind erosion on a stabilized drift sand with *Corynephorus canescens* vegetation (Riksen and Goossens, 2005; Ketner-Oostra and Riksen, 2005)

	Tilling technique			
Assessment criterion	**Rotary cultivator**	**Sod sieving machine**	**Disk harrow**	**Excavator**
Aeolian dynamics:				
Soil loss	++	++	+	+
Sediment transport	+	++	-	++
Loss of organic matter	+	++	+	o
Surface conditions:				
Compaction	++	++	+	o
Surface roughness	++	++	-	++
Texture	++	++	o	o
Plant residue	++	++	o	++
Total physical assessment	+	++	o	o
Costs (€ ha^{-1})	300	1200	250	1100
Applicability:				
Availability of the equipment	general	rare	general	general
Terrain conditions which reduce the effect and efficiency	Steepness, terrain roughness and soil moisture	Steepness, terrain roughness and soil moisture	No restrictions	No restrictions for excavator with caterpillar tracks
Work speed (ha h^{-1})	0.17	0.05-0.075	0.50	0.10
Total assessment	+	+	o	o

+ is positive; o is neutral; - is negative

For the sod sieving machine also known as beach-sand cleaner, the rotary cultivator and the disk harrow the end result is best under dry conditions. Fewer plants will survive or recover due to water stress. The best period of implementation is therefore during a dry spell in winter or autumn in which plant growth is minimal. This is also the period in which the least possible harm is done to the fauna.

In terms of disturbance of the ecosystem, removing the complete topsoil will also result in the highest loss of the present soil organism like the sand earwig. The meaning of this can become important if the measure is applied at a large scale. For the effect of the different methods on the flora and fauna in the long term, further research is therefore needed.

The cost per hectare of the measures consists of rental cost of the machinery, labor cost and additional cost related to the transport of rest material from the fields (plant rests in case of the beach sand cleaner and soil with plant rests in case of the excavator). Not only the operation speed, which is lowest for the beach sand cleaner and the excavator, determines the price, also the availability of the machinery. In the Netherlands the sod sieving machine is not a common machinery while the other machines are general available at each contract work company. The prices may differ a lot between contract workers. Experience with this kind of work (quality) and flexibility to wait for the right field conditions for the execution of the measures are other important selection criteria.

The applicability of the methods in the field depends on their functioning under different terrain conditions. The excavator (caterpillar tracked) can handle most terrain conditions, but the operation speed is slow (Table 9.3.). The disk harrow and the rotary cultivator are easier to operate even in rough terrain, but they can’t handle very steep slopes. For all three counts that soil moisture does not influence the operation speed. The sod sieving machine is more difficult to operate and works slower and less efficient under moist conditions. Under moist conditions less sand is falling through the sieves and will be transported to the waste container.

In the Netherlands the main problems with the clearing of forest to improve the wind fetch, are the high cost and the national legislation (Dutch forestry law). The cost to clear 1 ha of trees and topsoil is approximately € 20,000 per hectare (source: Mr. G. Koopmans of the Forestry Group Central Netherlands, Ede, the Netherlands). Without sod-cutting and removing the tree stumps, the cost per hectare is approximately € 5,000. The exact costs mainly depend on the method used and the marketability of the wood.

The question is whether one should wait twenty years or more before taking (restoration) measures again or maintaining the erosion risk at a certain level. Table 9.4 shows a comparison between a scenario with no maintenance after restoration and a scenario with scheduled maintenance. The table shows the results for three different average annual stabilization rates of respectively 1, 5 and 10 percent of the active area per year. It is assumed that in the first 6 years after stabilization an area can be treated with the rotary cultivator at 250 € per ha and after 6 year by sod cutting at € 1,100 per year. The table shows that the total cost for scheduled maintenance of the wind erosion potential is in most cases much cheaper than in the long-term management strategy with only restoration measures. Also the scale of disturbance is relatively small. Another major advantage of scheduled maintenance is the almost stable size of area with bare sand and open pioneer vegetation.

Table 9.4. Area status and accumulated costs for different management scenarios for an area of 100 ha

	Average annual stabilization rate (% y^{-1})					
	1		5		10	
year	Area stabilized (%)	Total costs at year (€)	Area stabilized (%)	Total costs at year (€)	Area stabilized (%)	Total costs at year (€)
Scenario costs restoration erosion activity without maintenance						
10	10	6,556	40	29,260	65	51,091
20	18	16,447	64	61,658	88	89,460
40	33	33,483	87	92,670	99	107,503
60	45	47,416	95	103,787	100	109,696
Scenario costs with maintenance						
1	1	250	5	1,250	10	2,500
10	1	2,500	5	12,500	10	25,000
20	1	5,000	5	25,000	10	50,000
40	1	10,000	5	50,000	10	100,000
60	1	15,000	5	75,000	10	150,000

9.10. Monitoring and evaluation of process management

Yearly monitoring the effects of process management is needed to:

- evaluate the measures on their effect on:
  - The processes: wind erosion activity and stabilization;
  - The quality of the drift-sand area: the target vegetation and fauna;
- plan maintenance and restoration measures;
- gain more knowledge in the long term effect of the different measures and management strategies.

There exist several techniques to monitor the effect of measures on wind erosion activity: indirect by a field inspection and soil properties; direct by measuring accumulation and soil loss with erosion pins or measuring transport with sediment catchers. However methods used for monitoring erosion activity and sustainability should be cheap and easy to handle by field workers.

In general a yearly field inspection of all selected deflation zones on erosion features, vegetation cover and algae crusts will be enough to check whether a deflation zone is still active. The best period for a field inspection is in August - September during or after a dry period with wind speeds of 4 Beaufort or higher. Ephemeral erosion features (see Figure 9.7) points to recent wind erosion activity.

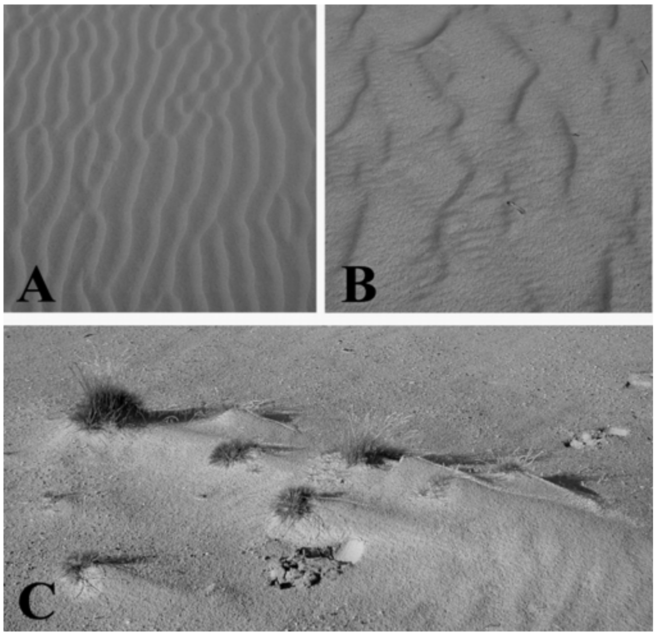


Figure 9.7. Ephemeral wind erosion features: A and B: ripples and C: shadow dunes.

A significant increase in vegetation and/or algae crust points to stabilization and action is required.

In case a location shows little or no erosion features compared to other locations, one should also look at the presence of coarse soil material or soil moisture. In drift-sands an increase of gravel (Ø > 2 mm) in the soil points to fluvioperiglacial material of the layer below the cover sand. In this case the location is a so-called 'blown-out' area (Castel *et al.*, 1989), no longer suitable to function as an active deflation zone.

High concentrations of fine uniform gravel on the soil surface in the deflation zone (also known as desert pavement) can locally stop deflation especially during weak or moderate events. However accumulation of this type of gravel along car tracks and on slopes showed that these local high concentrations are not always the direct result of deflation but often the result of the sorting effect during deposition. Given the very local and temporary character of this phenomenon no further action is required.

The organic matter content can also be used to predict the risk for rapid stabilization (see Section 9.4). Table 9.2 showed the measures for each vegetation succession stage, and the soil properties before and their target values after the measures are executed. Ketner-Oostra and Riksen (2005) found that the organic matter content in the topsoil (0 – 0.05 m) after restoration work give a good indication of the risk for rapid re-stabilization. Ketner-Oostra and Riksen (2005) found little vegetation development on sites where the organic matter in the top-soil was be below 0.4 %, and rapid stabilization by vegetation on sites where the organic matter in the top-soil was higher than 0.8 % after execution of the measures. Further research is needed on the relation between the pH and vegetation and/or algae development.

The results can be used to plan additional measures within the scheduled maintenance scheme (Figure 9.6, dotted circle). The flow chart in Table 9.4 gives when and what type of action is preferred to maintain the wind erosion potential.

Table 9.4. Flow chart for selection of suitable deflation zones in inland drift-sand areas and required interventions

1	Is there a sufficient supply of erodible material present in the upper soil layer? (Layer thickness C_1-horizon: consisting of cover or drift sand: > 0.4m)	<No> Not suitable as deflation zone.
	<Yes, continue>	
2	Is wind erosion controlled by a high water table? (water table within 0.7m range from the surface)	<Yes> The selected area is not suitable as deflation zone.
	<No, continue>	
3	Is the nature value at the present moment high? (presence of protected (red-listed) vegetation and/or fauna species)	<Yes> Intervention at this stage is not preferred. Requires small scale pattern management. Select a new area.
	<No, continue>	
4	Is the wind in the area obstructed?	<Yes> The selected area is less suitable to function as a deflation zone (select a new area) unless the obstacles can be removed (continue at step 5).
	<No, continue>	
5	Is the present vegetation-succession within stage 0 - 4 ?	<No> creating an active deflation zone is only possible by removing vegetation including the topsoil as far as the layer with drift or cover sand.
	<Yes, continue>	
6	Covers the area stabilized by vegetation and/or algae crust less then 5%?	<No> Prevent further stabilization: tillage with rotary cultivator or beach-sand cleaner.
	<Yes, continue>	
7	Is the organic matter content below 0.4%?	<No> be alert for rapid development of vegetation.
	<Yes, continue>	
8	Bare sand, no further action required in this year	

Most effects of the measures on vegetation and fauna are expected in the transition zone adjacent to the deflation zone. In this zone the vegetation can be monitored in permanent plots of 2 x 2 m according to the Braun-Blanquet method using the Code of Barkman, Doing and Segal (Barkman *et al.*, 1964). The results should be evaluated on vegetation cover and composition and compared with these characteristics for the different vegetation succession stages (Table 9.1). A shift to the drift-sand pioneer species indicates that the sand mobility in the deflation zone is high enough to create or maintain the extremely poor conditions (habitat) in which only this type of vegetation and fauna can survive.

The fauna can be yearly monitored on the presence of target species such as the Tawny Pipit (Aves: *Anthus campestris*), Tree Grayling (Lepidoptera: *Hipparchia statilinus*) and Giant Earwig (Dermaptera: *Labidura riparia*).

Insects living on and in the soil can be monitored locally in and around the treated areas and in similar but untreated areas. Butterflies like the Tree Grayling need to be monitored in zones and birds can best be monitored for the whole drift-sand area within the National monitoring program. In this way different developments in local populations can be addressed to the local incentives and or management strategy.

9.11. Conclusion

Without external disturbance all drift-sand areas show a relative rapid regeneration under the present environmental conditions in the Netherlands. Till now the general assumption was that additional measures after restoration would not be needed for several decades. The rapid stabilization in the last 40 years of large drift-sand areas like Kootwijkerzand (300 ha active drift-sand) show that this is not realistic.

Process management with scheduled maintenance will result in a more stable drift-sand habitat in which the typical drift-sand vegetation and fauna species are better able to survive. In other words, the answer to the question ‘How to use wind erosion to restore and maintain the inland drift-sand ecotype?’ is blowing in the wind if we maintain the optimum conditions for wind erosion.

Acknowledgements

This study was carried out as part of the research project "Making use of Wind and Water Erosion Processes in Dutch Landscape Development", of the Erosion and Soil & Water Conservation Group of Wageningen University, and was funded by the Dr. Ir. Cornelis Lely Foundation, Wageningen University, the C.T. de Wit Graduate School of Product Ecology and Resource Management, and OBN funds from the Dutch Ministry of Agriculture, Nature and Food Quality.

Many thanks goes to Dirk Goossens, Wim Spaan, Eric Kleinlebbink, Wim Huijsman, Aalt Boonen, Hans Snel, Gerrit Holtslag, Alfred Harmsen, Jan Bijker, Peter Mulder, Piet Peters, Huiberdien Sweeris, Pim Jungerius, Rita Ketner-Oostra, Marijn Nijsen, Chris van Turnhout and Nicoliene Peet for their contribution to this research project. I also would like to thank Gerard Koopmans of the Forest group, Central Netherlands, for sharing information and photographs for this paper.

Chapter 10

SYNTHESIS

Michel Riksen

In: Wind Born(e)Landscapes
(M.J.P.M.. Riksen) Wageningen, 2006, pp. 203 -214.

10. Synthesis

'Landscapes can really remind people of who they are' (Aldous Huxley, 1984)

Physical processes have had and still have a big impact on the landscape. The features of large-scale wind and water erosion have influenced landscape characteristic such as relief, soil and hydrology. Since the Neolithic, mankind has tried to adapt the land to their needs.

Until the 1990s land and water management in Northwest Europe mainly focused on controlling the local conditions in favor of economic benefits, such as lowering the water table in favour of agriculture and the canalization of rivers and streams in favor for navigation. The effects of these interventions do not stop at the field border, but also had implications for a wider region. After WO II the main focus was on food production and lowering of production cost. In this highly managed landscape there was no room for a dynamic physical environment. The man-made changes in the landscape and the intensive land management led to undesirable effects in natural habitats and loss of biodiversity.

However the West-European society is rapidly changing. New insights on climate change, environmental pollution and developments in society in the last few decades have led to new trends in land and water management: creating more room to store water to decrease the risk of flooding; restoring natural processes in the nature reserves to preserve or improve biodiversity; realization of an ecological main structure by creating ecological corridors between nature reserves and; and creating room for recreation near densely populated areas. The sustainable development of the rural areas and the welfare of the rural community are also important topics on the agenda of the European Commission (EC) (see Textbox 10.1).

The role of soil erosion in this new landscape paradigm is the main subject of my PhD research project “Making use of wind and water erosion in landscape development”, which started in 2001. The way, intensity and scale the detachment, transport and deposition of soil material occurs at is very diverse and so their effects. In this light, the main question was:

What are the effects, positive or negative, of erosion on our landscape and is there a need to (further) manage these physical processes in the future and if so, how?

Textbox 10.1. EC support for the protection of the environment, landscape and its features, natural resources and genetic diversity

> Support should continue to be granted to farmers to help address specific disadvantages in the areas concerned resulting from the implementation of Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds (1) and Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (2) in order to contribute to the effective management of Natura 2000 sites, while support should also be made available to farmers to help address disadvantages in river basin areas resulting from the implementation of Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for the Community action in the field of the water policy.
>
> Agri-environmental payments should continue to play a prominent role in supporting the sustainable development of rural areas and in responding to society's increasing demand for environmental services. They should further encourage farmers and other land managers to serve society as a whole by introducing or continuing to apply agricultural production methods compatible with the protection and improvement of the environment, the landscape and its features, natural resources, the soil and genetic diversity. In this context the conservation of genetic resources in agriculture should be given specific attention. In accordance with the polluter-pays principle these payments should cover only those commitments going beyond the relevant mandatory standards.
>
> Sourse: COUNCIL REGULATION (EC) No 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD), 21.10.2005 EN Official Journal of the European Union L 277/1)

While I have studied water as well as wind erosion, the role of wind erosion in nature development in the Netherlands became the main focus of my PhD study. The results fitted well together with earlier views on the role of wind erosion in an agricultural environment. These I obtained within the framework of an EU-funded wind erosion research project entitled 'Wind Erosion on European Light Sandy soils (WEELS)'. I therefore decided to combine my two wind erosion studies in this thesis.

The thesis explains the (negative) role of wind erosion on agricultural land on light sandy soils of the Northwest Europe and the (positive) role of wind erosion in nature development in the inland drift-sand areas. In this synthesis I further discussed the results of both studies looking at the differences and similarities between these two cases on: (1) effects of wind erosion, (2) factors controlling wind erosion, and (3) measures to control wind erosion. In the last section, a summary is given of the major conclusions and recommendations for each case study.

10.1. Effects of wind erosion

On-site effects

On-site effects can be defined as those effects caused by wind erosion in the landscape unit, in this case an arable field or drift-sand area, where deflation occurs (Chapter 2 and 3). Effects caused by transport and deposition of soil material within the same unit is also considered as on-site effects.

Effects on soil properties

Most farmers interviewed mentioned the low water-holding capacity as one of the main problems with farming on their fine sandy soils. On the contrary, in the inland drift-sand areas the low water holding capacity is one of the main factors in favor of the typical pioneer vegetation.

Farmers do not see the loss of (fertile) top-soil as the main problem of wind erosion. Several farmers said that they did not mind the soil loss because there is nothing in it. The fact that organic matter content can indeed be very low in areas regular subject to deflation, can be noticed in the drift-sand areas where values below 0.3 % are common in the surface soil layer in the deflation zones (Chapter 6). Soil degradation, the loss of soil fertility through the loss of very fine mineral and organic particles, is often disregard by the farmers and masked by the use of fertilizers.

Effects on plants

Saltating soil material causes crop damage on arable land, mainly by abrasion of young plants. When this happens early in the crop season the damage will be restricted to the costs of re-sowing and lower yields, but when it is too late for re-sowing the whole growing season may be lost resulting in a negative Gross Margin. For sugar beet and oilseed rape for instance, the costs can be as much as €500 per ha once in five years (Chapter 2). The pioneer vegetation in drift-sands are well adapted to the extreme circumstances. Grey hairgrass, the common pioneer vegetation in drift-sands, has strong thin curled leaves and easily survive regular abrasion.

In the deflation zone the seed (bank) and (young) vegetation may also completely lost or roots and tuber crops laid bare, resulting in extra costs for re-sowing and/or extra tillage. In the inland drift-sands deflation prevents the stabilization of the deflation zones by vegetation. This is only when the erosion activity is sufficient high in frequency, intensity and duration. Figures of the area of active drift-sands show that the erosion activity is often too low to prevent further stabilization. From the 60 km^2 that remained in the Netherlands after the major period of reforestation, only 40 km^2 remained around 1980 and no more than 1,500 ha in 2002 (Jungerius, 2003).

Most deposition in arable field will take place very locally due to an increase of the surface roughness or soil moisture or due to the presence of an obstacle such as a fence or hedge. Deposition may bury the plants completely. Most arable crops can only stand little deposition. The soil quality in zones with regular deposition is low and not suitable to grow cash crops like sugar beet and potato (Chapter 2). In drift-sands, pioneer vegetation like Grey hairgrass can withstand a moderate amount of deposition. This grass shows a more vital development with regular accumulation of sand than without it. The pioneer moss *Polytrichum piliferum* can also grow through a layer of accumulated sand. The exotic moss *Campylopus introflexus* disappears when covered with a small amount of sand but recovers if this only happens incidentally (Chapter 6).

Effect on fauna
Soil life in soils with little or no organic matter is low. One farmer in the Breckland district started to used high quantities of organic matter 25 years ago. He told me that he clearly noticed an increase in the presence of organism in the soil (Chapter 2). The typical inland drift-sand fauna is strongly adapted to the poor conditions. Species such as the Great earwig and the Tree grayling need the bare sand for warming-up. The Tawny Pipit needs a sufficient large area with sparse vegetation for hunting. Regular wind erosion activity helps to maintain these poor conditions (Chapter 6 and 7).

Off-site effects
When soil material is transported beyond the field border it may cause off-site damage. Adjacent ditches can get clogged and roads blocked. In regions where fine sandy soils contain sufficient clay, loam or organic matter (peat), dust may cause severe off-site damage. However, the extent of wind erosion-induced off-site damage is relatively small in the northwest European countries, especially when it is compared to the damage caused by the large-scale dust storms that occur in other parts of the world, such as in Northern Africa, Southeast Asia and North America (Chapter 3). Compared to these regions, the regions in northwest Europe prone to wind erosion are smaller and land use is more diverse. The comparison between the Dutch and the German study sites (Chapter 3) showed a higher risk for off-site damage in the Dutch Veenkoloniën due to the open landscape and a more uniform land use with mainly potato and sugar beet (70%). The German site showed a higher landscape roughness reducing the average wind speeds and farmers grow more cereals (63%), the area unprotected at the same time is smaller. In other words the actual wind erosion risk in a diverse landscape is lower. Therefore dust storms in Europe are generally rare, only known as a local problem like in the Dutch Veenkoloniën.

However when the source area consists of arable fields with a high nutrient content due to the addition of high quantities of fertiliser and/or manure, as in Europe, eutrophication of vulnerable nearby ecosystems can occur. Rutherford *et al*. (1999) reported a significant increase in respiratory problems in people in the affected area immediately after an event when there was a substantial amount of agricultural dust in the air. Williams and Young (1999) defined dangerous events as periods when the concentration of PM10 particles in the air exceeds 150 µg m^{-3} during at least one hour. Health problems associated with the increasing atmospheric dust load include eye irritations, skin irritations and diseases, shortness of breath, and other respiratory disorders such as asthma. It is generally believed that airborne dust from arable fields in highly densely populated countries like the Netherlands seriously contribute to the occurrence of such health problems (Chapter 3).

Wind erosion events in the drift-sand areas generate hardly any dust. The content fine soil particles and organic matter is in general very low in the young cover-sand and drift-sand (Chapter 7).

The extent of wind erosion events, their frequency, intensity and duration show great variation in time and space and is controlled by various factors. The main factors controlling wind erosion on agricultural land and in drift-sands will be discussed in the next section.

10.2. Factors controlling wind erosion

The main factors controlling the extent of wind erosion are: climate, landscape roughness, soil erodibility, vegetation cover and soil moisture. Climate, landscape roughness and relief determine the wind force near the surface. Soil erodibility, vegetation cover and soil moisture determine the threshold value of the wind velocity wind at which erosion starts. The actual wind erosivity and threshold value together determine the duration (erosion hours) and intensity (deflation, transport and deposition rate) of an erosive event. From this study came forward that the landscape roughness and vegetation cover are the most important factors.

Landscape roughness
The average wind velocity near the surface in a landscape with little or no obstacles is higher than in an area with a dense network of wind breaks (Jensen, 1985; Wieringa and Rijkoort, 1983). The landscape roughness is mainly determined by the presence of shrubs, trees, wind breaks, forest, buildings and hills. Beside a reduction of the average wind velocity, obstacles also give protection by reducing the wind velocity at the lee-side up to a distance of 30 times the obstacle's height (H) and four times its H on the wind-ward side. In Chapter 4 the sheltering effect of wind breaks is clearly illustrated by the WEELS-model for a scenario with a wind break net-work and without wind breaks. The maximum annual transport for the extended wind break scenario is 12% of the maximum annual transport of the scenario without wind breaks.

Major expansion of the drift-sand areas took place at the late Middle Age, when the landscape was very open with mainly heath land. In the nineteenth century the size of most drift-sand areas remained more or less stable. Most of the drift-sands and heath land in Northwest Europe were afforested at the begin of the twentieth century. With this large-scale afforestation the landscape roughness increased enormously. This led to a clear reduction of erosion activity and increase in vegetation development in the remaining drift-sand areas (Chapters 6 and 7).

Vegetation cover
Vegetation protects the soil against erosive winds. Its effect depends on plant size and shape but mostly on plant density. The sediment transport rate increases exponentially with the decrease in vegetation cover as shown in Chapter 7. Wind erosion activity is negligible at a vegetation cover higher than 30 - 40%.

Erosion risk on arable land is highest when the soil is left bare, especially after tillage and seedbed preparation, and until a vegetation cover of 30-40% has become established. Arable crops that need a relatively long period to produce a 30% cover, such as sugar beets and potatoes, are most sensitive to wind erosion. Fast-growing crops that produce the 30% cover in a relatively short time, such as maize, spring-sown cereals, oilseed rape and peas, are less sensitive to wind erosion. One of the most effective conservation methods is to reduce the period in which the land is not protected by using cover crops or mulch.

Before the forestation the vegetation development was controlled by wind erosion in the large drift-sand areas. The development of sparse vegetation was slowed down or set back during severe sand storms. Under present environmental conditions a bare drift-sand area can be stabilized by vegetation in a relatively short period: less than two years. In a drift-sand ecosystem the area of bare sand should be at least 25%. To guarantee sufficient high erosion activity it is advised to keep the percentage bare sand between 40 and 60%.

Do we need to manage the wind erosion process?

In both cases, nature development in drift-sands and arable farming on light sandy soils, there is a need to control wind erosion. Management of the wind erosion problem on arable land is needed to minimize the risk of the on-site and off-site damage and to stop further degradation of these soils.

The need to manage the wind erosion process in inland drift-sands of the Netherlands is of a totally different order. Inland drift-sands form a ecotype that is rare for western Europe with rare (thus protected) vegetation and fauna species. These species can only survive in this by wind erosion degraded landscape. However without active management the remaining drift-sand areas with regular wind erosion activity rapidly decline under present environmental conditions.

10.3. Measures to control wind erosion

Technical measures

In an agricultural landscape most wind erosion control factors can be influenced by land use, crop management and additional conservation measures. More or less permanent measures such as a dense shelterbelt network or a change in land use which provide a more permanent soil cover, would be, from a technical point of view, the best and most sustainable solution to minimize the wind erosion risk.

The main question is if farmers can and are willing to take the necessary soil conservation measures to minimize the erosion risk on their arable land. Farmers are generally well aware of the erosion hazard. However if and what kind of measures they take depends on their perception of erosion and the erosion risk, financial consequences (which may differ per crop type), the perception of the social community, subsidies and legislation. The influence of market prices and national and European agricultural policies can force farmers to change their land use and land management practices. Given recent discussion on the strong reduction of agricultural subsidies in the EC countries, the further industrialisation of arable farming forms a realistic scenario for the nearby future. Heavier mechanisation and larger fields will make agricultural regions more vulnerable to wind erosion. A shift from arable farming to animal husbandry is an alternative land use which can reduce the wind erosion risk (Chapter 5). To increase the landscape roughness the local and regional government can plant shelterbelts on community property like along roads, and stimulate farmers to plant hedges along the field borders.

In contrast to the preferred increase of the landscape roughness in the agricultural setting, reducing the landscape roughness by changing forest into heath land or drift sand would have a positive effect on the wind erosion activity in the drift-sand areas. However this is not always possible because of national legislation, high cost or opposition of the local community.

Other techniques control the wind erosion process for only a short period. Common practices in agriculture are: minimum tillage, planting in the stubble, furrow pressing or leaving the land 'rough' after ploughing. All of these techniques aim to decrease the erodibility of the surface. These techniques are relatively cheap but only provide protection against moderate wind velocities. Techniques that can protection to the soil surface for a longer period such as cover crops, artificial crusts or mulching (Riksen *et al*., 2003) are either too expensive or restricted in use because of national legislation and therefore only used in special situations. A good alternative to minimize the period in which the soil is bare, is the sowing of a second crop (green-manure crops) which provides a soil cover in autumn and winter till the next growing season.

In the drift-sands it is preferable that soil particles in the deflation zone remain available for the wind erosion process. Under present environmental conditions wind erosion activity is not high enough to keep the system going (self-regulating). The general trend since the large-scale afforestation is that most deflation zones show (partly) stabilization in periods in which the growing conditions for vegetation and algae are good with little or no erosion activity. Since the 1960s this process has been further accelerated by the high Nitrogen deposition (Chapter 6). A more active management is needed to keep a poor (degraded) landscape. The situation which we try to prevent on arable land, where the wind erosion risk is highest after seedbed preparation can be applied here. Techniques tested at Kootwijkerzand (see Chapter 8) showed that a rotary cultivator or beach-sand cleaner (sod sieving machine) preformed best to re-activate an area that had been stabilized with grey hairgrass and algae. The Grey hairgrass partly survived tillage with the disk harrow forming vegetated clumps at the surface and increased the surface roughness. The same effect is noticed by farmers in the Dutch Veenkoloniën after ploughing (under moist conditions). The surface after removing the vegetation with an excavator was too smooth and compact with a low amount of loose grains at the surface. Computer simulations with the WEPS model confirmed this finding (Riksen and Visser, 2004).

Management strategies and Policy measures

Defining a management strategy can help land users to control wind erosion. For arable land this strategy can be formulated in a Code of Good Agricultural Practice GAP (Chapter 5). The GAP describes the minimal management measures needed to keep the wind erosion risk at an acceptable level.

The management of drift-sands should focus on maintaining the erosion potential at a minimal level. It describes the minimal restoration measures for a period of 10 to 15 years needed to meet this objective and periodical measures for periods of 1-3 years to maintain the erosion activity.

In both agricultural and natural systems regional, national and European policies could help to preserve the preferred landscape values. The linkage of environmental and conservation conditions to farmers income support must tie in, wherever possible, with the conservation and environmental standards demanded by society. For this reason, the measures will have to be appropriate and geared to specific nationally and regionally distinctive environmental features. Moreover, the standards that are laid down for the Code of Good Agricultural Practice must be tightened. Similar developments in GAP would also have implications for agri-environmental policy. With the tightening of the standards of environmental quality, measures that are currently eligible for income support may well apply as conditions for income support in the context of market and price control policy.

In case of nature development the national legislation should be adjusted so that it becomes easier to make the necessary adjustments in the landscape to restore preferred ecosystems and their driving processes. In case of the drift-sands this implies a change in the national forestry law. Cutting forest to improve the wind force in the area should become more easier.

10. 4. Conclusions and recommendations

In North-west Europe the impact of wind erosion activity on the landscape takes place at a relatively small scale compared to other regions in the world. Also compared to the historical role of wind erosion in landscape formation like the formation of the cover-sands and drift-sands, the impact of wind erosion now is very local. However these lessons from the past should be kept in mind as the area classified with a high potential wind erosion risk in North-west Europe covers more than 3 million ha. There is little doubt that wind erosion problems since the Neolithic were induced by changes in land use and land management. Future developments in agriculture should therefore be checked for their consequences for the wind erosion risk.

In agricultural as well as in natural systems a long period without a severe wind erosion event forms a threat. In agriculture the awareness of the wind erosion risk might be lost and farmers tend to take more risk by farming without conservation measures. In the drift-sand areas a long period without severe wind erosion can result in the complete stabilisation of the drift-sand and a loss of the unique drift-sand ecosystem.

*10.4.1 Main conclusions and recommendations from the wind-erosion study in a changing **agricultural environment***

1. In intensively cultivated areas with light soils in Europe, wind erosion can have important on-site and off-site effects. The actual occurrence of wind erosion damage highly depends on the landscape and the land use.
2. Farmers are generally well aware of the erosion risk. Depending on the contribution of a crop to the net farm income farmers apply certain control measures. With these measures the average annual costs of wind erosion can be reduced considerably.
3. Most measures are taken at cropping level. Measures such as planting shelterbelts or reducing field size are applied only in profitable cases and where a shelter is very beneficial, for example near buildings.
4. For future landscape management, land-use planning and the planning of measures it is essential to quantify the erosion risk more precisely at farm and regional level to avoid an increase of wind erosion problem.
5. In the Northwest European regions with a high wind erosion risk, the extent of the off-site damage is very diverse. Realistic estimates of the off-site damage and related costs are difficult to make due to: (1) the diversity of the on-site and off-site factors and their interaction; (2) variations in the extent and intensity of wind erosion events over the years and (3) the lack of a complete picture of off-site damage caused by wind erosion events.
6. To better understand the off-site damage, effects that have the highest impact on society (in economic, ecological and sociological terms) should first be identified. Next, the extent and the related social, economic and ecological consequences of these effects should be studied.
7. The scenario runs with the WEELS wind erosion model give insight into the general change in erosion risk per month. With this information, the possible consequences for on-site and off-site damage can be estimated, and from this estimation, additional (policy) measures for controlling wind erosion can be formulated for the region in question.
8. Several tools are required for the proper implementation of Codes of Good Agricultural Practice. These include the provision of wind-erosion risk maps; mapping of the vulnerability for off-site damage; and regulations for the management of arable land in erosion-risk classes.
9. In case of off-site effects of wind erosion the source area often remains difficult to identify, and individual farmers can not be held responsible. This complicates the monitoring of measures taken by the farming community and of the benefits of controlling wind erosion. The difficulties of linking measures taken by farmers to the occurrence of wind erosion hamper the application of cross compliance because it constitutes of environmental conditions for direct payments. Proper monitoring of wind erosion would be essential if a link were to be established between the measures taken out the provision of payments to compensate farmers for their foregone income.

10.4.2 Main conclusions and recommendations from the study of the role of wind erosion in ***nature development*** *in inland drift-sands in the Netherlands*

1. The decline of active inland drift-sand in northern Europe is explained by various factors. Wind erosion activity in the remaining drift-sand areas is drastically reduced since the large scale forestation of large parts of the drift-sand areas and the heath lands.
2. Due to the reduced erosion activity, natural regeneration became the dominant process in the remaining drift-sand areas. Other factors, such as increased N-deposition, and the establishment of exotic plant species, accelerate the regeneration process by causing higher biomass production and a more rapid soil formation. In many drift-sand areas this had led to a rapid evolution of the whole or large parts of the area into a closed forest. In the remaining drift-sand areas this development causes a further increase of the landscape roughness and therefore a further reduction of wind erosion activity, increasing the demand to take action.
3. Most pioneer vegetation needs to be regularly covered with a small amount of drift-sand to remain vital. For the typical drift-sand fauna the combination of bare sand with a vital transition zone and other ecotopes seems to be crucial to survive.
4. Only severe storms (high intensity and/or long duration) can generate sufficient sediment transport into the vegetated zones to set succession back.
5. If the area of bare sand becomes too small, sand transport during these severe storms also becomes too small and the disturbance of the regeneration process will be minimal.
6. In general one can conclude that, under present condition, wind erosion no longer acts as a large-scale landscape differentiation process as was the case during the development stage of the drift-sand areas. Instead wind erosion has become a local process. Without proper management the erosion activity will further decline and the landscape will lose one of its main characteristics.
7. This study evaluated four tillage techniques for reactivating aeolian erosion in drift-sand areas colonized with Grey hairgrass, algae crusts and *Polytrichum* moss. The techniques significantly differ in their efficiency to reactivate aeolian drift-sand. The physically most effective method is the beach sand cleaner, followed by the rotary cultivator, the excavator and the disk harrow. The excavator and the disk harrow score considerably lower, especially the disk harrow, which does not show much difference with an untreated field for several of the key parameters considered.
8. With respect to the aeolian reactivation of drift-sand stabilised by Grey hair grass and algae, surface roughness and compaction of the topsoil are the key factors immediately after tilling. Any choice of techniques for increasing the erodibility of stabilised drift-sand should therefore not only be based on the ability of the techniques to remove or disturb the vegetation, but also on the impact they exert on surface roughness and compaction. In later stages of the

succession, other criteria (like the amount of organic matter and/or seed remaining in the top soil) may become more dominant.

9. Until now the general assumption was that additional measures after large-scale restoration would not be needed for several decades. The rapid stabilization in the last 40 years of large drift-sand areas like Kootwijkerzand (300 ha active drift-sand) shows that this is not realistic.
10. A comparison between a scenario with no maintenance after restoration and a scenario with scheduled maintenance showed that the total cost for scheduled maintenance of the wind erosion risk is in most cases much less than in the long-term management strategy with only large-scale restoration measures once every 20 to 40 year.
11. A major advantage of scheduled maintenance is that there will be an almost stable size of area with bare sand and transition area with pioneer vegetation. Process management with scheduled maintenance will result in a more stable drift-sand habitat with minimal disturbance from out-site, in which the typical drift-sand vegetation and fauna species are better able to survive.
12. Every drift-sand area is unique as they strongly differ in size, availability of cover-sand and/or drift-sand, hydrology, relief and vegetation development. To find the optimum balance between vegetated and bare sand area with wind erosion activity, a detailed study of all these factors is needed. To evaluate the proposed process management strategy on its effect on nature development, a long-term monitoring program is recommended.

In: Wind Born(e)Landscapes
(M.J.P.M.. Riksen) Wageningen, 2006, pp. 215 -224.

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In: Wind Born(e)Landscapes
(M.J.P.M.. Riksen) Wageningen, 2006, pp. 224 -228.

Summary

People are constantly adapting the landscape, a process steered by the society's needs, changing insights, environmental threats, politics and economical developments. This thesis focus on the role of erosion in this changing landscape. The way, intensity and scale of the detachment, transport and deposition of soil material is very diverse and so the effects caused by them. The main question was:

What is the contribution, positive or negative, of erosion processes to our landscape and is there a need to (further) manage these physical processes and if so how?

The role of wind erosion in an agricultural environment

In intensively cultivated areas with light soils in Europe, wind erosion can have important on-site and off-site effects. In the framework of the EU research project Wind Erosion on European Light Soils (WEELS), an assessment has been made of these effects and of the order of magnitude of the damage and costs caused by these effects. An analysis was made of land use and cropping on four selected sites, and farmers have provided information about the damage from wind erosion. This damage mainly consists of crop losses and additional inputs in the case of re-sowing. Detailed information from one of these sites shows that depending on the crop the average annual on-site costs in high-risk areas may amount to about €60 per hectare. However, for sugar beet and oilseed rape the costs can be as much as €500 per hectare once in five years. Farmers are generally well aware of the erosion risk and do apply a variety of control measures. With these measures the average annual costs of wind erosion can be reduced significantly.

The off-site effects of wind erosion are quite diverse in space and time and often difficult to quantify. Most off-site effects are related to the fine soil particles emitted. Most off-site damage is caused by short-term suspended material. The actual damage in the transport and deposition zone depends on landscape roughness, which determines the size of the area in which off-site effects can be observed. Characteristics such as the number of households, enterprises and the vulnerability of ecosystems in this area determine the type and extent of the effects.

An evaluation of current and potential future trends is needed to safeguard sustainable land-use practices and management strategies for the future. A sensitivity analysis using the WEELS model to simulate wind erosion was performed for two alternative climate, two windbreak and three land-use scenarios separately. The results provide spatially extended information on increase and decrease of the erosion risk per month, expressed in terms of projected erosion duration and maximum "Bagnold" sediment transport rates. By combining this information with information on farming practices and actual wind erosion damage for the scenario which represents actual land-use, it is possible to determine for each other scenario if and when additional wind erosion control measures and/or policy measures are desired.

A great variety of measures have been developed in the last few decades. Most farmers, however, only use measures to protect their high value crops. In existing policies little

attention is paid to the off-site effects and long-term effects of wind erosion. There are no direct policy measures at the European level to control soil erosion, and few measures exist in individual Member States. Agricultural or environmental EC policies offer different policy tools to approach the wind erosion problems related to agricultural practices. Tools like subsidies for the re-afforestation of arable land can help regional policy makers with the implementation of wind erosion control measures. A case study concerning the ‘Code of Good Agricultural Practice’ shows that regional differences result in different control measures that fits best given the physical, social and economic context. The formulation of the practical details of such Code should therefore remain a task of the local or regional government. The main objectives of a Code of Good Agricultural Practice could be formulated at national or European level.

The role of wind erosion in a 'natural' landscapes

In the Netherlands the total active drift sand area has been declining rapidly during the last 50 years. To preserve the inland drift-sand ecosystem, it is necessary to understand its origin and development and the role of human activity in this semi-natural ecotype. The objective of this study was to describe the development of the drift-sand ecotopes, to explain the rapid decline of the active drift sands, and to develop a management strategy for the remaining active drift sands. This study was conducted within the framework of the research project entitled 'Making use of water and wind erosion processes in landscape development in the Netherlands' funded by the Dr. ir. Cornelis Lely Foundation and started in January 2001. The overall goal of this project was to design and evaluate measures that stimulate erosion on locations where this is preferred. Attention was also paid to management aspects such as planning, applicability of the interventions and costs.

Drift-sand landscapes are relatively young landscapes of Holocene age. They often occur as oval-shaped cells with a length of 1.5 to over 6 km in the direction of the prevailing wind. These cells presumably represent reactivated deposits of Younger Cover Sands. Large-scale erosion events in combination with human activity suppressed the development of vegetation. After the change in land use in the first half of the twentieth century in which most of the drift sands were re-afforested, the vegetation succession started to show a progressive development. In this stage inland drift-sand ecotopes developed in most of the remaining drift sands with all forms of the typical succession stages from bare sand to forest. The rate at which this development took place mainly depended on the geomorphological development stage of the area, the area size and human activity. Since the 1960s the increased nitrogen deposition has accelerated the vegetation succession, not only resulting in the further decline of the drift sands, but also in a loss of the fragile balance between the different ecotopes and loss of its typical inhabitants like the Tree Grayling and Tawny Pipit.

Between 2001 and 2005 experiments and observations were carried out at the inland drift sand area of Kootwijkerzand (central Netherlands) to learn more about the extent, the intensity and the role of wind and splash erosion in a drift-sand ecosystem. Measurements were made of the horizontal sediment flux, the vertical accumulation flux, the raising and lowering of the surface, the organic matter content of the topsoil, the saltation activity and the weather conditions. An attempt was also made to evaluate the effect of various measures to re-activate erosion.

Without sufficient erosion, the scattered drift-sand vegetation will rapidly change into a closed, grass-dominated vegetation. The role of erosion in the drift-sand ecosystem is therefore crucial: erosion slows down the succession rate as it causes the regular deposition of nutrient-poor sediment, and it facilitates the regular renewal of the vegetation by creating new locations with extremely poor conditions (blown-outs).
On the bare drift- or cover sand wind erosion is the dominant process. Here the transport generated by splash drift can be of the same magnitude as during a moderate wind erosion event, but splash drift events are less frequent and also shorter than wind erosion events. They normally represent less than 10 percent of the total sediment transport. In the scattered drift-sand vegetation areas, on the other hand, splash erosion and splash drift dominate. Here the organic matter content of the transported (and later deposited) sediment is equal to the organic matter content of the parent soil, showing that splash (drift) has been the main transport mechanism. Biological crust developed in these areas may later reduce the influence of splash. .

Large transport rates are needed to reactivate wind erosion in the vegetated areas. Under the present conditions the erosion activity in most drift-sand areas is too small. An increase of the area prone to wind erosion is mainly observed after extreme storms. However this increase is not enough to compensate the decrease caused by the regeneration process in the periods between two heavy storms. Without human interventions, many drift-sand areas, with their characteristic flora and fauna, will disappear and turn into forest. It is especially the zones immediately downwind of still active deflation zones where measures to increase the erosion activity in the first succession stages may be undertaken. In areas completely stabilized by vegetation, the best locations for creating new spots with high wind erosion activity are the upper terrain parts that contain a sufficiently thick layer of drift - or cover sand.

Four techniques that reactivate, or benefit, the aeolian processes (rotary cultivator, beach sand cleaner, disk harrow and excavator) were evaluated during an 8-month experiment on drift-sand stabilised by Grey hairgrass and algae crusts at Kootwijkerzand, Netherlands. The effect of the techniques was measured using five key-parameters: the raising and lowering of the surface due to aeolian activity, the horizontal sediment transport flux, the vertical sediment accumulation flux, changes in the grain size of the top layer due to aeolian processes, and changes in the organic matter content of the topsoil. The effect of each technique on soil compaction, surface roughness and the amount of plant residue left on the field is also discussed. The highest aeolian activity was observed on test fields treated with the beach sand cleaner and the rotary cultivator. The changes in grain size and organic matter content of the top layer were also highest in these fields. Of the four techniques tested, the beach sand cleaner and the rotary cultivator are thus the recommended methods to reactivate drift sand stabilised by grey hairgrass and algae crusts. The disk harrow and the excavator may also lead to a reactivation, but they are less effective and therefore less recommended.
The selection and planning of interventions to manage wind erosion to restore erosion habitats in the inland drift-sand ecotype is the main objective of process management. Wind plays an important role by maintaining the extreme poor conditions in which only the for drift-sands characteristic vegetation and fauna can survive. The wind can only maintain this poor drift-sand habitat if the area susceptible to wind erosion is sufficient large. For the preservation of the present biodiversity or the re-entry of lost species in the remaining drift-sand areas, the landscape differentiating processes should first be restored. The main objective of our new management strategy is to maintain optimum field

conditions for erosion in a way and scale that it can act as a landscape differentiating process. This process management strategy consists of: (1) an overall management plan or strategy for a period of 10 to 15 years and (2) a short term (1 – 3 years) maintenance plan to keep the erosion potential in the selected deflation zones sufficient high. The overall management strategy takes place at landscape level. The first step includes the problem identification and formulation of the mid- or long-term objectives. These objectives can be translated into scenarios each containing a set of measures in which the drift-sand area is divided into zones according the preferred function e.g. recreation versus nature development. Each zone is then subdivided according to its potential into stable zones with mainly vegetation development (regeneration) and zones under influence of wind erosion (degradation). In the next step a detailed plan and time schedule for the selected restoration works is made for the selected scenario. After the execution of the restoration measures two types of monitoring should take place: (1) a general monitoring program focused on the general development and quality of the drift-sand area (once every year) based on the main objectives and targets and (2) a special monitoring program for the actual erosion in the deflation zones (once every 1 to 3 year) to actualize the maintenance schedule. A comparison between a scenario with no maintenance after restoration and a scenario with scheduled maintenance showed that the total cost for scheduled (1-3 years) maintenance of the wind erosion potential is in most cases much cheaper than in the long-term management strategy with only (large-scale) restoration measures. In the scenario with scheduled maintenance the scale of disturbance of the eco-system by the interventions is relatively small and the size of area with bare sand and open pioneer vegetation remains more or less the same. Process management with scheduled maintenance will thus result in a more stable drift-sand habitat in which the typical drift-sand vegetation and fauna species are better able to survive.

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Samenvatting

De mens past het landschap voortdurend aan op basis van zijn behoeften, voortschrijdend inzicht, bedreigingen van het milieu, de politiek en economische ontwikkelingen. Dit proefschrift gaat in op de rol van erosie in het veranderende landschap. De wijze, intensiteit en schaal waarop bodemdeeltjes van het oppervlak loskomen, het transport en de depositie van bodemmateriaal is zeer verscheiden en dientengevolge zijn hun effecten dat ook.

De probleemstelling van dit onderzoek luidde:

Wat is de bijdrage, hetzij positief of negatief, van erosieprocessen op ons landschap, dienen we deze fysische processen (verder) te beheren en zo ja, hoe?

De rol van winderosie in landbouwgebieden

Op de lichte zandgronden in noordwest Europa veroorzaakt wind erosie op intensief bewerkte akkers nog regelmatig schade aan gewassen en omgeving. In het kader van het EU-onderzoeksproject Wind Erosion on European Light Soils (WEELS) is een inschatting van de effecten van wind erosie gemaakt en de kosten die dit met zich meebrengen. Met behulp van interviews met boeren in stuifgevoelige gebieden in vier West-Europese landen werd een inventarisatie gemaakt van het landgebruik, gewasrotaties en teeltmethoden. Ook werd de boeren informatie gevraagd over de schade door winderosie, welke maatregelen ze nemen tegen welke kosten. Deze schade bestaat uit de noodzaak extra middelen in te zetten bij de nieuwe inzaai en/of oogstverlies. Uit de interviews blijkt dat, afhankelijk van het soort gewas, de gemiddelde jaarlijkse schade in risicogebieden kunnen oplopen tot 60 euro per hectare. Voor suikerbiet en koolzaad kunnen de kosten echter wel €500 per hectare in vijf jaar belopen. Boeren zijn over het algemeen goed bekend met het erosierisico en passen verschillende maatregelen toe om dit risico beheersbaar te houden. Dankzij deze maatregelen kunnen de gemiddelde jaarlijkse gewasschade door winderosie behoorlijk worden teruggebracht.

De effecten van winderosie buiten de directe locatie kunnen sterk verschillen, zowel ruimtelijk als in tijd. Bij de meeste van deze effecten gaat het om fijne stofdeeltjes die tijdelijk rondzweven. De omvang van het gebied waar de effecten van een stofstorm merkbaar is hangt af van de omvang van het brongebied, de duur en intensiteit van de stofstorm en de ruwheid van het bovenwindse landschap. Naast de concentratie en samenstelling van het stof bepalen factoren als het aantal huishoudens en bedrijven, kwetsbaarheid van het ecosysteem in het getroffen gebied het type en de ernst van de geleden schade.

Er is behoefte aan een evaluatie van huidige en toekomstige tendensen om een duurzame landgebruik voor de toekomst te waarborgen. Daartoe werd een gevoeligheidsanalyse uitgevoerd op basis van het WEELS model waarmee de netto erosie en accumulatie kan worden berekend voor verschillende scenario's. Twee verschillende klimaatscenario's, scenario's met en zonder windsingels en drie teeltplannen werden op deze manier met elkaar vergeleken. De resultaten ervan geven informatie over de toename

en afname van het erosierisico per maand, uitgedrukt in duur en maximum omvang van de erosie ("Bagnold"-indicatoren voor sedimenttransport). Door deze informatie te combineren met de informatie over de gebruikte landbouwmethode en over de reële schade ten gevolge van winderosie in het scenario dat feitelijk landgebruik in beeld brengt, kan men ook voor de andere scenario's bepalen of en wanneer additionele maatregelen ter beteugeling van winderosie of andere beleidsmaatregelen wenselijk zijn.
Hoewel er de afgelopen decennia een baaierd aan maatregelen is ontwikkeld, nemen de meeste boeren voornamelijk maatregelen waarmee ze hun gewassen met een hoge waarde beschermen. Bestaand beleid besteedt maar weinig aandacht aan de effecten buiten de locatie en de langetermijneffecten van winderosie. In 2000 waren er geen directe beleidsmaatregelen op Europees niveau om bodemerosie te beteugelen en maar weinig maatregelen in afzonderlijke lidstaten. We reiken het landbouw- en milieubeleid van de Europese Unie beleidsinstrumenten aan waarmee winderosierisico die verband houdt met landbouwmethoden verder kan worden terug gebracht. Instrumenten als subsidies voor herbebossing van akkerbouwgrond kan beleidsmakers op regionaal niveau helpen bij de implementatie van winderosiemaatregelen. Uit een casestudy over de 'Code of Good Agricultural Practice' (Gedragscode voor Verantwoorde Landbouwmethoden) blijkt dat regionale verschillen tot verschillende maatregelen leiden die het meest passend zijn gezien de fysieke, sociale en economische context. De formulering van de praktische details van een dergelijke Code zou daarom op het bordje moeten komen van lokaal of regionaal bestuur. De belangrijkste doelstellingen van zo'n Code Good Agricultural Practice zouden dan kunnen worden geformuleerd op nationaal of Europees niveau.

De rol van winderosie in een 'natuurlijk' landschap

De resten actief stuifzand in Nederland herinneren ons eraan waartoe verkeerd landgebruik kan leiden. Dat in Nederland deze restanten actief stuifzand nu worden gezien als waardevolle natuur is een feit. In Nederland is echter het totale stuifzandgebied de afgelopen 50 jaar snel teruggelopen. Om stuifzand als ecosysteem te kunnen behouden zal men inzicht moeten krijgen in de oorsprong, ontwikkeling en rol van menselijke activiteiten in dit halfnatuurlijke ecotype. Het doel van dit onderzoek was de snelle terugloop van actieve stuifzandgebieden te beschrijven en begrijpen, en een beheersstrategie te ontwikkelen voor het resterende stuifzand. Dit onderzoek is uitgevoerd binnen het kader van een onderzoeksproject 'Making use of water and wind erosion processes in landscape development in the Netherlands', bekostigd door de Dr. ir. Cornelis Lely Stichting en begonnen in januari 2001. Het algehele doel van het project was maatregelen te ontwerpen en evalueren die erosie juist stimuleren op locaties waar dit wenselijk is. Het onderzoek besteedde tevens aandacht aan beheersaspecten zoals planning, toepasbaarheid van de interventies en de kosten ervan.

Een stuifzandlandschap is relatief jong landschap. Vaak is het een ovale cel met een lengte van anderhalf tot ruim 6 km in de richting waarin de wind het meest waait. Dergelijke cellen zijn vermoedelijk gereactiveerde jonge dekzanddeposities. De combinatie van grootschalige erosieactiviteit, zoals zandstormen, met menselijke activiteit werkte vegetatiegroei tegen. Na de verandering in landgebruik in de eerste helft van de twintigste eeuw waarin de meeste stuifzandgebieden herbebost werden, vertoonden de vegetatieve successiestadia een progressieve ontwikkeling. In dit stadium ontwikkelden zich stuifzandecotopen op het meeste nog overgebleven stuifzand, met alle vormen van karakteristieke successiestadia van kale zandgrond tot bos. De snelheid waarmee deze ontwikkeling plaatsvond hing vooral af van het geomorfologische ontwikkelingsstadium waarin het gebied zich bevond, de omvang ervan en de menselijke activiteit die er plaatsvond. Sinds de jaren zestig heeft zich de vegetatieontwikkeling door de toegenomen stikstofdepositie versneld, waardoor niet alleen stuifzandgebieden verder achteruit gingen, maar ook het kwetsbare evenwicht tussen de verschillende ecotopen teloor ging, evenals typische bewoners zoals de duinpieper en kleine heidevlinder.

Tussen 2001 en 2005 werden experimenten en observaties uitgevoerd in de stuifzandgebied Kootwijkerzand in centraal Nederland om meer te weten te komen over de omvang, intensiteit en rol van wind en spaterosie in een stuifzandecosysteem. Het horizontale sedimenttransport werd gemeten, de verticale accumulatie, het stijgen en dalen van de bodem, de hoeveelheid organisch materiaal in de bovenste bodemlaag, de saltatie-activiteit en de weersomstandigheden. Ook werd getracht het effect van verschillende maatregelen om het erosieproces te reactieveren in te schatten.

Zonder voldoende erosie neemt de vegetatiebedekking snel toe zodat zich een gesloten vegetatiedek ontwikkeld waarin gras de overhand heeft. De rol van erosie in het stuifzand-ecosysteem is daarom van cruciaal belang: erosie vertraagt het tempo van vegetatie ontwikkeling doordat het voor een geregelde depositie van nutriëntarm sediment zorgt. En in periode met extreme erosie activiteit kunnen er door intensieve overstuiving en uitstuiving nieuwe locaties ontstaan waarin de omstandigheden extreem (voedsel)arm zijn (degradatie). Op kale stuif- en dekzanden overheerst winderosie. Hier kan het transport ten gevolge van spatdrift van dezelfde omvang zijn als tijdens een winderosiegebeurtenis van matige omvang, maar spaterosie komt minder vaak voor en duren ook korter dan winderosiegebeurtenissen. Normaal gesproken maken ze minder dan 10 procent uit van het totale sedimenttransport. In de zones met een bodembedekking boven 30 á 40 % daarentegen overheerst spaterosie en spatdrift. Het organisch stofgehalte van het bodemmateriaal in de sedimentvallen is in deze zone even groot als het organisch stofgehalte in de bovengrond in de directe omgeving, waaruit op te maken is dat spaterosie of -drift hier het voornaamste erosie proces is. De vorming van algenkorsten in deze gebieden kan de invloed van spaterosie beperken.

Reactivering van winderosie in begroeide gebieden door overstuiving vereist sediment transport van grote omvang. Onder de huidige omstandigheden is de erosieactiviteit op de meeste stuifzandgronden gewoon te beperkt. Een toename van het gebied dat onderhevig is aan winderosie vooral waar te nemen na extreem hevige stormen. Onder de huidige omstandigheden is deze toename is echter niet voldoende om tegenwicht te bieden aan de regeneratieprocessen tussen twee hevige stormen in. Zonder menselijk ingrijpen zullen veel stuifzandgebieden, met inbegrip van hun zo karakteristieke flora en fauna, verdwijnen. Voor de uitbreiding van het actieve areaal kan men het beste die gebieden selecteren met voldoende dikke laag dekzand of stuifzand met geen of minimale bodemvorming en een beginnende vegetatie ontwikkeling (vaak grenzend aan actieve zones).

In een experiment van acht maanden zijn op het Kootwijkerzand vier technieken waarmee windactiviteit kan worden gereactiveerd of bevorderd (landbouwfrees, stuifzandreiniger, schijveneg en graafmachine) uitgetest op stuifzand dat door Buntgras en algenkorsten is gestabiliseerd. Het effect van die technieken werd gemeten op vijf kernparameters: het stijgen of dalen van het bodemoppervlak als gevolg van sedimentatie dan wel deflatie; horizontaal sedimenttransport; verticale accumulatie; veranderingen in de korrelgrootte van het bodemmateriaal aan het oppervlak ten gevolge van windactiviteit, en het organische stofgehalte in de bovenlaag. De grootste winderosieactiviteit werd gemeten op de proefvelden bewerkt met de stuifzandreiniger en de landbouwfrees. De verandering in korrelgrootte en hoeveelheid organisch materiaal van de toplaag waren in deze velden ook het hoogst. Van de vier uitgeteste technieken zijn de stuifzandreiniger en de landbouwfrees dus aan te bevelen methoden om stuifzand dat door buntgras en algenkorsten is gefixeerd te reactiveren. De schijveneg en de graafmachine kunnen een gebied ook wel reactiveren, maar ze zijn minder effectief.

Procesmanagement houdt zich bezig met de vraag welke maatregelen waar, op welke schaal en met welke regelmaat nodig zijn om het stuifzand ecosysteem te herstellen en duurzaam in stand te houden. De wind speelt een belangrijke rol bij het in stand houden van de extreme omstandigheden waarin alleen die vegetatie en fauna, die karakteristiek voor stuifzanden is, kan overleven. Voor het behoud van de huidige biodiversiteit en de terugkeer van verdwenen soorten in de nog overgebleven stuifzandgebieden dienen eerst de landschapsdifferentiërende processen te worden hersteld. Het hoofddoel van onze nieuwe managementstrategie is voor erosie optimale veldomstandigheden in stand te houden op een wijze en een schaal dat het weer een constante factor in het stuifzandlandschap gaat vormen. De strategie bestaat uit: (1) een lange-termijn managementplan of -strategie voor een periode van 10 tot 15 jaar en (2) een korte-termijn-onderhoudsplan (1 – 3 jaar) om het erosierisico in de geselecteerde deflatiezones optimaal te houden en vastlegging te voorkomen. De lange termijn strategie vindt plaats op landschapsniveau. De eerste stap betreft probleemidentificatie en –formulering van de doelen voor de middellange en lange termijn. Deze doelen kun je vertalen in scenario’s, elk met een aantal maatregelen, waarin het stuifzandgebied is onderverdeeld op grond van de voorkeursfunctie, bijv. recreatie versus natuurontwikkeling. Elke zone wordt vervolgens naar potentieel verder onderverdeeld in stabiele zones waarin zich voornamelijk vegetatie ontwikkelt (regeneratie) en zones die onderhevig zijn aan winderosie (degradatie). De volgende stap bestaat uit een gedetailleerd plan en tijdpad voor de geselecteerde herstelwerken voor elk scenario. Na uitvoering van de herstelmaatregelen zijn twee typen monitoring nodig: (1) een algemeen monitoringsprogramma gericht op algemene ontwikkeling en kwaliteit van het stuifzandgebied (eens per jaar) gebaseerd op de hoofddoelen en (2) een speciaal monitoringsprogramma dat de erosie activiteit in de deflatiezones bijhoudt (eens per 1 tot 3 jaar) om het onderhoudsplan actueel te houden.

Een vergelijking tussen een scenario zonder onderhoud na herstel en een met gepland onderhoud laat zien dat de totale kosten aan planmatig (1-3 jaar) onderhoud van het winderosiepotentieel in de meeste gevallen veel goedkoper is dan zonder waardoor na verloop van tijd, afhankelijk van de snelheid waarmee het zand weer wordt vastgelegd, weer grootschalige herstelmaatregelen nodig zijn. In het planmatig onderhoudsscenario is de mate waarin de interventies het ecosysteem verstoren naar verhouding klein, terwijl de omvang van het oppervlak kaal zand en open pioniervegetatie (buntgras) min of meer gelijk blijft. Procesbeheer met gepland onderhoud resulteert dus in een stabielere stuifzandhabitat waarin de karakteristieke vegetatie en -fauna zich beter in stand kunnen houden.

In: Wind Born(e)Landscapes
(M.J.P.M.. Riksen) Wageningen, 2006, pp. 232.

Curriculum vitae

Michel Riksen (1965) is an agricultural engineer who specialies in soil erosion and soil and water conservation. He was born on 10 September 1965 in Dongen, the Netherlands. After he graduated from secondary school in 1984, he went to Deventer to study tropical agriculture at the Agricultural High School Larenstein. In 1987 he worked in North Sumatra, Indonesia for 8 month to to do his practical work. There he preformed a field experiment on phosphate fixation on an Andosol for his B.Sc. thesis. In 1990 he obtained his B.Sc. in tropical agriculture with specialization tropical soil and water management.

In 1991 he started the M.Sc. course Tropical Land Use, specialization Irrigation and Drainage and Erosion and Soil and Water Conservation, at Wageningen University. In 1993 he went to Jamaica for four months to evaluate a soil conservation project of the 1970s. In 1994 he obtained his M.Sc. at Wageningen University.

From 1994 until 1998 he worked part-time at the field study center/Youth hostel 'De Kleine Haar' in Kring van Dorth, the Netherlands. In this period he carried out some freelance work for Wageningen University. From 1998 until 2001 he was employed by Wageningen University, doing research for a European wind erosion project 'Wind Erosion on European Light Soils (WEELS). In this research project he looked into the social, economical and policy aspects of wind erosion and conservation measures on agricultural land and compared four study sites located in Sweden, England, Germany and the Netherlands.

In 2000 he was invited by the Erosion and Soil & Water conservation (ESW) group of Wageningen University to formulate a PhD research proposal. This project looked into the (positive) role of erosion in landscape development. After the proposal had been approved by the C.T. de Wit Graduate school PE&RC and granted with a scholarship from the Cornelis Lely Foundation, he was offered a doctoral research (AIO) position with the ESW group. Between 2001 and 2005 he conducted the research project concerning the role of erosion in nature development involving a major case study of the role of wind erosion at the largest active drift-sand area of Western Europe, Kootwijkerzand, and two minor cases concerning erosion and sedimentation in the Beerze brook near Boxtel, the Netherlands and gully erosion in a former sandpit, 'De Dikkenberg'; now known as Kwintelooijen located between Rhenen and Veenendaal in the Netherlands.

Within these case studies he worked close together with scientist of various disciplines such as geomorphologists, plant ecologists and soil scientist, but also with the different organizations managing the terrains in these case studies, State Forestry (SBB) and Natuurmonumenten. In 2003 he became a member of the advisory commission for coastal dunes and inland drift sands (*OBN droge duinen en stuifzanden*).

Since January 2006 he works part-time as a Post doc researcher with the ESW Group of Wageningen University. In January 2006 he started a consultancy: "Advies Bureau Dynamisch Landschap".

Author's publications / presentations

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Riksen, M., Spaan, W. and Stroosnijder, L., 2006. The answer is blowing in the wind. How to use wind erosion to restore and maintain the inland drift-sand ecotype? Submitted to Nature conservation.

PE&RC PhD Education Statement

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 22 credits (= 32 ECTS = 22 weeks of activities)

Review of Literature (3 credits)
- Off-site effects of wind erosion on agricultural land in Northwest Europe (2004)

Writing of Project Proposal (6 credits)
- Making use of water and wind erosion processes in landscape development in the Netherlands (2000)

Post-Graduate Courses (3 credits)
- Basic statistics (2001)
- Wind and water erosion: modelling and measurement (2003)

Deficiency, Refresh, Brush-up and General Courses (2 credits)
- Scientific writing (2001)
- Arcview 8 (ArcGIS) (2004)

PhD Discussion Groups (3 credits)
- Sustainable land use and resource management (2001-2005)

PE&RC Annual Meetings, Seminars and Introduction Days (4 credits)
- Nature in an agriculture environment (2001)
- Effects of climate change on nature(2003)
- PE&RC annual meeting: "Biological disasters"(2004)
- Water management, food security and climate- the way forward (2004)

International Symposia, Workshops and Conferences (3 credit)
- European workshop on wind erosion of agricultural land. COST 623 meeting, Thetford, England (2001)
- Soil erosion patterns. COST 623, Münchenberg, Germany (2002)
- The world conference on ecological restoration. Society for ecological restoration international, CSIC, ipeCSIC and CIHEAM, Zaragoza, Spain (2005)

Laboratory Training and Working Visits (1 credit)
- Gully erosion. Laboratory for Experimental Geomorphology, K.U. Leuven, Belgium (2001)

Dit onderzoek werd mede mogelijk gemaakt door de Dr. Ir. Cornelis Lely stichting.