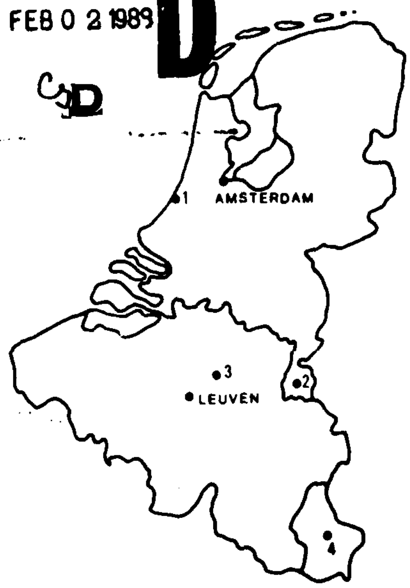
(2)

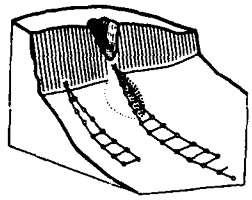
EXCURSION GUIDE

4th. BENELUX COLLOQUIUM

ON

GEOMORPHOLOGICAL PROCESSES AND SOILS





IGU -

COMTAG

April 24 th. - May 2 nd.
1988

University of Amsterdam

University of Leuven

Contents

PREFACE

This Field Guidebook provides background information and material to assist the participants of the excursions, forming part of the Fourth Benelux Colloquium / COMTAG meeting on Geomorphology and Soils held in Amsterdam and Leuven between April 24 th. and May 2 nd. 1988. The material presented is a mixture of previously published and unpublished work. We request that those wishing to reproduce or refer to the material not published elsewhere, contact the authors who in most cases will be able to provide them with more extensive information currently in press.

The Benelux Colloquia on Geomorphological processes are organised at four- yearly intervals by the various Universities in Belgium and The Netherlands who are actively pursu ing research in the general field of process geomorphology. The previous three meetings were held in Leuven, Utrecht and Liége. The colloquium is being organised by the Laboratoy of Experimental Geomorphology, Catholic University of Leuven and the Laboratory of Physical Geography and Soil Sciences , University of Amsterdam. It is being sponsored by the European Research Office of the U.S. Army. Assistance has also been received from the Dune Drinking Water Authority of The Hague, the Experimental farm "Wijnandsrade"& the Ministery of Housing, Physical Planning and Environment (VROM), The Netherlands.

Many people have contributed to the production of this volume. Special thanks are due to the authors whose names appear under the list of contributors and to various editors of different parts of this guide. Also we thanks Ms. C.G. Keijzer, who prepared the manuscript, Mr. L. Huijsen for the reproduction and Ms. M. Vlaanderen who managed the production of this Guide.

Dr. A.C. Imeson

Chairman of the organising committee

INTRODUCTION

The locations of the four excursions which form part of the Fourth Benelux Colloquium/COMTAG meeting are shown on the title page.

The first excursion on the afternoon of Thursday 26th April is to the area of the coastal dunes north of The Hague. The leader of the excursion will be P.D.Jungerius. Before visiting the field sites we will be guests of the Dunewater Company of The Hague.

The second excursion ~~will~~ begin in Amsterdam and end in Leuven. The sites ~~to be~~ visited are in the loess region of South Limbourg where various teams are undertaking research. During the excursion, led by F.J.P.M.Kwaad, we will visit the experimental farm at Wijnandsrade.

The excursion on the afternoon of Saturday 30th April is to the research sites of the University of Leuven, near Huldenburg in Brabant. The excursion leader will be J.de Ploey.

On Sunday May 1st the excursion will lead to the sites in Luxembourg where geomorphological processes are being studied in a mixed oak-beech forest. The excursion leader is E.Cammeraat.

EXCURSION GUIDE FOURTH BENELUX COLLOQUIUM

Part 1: Dutch Coastal Dunes

I. THE DUTCH COASTAL DUNES
Some geological, geomorphological and hydrological aspects and their international scientific importance

1. The north-western European context

The 150 square miles of Young Dunes to be found in the Netherlands are part of a long and mainly narrow range of dunes stretching from Caials (northern France) to the northern tip of Denmark. Within this range, the Dutch dune area is exceptional in that it covers a relatively large surface, its biological diversity (for example, the great richnes of species), as well as its intact condition.

The Young Dunes began to develop between the eleventh and twelfth century A.D. and have been largely exempted from culture-technical intervention until about 1850. Because of sand drift the area was regarded as unprofitable and even hostile well into the seventeenth century, although it was still used as a hunting ground. Ever since, human intervention has increased. At first, the dune valleys were cultivated for crops, but this trend did not really take off, usually lasting for only a short period.

From the second half of the nineteenth century human activity in the dune area increased:
- large areas were excavated and the sand was used to raise the low polders in the hinterland so that it could be used for urban development;
- the small coastal villages in the dunes grew into considerable sea-side resorts;
- urban expansion swallowed up a large part of the dunes for new housing;
- industry settled around the Rhine delta and the newly constructed North-Sea Canal;
- the drinking-water supply for western Holland was drawn from the dunes and caused large areas to dry out;
- finally, the dunes served as a protection from the sea. Sand dykes have been relocated to protect the hinterland and a lot of effort has been put into fixation by dune plantation.

The list of human intervention is long; nevertheless, the Dutch dune area is very much intact and is, generally speaking, still quite varied compared with those of the surrounding countries. The narrow dune strip of northern France and Belgium is very much affected by building, excavation and road construction. Dune areas with a lime deficiency on the German and Danish Wadden Islands and in Jutland are as undamaged as those on the Dutch Wadden Islands. However, these areas are generally much less varied than the Dutch dunes, even in their unaffected natural state.

2. Some important macro-gradients in the Dutch dunes

Two important landscape components of the Dutch dunes, the atmospheric and geological states, are characterised by great variation. Table 1 gives a rough zoning of the Dutch coastal area into districts on the basis of a number of factors concerning climatic variation along the coast. Three districts may be distinguished, each with a more or less specific characteristic.

One of the geological factors, the lime content of the subsoil, shows much more dramatic variations. Table 2 gives the primary lime content of 16 districts along the Dutch coast.

Table 1. Survey of the values of a number of climatic factors in three areas along the Dutch coast (+ maximum for the Dutch coastal area; - minimum; o intermediate)

Climatic factors	Zeeuws Vlaanderen Goeree	Voorne-Camperduin	Petten-Schier-monnikoog
wind velocity (m/s)	6.1 (o)	6.0 (-)	6.5 (+)
relative humidity of air (%)	69 (o)	68 (-)	73 (+)
evaporation Eo (mm/y)	760 (o)	750 (-)	780 (+)
absolute humidity of air (mbar)	14.9 (+)	14.7 (o)	14.7 (-)
average temperat. (degrees Celcius)	10 (+)	9.5 (o)	9 (-)
precipitation (mm/y)	675-725 (-)	725-800 (+)	700-740 (o)
summer days per year	10 (+)	10 (o)	<5 (-)
days of frost per year	<40 (-)	50-60 (+)	40-50 (o)

Table 2. Survey of the primary lime content of dune sand from 16 districts in the Dutch dunes

District	Primary lime content (%)
Schiermonnikoog	0.5 - 2
Ameland	0.2 - 0.8
Terschelling	0.1 - 0.8
Vlieland	0.2 - 0.5
Texel	0.5 - 2
Den Helder - Petten	0.1 - 0.4
Camperduin - Bergen a.Zee	0.2 - 0.6
Bergen a.Zee - Egmond a.Zee	0.9 - 2.3
Egmond a.Zee - IJmuiden	2.7 - 4
IJmuiden - Noorwijk a.Zee	2 - 10
Noordwijk a.Zee - Scheveningen	2.9 - 4.3
Scheveningen - Hoek v.Holland	2 - 7
Voorne	4 - 5
Goeree	1.7 - 3.5
Schouwen	2 - 4
Walcheren	0.4 - 1.2

Thus climate and geology are responsible for great variation in the original situation. Within this situation, two factors are effective in the process of sophistication of the landscape: soil forming and human activity.

Soil forming often results in a very clear gradient starting at the outer dunes and moving inland. The outer dunes render almost pure original sea sand, whereas the inner dunes have been subjected to soil forming for centuries, showing lixiviation and humus accumulation. The areas that run more or less parallel to the coast have been subjected to different developments throughout their history. For instance, the primary lime content of the subsoil of the inner-dune area is often considerably lower than in the rest of the dune areas.

Long-term human intervention has become a geological and geomorphological factor in the structuring of the landscape, particularly in the vicinity of fisherman's villages and farming hamlets. Thus a particular type of landscape has developed that is characterised by, for instance, its specific vegetation and its summer birds. H.Doing calls this type of landscape "sea-village-scapes".

Human activities have also led to loss of natural qualities, particularly as a result of water catchment and infiltration, road construction, cultivation and the more recent development of recreation. From the middle of the nineteenth century the dunes became important for the water supply of western Holland. Large areas are now used for water catchment. The ground-water level came down dramatically and caused one of the richest environments, the wet dune valleys, to deteriorate or to disappear completely. From the middle of the present century, water from outside the dune area (the Rhine) has been fed into the dunes for water catchment and has caused the ground-water level to rise again and restore the wet dune valleys. However, this has not led to the return of the original vegetation because the infiltration water has carried a lot of nutrients and other materials which have created a eutrophic environment.

Although water catchment has caused some negative developments, it has also spared the dunes from many other human activities. More serious damage to the dunes caused by, for example, urbanisation and industrialisation, has been restricted to a small area and the complete loss of dunes has been confined to just a few places: the urban development of The Hague, the construction of Europoort and the North-Sea Canal with the Hoogovens and IJmuiden, and the levelling of the inner dunes for bulb and limestone industries.

The diversity of the Dutch coastal dunes is due to the variation in the four factors of climate, geology, soil forming and human interference as well as the occurrence of three quite different types of dunes along the Dutch coast (see the discussion on main types of Young Dunes below). This often means that dune areas, or small sections thereof, show characteristics that are not found elsewhere, making them very rare indeed.

The following paragraphs will give a short account of the variation discussed here. But first let us turn briefly to the characteristics of the Old Dunes.

3. The Old Dunes

The dunes that were present in the Netherlands before the development of the Young Dunes (12th-13th century A.D.) are known as the Old Dunes. During the Holocene, the sea level rose by about 45 metres because of an increasingly warmer climate. The North-Sea basin filled up with water and sand banks and dunes were formed at the boundary between land and water.

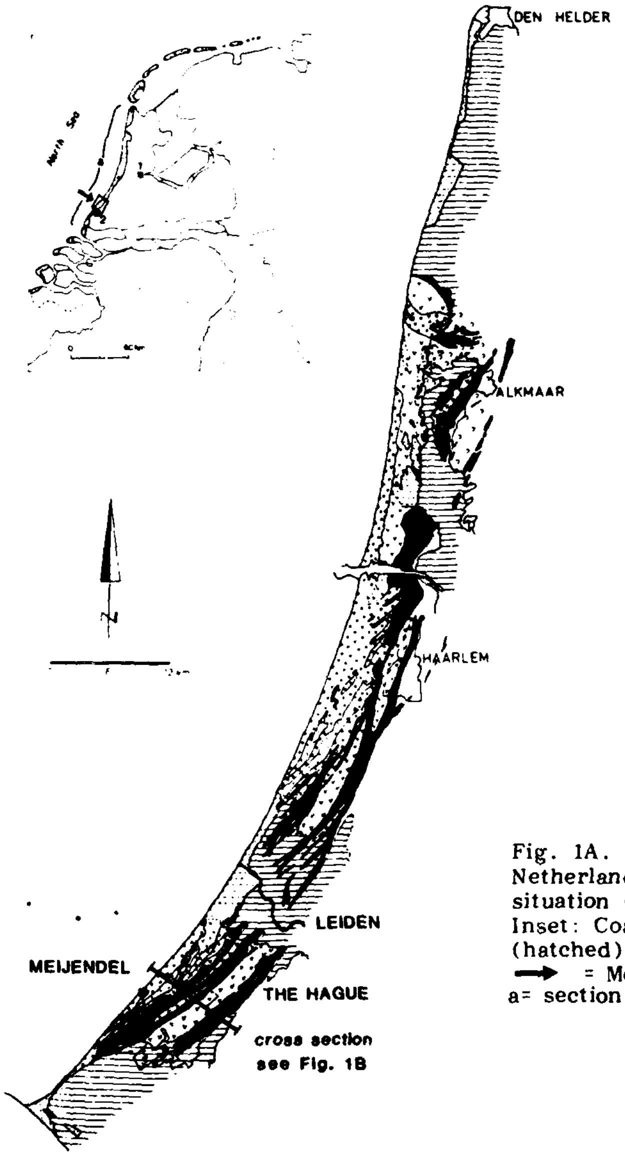


Fig. 1A. Mainland dunes of the western Netherlands, geological and topographical situation (after Bakker et al.,1979). Inset: Coastal dunes of the Netherlands (hatched). 1= Amsterdam, 2= The Hague, ➞ = Meijendel dunes. a= section enlarged.

LEGEND	
YOUNG DUNES	DUNKIRK DEPOSITS ON PLEISTOCENE
YOUNG BEACH	DUNKIRK DEPOSITS, LOCALLY HOLOCENE PEAT
YOUNG DUNES AND BEACHES ON OLD DUNES AND BEACHES	YOUNG DUNES AND BEACHES ON DUNKIRK (LOCALLY PEAT)
COASTAL BARRIERS AND OLD DUNES	PEAT IN THROUGHS BETWEEN COASTAL BARRIERS
OTHER OLD DUNE DEPOSITS	IBID, COVERED WITH YOUNG DUNES AND BEACHES
PLEISTOCENE OUTCROP	ARTIFICIAL TERRAIN

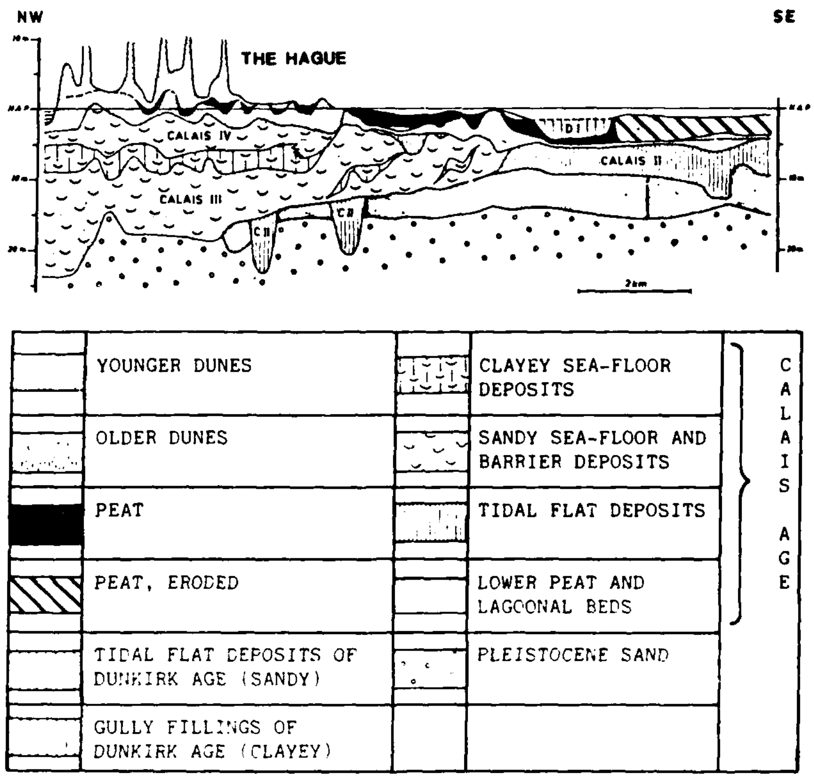


Figure 1B

Fig. 1B. Cross-section of the coastal barrier complex near The Hague (from Jelgersma et al., 1970)

For a long time dune accumulation on the sand banks must have developed at a very slow pace because these small dunes would have been flooded constantly due to the rising sea level. When the rising of the sea level began to slow down the dunes were able to establish themselves and a seaward movement of the coastline followed. The sandbanks furthest inland that were formed in 2800-2100 B.C. have been found in North- and South-Holland. A second range to the west of these was formed between 1200-1500 B.C. Younger dunes to the west of this range have been swept away or reformed as Young Dunes (fig. 1A and 1B).

Sand banks and their dune relief (Old Dunes) are alternated with low, flat slacks - former beach plains - which have often become peaty. Sand banks including old dune deposition are now rarely found in the south-west of the Netherlands, as they have been washed away by the sea. The Wadden

Islands still show old dune depositions. Part of the Old Dune landscape (marine depositions and Old Dunes) has been covered by Young Dunes since 1100-1200 A.D. The remaining part has been excavated or cultivated for the bulb industry. This may indicate the value of the unaffected areas, both for their original relief and for rich vegetation, owing to afforestation that has its chief national distribution in these areas (north of The Hague, Zuid-Kennemerland and around Bergen).

4. Main types of Young Dunes

Three characteristic coastal types, each with a specific dune accumulation process, may be distinguished along the Dutch coast:

A. estuary coast
B. mainland coast
C. Wadden coast

The map presented in fig. 2 shows the position of these coastal types. The former Wadden coast of North-Holland North is shown as a separate area.

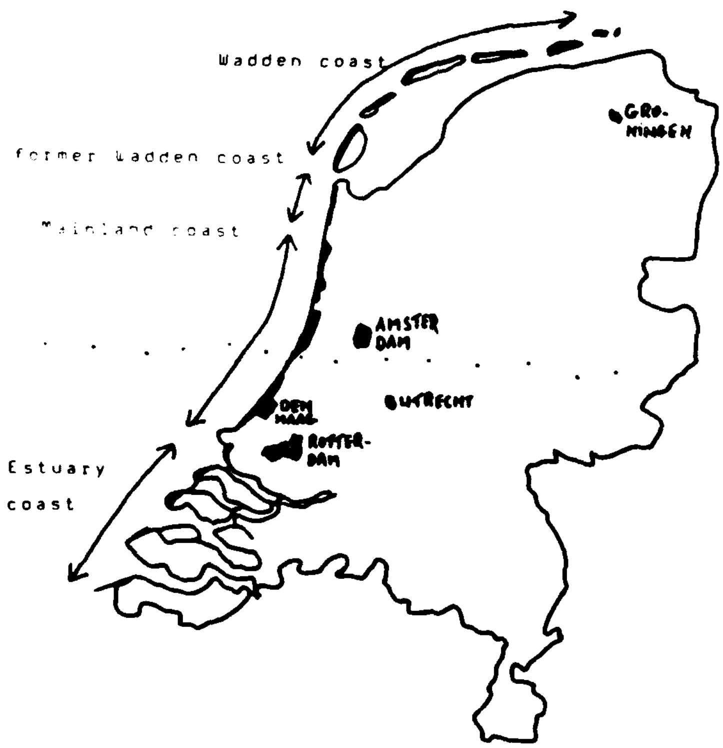


Fig. 2. Different coastal types along the Dutch coast

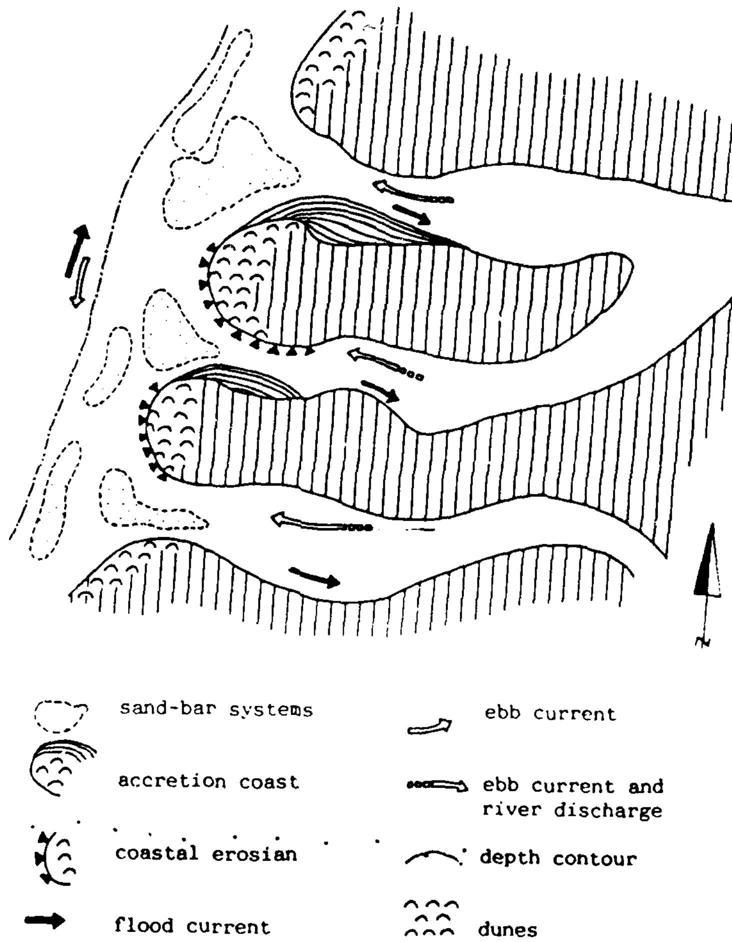


Fig. 3. Coastal forms and processes of an estuarian coast

A. <u>The estuary coast of the islands of Zeeland and South-Holland</u>

A number of islands and peninsulae, separated by wide inlets, may be found in the (former) estuaries of the rivers Rhine, Maas and Schelde. The inlets are wedge-shaped because of the strong tidal current. Elaborate systems of sand banks and tidal areas in the estuaries are typical (see fig. 3).

The configuration of the banks and gullies changes constantly. In some places where islands are eroded they wear away and cave in. In other places growing flats enlarge the islands. As a result the coastal area is very dynamic, with rapid coastal deteriora*ion and growth.

After the disastrous storm of 1953 (Zeeland) it was decided to close most of the inlets. This has had an enormous effect on the coastal processes. The typical estuarian character has disappeared completely and mainland characteristics have been fostered.

A brief description of the dunes

The turbulent historical development of the coast has given it a varied geomorphological composition. Although erosion has dominated, coastal growth has locally led to the formation of beach plains which are sometimes enclosed, as in northern Walcheren, Noord-Schouwen, Goeree, and a beautiful example is to be found on Voorne. The latter dune area also has two dune lakes. Goeree has a young and beautiful area of nearly closed-in beach plains, flowing into mud flats. Schouwen has blowout dune systems. The relatively old transitional areas with low relief, the so-called "kopjes"-dunes (see fig. 4), are specific to the Netherlands (the intermediate dunes of Schouwen, the western, middle and eastern dunes of Goeree and the Heveringen on Voorne). The oldest sections of these dunes form the boundary between Old and Young Dunes. They are relatively decalcified and uneven. The best developed examples are to be found around Ouddorp and Goeree (Westduinen). Some coastal areas only have a single but occasionally high range of outer dunes (up to 45 metres in southern Walcheren) caused by continuous erosion. Coastal erosion is a current problem, as can be concluded from the deterioration and mobility of the outer dunes. Large active sand hollows are only found on Schouwen. Vegetation, morphology and lime content of the subsoil vary significantly per area because of age difference and different historical development. The balance between accretion and erosion changes from south to north with a maximum loss on Walcheren and a maximum growth on Voorne.

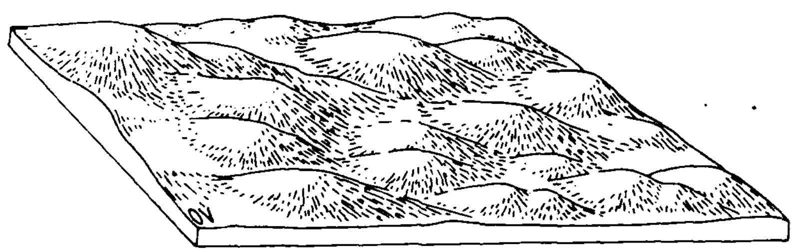


Fig. 4. The so-called "kopjes"-dunes

The complex variation in environmental circumstances in the dunes is very clearly reflected in the vegetation. Some species occur which are extremely rare elsewhere in the Dutch dunes or not to be found at all. The vegetation of the wet dune valleys is of particular interest, although it must be noted that large areas are subjected to considerable disturbance of the water balance. Some parts of Schouwen and Goeree have arid areas, without wet valleys, and places where water is recharged from outside the dunes for water supply. However, unaffected areas are found mainly on Voorne and in some parts of Schouwen and Goeree and are well endowed with wet dune valleys.

B. The mainland coast of North- and South-Holland

This part of the coast forms a continuous and almost straight coastline. The erosion/sedimentation dynamics are basically in balance. Changes in the coastline and the foot of the dunes have therefore been relatively insignificant over the past century. Erosive parts may be found in the north (Egmond-Den Helder) and in the south (south-east of The Hague).

The so-called lime boundary at the level of Bergen is an important phenomenon on the Dutch mainland coast (see Table 2). Lime deficiency occurs north of the Bergen boundary, whereas a high lime content is found to the south. It should further be mentioned that in this area a large range of Old Dunes is still present behind the Young Dunes although they have often been excavated. Two sub-areas may be distinguished: Hook of Holland-Bergen and Bergen-Petten.

Calcareous dunes between the Hook of Holland and Bergen

With the exception of some small dune areas near the Hook of Holland, this area is characterised by dune ranges and valleys that run parallel to the coast. Almost the entire area has a sand-drift morphology with, for example, secondary barchans ("loopduinen"; often on the inner dune range, see fig. 5), and the comb dune ranges or parabolae (see fig. 6), all characterised by compound blowout valleys and "kopjes" areas. The zone directly bordering on the coast (outer dunes) often consists of macro-parabolae and single blowout valleys.

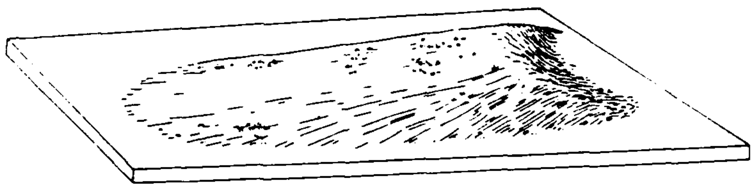


Fig. 5. Secondary barchans

Broad dune areas alternate with narrow dune areas. Narrow dune areas may be found in places where there were formerly tidal inlets, for example in the estuary of the Old Rhine (Katwijk) and the IJ-estuary (IJmuiden). The broad dune areas each have a specific morphological and vegetational zoning. The Young Dunes often have covered the Old Dunes and slacks. Therefore, the inner dune range shows contact zones. Dune valleys of the Young Dunes are sometimes eroded down to (or very near) the surface of the Old Dunes. The contact dunes between the Old and the Young Dunes, such as those near Monster and De Zilk, are of special interest.

The coastline and the foot of the dunes in this coastal area have remained fairly stable over the centuries, with the exception of the part to the south of The Hague. Cliff forming in the outer dunes is rare and is maintained only briefly as a result of human intervention and other factors. Sand drift - necessary in preventing the formation of biotopes related to the early stages of the secondary succession - is now sometimes allowed on a limited scale, but is generally rare.

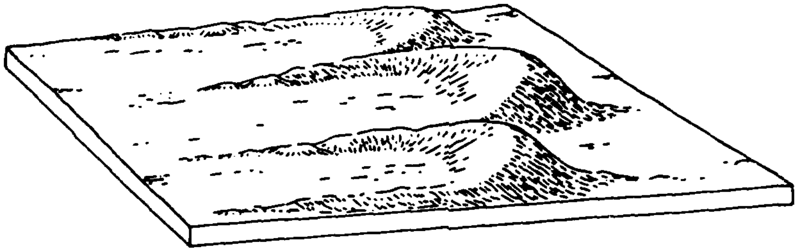


Fig. 6. Comb dunes

The dunes of this area have been affected by disruption of the ground-water system more than any other Dutch dune area. Nearly all dune areas have been affected by water extraction for the water supply. Only in areas directly behind the outer dune range between Castricum and Egmond aan Zee and in the Kennemerduinen do we find some remaining dune valleys with only a small drop in the water table. This is where the very last near-natural wet-valley environments are still to be found. Although the ground-water table has risen in and around the infiltration areas and has come within the reach of the vegetation, the ground-water condition in these areas is even more seriously damaged. Both the soil and the ground-water are polluted by materials in the infiltration water. Locally, a lens of precipitation has formed on top of the infiltrated water, for instance at the level of Vogelenzang, and has an obvious effect on the vegetation. Fluctuation routes and velocity of the ground-water are usually very different from the natural situation.

Nevertheless, the broad dune areas are still particularly valuable. They are characterised by a specific zoning and a rich mosaic of communities, especially on the arid dune slopes. The so-called Dewberry biotopes of the calcareous comb dune zones and the Burnet-Rose slopes of the inner dune range are unique in the Netherlands, as are the rich brushwoods.

Dunes with a lime deficiency between Bergen and Petten

The lime boundary at Bergen is one of the most interesting parts of this area. The subsoil to the north of Bergen has a general lime deficiency. To the south of Bergen we find a higher lime content. The area north of the lime boundary reveals characteristics of a long period of heavy erosion. The lack of minerals and the low fixation quality of the vegetation are reflected in the shape of the dunes. A large part consists of secondary barchans and related beach plains. The high dune ranges to the east including the inner dune range (50 metres and higher) have brought each other to a halt. This is largely due to human interference: the inner range of dunes was fixed and was from then on immobile. Cliff forming to the west indicates a mobile range of outer dunes and coastal erosion. This dune area has also been subjected to a considerable drop in the ground-water table, causing nearly all wet valleys to dry out. The strongly increased evaporation caused by large-scale afforestation (coniferous) is also an important factor in the process of drying out.

The typical vegetation of wet dune valleys has almost entirely disappeared from the area between Hook of Holland and Petten. But the vegetation of the dry dunes currently has a high quality. It shows subtle landscape zoning. Some types of landscape on the main land of North- and South-Holland are unique in the world.

The falling water table, resulting in drying out of the valleys, is mainly caused by water catchment. Regeneration of the dry valleys is therefore not difficult to achieve. However, regeneration is more difficult in the infiltration areas. Parts of the mainland dunes have been lost as nature reserves, such as what is now Europoort (De Beer), the land on which The Hague expanded, and IJmuiden with its Hoogovens (steel industry) and the North-Sea Canal.

C. The Wadden coast including the North-Sea Islands

This is the last typical range of the Dutch coastal dunes. It shows some similarity to the estuarial coast. However, the Wadden Islands are parallel to the main coastline, in contrast to the estuarial islands, and are separated by inlets that connect the North Sea with the Waddenzee. This configuration is possibly even more dynamic and shows spectacular coastline developments to such an extent that the islands appear to be mobile. Here too, the system of sand banks or "outer delta" outside the inlets has an important role. These sandbank systems protect the islands from waves and coastal drifts at the inlets (fig. 7). In addition, they play a part in the regular process of erosion and growth of the islands. The gullies and tidal flats of the sandbank systems in the inlet move eastward with the main stream. This results in periodical "running ashore" of tidal flats on the west tip of the neighbouring island. Occasionally sand accumulates on the east tips of the islands.

The shifting of gullies can also result in considerable losses in a short timespan, to such an extent that islands can lose hundreds of metres of land within a single century. Occasionally the North Sea breaks through to the Waddenzee.

The Wadden Islands: Texel to Rottum

The Dutch Wadden Islands are related to the German and Danish Wadden Islands in their geomorphological and vegetational aspects. Within this dune area with a lime deficiency, the Dutch and East-Frisian islands can be regarded as relatively high in lime content and are characterised by sea-buckthorn thickets and dune grassland. The Wadden Islands of Schleswig-Holstein and Denmark have hardly any lime at all in the subsoil and therefore have a mainly ericaceous vegetation in the older parts.

The dunes on the Dutch Wadden Islands have experienced a dynamic development with an ever moving coastline and dramatic erosion and accretion. Related to this is the fact that young dunes keep appearing on the beach plains and make up for lost ground. An extreme case is Schiermonnikoog, where half the island dates from the last century. The most striking changes occur at the far tips of the islands. It is there that most of the enclosed beach plains are to be found; on the east tips they are only partially enclosed. The latter often reveal unusual gradients towards mud flats.

The dune structure of some islands betrays their composition of smaller cores which are often linked by sand-drift dykes. These linkages are recognisable by the presence of enclosed beach plains (Texel, Ameland).

The slightly older dune areas consist mainly of eroded dunes. Parabolic shapes and blowout valleys dominate. Vlieland and Terschelling, both characterised by a low mineral content, have some fine examples of secondary barchans.

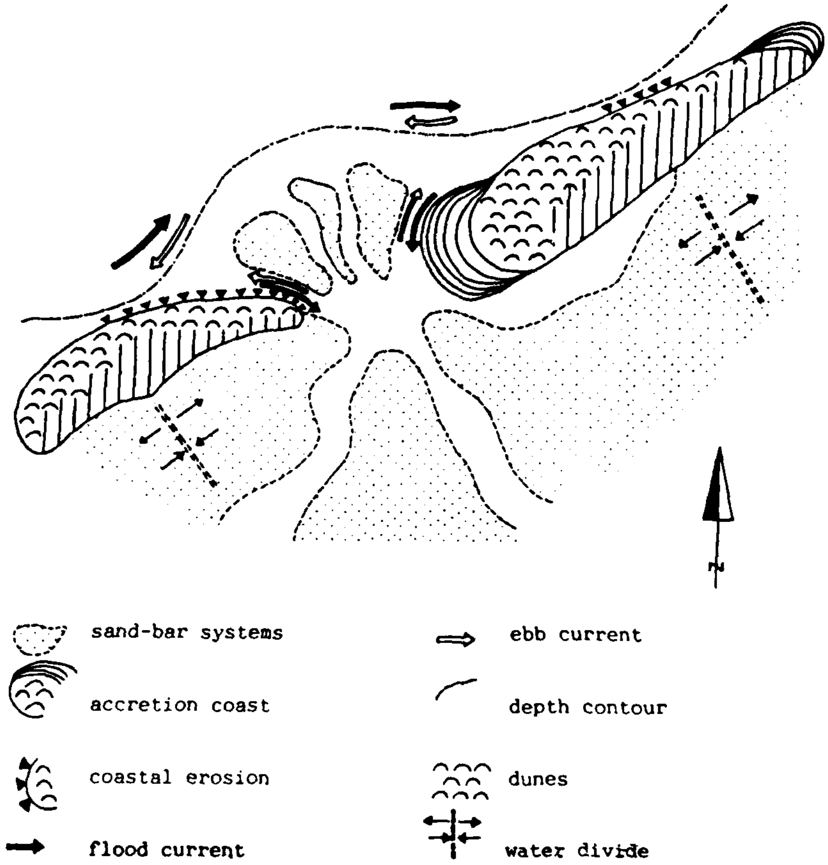


Fig. 7. Coastal forms and processes of a "Wadden coast"

The forming of beach dunes and new slacks can still be seen on all of the islands (fig. 8). Sand drift in fixed dunes causes the forming of new valleys, particularly on Vlieland, Terschelling and Schiermonnikoog. Coastal erosion and related dune-cliff forming or rolling foredunes affect large parts of the coast of Texel and Vlieland and parts of Terschelling en Ameland.

Each island has *its own specific landscape characteristics*. This is related both to the factors mentioned in Table 2 and also to the size and stability of the islands (for instance, the Pleistocene core of Texel) and its former agricultural usage. (On Terschelling and Vlieland the grazing intensity was high due to the lack of suitable pasture). Due to these factors the vegetational variation between the islands is *striking*. This part of the Dutch dunes has the least affected ground-water situation. Local fall in the ground-water table has occurred, but hardly ever caused wet dune valleys to dry out.

Each island shows internal landscape zoning as a result of recent accretion (with a calcareous vegetation), sand drift (open vegetation) or long-term stability (closed vegetation). Through the salt marshes, the islands are inextricably linked to another very important nature reserve, the Waddenzee.

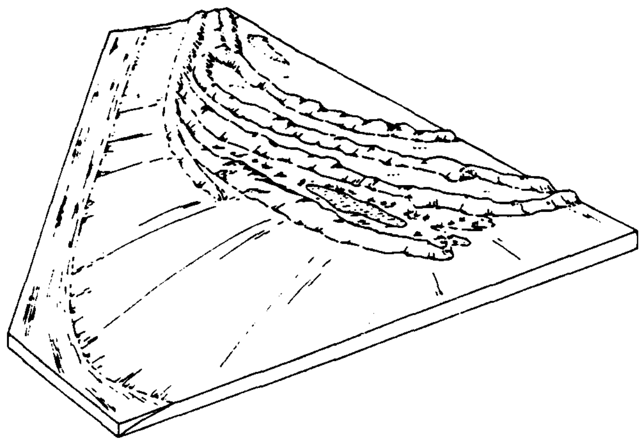


Fig. 8. Primary dune ridges and slacks

The former Wadden coast between Petten and Den Helder

For a long time this area formed a mudflat with the islands 't Oghe (Callantsoog) and Huisduinen at its core. When the inlets had filled up with sand these cores were linked by sand or sand-drift dykes, ca. 1600. Due mainly to human activity *new dune ranges developed to the west of* these dykes. West of the Zijperzeedijk, between Petten and Callantsoog, a fine example of enclosed beach plains has developed as well as large dune lakes (Zwanenwater). The dunes between Groote Keeten and Huisduinen consist of no more than a (double) range of coastal dunes. Most of the coast is being eroded, which can be seen from the active dune cliff and a coastal dune range "rolling" inland.

At present, this coastal area is similar to a closed mainland dune range as described above. The ground-water table in this area has not been affected much. Large areas have wet dune valleys and the Zwanenwater has two large dune lakes. Recently, the dunes of Den Helder began to reestablish their dampness, when water catchment activities had been stopped, which is a unique event.

5. Conclusions

We may conclude that the Dutch dunes cover a wide area and have a wide variety of gradients of which the natural ecosystems have been well preserved and better than other European coastal dune areas. Those areas in which the morphological and vegetational qualities have degenerated owing to human activity are essential to a proper understanding of the larger ecosystem and have their own potential biological qualities.

It would not be justifiable to point out specific areas for preservation. The entire Dutch dune area should be regarded as a single unit and should be preserved as such. In this light, human interventions in soil and relief, such as cutting trenches and excavation, are even more damaging than its disruption of the vegetation.

References

Bakker, T.W.M., J.A.Klijn and F.J.van Zadelhoff, 1979. Duinen en duinvalleien: een landschapsecologische studie van het Nederlands duingebied. Wageningen: Pudoc, 201 pp.

Doing, H. (forthcoming). Landschapsoecologie van de Nederlandse kust. Leiden: Stichting Duinbehoud.

II. THE MEIJENDEL DUNES NEAR THE HAGUE

a) Area and landscape

Meijendel is a dry coastal dune area of about 2000 ha (3,5 x 6 km) in size, stretching along the North Sea near the city of The Hague (see fig. 9). It forms part of the country's last major nature conservation areas, the dunes, and has a high diversity of landscapes and associated biocoenoses.

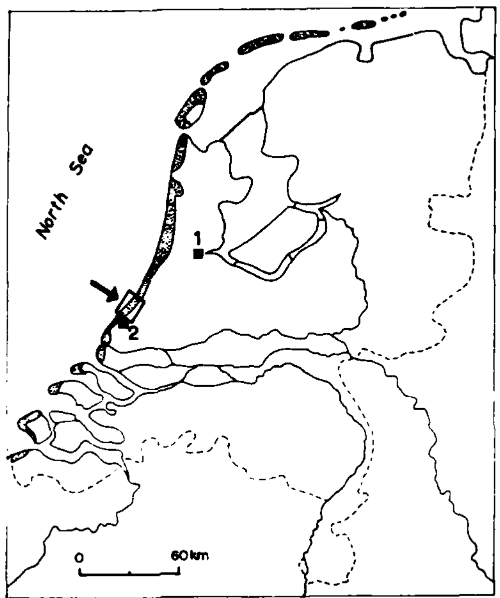


Fig. 9. Coastal dunes in The Netherlands (hatched) and location of Meijendel area (1: Amsterdam; 2: The Hague)

The dunes consist of calcareous (< 3% free $CaCO_3$) marine sands, deposited since about 1000 A.D. over an older landscape which is referred to as the "Old Dunes", a coastal barrier complex. The latter still crop out to the east of Meijendel.

Geomorphologically, the area consists of mainly secondary dune forms including: regularly ridged foredunes, parabolic dunes alternating with (irregular) depressions, extensive flats with abandoned 19th-century farmlands and a broad, more or less transverse inner dune ridge with main crest perpendicular to the prevailing winds and with a steep leeward inner dune face. These main landscape types have developed almost parallel to the coastline (see map).

This is a regression coast at present (e.g. Doing, 1974; Jelgersma et al., 1970) with a steep erosion dune cliff. However, because of stabilising techniques, actual retreat of the coast is prevented. Parabolic dunes consist of a more or less arcuate sand body with trailing "arms" aligned in the direction of the prevailing onshore westerly winds.

They often have short steep (> 15°) slopes and hillsides which are alternatingly exposed in northern/southern or landward/seaward directions. Their average height above sea level is 10-20 m. Most depressions lie at 2-8 m. Highest elevations are at the northern inner dunes (25-35 m; valley bottoms at 5-10 m). In the southern part, inner dunes are low (2-10 m) and the "Old Dune" landscape is at or near the surface. Somewhat decalcified and humose topsoils (0-10 cm) mostly occur in land inward dunes and at sheltered positions. Deep (0-50 cm) decalcified sands were found at abandoned farm lands. Highest pH values (8-8.5) were recorded in fore-dunes, lowest (3-4) in old fields. Locally, wet dune valleys are present. They are fed by precipitation and artificial groundwater recharge.

Plant communities of the xerosere prevail: sparse pioneer vegetation (Ammophila, Carex, Elymus) (Ammophilion) is found in wind-active parts; "grassland" (with Festuca's, Rubus and much moss and lichen) (Galio-Koelerion) and dwarfshrubland (Salix, Ligustrum, Hippophaë) (Berberidion) is common on the more stablised sites; open short vegetation (Cornicularia, Campylopus, Didranum, Corynephorus, Cladonia's) (Galio-Koelerion) of stable sands, decalcified at the top, are locally common in the inner dune landscapes.

Taller shrubland (Crataegus) (Berberidion) mostly covers sheltered position of northern/landward slopes and valleys. Summergreen forest (Betula, Quercus Populus) (Ulmion, Quercion) is found in inner dunes and on flats. Afforestation with Pinus-trees has occurred locally. Planting of young trees and shrubs is mainly restricted to Meijendel Valley, a centre of intensive recreation. The names of the phytosociological syntaxa (after Westhoff and den Held, 1975) are given in brackets.

A vegetation map (1:5000) of the entire area was made earlier by Boerboom (1960).

b) Utilisation, management and research

The Meijendel dunes are an example of the integration of environmental conservation and civil engineering in one and the same area: they are used as a catchment area for public drinkwater supply for the city of The Hague and environs (over 1 million inhabitants) by the Dune Water Works of the city. At the same time, this factory is also responsible for nature conservation and management and for the supporting applied ecological research in the area.

Because of their proximity to the country's most densely populated industrial parts (Rotterdam, The Hague, Leiden), the dunes fulfill a number of functions for society. Besides drinkwater catchment and nature conservation, recreation and coastal defence are the main present uses. Sometimes these functions are conflicting, sometimes they support one another. Because Meijendel is too small to separate functions, they often have to be integrated in one and the same area. Public drinkwater supply systems for the city of The Hague have been developed since 1874. Since 1955, the system applied is (i) artificial groundwater recharge with purified river water in open surface reservoirs and abstraction with undeep recovery means (wells, pipelines), (ii) slow sand filtration in the dunes, and (iii) recovery and post-treatment before distribution into the city. In 1982 about 47 million m^3 of drinking water was produced in this way. The "wet surface" (artificial dune lakes) of Meijendel is about 10 ha (5% of total).

Because of coastal defence, dunes are routinely stabilised. This activity drastically reduces the natural geomorphic dynamics of the dunes.

The proximity of large cities leads to a high demand for recreation. More than 1 million visitors per year come to the area.

Land ecological research in recent years has yielded much information about physic and biologic characteristics of the dune reserve. This information is being used as a basis for management in an integrated manner, that is a form of management which takes into account different kinds of utilisation in one and the same area. A dynamic conservation practice is essential. The management aims at the conservation of ecological processes. It is a primary principle that management should work within the framework of natural patterns and cycles, rather than change them. To support this kind of management the Landscape en Environmental Research Group of the University of Amsterdam carries out an applied research programme in the area. This programme consists of process-monitoring, computer-modelling of processes and land ecological mapping.

During the excursion you will see some of this work. The projects are being carried out in co-operation with the Department of Dune Management of the Water Work Company, which is responsible for the management.

III. EXCURSION SITES IN MEIJENDEL

A LANDSCAPE MAP FOR COASTAL DUNE MANAGEMENT - MEIJENDEL, THE NETHERLANDS

ABSTRACT

A 2000 ha coastal dune area near a densely populated part of western Holland serves multiple functions: nature conservation, water catchment, recreation and coastal defence. The area has been mapped at scale 1:5000 to aid in the development of management policies taking all four uses into account. The final landscape map and legend are based primarily on terrain form and associated vegetation structure; floristic composition is also indicated. The importance and limitations of the map for management planning are discussed.

Fig. 10. Airphoto of part of the Meijendel dunes with contours of the final landscape map.

From north to south, the following landscape types can be seen: extensive dune valleys mainly with tall Crataegus shrubland (legend unit 27), infiltration lake (33) and recovery systems (32); parabolic dunes with sparsely vegetated southern slopes (7) and northern slopes carrying more dense and taller vegetation (8, 9, 10); former farmlands, with dune forest of birch, poplar and hawthorn (30).
(photo: E.A.J.Wanders, from 1:5000 true colour photo, 1982).

BLOWOUTS

For more than a century, dune management in the Netherlands has been concerned with fixation of wind erosion surfaces. Gradually, the regulations have been slackened somewhat and sand is allowed to move more freely. It saves the costs of expensive stabilisation measures and restores the dynamic character of the dune landscape.

To preclude undesirable developments, it is necessary to understand the wind erosion processes. Fpr this purpose a monitoring programme was started in 1983, in a part of Meijendel near The Hague. All stabilising measures in this area were suspended for an indefinite period. The terrain is closed to the public. The size of the area is about 40 ha.

Wind erosion is most apparent in blowouts, shallow depressions of round or elongated outline, which are particularly sensitive to wind action because they are free of vegetation. The orientation of the blowouts shows that they are modelled mainly by the prevailing SW winds. However, the strongest winds along the coast are mostly from the NW. Irrespective of direction, wind speeds between 9 and 10 m/s are most effective (Jungerius et al., 1981). It appears that blowouts are adjusted to an aerodynamic system operative when wind speeds are within this range. With stronger winds, deep blowouts show a tendency to be filled in. This is presumably due to increased turbulence which prevents transport of sand in the main direction of the wind.

Up to the winter of 1987, there were some more than 30 blowouts. Each blowout is marked with 5 erosion pins (fig. 11). Surface lowering or raising, and growth or decrease in size of the blowouts is measured relative to these erosion pins. Changes are measured twice each year.

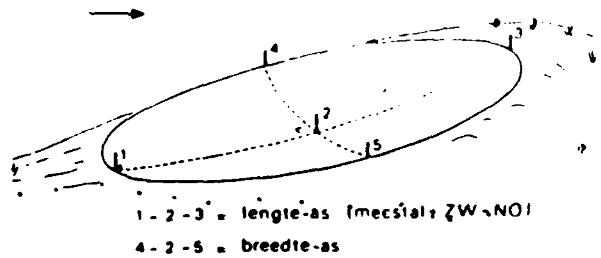


Fig. 11. The position of the erosion pins in the deflation part of the blowout. The arrow indicates the direction of the prevailing wind (Jungerius and van der Meulen,1985)

Some of the results so far:

- Blowouts have a preferred length and width (fig. 12). Apparently nature itself provides a number of mechanisms that impede the growth of blowouts beyond a certain size.
- From November 1983 to December 1986 the average length decreased from 26.8 to 25 m (n = 32). Decrease was measured mostly at the leeward side, where marram grass captured sand blown from the blowout. In spite of the decreasing length, most blowouts grew in length against the prevailing southwesterly wind: only 4 blowouts became shorter at the leeward side. At least two of these are probably stabilised by algae.
- In the same period, there was an increase in the average width, from 12.7 to 14.3 m. As a result, the total deflation area increased about 12% in three years time, from 1.14 to 1.28 (i.e. from 2.8% to 3.2% of the total terrain).

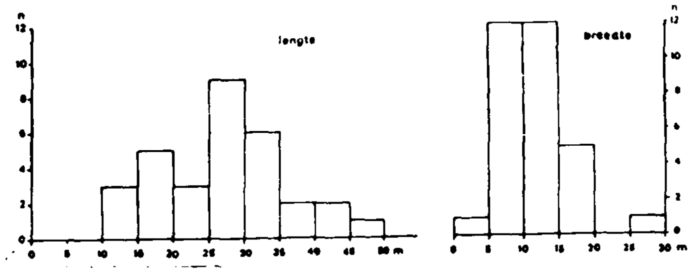


Fig. 12. Blowouts classified according to length and width

The sudden increase in number in 1987 is considered to be site-specific, due to a sequence of dry and wet periods during which erosion by water and by wind alternated. Humic sand was washed from the slope and exposed yellow sand which is sensitive to wind erosion at the upper side of the slopes. In "De Blink" near Noordwijkerhout, another area where dune research of the FGBL is concentrated, there was much increase in deflation area between 1984 and 1986 (fig. 13).

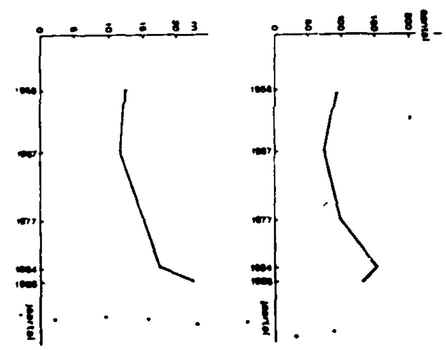


Fig. 13. Increase in blowout number (upper part) and length (lower part) in "De Blink" near Noordwijkerhout (Hopman and Jungerius, 1987) as measured from sequential air photographs.

The formation of blowouts begins with deflation patches a few metres in diameter. Most of these disappear within the year. Why others gradually deepen and become full-grown blowouts, is not known.

The growth of most blowouts stagnates after some time. In "De Blink", some blowouts have expanded to deflation planes 100 m or more in length. It was found that these blowouts were located in ridges where the leeward slope of the terrain is between 6° and 10° downward (fig. 14). Wind regime on these planes is continuous, as against gusty in the blowouts. This means a manifold increase in efficiency for erosion and transport.

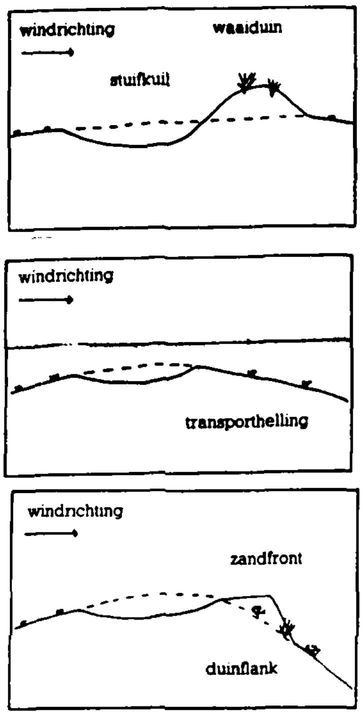


Fig. 14. The dependence of blowout growth on terrain slope at leeward.

a) upward slope: accumulation of sand inhibits further growth;
b) downward slope of 6° to 10°: the blowout can develop into a deflation plane;
c) steep downward slope: accumulation of sand slows down blowout growth (Noest, 1987)

(van Gelder, 1988). Thus, for characterising water repellence under field conditions, sampling over larger areas than is done by the WDPT test, is necessary.

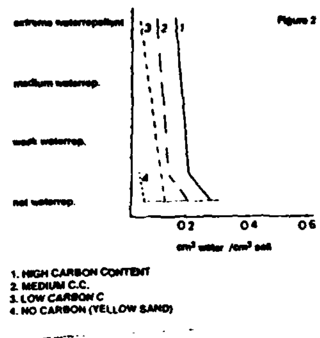


Fig. 16.

Wessel also found a positive relationship between water repellence and organic matter content in dune soils (fig. 17). Later research has made it clear that not all organic matter in dune soils if highly water repellent when dry. It appears that it is the organic matter produced by mosses, and possibly algae and lichens which show this property. Making surface sand water repellent could be regarded as a strategy of these shallow rooting plants to keep the rainwater they need from disappearing into the soil.

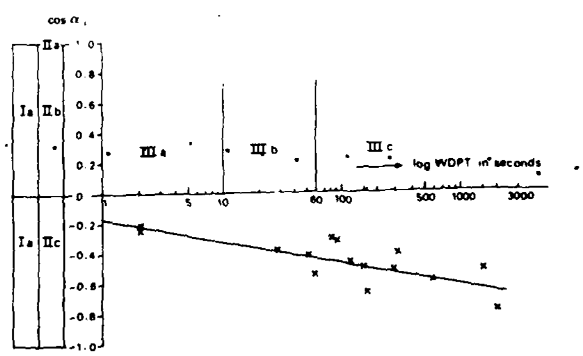


Fig. 17. Relationship of the logarithm of the WDPT and the cosine of the initiative effective contact angle, α'i:

$$\cos \alpha'i = -0.151 \log WDPT - 0.17 \qquad R = 0.64$$

The classification indices of both Fink and Rietveld are written in the vertical axis. The classification index of water repellency according to the WDPT by Adams et al. (1969) is shown on the horizontal axis.

Fink: Ia = non repellent
Ib = water repellent
Rietveld: IIa = non repellent
IIb = low to moderately repellent
IIc = extremely repellent
Adams et al.: IIIa = non repellent
IIIb = slightly repellent
IIIc = strongly repellent

Water repellence may be beneficial for certain plant forms, it is bad for slopes in terms of slope instability and soil erosion. Table 3 shows for a dune ridge near Noordwijkerhout that on an annual basis, most material is washed from south expos. J slopes in summer when soils are water repellent. In an erosion survey north of IJmuiden it appeared that the surface of dune slopes are much more affected by water erosion than by wind erosion (Table 4).

Table 3. Amount of sand reaching the base of a dune slope near Noordwijkerhout in the period between 1.1.1979 to 30.10.1980. The figures have been calculated from data by Rutin (1983)

Process	exposure of slope	season	vegetation cover(%)	transport (cm^3 per m slope width)
splash	north	winter	50	38
		summer	76	8
	south	winter	12	256
		summer	18	145
slope wash	north	winter		0
		summer		224
	south	winter		3431
		summer		12072
wind	north			<250
	south			250-2500
rabbit diggings				16

Table 4. The surface of landscape units with a discontinuous vegetation cover which has been eroded by wind and water in a surveyed area north of IJmuiden (Jungerius and van der Meulen, 1988

landscape unit	total surface ha	erosion wind ha	erosion wind %	erosion water ha	erosion water %
interdune area	36	18	50	2	6
do, with secondary dunes	23	11	48	4	17
parabola, moderate slope	25	4	16	10	40
do, steep slope	50	17	34	42	84
do, level summit area	19	5	26	4	21
total	153	55	36	62	41

The colour of the sand exposed at the surface can be used as a criterion of sensitivity to erosion: clean, yellow sand is incoherent and easily taken up by wind, byt extremely permeable and therefore relatively unaffected by runoff, whereas humic, grey sand is water repellent when dry and sensitive to erosion by water but not by wind (see Table 5). With these simple field criteria is has been possible to map erosion resistance and hazard in dune areas.

It has recently become clear that water repellence is indirectly also an important cause of wind erosion. One of the research topics demonstrated during the excursion is blowout development. In an area of about 40 ha in Meijendel, all blowouts have been measured twice a year since 1983. Up to Januari 1987, the number of blowouts remained more or less constant at 30 to 33 individuals. In June 1987, their number had suddenly increased to over 50. The reason is that in the spring of that year, one or two rainstorms washed water repellent grey sand from slopes. The underlying clean, yellow sand became exposed at the surface of the upper slope sections. It was here that in a subsequent period of easterly winds the new blowouts were formed.

Table 5. The distribution of the observations over the resistance classes and the classes of erosion by wind and overland flow. Each observation represents a mapping unit (Hulshoff et al., 1986)

	wind		water		total
	0	1	0	1	
yellow, clean sand exposed	31	106	53	84	137
grey, humic sand exposed	307	107	33	381	414
closed vegetation <1 m high	623	15	600	38	638
closed vegetation >1 m high	141	1	136	6	142
total	1102	229	822	509	1331

THE CONTRIBUTION OF ALGAE TO THE NATURAL STABILISATION OF BLOWOUTS

An important role in the early stabilisation of drifting sand is played by micro-organisms. The vegetation development on eroded surfaces often begins with algae which increase the resistance of the surface to deflation by forming crusts. Algal crusts consist of cyanobacteria (blue-green algae) and green algae.

In co-operation with the Laboratory of Microbiology of the University of Amsterdam the contribution of algae to the natural stabilisation of wind erosion surfaces is being studied. In 1986 the investigation started in the coastal dune area of Meijendel, near The Hague. This study is still going on and shows that cyanobacteria, mainly Oscillatoria and Microcoleus are the first colonizers of blowouts (fig.18). The algal surface layer starts to grow during wet periods when sand containing plant debris and algal cells is deposited into the blowouts. Most of the initial algal colonization can only be onserved by microscopic study. Under stable conditions the cyanobacteria are followed by the green alga Klebsormidium flaccidum, which develops an algal mat above the sand surface. Due to this difference the green alga predominates in the centre of the well developed algal mats, while relatively more cyanobacteria are found towards the boundary (fig.19).

Fig. 18. Picture of a light microscopic plate taken from a wet sample of a Microcoleus-dominated crust.

Algae bind soil particles together by:
- entwining them in a mechanical fashion by the filaments;
- cementing them with slime (polysaccharides) located on the mucilaginous sheaths surrounding the algal cells (fig. 20).

Sand samples covered by different types of algal crusts are collected in the field or cultivated in the laboratory to determine the resistance against wind erosion, using a wind simulator. The extent of stabilisation of sand surfaces by algal crusts is assessed from the determination of

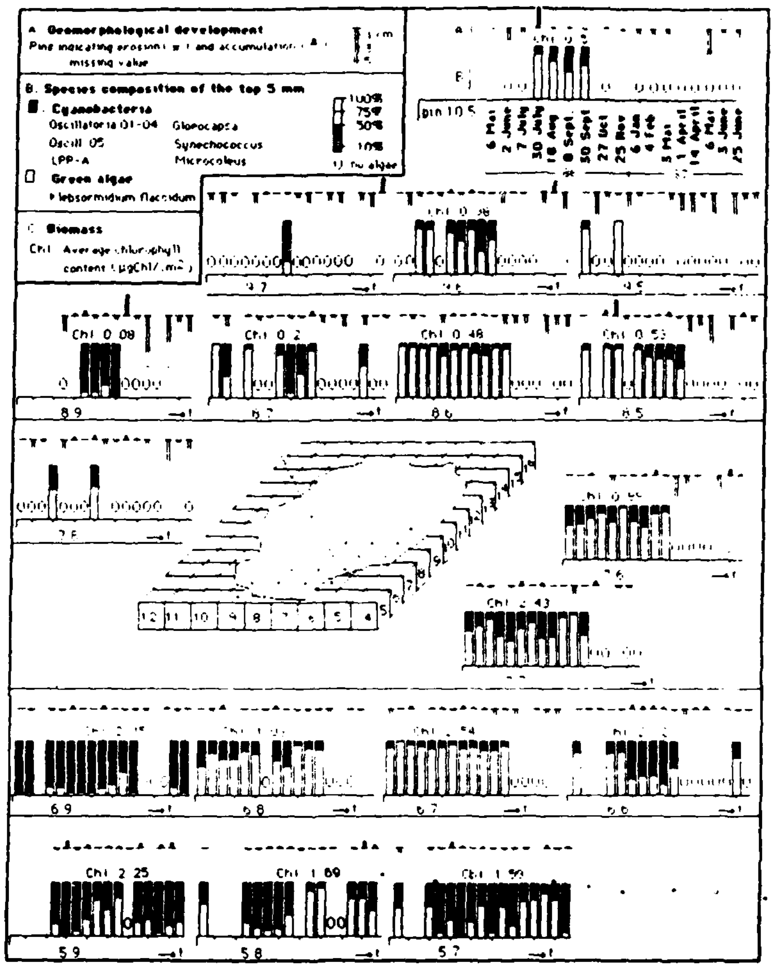


Fig. 19. Blowout no. 18; course in the ratio between the cyanobacteria and green algae present (B) and the geomorphological development at the sampling sites (A).

the threshold wind velocity value. It is observed that most types of algal crusts face little threat of being blown away but are more damaged by the mechanical action of the constantly movin; sand grains.

Monthly observations are being made of the geomorphological development of blowouts in relation to the algae present. These show that spatial patterns in stabilisation are generally determined by the local geomorphological situation at the blowouts, which causes differences in sand dynamics (frequency and amount of sand transport) in blowouts at a certain wind force and wind direction. Generally algae are able to colonize small blowouts completely, while in large blowouts algae are found periodically at the windward part of the blowout (fig. 21).

Fig. [illegible]. Scanning electron micrograph showing a dry crust sample containing small cyanobacteria of the LPP group on the surface of the sand grain and large filaments of *Oscillatoria*.

Temporal fluctuations in algae density are dependent on a number of factors of which climate is one of the most important. During the dry spring of [illegible] the biomass, expressed as the amount of chlorophyll was at the lowest level: 0.1-0.3 $\mu g/cm^2$, while the year before, during the rainy period from July till November, it was 5 times as high.

To establish how representative the situation in Meijendel is of sand drift areas, new investigations are being started on the island of Schiermonnikoog, along the coast of North- and South-Holland and in an inland dune area near Hilversum.

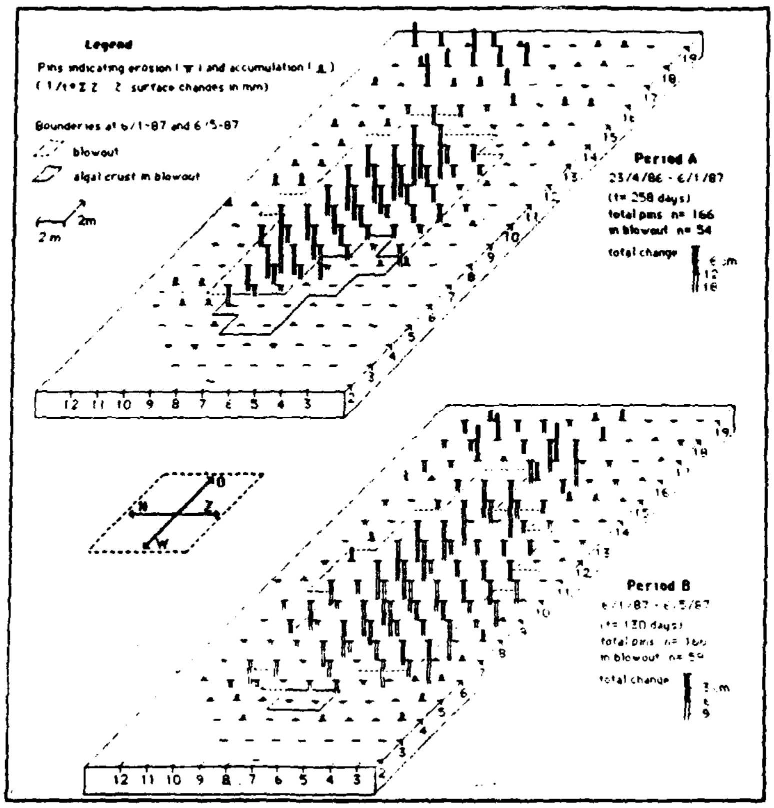


Fig. 21. Until January 1987 the algal surface in blowout no.18 contributed to the stabilisation of a part of the blowout. During the period thereafter the algal crust was not strong enough to resist erosion.

HYDROLOGICAL AND CLIMATOLOGICAL RESEARCH IN THE DUNES

In the dune area of Meijendel, located near The Hague, the Department of Physical Geography and Soil Science of the University of Amsterdam, and the Municipal Drinking Water Company of The Hague jointly operate a site for measuring hydrological and meteorological variables. The measurement site is located on a south-west oriented slope in the dune area. For two small areas of 10 m^2 each, weekly runoff and sediment catch is registered. Monitoring takes place of soil temperature and soil moisture profiles, of groundwater levels (at both the top and the bottom of the slope), and of rainfall, air humidity and temperature, and wind velocity and direction. Also several splash boards, sand traps and erosion pins are installed. The measurements started at the end of 1986, but monitoring started only recently. Monitoring interval is an hour. The chemistry of rainfall, runoff and groundwater is analysed on a weekly (anorganic constituents) and monthly (organic) time-basis.

The measurements are particularly directed towards:

- modelling of infiltration characteristics of dune sands. Following prolonged dry periods, the dune sand becomes strongly water repellent, and showers then lead to erosion by surface runoff;
- modelling of transport of solutes to the groundwater reservoir. As groundwater is used for drinking water production, and as rare plant species may locally depend on groundwater, pollution has harmful effects;
- characterisation of hydrological and climatological conditions in dune valleys, to be used in ecological modelling.

Special attention is focussed on water repellency of the dune sands. Results of earlier measurements by the Department of Physical Geography and Soil Science (Rutin, 1981), as well as preliminary data analysis of data on rainfall and runoff from the measurement site, indicate that generally runoff coefficients are very low in the dunes (about 1%). Nevertheless, because of water repellency, runoff coefficients for individual rainfall events can be rather high. In fact, the portion of the Meijendel dune area affected by water, as mapped by Van der Kraaij (1985), is larger than that affected by wind erosion. It has been found convenient to complement field measurements of water repellency (by means of the water drop penetration time test) by experiments in the laboratory (Van Gelder, 1988).

Literature

Rutin, J., 1983. Erosion processes on a coastal dune sand, De Blink, Noordwijkerhout, The Netherlands. Ph.D. thesis, Department of Physical Geography and Soil Science, Amsterdam.

Van der Kraaij, L.V., 1985. Een erosie-kwetsbaarheidsonderzoek door middel van de gevolgen van wind- en watererosie in Meijendel, Den Haag. M.Sc. thesis, Department of Physical Geography and Soil Science, Amsterdam.

Van Gelder, A.J., 1988. Water repellency of dune sands (to appear). M.Sc. thesis, Department of Physical Geography and Soil Science, Amsterdam.

VEGETATION SUCCESSION ON OLD FIELDS IN THE DUNE VALLEY "BIERLAP", INTERPRETED FROM AERIAL PHOTOGRAPHY BY MEANS OF A GEOGRAPHICAL INFORMATION SYSTEM

In this study, four sets of aerial photographs (1938, 1953, 1975 and 1985) are used for studying the changes in vegetation structure, as characterised by the occurrence of several dominant species. Changes in vegetation structure have been analysed instead of changes in the vegetation on a species level. These changes occur too rapidly in relation to the time interval chosen and can not be distinguished on the oldes three sets of photographs.

The photographs used differ greatly. The first two sets are in panchromatic black and white, scale 1:10,000, while the other two sets are in false colour, scale 1:2,500. From these photographs maps have been derived by using a legend with 8 types of vegetation structure. The legend, with some of the dominant species, reads:
1. bare sand; 2. moss and grassland vegetation; 3. open low shrub (Hippophae rhamnoides); 4. closed low shrub (idem); 5. open high shrub (Crataegus monogyna); closed high shrub (idem); 7. open woodland (Betula pendula, Populus tremula); 8. closed woodland (idem); 9. disturbed areas.

Each of the four maps has been converted into 1:5,000 raster maps, which have been analysed by using a geographical information system on a raster basis with a grid size of 12,5 x 12,5 m in the field. From these raster maps a transition diagram of the vegetation structure has been derived (fig. 22). This diagram reveals the vegetation succession in the past half century in the dune valley "Bierlap".

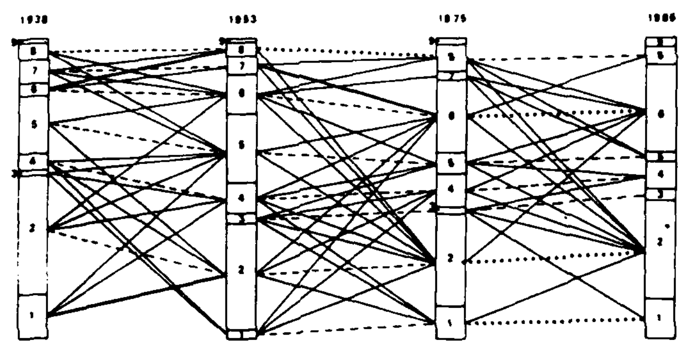


Figure 22

The stacked bars show the relative area (in percentage of the total area) of each vegetation structure type. Thin lines represent 10-50% frequency, thick lines: more than 50% frequency, interrupted lines: auto transitions with 10-50% frequency, dotted lines: auto transitions with more than 50% frequency (after Van Dorp et al., 1985).

Although the number of transitions is overestimated, because of locational errors, some conclusions can be drawn from this figure:
1. The vegetation succession is very dynamic; 2. Multiple pathways do occur; 3. While the area of moss and grassland vegetation does not significantly change, it is involved in a great number of transitions; 4. The area with closed high shrub steadily increases, particularly at the cost of moss and grassland vegetation and open high shrub; 5. The area with open high shrub steadily decreases, which leads to an increase in moss and grassland vegetation and closed high shrub.

Literature

Dorp, D.van, R.Boot and E.van der Maarel, 1985. Vegetation succession on the dunes near Oostvoorne, The Netherlands, since 1934, interpreted from air photographs and vegetation maps.Vegetatio 58: 123-136.

A GEOGRAPHICAL INFORMATION SYSTEM AS A TOOL FOR MANAGING THE COASTAL DUNES OF THE NETHERLANDS

In light of the ecological complexity of the dunes and in the light of the different functions of the Dutch coastal dunes (coastal defence, supply of drinking water, recreation, nature conservation; van der Meulen et al., 1985) managing a coastal dune area is rather complex. Interpretation and integration of the different aspects of the dune landscape can be facilitated by the use of a Geographical Information System (GIS). A GIS is a dataset of geographical information (maps) with special computerprograms to process the different types of information. Within the Department of Physical Geography and Soil Science of the University of Amsterdam, a research program is carried out in order to investigate the feasibility of GIS in the context of dune management.

In the first instance a raster data structure has been adopted. A disadvantage of this type of data representation is the generalisation of natural boundaries of the land units into right angle boundaries of the land units (fig. 23). Main research issues are:
- which aspects of the landscape have to be considered in GIS
- what size of grid cell is best
- in what way are the different types of information to be combined into meaningful conclusions with respect to management

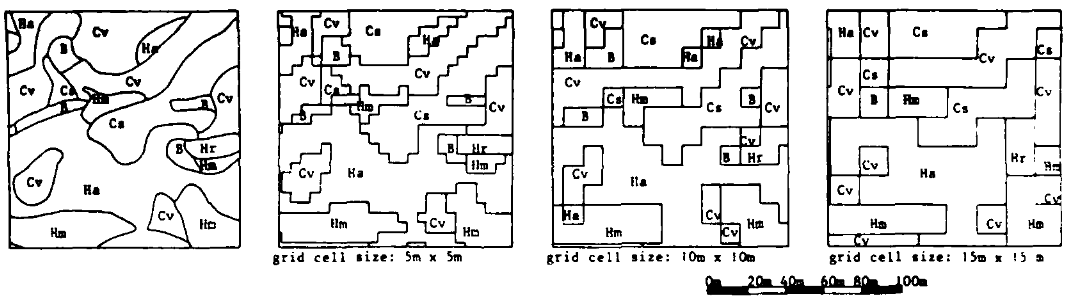


Fig. 23. Part of the soil map of De Blink and raster maps of the same area with different grid cell sizes.

In selecting the aspects of the landscape to be surveyed a hierarchical landscape model has been adopted (Bakker et al., 1981). In this model the following components are to be distinguished: climate, geology, relief, groundwater, soil, vegetation and fauna. The components are influenced by certain processes, such as climate change, succession, erosion, etc. Then, in GIS characteristics of selected landscape components and processes are stored, in order to predict certain changes in the landscape and to predict the effect of management strategies.

The sensitiveness of the landscape components to certain processes (for example, erosion by water or wind activity) will be evaluated by multivariate regression. This sensitiveness tells the terrain manager which areas are to be given priority in management. For certain combinations of processes and landscape components, measures of sensitiveness can be found in the literature (for instance: Noest, 1987).

To select an optimal grid cell size, a survey has been carried out in two sample areas: De Blink and Zwanenwater (fig. 24). On the basis of a morphological survey, a soil survey and a vegetation survey of a small part of the sample areas, five components of the landscape have been researched at a scale 112.000 (Assendorp, 1988). These components are,

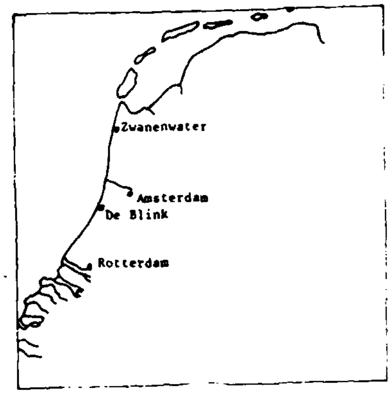


Fig. 24. The Dutch coast with the two survey areas

in their hierarchigal sequence: physiography (relief), exposition, soil, soil coverage and vegetational structure. For every component in both areas raster maps have been made with grid sizes of 15 m x 15 m, 10 m x 10 m and 5 m x 5 m. The mismatch is the total area of wrongly allotted characteristics in the raster map, as compared to the base map. Table 6 gives the results for all maps and for the three grid cell sizes. Assuming a mismatch of 10% or less (Ankum, 1986) to be acceptable, it must be concluded that, for the legend adopted, a grid cell size of 5 m x 5 m would be necessary.

Table 6. Total mismatch per map for each gril cell size

fys - physiography
bod - soil
exp - exposition
bed - soil-coverage
veg - vegetation structure

bl - De Blink
zw - Zwanenwater

	type map									
grid cell:	blfys	zwfys	blexp	zwexp	blbod	zwbod	blveg	zwveg	blbed	zwbed
15m*15m	19%	14%	20%	9%	22%	18%	25%	23%	20%	1%
10m*10m	14%	11%	15%	9%	16%	16%	18%	18%	14%	1%
5m* 5m	7%	7%	8%	7%	9%	10%	9%	10%	8%	1%

DUNE RESEARCH OF THE LABORATORY OF PHYSICAL GEOGRAPHY AND SOIL SCIENCE (FGBL)

The natural landscape of the dunes along the Dutch coast is the result of the interaction of geomorphological and biological processes (fig. 25). The geomorphological processes comprise the activities of wind and water. Generally they introduce elements of instability in the landscape. Biological processes include i.a. the production of living and dead biomass, both above ground and underground. These processes contribute to the landscape stability. Like the landscape, the soil is also the product of the interaction of the two groups of processes. The soil profile therefore reflects the balance between geomorphological and biological processes at any point in the terrain, and can therefore be used for mapping the dynamics of landscape formation. Dune research of the FGBL is focussed at this interaction of landscape forming processes in its widest sense.

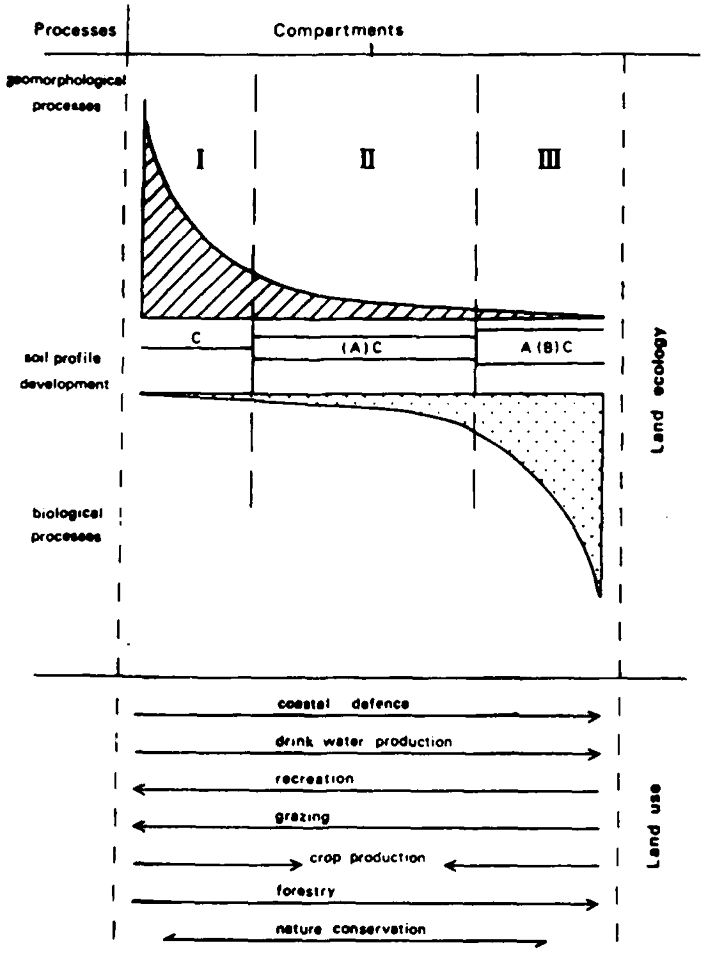


Figure 25

Modern dune management is process-oriented. To satisfy the needs set by the many functions of the dune landscape (coastal defense, water extraction, nature conservation, recreation, etc.), continuous interference with these processes is necessary. The FGBL co-operates with the Dune Water Works of The Hague in a common research programme, aimed at providing the scientific nase for effective management.

Current research topics are:

- the natural development of blowouts
- the role of algae in the spontaneous stabilisation of blowouts
- the contribution of moss sp. to the production of humic, water-repellent dune sand
- hydrology of a dune slope:
  * the contribution of rainwater to quantity and quality of groundwater, including the effect of vegetation and soil filters
  * the relationship between precipitation, water repellence, soil water infiltration characteristics, runoff and sediment production
- sequential airphoto analysis to register changes in vegetational structure and erosional features in the course of time
- soil development under different types of vegetation and in different geomorphological regimes
- adaptation of species composition to surface dynamics in accumulation sites
- the development of a geographical information system (GIS) for management purposes
- an interaction model of vegetation composition and groundwater level (in (co-operation with the University of Uppsala, Sweden)
- natural rejuvenation of forest ecosystems (in co-operation with the University of Uppsala)
- experiments with different methods of surface stabilisation

ARTIKELEN EN RAPPORTEN

Ancker, J.A.M.van den & Jungerius, P.D., 1985. Recente duinvormingsprocessen langs de Franse westkust. Intern Rapport FGBL, 60 p.

Ancker, J.A.M.van den, Jungerius, P.D. & Mur, J., 1985. The role of algae in the stabilization of coastal dune blowouts. Earth Surface Processes and Landforms 10, 189-192.

Ancker, J.A.M.van den & Winder, B.de, 1985. De rol van algen bij de stabilisatie van duinterreinen. Duin 8, 4, 18-20.

Aris, P., Wäckerlin, J. & Waveren, E.van, 1982. De hoedanigheden en de potenties van het afgegraven binnenduinlandschap tussen Castricum en Egmond a/d Hoef. Rapport FGBL, 71 p.

Beemster, J.G.R., 1986. De relatie tussen vorm en gedrag van zandkorrels in eolische processen. Intern Rapport FGBL, 39 p.

Bergmeijer, M., 1981. Processen in kustduingebied "De Blink", Gemeente Noordwijk. Intern Rapport FGBL, 76 p.

Bergmeijer, M. & Duysings, S., 1977. Statistisch onderzoek naar het verband tussen hoogte en expositie van steilwandjes in de windkuilen van duinterrein "De Blink" te Noordwijkerhout. Interne Rapporten van het FGBL 3, 15-24.

Bisseling, C., Buuren, N.van, Duijnhouwer, I., Manganas, I., Post, M. & Smet, S.de, 1983. Natuurbehoud en recreatie: conflict of harmonie? Rapport FGBL en Provinciale Waterleiding Noord-Holland, 140 p.

Blok, H., Leltz, G. & Louman, E., 1985 (in voorbereiding). Onderzoek van (potentieel) natte- en vochtige duinvalleien in Meijendel t.b.v. het instandhouden of ontwikkelen van hun natuurlijke waarde.

Boer, D.de & F.Niekus, 1981. Sortering door winderosie. Intern Rapport FGBL 11, 71-97.

Bont, R.de & Vis, M., 1977. Statistisch onderzoek van de lengte-breedte verhouding van windkuilen in de duinen bij de Langevelderslag met behulp van de t-toets en de Mann-Whitney U-toets. Interne Rapporten van het FGBL 3, 25-47.

Brugmans, F. & Lebon, C., 1977. De ontwikkelig tot een meer langwerpige vorm van windkeuilen in een duingebied nabij Langevelderslag. Interne Rapport FGBL 3, 48-62.

Deppe, C. & C.Leermakers, 1979. Een toegepast landschapsecologisch onderzoek aan verlaten landbouwgronden in het Noordhollands Duinreservaat. Rapport FGBL t.b.v. Provinciale Waterleiding Noordholland,

Geertsma, G., A.Hopman & J.P.Op den Kamp, 1986. Stuifkuilen in de Haasvelder duinen. Deel I en II. Rapport FGBL en Gemeentewaterleidingen van Amsterdam, 122 en 61 p.

Hazelhoff, L. & O.M.de Vré, 1982. Geomorfologische kartering van het duingebied tussen Schoorl en Bergen. Deel 2: Classificatie van de Schoorlse loopduinen m.b.v. morfometrische gegevens. Intern Rapport FGBL, 45 pp.

Horn, H., 1982. "Strandpaal 46". Intern Rapport FGBL, 38 pp.

Hopman, A. en P.D.Jungerius, 1987. Zandverstuivingen in "De Blink". Zuidhollands Landschap 16, 3, 15.

Hulshoff, M., E.v.d.Meer, E.Schade & R.de Vos, 1985. De relatie tussen erosieprocessen en vegetatie in de duinen ten Z. van Bergen. Rapport t.b.v. Prov. Waterleiding bedr. Noord-Holland.

Hulshoff, R.M. and P.D.Jungerius. De samenhang tussen geomorfologische processen, bodem en vegetatie in de duinen bij Bergen aan Zee. Submitted to Landschap.

Jungerius, P.D., 1983. Stuifkuilen. Zuidhollands Landschap 4, 4-5.

Jungerius, P.D., 1984. Erosiekartering Noordhollands Duinreservaat, terreindeel Heemskerk. Rapport FGBL t.b.v. Prov. Waterl. Noordholland.

Jungerius, P.D. 1984. A simulation model of blowout development. Earth Surf. Proc. & Landf., 9, 509-512.

Jungerius, P.D., 1985. On the importance of high-magnitude events for landscape formation in the Dutch dunes and the Luxembourg forests. Lecture Workshop on soil erosion and hillslope hydrology with emphasis on higher magnitude events. Leuven, België.

Jungerius, P.D., 1986. Geomorfologische processe in het Nederlandse duin-

landschap: erosie door water, wind en konijnen. Duin 9, 4.
Jungerius, P.D. & Meulen, F.van der, 1987. Erosion processes in the dunes along the Dutch coast. Ingezonden naar Catena.
Jungerius, P.D., Verheggen, A.J.T. & Wiggers, A.J., 1981. The development of blowouts in "De Blink", a coastal dune area near Noordwijkerhout, The Netherlands. Earth Surface Processes and Landforms 6.
Jungerius, P.D. & Meulen, F.v.d., 1985. De ontwikkeling van stuifkuilen in het duinterrein Meijendel. Landschap, 2, 143-151.
Jungerius, P.D., 1987. Erosiekartering in het Noordhollands Duinreservaat. Duin 3, 75-77.
Jungerius, P.D. Geomorphology, soils and dune management. Proceedings Perspectives in coastal dune management. Accepted for publication.
Jungerius, P.D. and F.v.d.Mulen, 1988. Erosion processes in a dune landscape along the Dutch coast. Catena, accepted for publication.
Jungerius, P.D. & F.v.d.Meulen. The decision environment of the dune management. Proceedings Perspectives in Coastal Dune Managament. Accepted for publ.
Ketting, R., 1981. Veldwerkverslag van een landschapsecologisch onderzoek van een duingebied bij Overveen. Deel 2. Landevaluatie, 20 p.
Klijn, J., 1974. Een landschapsecologische studie op het oostelijk deel van Terschelling. Intern Rapport FGBL.
Koopmans, T. & Schenk, P., 1977. De toepassing van variantie-analyse en de Kruskal-Wallis toets bij het onderzoek naar zandverplaatsing onder verschillende vegetatietypen langs de randen van windkuilen in een duingebied bij Noordwijkerhout. Interne Rapporten van het FGBL 3, 63-76.
Kraay, L.V.van der, 1986. Kwetsbaarheidskartering Meijendel. Rapport FGBL t.b.v. Duinwaterleiding 's-Gravenhage.
Kwakernaak, C. & J.Tijmons, 1976. Kwetsbaarheid en recreatie in het Schoorlse duingebied. Intern Rapport FGBL, 37 p.
Levelt, Th.W.M., A.J.J.Bolt, C.Kwakernaak & A.P.A.Vink, 1978. Voorne-Putten, een landschapsecologisch onderzoek. Intern Rapport FGBL, 4, 110 p.
Ligthart, T. & A.de Wilde, 1985. De kwetsbaarheid van zuidelijk Meijendel. Rapport Duinwaterleiding van 's-Gravenhage en FGBL, 61 p.
Markus, A. & E.Kuypers, 1986. Beheersvormen in het Noord- en Zuidhollands kustgebied. Intern Rapport FGBL, 41 p.
Noest, V. (1987). Stabilisatie van stuifkuilen. Zuid-Hollands landschap,
Noest, V., 1986. Stabilisatie van stuifkuilen. De rol van vegetatie en dynamiek van het substraat. Rapport FGBL en Duinwaterleiding van 's-Gravenhage, 32 p.
Pluis, J.L.A., 1985. Simulatiemodel van de veranderingen in tijd en ruimte van het microreliëf van duinbodems onder invloed van variaties in graafactiviteit van konijnen in een duinlandschap. Rapporten van het FGBL, 25, 143-155.
Pluis, J.L.A., 1986. Landschapsecologisch onderzoek van het wilde konijn, Oryctologus cuniculus (L.), in Meijendel. Rapport FGBL en Duinwaterleiding van 's-Gravenhage, 69 p.
Pluis, J.L.A., 1987. Duinvergraving in het klein. Duin 3 52-54.
Rutin, J., 1983. Erosional processes on a coastal sand dune, De Blink, Noordwijkerhout, The Netherlands. Publ. Fys. Geogr. Bodemk. Lab. no. 35, 144 pp.
Sliedregt, R.van, 1985. Bodems en geomorfologische processen in een deel van het duinlandschap van Meijendel. Rapport Duinwaterleiding van 's-Gravenhage en FGBL, 59 p.
Vlaanderen, A. & Wen Ting-Tiang, 1977. Statistisch onderzoek naar de gevolgen van de toenemende recreatiedruk op de duinvegetatie van de Nederlandse Waddeneilanden. Interne Rapporten van het FGBL 3, 77-97.

Vos, C.de & A.Ankum, 1985. Bodems in de Jonge Kustduinen van Nederland, een literatuuronderzoek. Intern Rapport FGBL, 23 p.

Vré, O.M.de, 1982. Geomorfologische kartering van het duingebied tussen Schoorl en Bergen. Intern Rapport FGBL, 82 p.

Wessel, F., 1986. On using the effective contact angle and the water drop penetration time for classification of water repellency in soils. Ingezonden naar Earth Surface Processes and Landforms.

Wessel, F., 1986. Water repellency of dune sand in relation with the volumetric moisture content and the organic matter content. Gereserveerd voor Supplement Band Catena.

Winder, B.de, J.L.A.Pluis, L.de Reus and L.Mur, 1987. The characterisation of a cyanobacterial, algal crust in the coastal dunes of the Netherlands. Proceedings Microbiol. nets: ecological physiology of benthic microbial communities. Eilat.

V. SELECTED LITERATURE ON DUTCH DUNES

Doing, H. and Doing-Huis in 't Veld, C.J., 1971. History of landscape and vegetation of coastal dune areas in the province of North-Holland.

Eisma, D., 1968. Composition, origin and distribution of Dutch coastal sands between Hoek van Holland and the island of Vlieland. Thesis Leiden. Neth. J. Sea Res. 4: 123-267.

Jelgersma, S., J.de Jong, W.H.Zagwijn and J.F.van Regteren Altena, 1970. The coastal dunes of the western Netherlands; geology, vegetational history and archaeology. Meded. Rijks Geol. Dienst N.S. 21: 93-167.

Jelgersma, S. and J.F.van Regteren Altena, 1969. An outline of the geological history of the coastal dunes in the Western Netherlands. Geologie Mijnbouw 48: 335-342.

Jungerius, P.D., A.J.J.Verheggen and A.J.Wiggers, 1981. The development of blowouts in "De Blink", a coastal dune area near Noordwijkerhout, The Netherlands. Earth Surface Processes Landforms 6: 375-396.

Beeftinck, W.G., J.Rozema and A.H.L.Huiskes (eds.), 1985. Ecology of coastal vegetation. Junk, Dordrecht.

Rutin, J., 1983. Erosional processes on a coastal sand dune, De Blink, Noordwijkerhout, The Netherlands. Thesis Amsterdam.

Saeijs, H.L.F., 1982. Changing estuaries. A review and new strategy for management and design in coastal engineering.

Van den Ancker, J.A.M., P.D.Jungerius and L.R.Mur, 1985. The role of algae in the stabilisation of coastal dune blowouts. Earth Surf. Proc. Landforms 10: 189-192.

Van der Laan, B., 1985. Changes in the flora and vegetation of the coastal dunes of Voorne (The Netherlands) in relation to environmental changes. Vegetatio 61/62: 87-95.

Van der Maarel, E., R.Boot, D.van Dorp and R.Rijntjes, 1985. Vegetation succession in the dunes near Oostvoorne, The Netherlands; a comparison of the vegetation in 1959 and 1980. Vegetatio 58: 137-187.

Van der Meulen, F. and E.A.J.Wanders, 1985. Dynamics and management of some coastal dune woodlands near The Hague, The Netherlands. Vegetatio 62: 457-465.

Van der Meulen, F. and E.van der Maarel, 1988. Dry coastal ecosystems of the Central and Southwestern Netherlands. In: E.van der Maarel (ed.), Dry coastal ecosystems of the world. Elsevier, Amsterdam. In press.

Van der Meulen, F., E.A.J.Wanders and J.C.van Huis, 1985. A landscape map for coastal dune management. Meijendel, The Netherlands. ITC Journal 1985-2: 85-92.

Van Straaten, L.M.J.U., 1961. Directional effects of winds, waves and currents along the Dutch North Sea coast. Geol. Mijnb. 40: 333-346.

Van Straaten, L.M.J.U., 1965. Coastal barrier deposits in South- and North-Holland, in particular in the areas around Scheveningen and IJmuiden. Meded. Geol. Stichting N.S. 17: 41-75.

Westhoff, V., 1985. Nature management in coastal areas of Western Europe. Vegetatio 62: 523-532.

Zagwijn, W.H., 1984. The formation of the Younger Dunes on the west coast of The Netherlands (AD 1000-1600). In: H.J.A.Berendse and W.H.Zagwijn (eds.): Geological Changes in the Western Netherlands during the period 1000-1300 AD. Geol. Mijnb. 63:259-268.

VI. INVESTIGATIONS OF HUMUSFORM DEVELOPMENT IN CALCAREOUS COASTAL SANDS UNDER FIRST GENERATION PINE AND POPLAR STANDS, AND UNDER *CRATAEGUS-MONOGYNA*-BRUSHWOODS

Introduction

Although the coastal dunes in the Netherlands have been rather thoroughly investigated (Boerboom, 1963; Klijn, 1981; Rozema et al., 1985), most attention has been paid to the still active dune areas and to the vegetation and hydrology, whereas the soils in the forested parts, which cover large areas, hardly received attention. Most of these forests are in fact Pine plantations, while natural tree stands are relatively rare.

The introduction of Pine species can be expected to have led to the development of soils, quite strongly differing from those formed under natural vegetation, in particular on the calcareous dune sands. Major arguments for this are the differences in litter production, litter composition and nutrient uptake between pine and the naturally occurring, mostly deciduous trees.

The aim of the study was twofold:

a) comparison of two sites with distinct differences in vegetation, one being a planted *Pinus sylvestris* L. stand, the other being a naturally established *Populus nigra* L. stand. They offer good possibilities for a comparative study on soil formation under primary forest: the parent material is very homogeneous, groundwater generally occurs at a considerable depth and differences in macroclimate within the forested area are negligible. Moreover, the history of the dune area is very well known, allowing the selection of plots with first generation stands of equal age.

b) investigation of humusform development under naturally established *Hippophao Ligustretum* brushwoods by comparing two stands of different age and to characterise diversity caused by time and microclimate within these stands. The parent material is very homogeneous, groundwater generally occurs at a considerable depth and differences in macroclimate are small in relation to age differences. This offers perfect opportunities for investigation of humusform development under primary brushwood vegetation.

Stand age and differences in microclimate are factors determining stage and kind of humusform development. Two sites with *Crataegus monogyna* dominated *Hippophao ligustretum* were selected, clearly differing in structure and related microclimate; one being a relatively small cluster in an open brushwood of relatively recent and diverse age, the other being part of a closed stand of considerable age.

The four plots were surveyed, paying attention in particular to the humus forms and their spatial variability. Subsequently representative profiles were sampled for a more detailed study of their composition and of the seasonal variations in soil chemistry.

General information

a) The natural *Populus nigra* L. stand (tree density of about 9 trees per 100 m², dating from about 1910, is situated on a high sand dune complex with a pronounced eolian relief, at a distance of about 2200 m from the sea (52°08'52"NB; 04°21'56"EL; fig. 26).

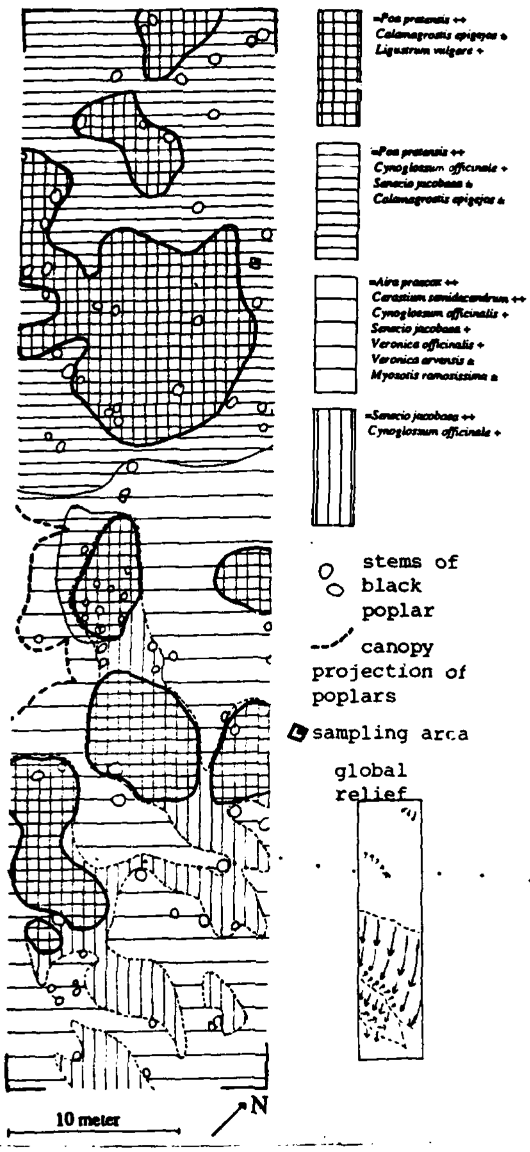


Fig. 26. Vegetation map of location in the poplar wood

The planted *Pinus sylvestris* L. stand (tree density of about 7 trees per 100 m²), dating from about 1907, is also situated in a high sand dune complex with a pronounced eolian relief, at a distance of about 2850 m from the sea (52°08'52"NB; 04°22'25" EL; fig. 27).

b) The younger *Crataegus monogyna* dominated *Hippophao ligustretum* brushwood is situated at a distance of approximately 1050 m from the sea (52°08'52"NB; 04°20'41"EL). It is part of a large closed brushwood in a sheltered dune valley, and according to aerial photos is has been closed since at least 1938. Stem density is lower (approximately 1.4 stems/ 10 m²), and stem circumferences determined at 1 m height varied from 40 to 150 cm. Trees are much older and have higher stems.

Conclusions

a) For the poplar and pine stands the initial environmenral conditions (climate, parent material, relief and drainage) were identical, while their ages are comparable. This implies that the observed differences in soil properties can be attributed to differences in vegetation. This study showed that within a period of about 80 years soils under *Pinus sylvestris* stands acquire properties, which strongly deviate from those of soils under naturally established *Populus nigra* stands (fig. 29).

The soils under pine have a mor humusform and a more or less promonent micropodzol. The soil variability within the stand is small and strongly connected with relief-controlled differences in vegetation; the soils of the interdunal depressions having more prominent mor characteristics than those of the dunes, which have a grass-dominated herbal layer. The soil studied in detail, representative for the interdunal depressions, exhibits all characteristics of the mor humusform such as a low decomposition rate, low concentrations of available nutrients, a low pH and minimal bioturbation.

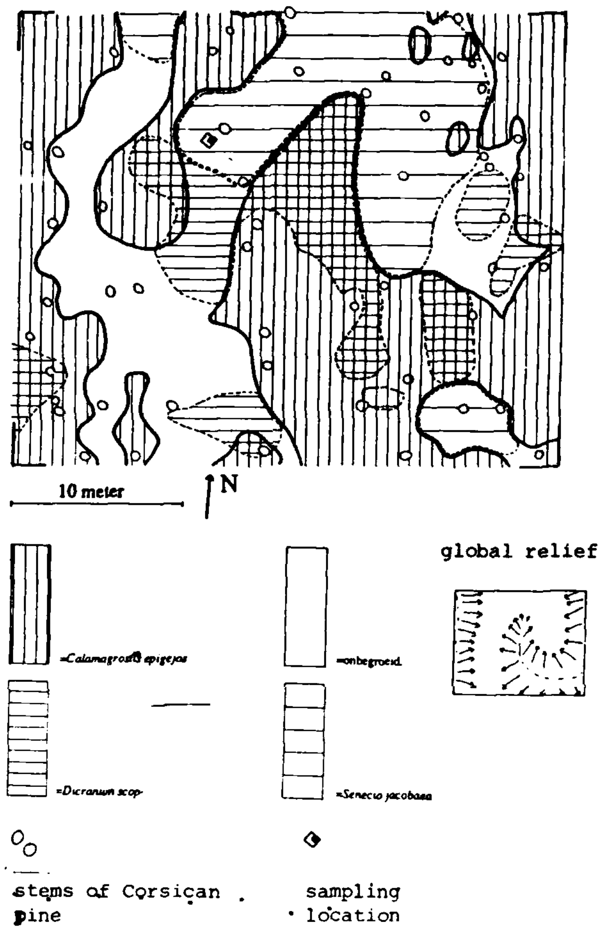


Fig. 27. Vegetation map of location in the Grove plantation in The Hague.

Soils under *Populus nigra* in the contrary have a mull humusform with a fairly thick Ah horizon. The soil variability is considerable and probably largely due to the strong effect of relief on microclimate and to a higher susceptibility of the litter transport by wind. The soil studied in detail is representative for the "average soil profile" and is slightly acid to near neutral. It has a CN-ratio of about 20, which is high for mull-type humusforms and points to a somewhat retarded decomposition.

In spite of these strong differences in soil development, which are clearly related to differences in nutrient uptake and in litter composition and decomposition, the results indicate that total amounts of soil organic matter do not differ strongly and will be in the order of about 65 tons/ha in the polar plot and of about 100 tons/ha in the pine plot. This can be partly ascribed to the low litter production of the pine stand, which is probably due to the combined negative effects on their biomass production

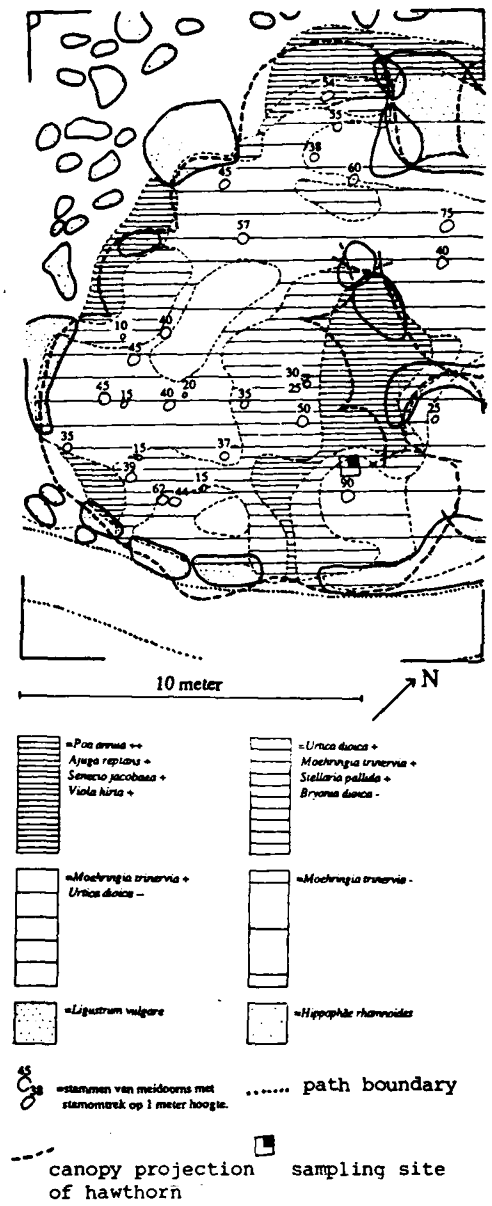


Fig. 28. Vegetation map of brushwood location Bierlap.

of rather unfavourable Na/(Ca+Mg) ratio, resulting from atmospheric deposition of salt in combination with a low level of Ca and Mg cycling, of a very strong pH gradient at shallow depth, which probably inhibits deep rooting and of unfavourable climatic conditions (strong winds and salt spray).

Taking into account the age of the pine stand (80 years) and the total amount of soil organic matter accumulated (about 100 tons/ha) such a low litter input, which might be in the order of 2 tons/ha. year, clearly implies that litter turnover rates in this stand are very low.

The results from this study show that the introduction of *Pinus sylvestris* stands in the calcareous dunes leads to the development of soils which strongly differ from those under naturally established forest stands and resemble the soils developed on the noncalcareous *eolian sands* elsewhere in the Netherlands.

b) In general, the humusform developing under *Crataegus monogyna*-dominated *Hippophoa ligustretum* can be classified as an acid mull (Bal, 1982), having poorly developed ectorganic horizons, a well developed Ah, low pH values (4.2) and high CN-ratios (20). Retarded decomposition causes substantial amounts of incorporated organic material to accumulate, especially in the upper part of the Ah (up to 40% in Ah1). Probably due to these low pH values, ammonification rather than nitrification is the main process supplying mineral nitrogen to the system.

High ammonium levels in the Ah were found in November, dropping substantially in spring, probably due to uptake by plants.

In investigating the spatial variability in humusforms within brushwoods, stand age and microclimate were believed to be major factors. As time proceeds, vegetation structure changes, causing a more stable and uniform microclimate to evolve. Decalcification of the top soil causes lower amounts of Ca, K and Mg in the litter of *Crataegus monigyna*, which obviously

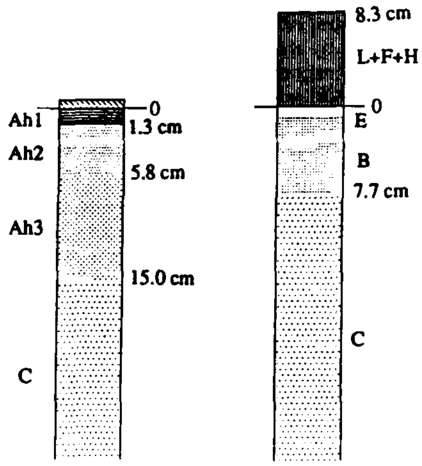


Figure 29

fail to adequately recycle these elements. The acid mull characteristics become more pronounced, judging lowering pH values, and rising CN-ratios, together with progressively more organic matter accumulating especially in the top part of the Ah (about 170 and 190 tons C/ha after respectively ca. 100 and 150 years of humusform development), while total depth of the humusform remains relatively constant (ca. 30 cm; fig. 30.

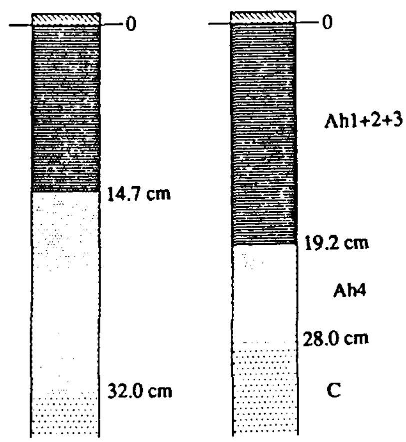


Figure 30

Light, and possibly also water, are the major microclimatic factors determining spatial variability in humusforms variability in humusforms of brushwoods. The more favourable moisture conditions in the herbal layer will enable herbs and also soil micro-organisms to quickly react to nutrient release, and through their above and below ground input of easily decomposable organic material cause a stronger nutrient cycling to take place. Decalcification on densely vegetated spots is less intense, the humusform is less acidic, and CN-ratios are lower. Also organic matter accumulates to a lesser degree (90-100 tons C/ha) and thus the humusform closer resembles a typical mull.

When comparing these brushwoods to the pine and poplar stands, accumulation turns out to be much higher. In poplar stands (65 tons C/ha) a more favourable litter composition will cause faster decomposition and mineralisation, while nutrient cycling adequately prevents decalcification (together with a usually well developed herbal layer which also prevents nutrient leaching), thus causing less organic matter to accumulate. In Scots Pine stands (100 tons C/ha) an early senescent state (due to that fact that Scots Pine represents an introduced species, as opposed to the native brushwoods and poplar stands) is evident, causing growth and litter production to decrease quickly, and less organic matter to be accumulated.

VII. TOWARDS A EUROPEAN STRATEGY FOR DUNE CONSERVATION AND COASTAL MANAGEMENT

Coastal ecosystems are highly diverse and complex environments. Because of their location on the border of land and sea they are multifunctional systems with great economic importance for society (recreation, coastal defence, nature conservation, drinking water catchment). Adequate management of these systems is therefore urgently needed. An important recent development is the international attention dunes attract in a European context. In September 1987 a European Dune Congress was held in Leiden, The Netherlands. One of the outcomes of this congress was the establishment of a European Union for Dune Conservation and Coastal Management (EUDC). Main objectives are:

- promote the exchange of information between researchers and managers of dunes and neighbouring areas
- the listing of areas of special ecological interest (in terms of geomorphology and well as plant and animal ecology)
- the listing of endangered coastal ecosystems
- the support of activities aiming at the protection of coastal ecosystems (incl. research, management, politics)

At present, the union is in the first phase of planning, structuring and financing its activities. Experts from more than 10 European countries take an active part in this. Research activities will especially concentrate on process-studies and applied research projects. When you are interested in the EUDC, please contact Dr. F.van der Meulen (Vice-Chairman) or Prof.Dr. P.D.Jungerius (thesaurier general), both at the Landscape and Environmental Research Group, University of Amsterdam.

Part 2: South Limbourg

1) Introduction, Wijnandsrade and Ransdalerveld
   F. Kwaad, University of Amsterdam

2) Moddelling soil erosion in the Catsop watershed
   A.P.J. de Roo, University of Utrecht

3) Primary loess ridges in Haspengouw
   E. Paulissen, K.U. Leuven

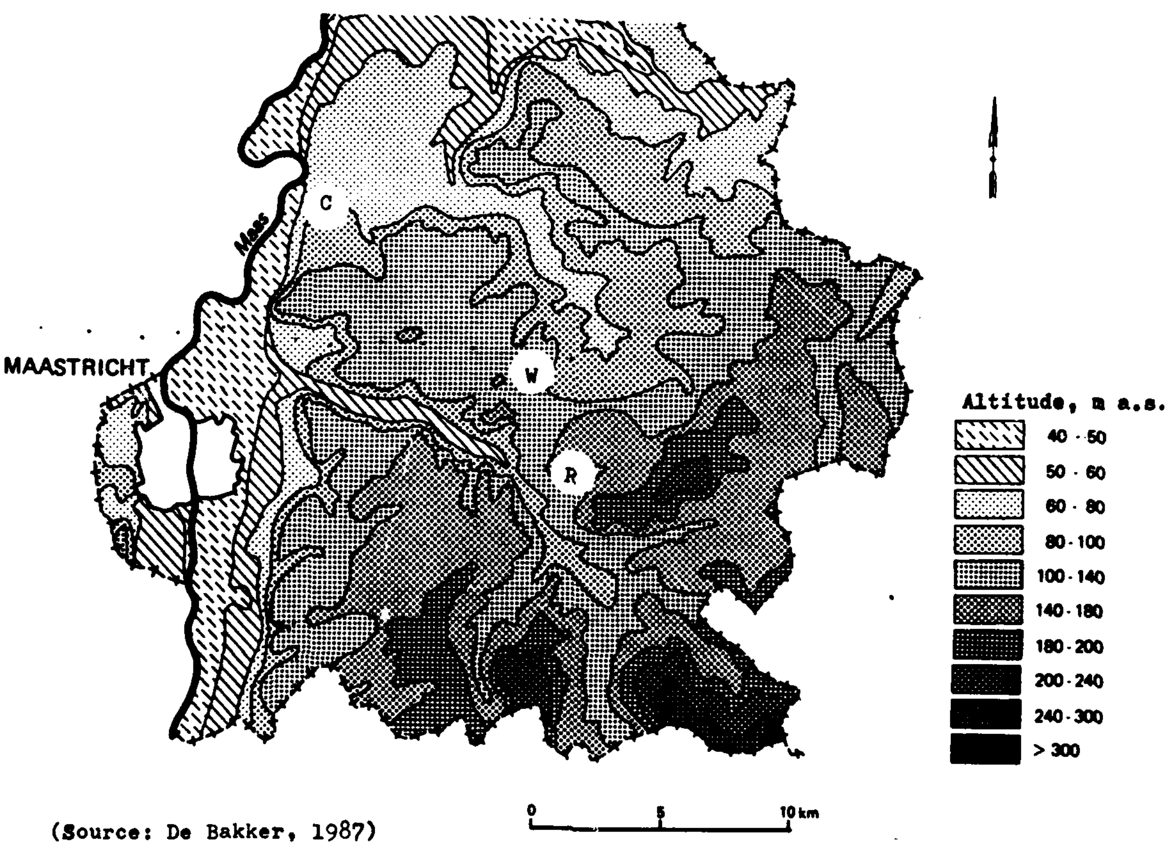
Program of excursion to South-Limbourg

Departure from Amsterdam at 8.00 A.M.

Arrival in South-Limbourg at 11.00 A.M.

To prevent crowding at the excursion sites the two busses (A and B) will foll
separate routes in South-Limbourg. We will join again at lunch time.

	Bus A	Bus B
08.00-11.00	trip from Amsterdam to South-Limbourg	
11.00-12.15	Ransdalerveld (R)	Wijnandsrade (W)
12.30-13.30	lunch at Experimental Farm	
13.45-15.00	Wijnandsrade (W)	Catsop (C)
15.15-16.30	Catsop (C)	Ransdalerveld (R)
16.30-18.00	trip to Leuven	



(Source: De Bakker, 1987)

Excursion South-Limbourg - Introduction

One of the themes of the Benelux Colloquium on Geomorphological Processes and Soils is soil erosion and soil erosion control. This theme is central in the excursion to South-Limbourg. The aim of the excursion is to give an impression of the type of landscape, where rainfall induced soil erosion occurs in the Netherlands, and of the research that recently has been undertaken to combat the problem. Accelerated erosion in South-Limbourg is conditioned by the presence of loess in a landscape with a rolling topography. Loess is a very erodible soil material. However, since it is very suitable for agricultural purposes, it has been used for arable farming in South-Limbourg from the 10th century up to the present. This has given rise to the loss of top soil by rainwash. Recently the accelerated erosion of the loess soils in South-Limbourg seems to have increased. Especially the off-site effects of the erosion have become more serious, and more costly to repair. Off-site effects are flooding of villages, deposition of mud on the streets and in cellars, damage to paved roads by concentrated runoff water, and erosion of river banks due to increased peak discharges. The gravity of the problem necessitates, that measures are taken to reduce or prevent future damage. This requires an analysis of the causal factors, and testing of various possible measures.

During the excursion three locations will be visited:

(a) The "Ransdalerveld"-area. In this area a re-allotment program of land was completed in 1967. Since about 1975 a number of serious erosion events has taken place in this area.

(b) The Experimental Farm at Wijnandsrade. The farm is administered by a Foundation. The costs of the farm are shared by the farmers of the region and the Dutch Ministery of Agriculture. The work on the farm involves field trials of various crops, fertilizers, herbicides, pesticides, soil tillage techniques and methods of crop management on a level, which allows more or less direct application of the results in practice. In 1986 a plot study was started by the Experimental Farm in cooperation with the University of Amsterdam of the effect on runoff and erosion and on crop yields of three alternative cropping systems of maize.

(c) A small, instrumented drainage basin near Catsop. For this drainage basin computations of runoff and soil loss, under various land use scenario's, have been carried out by the University of Utrecht, using the ANSWERS-model. Runoff and sediment discharge measurements were carried out here by the Agricultural University Wageningen.

In the following pages information is given successively on: (a) the geology, geomorphology, soils and climate of South-Limbourg, (b) the experimental plots at Wijnandsrade, (c) the re-allotment program in the Ransdalerveld area, and (d) the drainage basin near Catsop.

Outline of the geology and geomorphology of South-Limbourg (Netherlands)

From old to young the following phases can be distinguished in the geological and geomorphological development of Dutch South-Limbourg:

Early and Middle-Carboniferous

During the Early and Middle-Carboniferous South-Limbourg was part of a large, slowly subsiding marine basin (a geosyncline). In this subsiding basin several thousands of meters of marine sediments were deposited (limestones, quartzites, sandstones, slates). Carboniferous rocks now only are exposed at the surface in a few small quarries along the river Geul, suth of Epen. During part of the Middle-Carboniferous (Westphalian), coal layers were formed. These coal layers have a total thickness of about 90 m, but separate layers are not thicker than 1.50 m. The coal layers have been exploited in mines down to a depth of 800 m below the surface. In 1974 the last coal mine in South-Limbourg was closed, but you still can see the spoil heaps of the mines in the former mining district. There is still coal left, and possibilities are considered of alternative means of exploitation.

Upper-Carboniferous

During the Hercynian orogeny folding took place of the Lower and Middle Carboniferous sediments, and an Alpine style chain of mountains was formed.

Permian, Triassic, Jurassic, Early and Middle-Cretaceous

During the Permian the Hercynian mountains were leveled to a peneplain, and during most of the Triassic, Jurassic, Early and Middle-Cretaceous South-Limbourg remained above sea level. It was part of a land area to the south of a large north-west European sedimentary basin.

Upper-Cretaceous (Senonian)

During the Upper-Cretaceous, the sea transgressed over the post-Hercynian peneplain in the South-Limbourg area. As a consequence of this, marine sediments were laid down, beginning with sands and ending with thick series of marls and chalk (soft limestone). The Senonian marls crop out of the surface in several places. They are exploited in large open pits for several purposes e.g. cement industry and agricultural use. These open pits are the subject of heated discussions, as they affect scenery and landscape. In the marls, zones occur, which are rich in flint. The marls weather into a very heavy and sticky residual clay, locally with flints. In the marls and chalk solution phenomena occur.

Early-Tertiary (Paleocene, Eocene)

During the Paleocene and Eocene the South-Limbourg area was land again. Weathering of the Senonian marls and limestones took place under tropical conditions, with the formation of karst features e.g. lapies and dolines.

Middle-Tertiary (Oligocene, Miocene)

During the Oligocene and Miocene, marine sands were deposited in South Limbourg. The Miocene sands are very pure quartz sands, which are exploited in open pits for the glass industry. In the Miocene sands same browncoal layers occur, which have been exploited in the past.

Upper-Tertiary (Pliocene)

Since the ending of the Miocene transgression, the South-Limbourg area has not been covered by the sea again. During the Pliocene, South-Limbourg was part of a low lying peneplain, which extended also across the Ardennes and the Eifel area, south of South-Limbourg. The climate was subtropical. Remnants of the Pliocene peneplain still occur in an elevated position in the south-east of Limbourg and as a few "islands" more to the north surrounded by Quaternary river terraces. The highest point of the Netherlands near Vaals (321 m a.s.l.) is a peneplain remenant.

Pleistocene

During the Pleistocene most of the present morphology of South-Limbourg was formed. The main events were: (a) an intermittent upheaval of the area due to epirogenic movements, and (b) an alternation of a series of cold and relatively warm climatic phases (the ice ages with intervening interglacial periods). As a consequence of the epirogenic rise of the area, interrupted by phases of rest, a series of terraces was formed by the river Meuse. These terraces have large lateral extensions ("plateau terraces"). They are covered with more or less thick deposits of fluvial sediment (coarse gravels and sands). In the course of the Pleistocene the river Meuse, which runs from south to north, has shifted from east to west in South-Limbourg. Due to this shift in a westerly direction, more than 90% of the terraces now lie to the right side of the river. See figs. 2 and 3 for relief of South-Limbourg.

The episodic incision of the river during the Pleicostence will have been aided by the changes in climate and the associated changes in sealevel. During the glacial periods of the Pleistocene, South-Limbourg has not been covered by ice. However, the cold climate of (some of) the glacial periods presumably has given rise to the formation of permafrost in South-Limbourg, as evidenced by frost cracks and cryoturbatic phenomena. The permanently frozen (sub)soil must have influenced the hydrology of the area, by preventing the infiltration of snow melt water and/or rain water in the water saturated surface layer. It is thought, that by this surface drainage the dry valleys of the present-day landscape were formed. A conspicuous feature of the dry valleys is, that some have an asymmetrical cross section. See fig. 14.

Another important event during the Pleistocene was the deposition of a cover of loess over the fluvially dissected terrace landscape. In the loess, three stratigraphic units can be distinguished: (a) a Lower-loess, of Saalian age, (b) a Middle-loess, of Weichselian age and (c) an Upper-loess, also of Weichselian age. The loess deposition was not restricted to South-Limbourg. The loess in South-Limbourg is part of a loess belt that extends from west to east across south-east England, north-west France, a large part of Belgium and parts of West-Germany. See figs. 1 and 12.
The thickness of the loess in South-Limbourg varies from place to place. It ranges from 10 to 20 m on the plateau-like river terraces to 2 - 5 m on valley side slopes. The unweathered loess is rich in calciumcarbonate. The loess was deposited on various types of subsoil, viz. Cretaceous marls or chalk; residual clay of Cretaceous marls; Tertiary sands; Pleistocene terrace deposits (gravels and sands). See fig. 4 for cross section.

Holocene

The Holocene, until the advent of man, was a period of rest and landscape stability, during which soil formation took place in the loess under a vegetation of deciduous forest. The soils that were formed, characteristically show an argillic illuviation or Bt-horizon. They can be classified as "Orthic Luvisols", "Typic Hapludalfs" or "Parabraunerden". In the Dutch classification they are named "Radebrikgronden". See fig. 13.
Around 4500 B.C. man began to exert an influence on the natural forest vegetation. Forest was cleared for agricultural purposes during Neolithic, Bronze Age, Iron Age, and Roman times. This first wave of deforestation, with associated accelerated erosion and colluviation, ended about 400 A.D.
The second period of deforestation began about 1000 A.D. Large areas were cleared in the 11th, 12th and 13th century. Since then, the forest has not returned in South-Limbourg. The forest clearance and agricultural use of the land have led to the loss of top soil on sloping fields. On slopes of 2 to 8% the original A1 and A2-horizons have been removed. The Ap-horizon on these slopes now consists of Bt-material. On slopes steeper than 8% also the Bt-horizon is lost. This implies that on slopes of 2 to 8% about 50 cm is gone and that on slopes steeper than 8% 100 cm or more of the original soil has been eroded. It is not known, whether the loss of topsoil was a gradual process since about 1000 A.D. or that changes in the rate of soil loss have occurred since 1000 A.D.
Due to soil loss on slopes, three groups of loess soils now can be distinguished in South-Limbourg (see also fig. 14):
- undisturbed loess soils (10.400 ha)
- truncated loess soils (20.100 ha)
- colluvial loess soils (9.800 ha).

The indisturbed loess soils occur on level watershed areas (plateau sites). The truncated loess soils are found on slopes steeper than 2%, and the colluvial loess soils mainly occupy lower slope positions and dry valley bottoms. In the past 10 years concern has increased in South-Limbourg regarding the erosion of loess soils and the associated off-site effects of flooding and increased sedimentation. It is not quite clear, whether this increased concern is due to an increased rate of erosion in recent years or to a decreased willingness to longer accept the burden, together with an increased awareness of the problem due to recent and repeated press reports. The problem certainly is not new. The recently increased pressure to do something about it, mainly comes from outside the agricultural world, from municipal authorities and private citizens, confronted with the costs of the off-site effects. See figs. 18 and 19.

People point to rationalisation and mechanization of agriculture and to larger fields (as obtained by re-allotment of land) as possible causes of increased runoff and soil loss. Others point to urbanisation and increased surface of paved roads as factors contributing to increased runoff.

A conspicuous feature of many slopes in rural South-Limbourg are the so called "graften", i.e. terrace-like steps, alligned parallel to the contour lines and often grown over with brushwood (lynchets in English). The "graften" have originated over the centuries along field boundaries as a consequence of the trapping of soil material, moving downslope in various ways (soil creep, tillage induced creep, slope wash), in hedges or fences of brushwood at the field boundaries. Another possible origin of "graften" is, that they have been constructed in the Early Middle Ages for the growing of wine grapes. There has been viticulture in the area until the second half of the 14th century. See fig. 15.

By some people an important role is ascribed to the "graften" in reducing runoff and erosion. Locally, "graften" have been removed to create larger fields. This was done for instance in the "Ransdalerveld", where a reallotment program was carried out in 1960 - 1967. Since about 1975, problems of erosion and flooding have increased in this area. Therefore, claims have been issued recently to undo the realloment, to reducefield lengths, to restore old "graften" and to throw up new ones.

Landuse in South-Limbourg

The total surface area of South-Limbourg is 69.000 ha, of which 34.000 ha is used for agriculture:

- 17.000 ha arable land (of which 4500 ha maize in 1984)
- 15.000 ha grass land
- 2.000 ha horticultural land.

Climate

South-Limbourg has a temperate humid climate with an average yearly rainfall of 700 mm. Average temperature of the coldest month (January) is +3°C. Average temperature of the warmest month (July) is 19°C.
As a consequence of relief there is a strong gradient in yearly precipitation from west to east across South-Limbourg (a distance of 30 km). The valley of the Meuse receives between 600 and 650 mm yearly. The area around Vaals, at an altitude of 300 - 320 in a.s.l., receives from 900 to 950 mm yearly. The rainfall is spread more or less evenly over the year. Relatively dry months are February - May (40-50 mm per month). The wettest month is July (75 mm on average). See figure 7.
There is a pronounced trend in rainfall intensities over the year. Of all rainfall events 9,3 % are "heavy rains". Of the heavy rains 94,8% occurs in the period April - November, with 69,9% in the months June - September; 20,8% of all heavy rains occur in July. See figure 8.
For recurrence intervals of rainfall intensities and durations see figures 9, 10 and 11.

Experimental runoff and soil loss plots at Wijnandsrade

No previous experience exists in South-Limbourg with protective measures against on-site and off-site effects of accelerated erosion, other than retention basins for the temporary storage of runoff water and sediment.
Last year, Provincial Authorities have issued regulations to the effect, that measures shall be taken to reduce soil loss, flooding and sedimentation.
One group of measures regards cropping system and crop management; all those effects that are included in the C-factor of the Universal Soil Loss Equation. Prediction of these effects under the conditions of climate, soil and topography in South-Limbourg was considered impossible without a local database of runoff and soil loss measurements. Therefore, an empirical study of runoff and soil loss under various cropping systems was initiated by the Experimental Farm of Wijnandsrade, in cooperation with the University of Amsterdam (Department of Physical Geography and Soil Science).
Three cropping systems of maize were selected (A, B and C) together with permanent fallow as a reference. The cropping systems and fallow condition are studied on experimental plots with three replications per system. Altogether, 12 plots were laid out in a randomised block design (3 blocks with 4 plots each). The 12 plots are alligned to form a row on a slope of approximately 6%. Within each block of 4 plots conditions are assumed equal. Between the blocks slight differences exist in angle of slope, soil type and moisture regime (influence of water table). See figures for lay-out of plots, topography and soils (figs. 20, 21, 22, 23).
The dimensions of the plots are length 25 m and width 10 m. A width of 10 m is necessary to have room for standard tillage, sowing, spraying and harvesting equipment and to minimize edge effects on crop yields. Within each field a runoff and soil loss plot is fenced off with a length of 22 m and a width of 1.80 m.
The purpose of the plot study is threefold:

(a) to determine the effect of cropping system on runoff and soil loss (conservation aspect)
(b) to determine the effect of cropping system on crop yield (economic aspect)
(c) to establish the practicability of the cropping systems (technical aspect).

The maize cropping systems can be described as follows (systems A and B are thought of as conservation alternatives of the conventional system C):

System A

Soil is ploughed immediately following the harvest of the preceding growing season in October. A seedbed is prepared and winter rye is sown. In April the winter rye is killed by spraying. Residu is left on the surface. Maize is sown without further tillage operations between the winter rye. Harvest of the maize in October.

System B

Directly after the harvest in Octber the soil is tilled with a cultivator (not ploughed). This leaves the soil in a rather coarse condition. Soil is ploughed in March and summer barley is sown. Summer barley is killed by spraying end of April. Early May maize is sown. Harvest in October.

System C (conventional system)

After harvest in October the land remains as a stubble field until end of April. Then the soil is ploughed, seedbed is prepared and maize is sown. Harvest in October.

System C[1]

Permanent falow condition, with all operations as in system C, including going over the plot with tractor and machinery during sowing and harvest time. No extra tillage to kill weeds. Chemical weed control.

It is a comparative study of the effect on runoff and soil loss of one factor, cropping system. All other factors, a.o. slope length, are held constant. This means that the results only have relative value. They may be used to evaluate the effect of cropping system on erosion under the experimental conditions.

The soils at the experimental site are formed in loess and loess derived colluvium. Texture is silt loam. Hydromorphic mottling is found at all depths below the plough layer (Ap-horizon) on all plots. Soils are:

(a) truncated gleyic luvisols, with the remaining part of the Bt-horizon directly below the Ap-horizon
(b) colluvial soils, with more than 35 cm colluvium overlying a truncated gleyic luvisol. Maximum thickness of colluvium is 80 cm. See map for soil pattern.

The equipment of the erosion plots was further subject to the following conditions / constraints:

(a) low budget
(b) interval between visits is 4 weeks
(c) removable installation, because of ploughing, sowing, spraying and harvesting with standard equipment
(d) runoff and sediment storage tanks semi-permanently installed at a distance of 10 m from the plots to provide turning space for tractor with attached implements.

The plots were laid out in October 1985. The first erosion plot was installed in June 1986. Three other erosion plots were installed in October 1986. Improved equipment was placed on all 12 plots in May 1987. Since then, reliable results have been obtained. Groundwater or seepage water in the pits with the storage tanks, remains a problem.

Runoff from the plots is collected wide, covered funnel shaped troughs, lying on the soil surface. They can easily be removed. Part of the sediment in the runoff settles here and is collected here during 4-weekly visits. Runoff is led through a 10 m long pipe-line to a system of storage tanks. The necessary slope and diameter of the pipe-line was calculated on the basis of the once in 100 year rainfall intensity, assuming 100% runoff. This rainfall intensity (180 mm/h) produces a discharge from a plot of 40m^2 of 2 l/sec. To accomodate this water flow, a pipe diameter of 52 mm at a slope of 2% was calculated, using the formula of Blasius and the formula of Fanning. In fact, a pipe with an internal diameter of 62 mm (external diameter 75 mm) was used. Unneccesary large diameters must be avoided. They are expensive and give rise to sedimentation in the pipe, due to low flow velocities. The pipe of 75 mm, that is used on the plots, remains free of sediment.

The runoff from the pipe-line either directly enters the first storage tank, or is first led through a small measuring flume (HS-flume with maximum water depth of 12 cm), that is connected to an automatic water stage recorder. The runoff is stored in a system of three storage tanks, with capacities of 74 l, 74 l and 98 l. Not all runoff is stored. That would require a storage capacity of 8000 l for a rainfall amount of 200 mm in 4 weeks and 100% runoff. See figure.
Instead, 10%-multislot divisors are used to sample the runoff.
In this way, the tanks can store the equivalent of 74 + 10 x 74 + 100 x 98 = 10.614 liter.

To secure the correct functioning of the divisors, the first and second tanks are placed on four 1 m long poles, driven into the soil, to keep the tanks level. Evaporation from the tanks is prevented by a plastic screen. The whole set up is covered with a tarpaulin.
During 4-weekly visits the water level in the tanks is measured to the nearest mm to calculate the runoff volume. The contents of the tanks are stirred vigorously for a few minutes, very carefully scraping the bottom of the tanks, and 500 ml samples are taken for sediment concentration determinations in the laboratory. Regularly, duplicate samples are taken.
See figures for results. Cropping system A seems very effective in reducing soil loss, as compared to the conventional maize cropping system C. A reduction of 92,5% in soil loss was obtained during the growing season of 1987, as compared to the conventional maize cropping system C. See fig. 24 for runoff and soil loss data, and figs. 16 and 17 for infiltration envelopes and aggregate stability of the loess soils.

Summary of paper by Kierkels, M.H.H., 1971,
Erosion and parcelling in re-allotment area "Ransdalerveld" (Cultuurtechnisch Tijdschrift, 11, pp. 78 - 84).

In 1967 a re-allotment of land was carried out in the "Ransdalerveld"-area. Total surface area involved was ca. 1900 ha. Soils in the area are mainly developped in loess as a parent material (80% of the area). Other parent rock is chalk, weathered into a heavy residual clay. Topography is rolling.

Changes in landuse

	before 1967		after 1967		change,%
	ha	%	ha	%	%
Arable land	1050	55	805	42	- 23
Orchards (short stem)	10	-	25	1	+150
Grass incl.tall stem orchards	763	40	980	51	+ 28
Wood	18	1	18	1	0
Built up area and roads	77	4	90	5	+ 17
Total	1918	100	1918	100	0

The change in arable/grass ratio had economic reasons.

Arable land per slope class

Slope class	Slope %	Before 1967	After 1967	Decrease, %
I	<4	470 ha	370 ha	21
II	4-8	250 "	205	18
III	8-12	180 "	135	25
IV	12-20	170 "	80	33
V	>20	30 "	15	50
Total		1050 ha	805 ha	23

Contour farming

On land in slope class II (4-8%) contour farming is desirable. For slope class III (8-12%) it is necessary. Preferred use is grassland. For slope class IV (12-20 %) grass is strongly advised. If used for arable farming, contour farming is a necessity.
The size of the fields increased from an average of 0,7 to 3,5 ha as a consequence of the re-allotment. Before 1967 cultivation parallel to the contours was not possible on 140 ha of arable land, where contour farming really was advisable or necessary. After 1967 this area is reduced to 90 ha. So, due to the re-allotment of land, contourfarming is now possible on an extra 50 ha.

Since Kierkels' paper of 1971, several serious erosion events have occurred in the "Ransdalerveld"- area. They were so serious, that measures must be taken. Some people even ask to undo the re-allotment.

Literature

Bergsma, E., 1980. Provisional rain erosivity map of the Netherlands. In: De Boodt, M. and Garbiels, D. (editors). Assessment of erosion. Wiley, Chichester, pp. 121-126.

Bouten, W., van Eijsden, G.G., Imeson, A.C., Kwaad, F.J.P.W., Mücher, H.J. en Tiktak, A., 1985. Ontstaan en erosie van de lössleemgronden in Zuid-Limburg, Geografisch Tijdschrift, 19, pp. 192-208.

Buishand, T.A. en Velds, C.A., 1980. Neerslag en verdamping. KNMI, 206 pp.

De Bakker, H., 1979. Major soils and soil regions in the Netherlands. Wageningen, 203 pp.

De Bakker, H., 1987. Regionale Bodemkunde van Nederland, lössgebieden. In: De Bakker, H. en Locher, W.P. (redactie), Bodemkunde van Nederland. Deel 2, Bodemgeografie, Hoofdstuk 36, pp. 167 - 176.

Geelen, P. en Kwaad, F.J.P.M., 1988. Bestrijding van watererosie. Jaarverslag over 1987 van de Stichting Proefboerderij Wijnandsrade, pp. 95-99.

Kierkels, M.H.H., 1971. Erosie en verkaveling in de ruilverkaveling "Ransdalerveld". Cultuurtechnisch Tijdschrift, 11, pp. 78-84.

Kuyl, O.S., 1980. Toelichting bij de Geologische Kaart van Nederland 1:50.000. Blad Heerlen (62 west en oost) RGD, Haarlem, 206 pp.

Levert, C., 1954. Regens, een statistische studie. Mededelingen en verhandelingen K.N.M.I., 62. Den Haag, 246 pp.

Mücher, H.J., 1973. Enkele aspekten van de loess en zijn noordelijke begrenzing, in het bijzonder in Belgisch en Nederlands Limburg en in het daaraangrenzende gebied in Duitsland. Geografisch Tijdschrift, 7, pp. 259-276.

Provincie Limburg, 1987. Streekplan Zuid-Limburg. Algehele herziening. 3 delen + 2 losse kaarten.

Schouten, C.J., Rang, M.C. en Huigen, P.M.J., 1985. Erosie en wateroverlast in Zuid-Limburg. Landschap, 2, pp. 118 - 132.

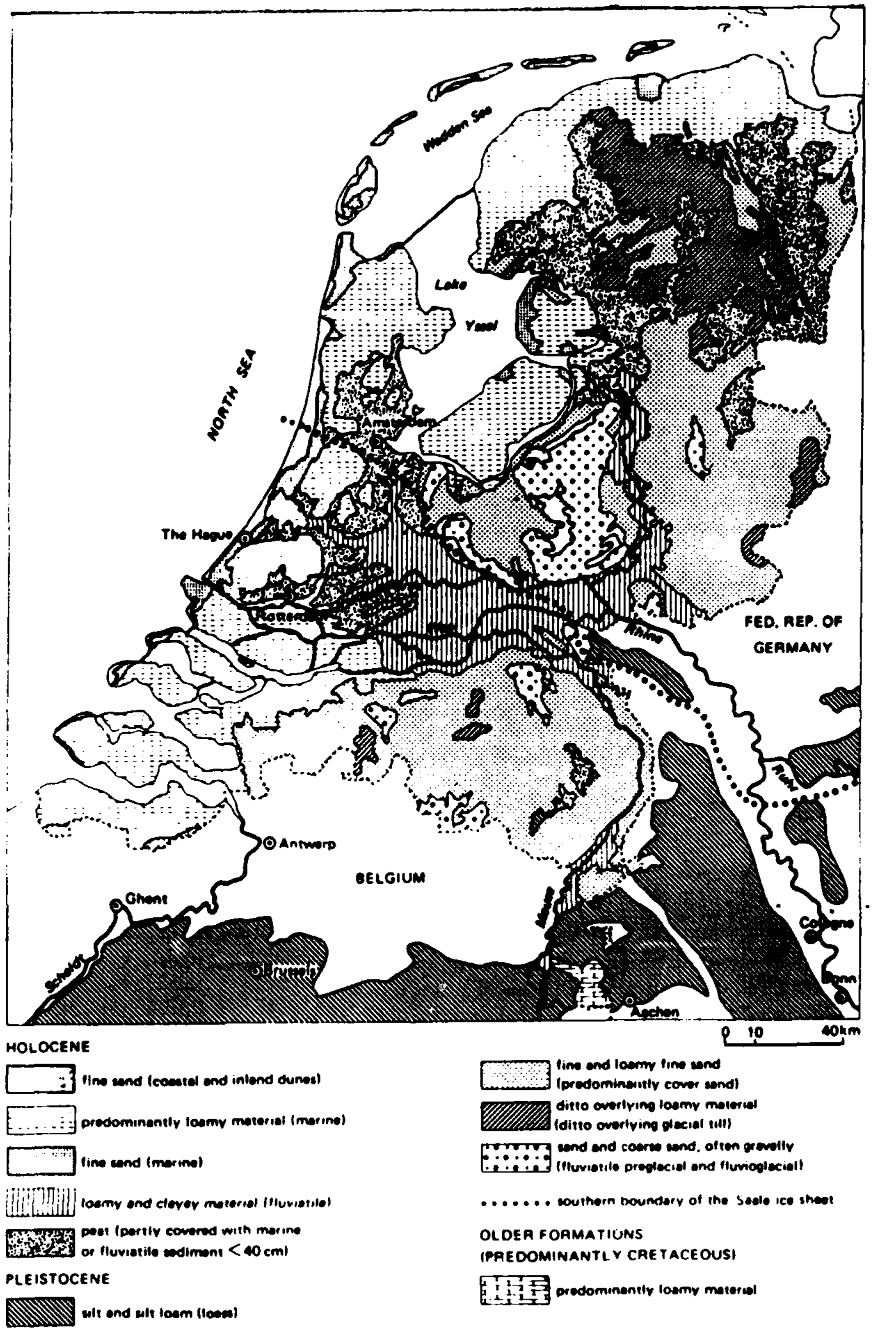
Stiboka, 1970. Toelichting bij de kaartbladen 59 (Peer) en 60 west en 60 oost (Sittard) van de Bodemkaart van Nederland, schaal 1:50.000. Wageningen, 138 pp.

Van den Broek, J.M.M., 1966. De bodem van Limburg. Toelichting bij blad 9 van de bodemkaart van Nederland, schaal 1: 200.000. Wageningen, 147 pp.

Van den Herik, A.G. en Kooistra, M.T., 1973. Vijf minuten regens. Grontmij, De Bilt, 56 p.

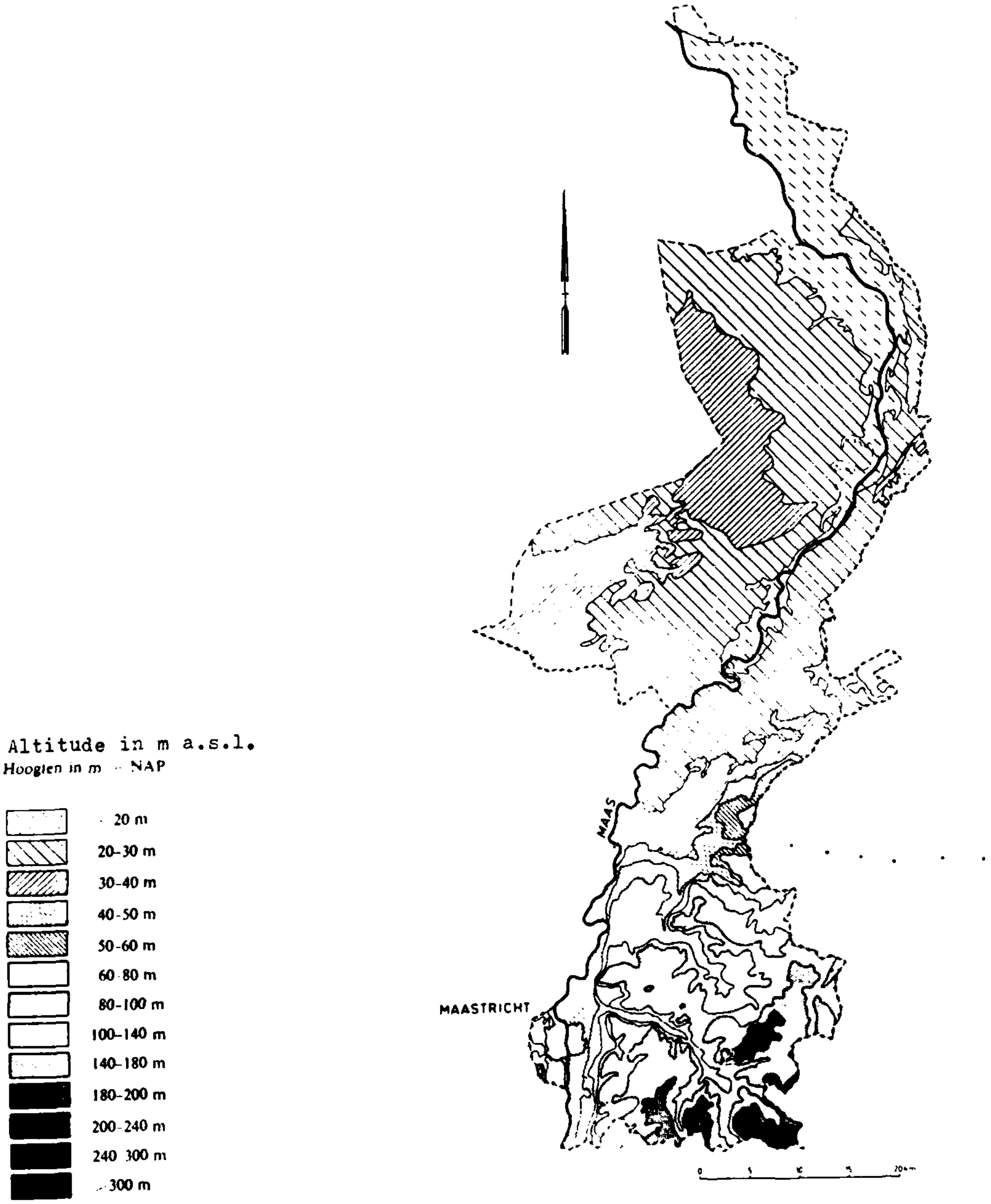
Van Eijsden, G.G., 1986. Bodemerosie op landbouwpercelen in een loessgebied. Verslag Fys. Geogr. en Bod. Lab. Univ. v. Amsterdam, 60 pp.

Van Eijsden, G.G. en Imeson, A.C., 1985. De relatie tussen erosie en enkele landbouwgewassen in het Randsdalerveld, Zuid-Limburg. Landschap 2, pp. 133 - 142.



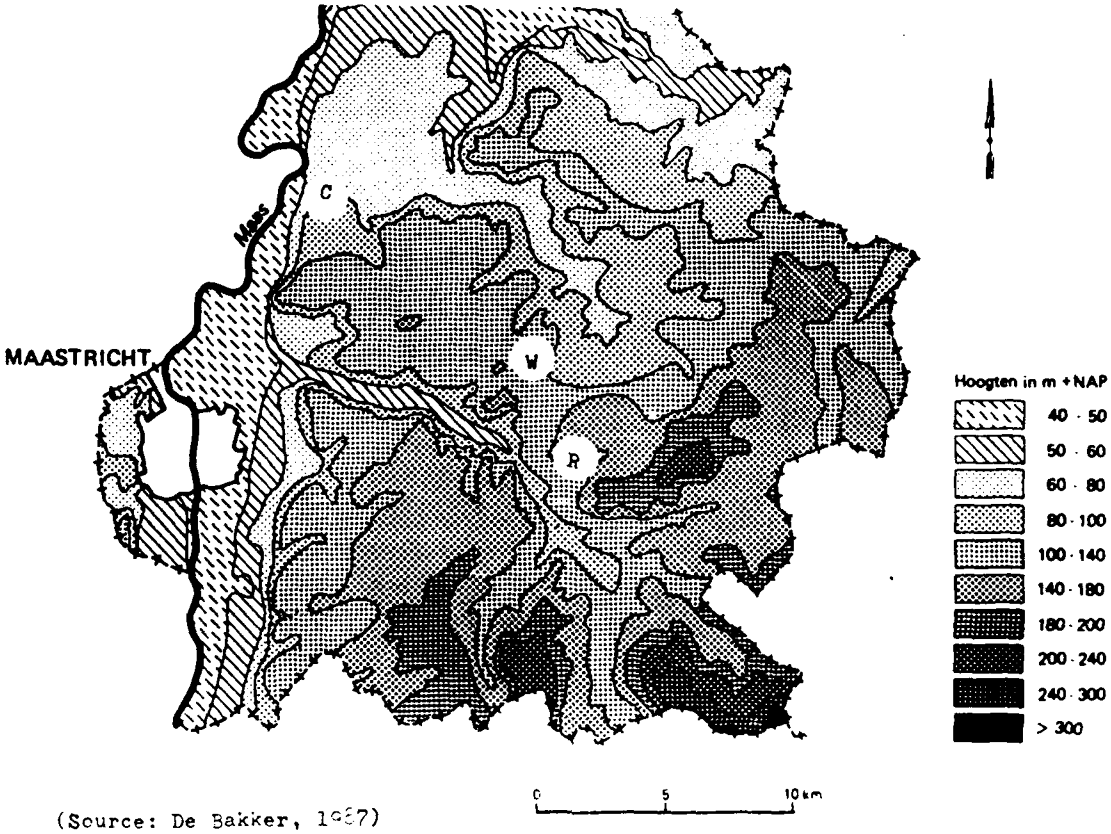
Parent material and surface geology in the Netherlands. In Belgium and in the Federal Republic of Germany only the loess is indicated.
(Source: De Bakker, 1979)

Fig. 1. Geological map of the Netherlands



(Source: Van den Broek, 1966)

Fig. 2. Altitude map of Limbourg.



(Source: De Bakker, 1987)

Fig. 3. Altitude map of South-Limbourg with location of excursion points, C: Catsop, W: Wijnandsrade, R: Ransdalerveld.

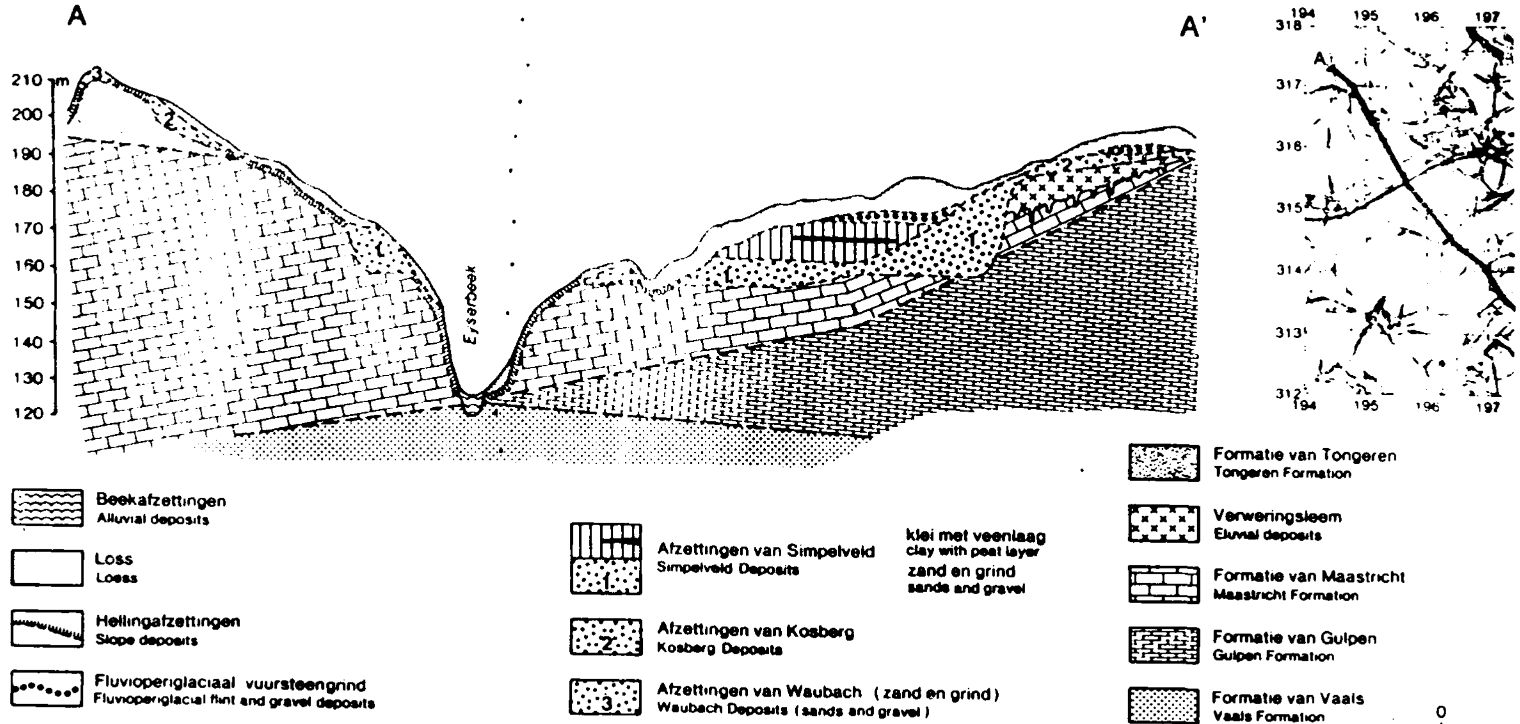
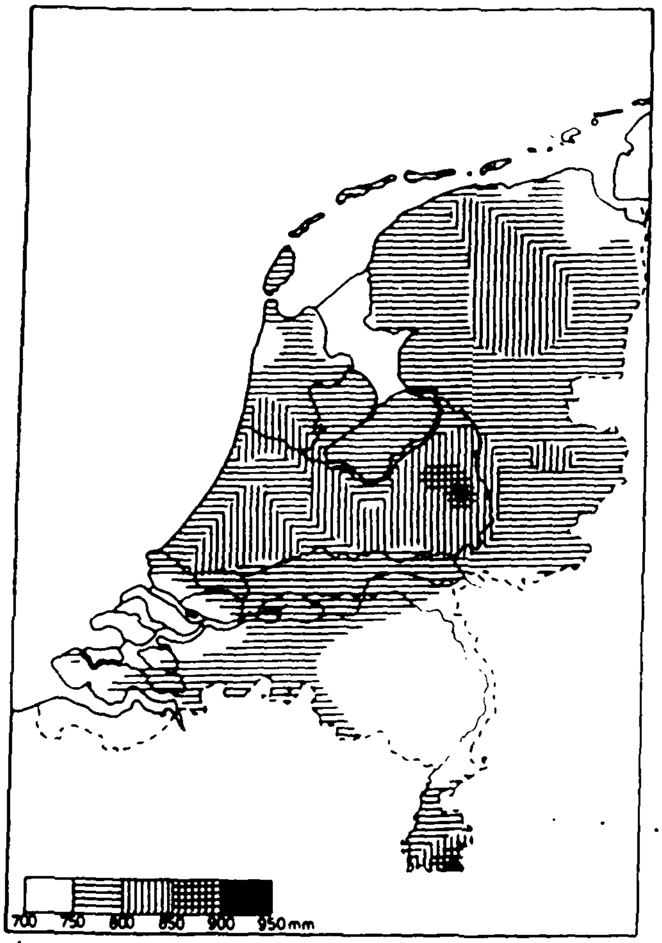


Fig.4. *Geologisch profiel over het dal van de Oost-Maas tussen Ubachsberg en Bocholtz.*

Geological section across the East Maas valley between Ubachsberg and Bocholtz (Source: Kuyl, 1980)



(Source: Buishand en Velds, 1980)

Fig. 5. Normal precipitation in the Netherlands, period 1941-1970. Yearly totals.

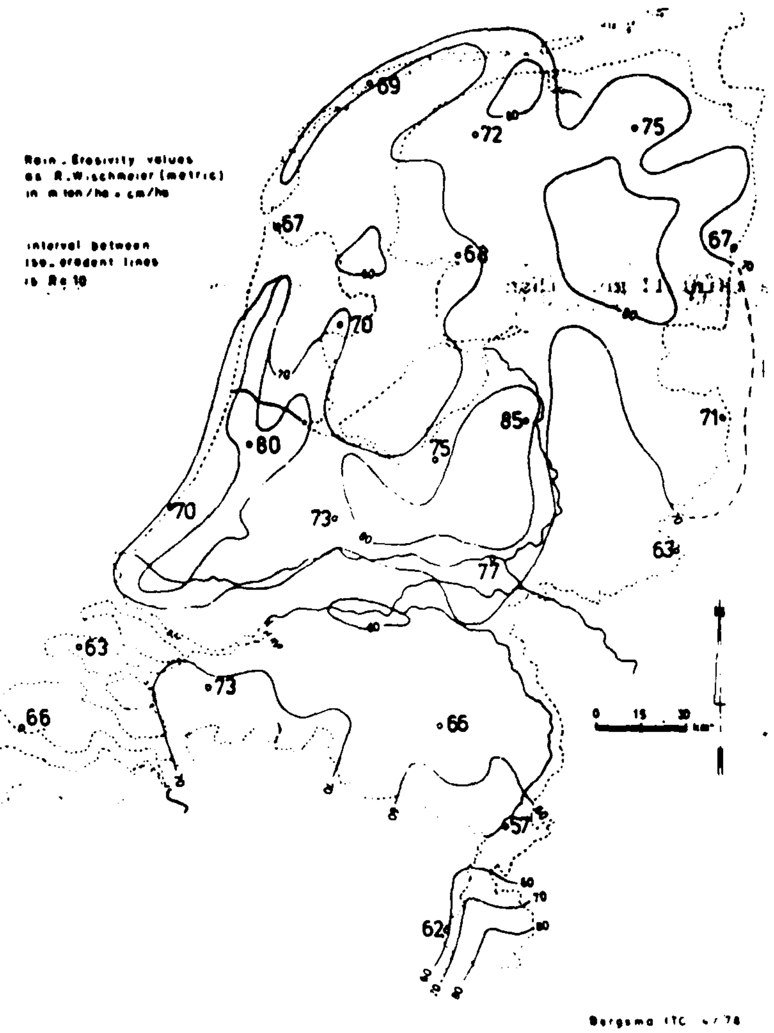
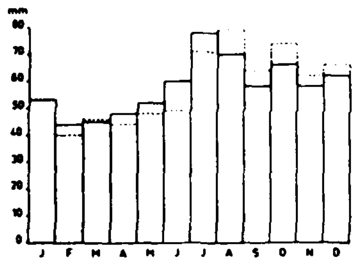


Fig. 6. Rain-erosivity map of The Netherlands. (From Bergsma, 1980)

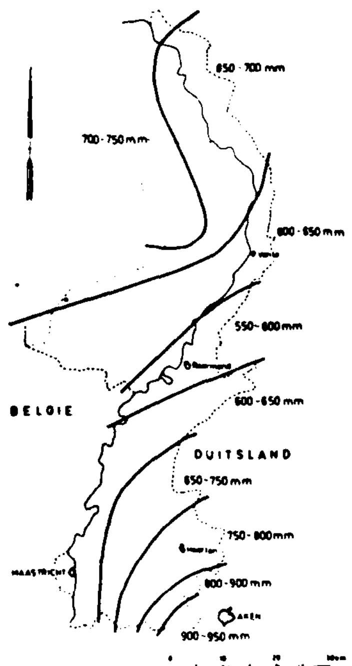
Gemiddelde neerslag in mm per maand in Limburg (naar: Van den Broek en Van der Marel, 1962)

(Average monthly precipitation in Limbourg, mm)



······ **landsgemiddelde** (Mean for the Netherlands)

Gemiddelde jaarlijkse neerslagverdeling in Limburg (naar: Van den Broek en Van der Marel, 1962)
(Yearly distribution of precipitation in Limbourg, mm)



(Source: Van den Broek, 1966)

Fig. 7. Precipitation data for Limbourg.

Fig. 8.

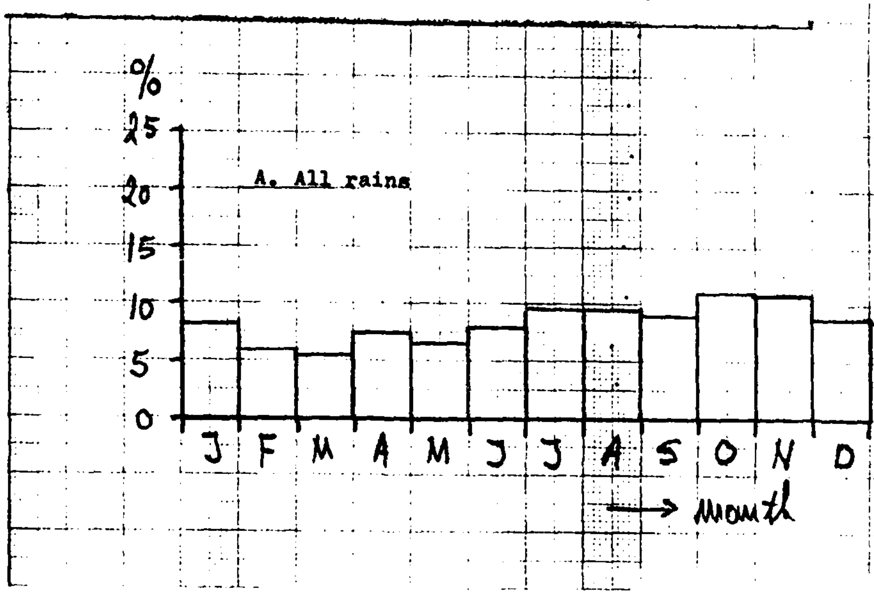
Number and seasonality of rains, heavy rains and very heavy rains in the Netherlands.

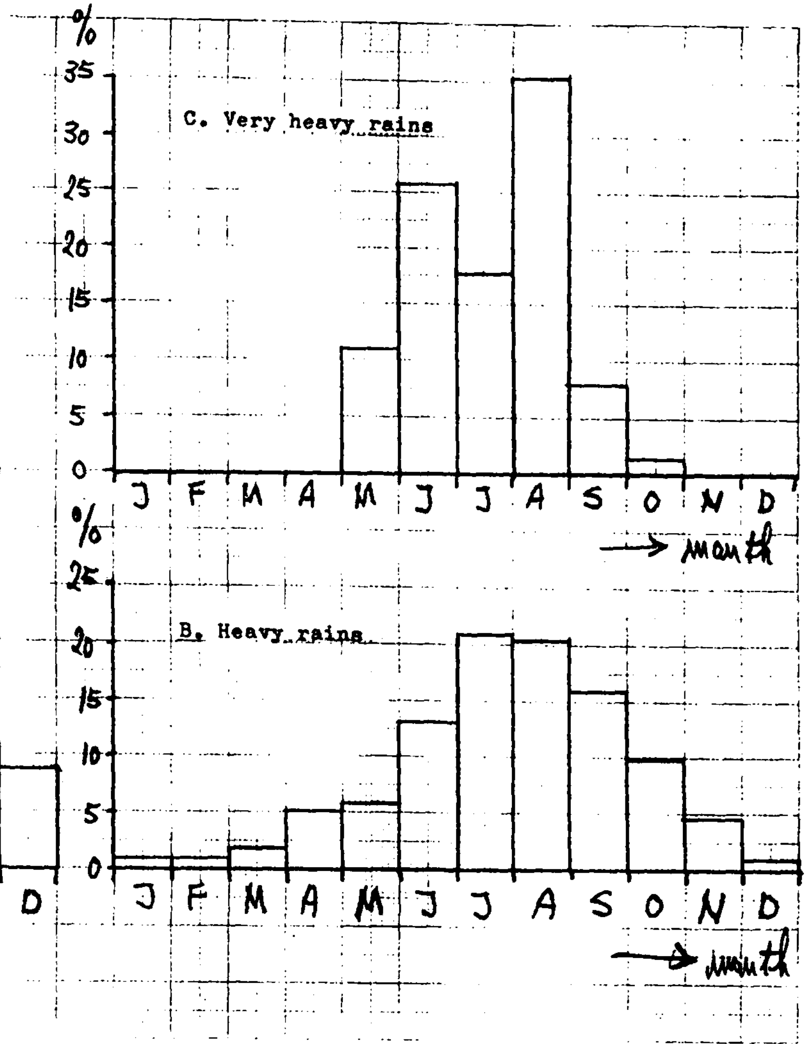
A. Monthly frequency distribution of rains of all intensities (average yearly total number of all rains is 364).

B. Monthly frequency distribution of heavy rains (average yearly total is 34). A heavy rain has an average intensity of 12 mm/hour or more.

C. Monthly frequency distribution of very heavy rains (average yearly total is 1.2). A very heavy rain has an average intensity of 60 mm/hour or more.

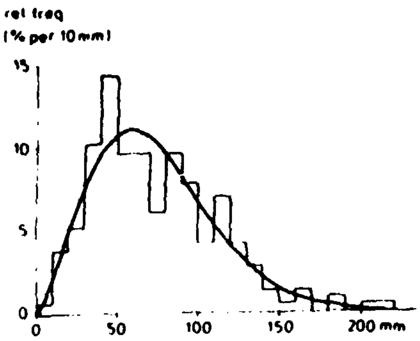
Data for "De Bilt" (after Levert, 1954)





Figuur 9.
Relatieve frequenties van 30-daagse sommen in het zomerseizoen (juni-augustus) voor De Bilt (1906-1977).

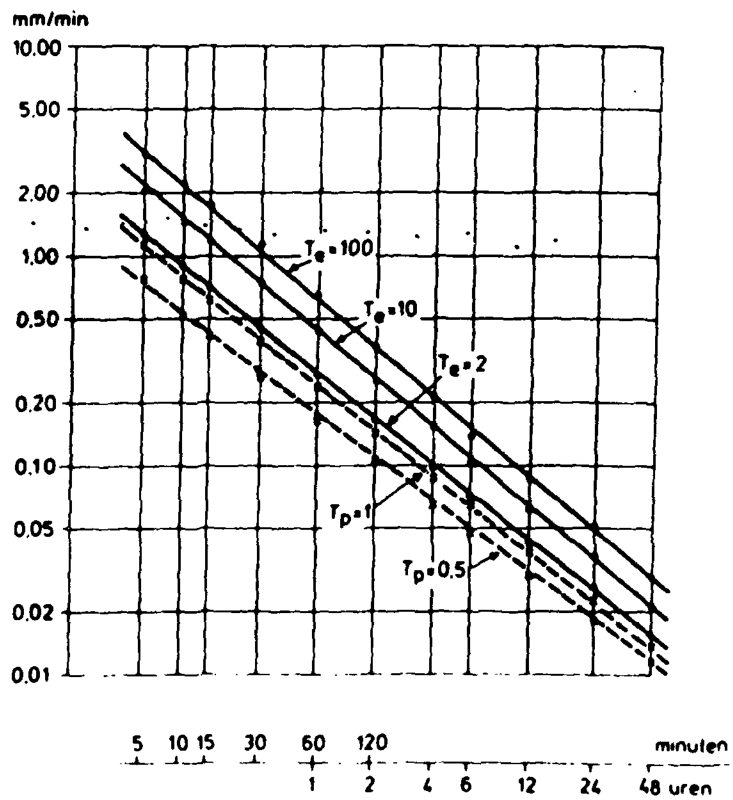
(Relative frequencies of 30-day rainfall amounts during the summer for De Bilt, 1906-1977)



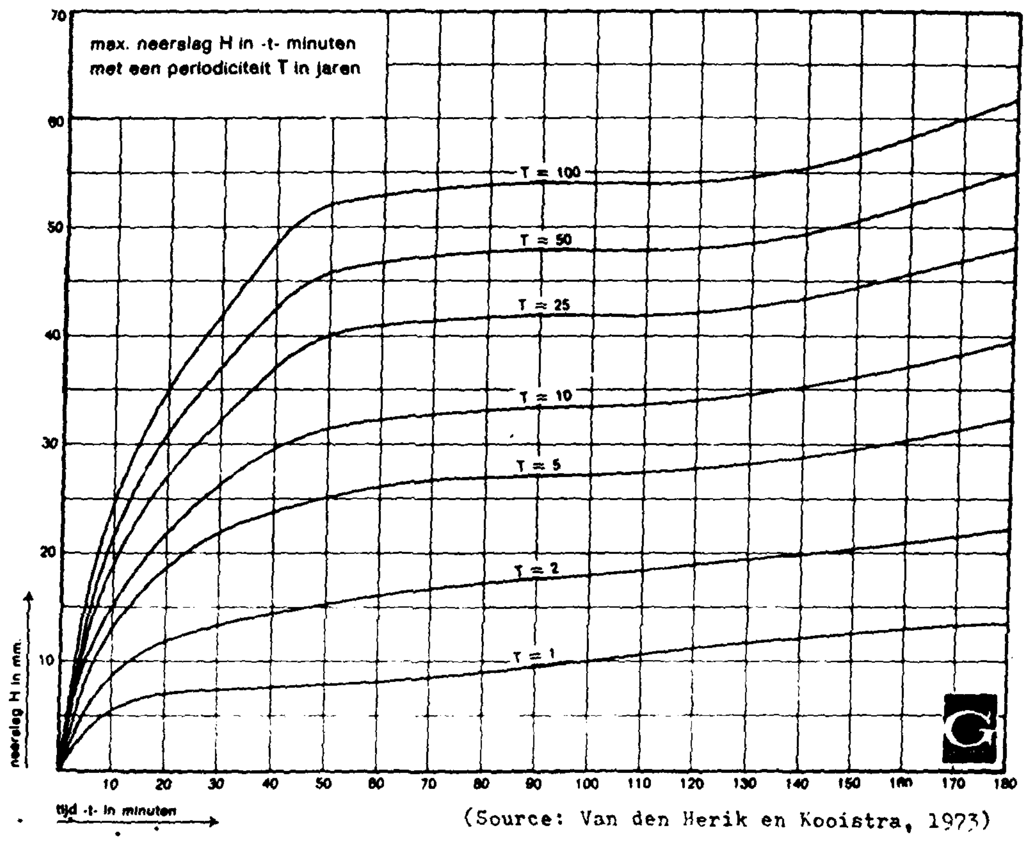
(Source: Buishand en Velds, 1980)

Figuur 10.
Extreme neerslagintensiteiten voor De Bilt (1906-1977) voor duren van 5 minuten tot 48 uren. De herhalingstijden T_p en T_e zijn uitgedrukt in jaren.

(Extreme rainfall intensities for De Bilt, 1906-1977, for durations from 5 minutes to 48 hours; recurrence intervals in years, T_p and T_e)



(Source: Buishand en Velds, 1980)



(Source: Van den Herik en Kooistra, 1973)

Te verwachten maximale neerslag gedurende perioden van 5 tot 180 minuten.

(Expected maximal rainfall amount H in t minutes with recurrence interval T years)

Fig. 11. Amount, duration and recurrence interval of rainfall in the Netherlands.

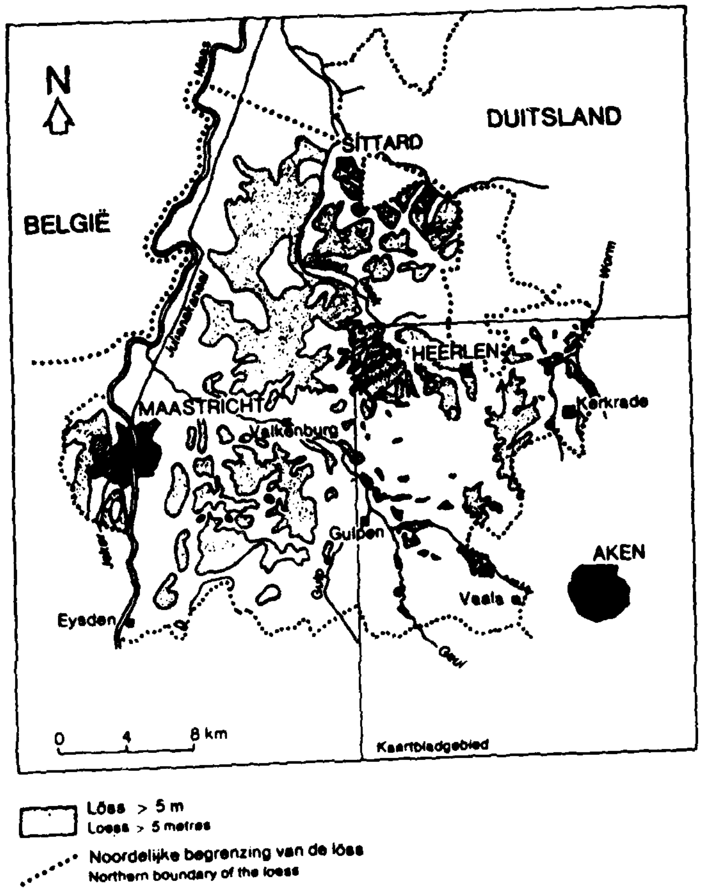


Fig. 12. *Verbreiding en noordelijke begrenzing van de löss in Zuid-Limburg.*
Distribution and northern boundary of the loess in South-Limburg.
(Source: Kuyl, 1980)

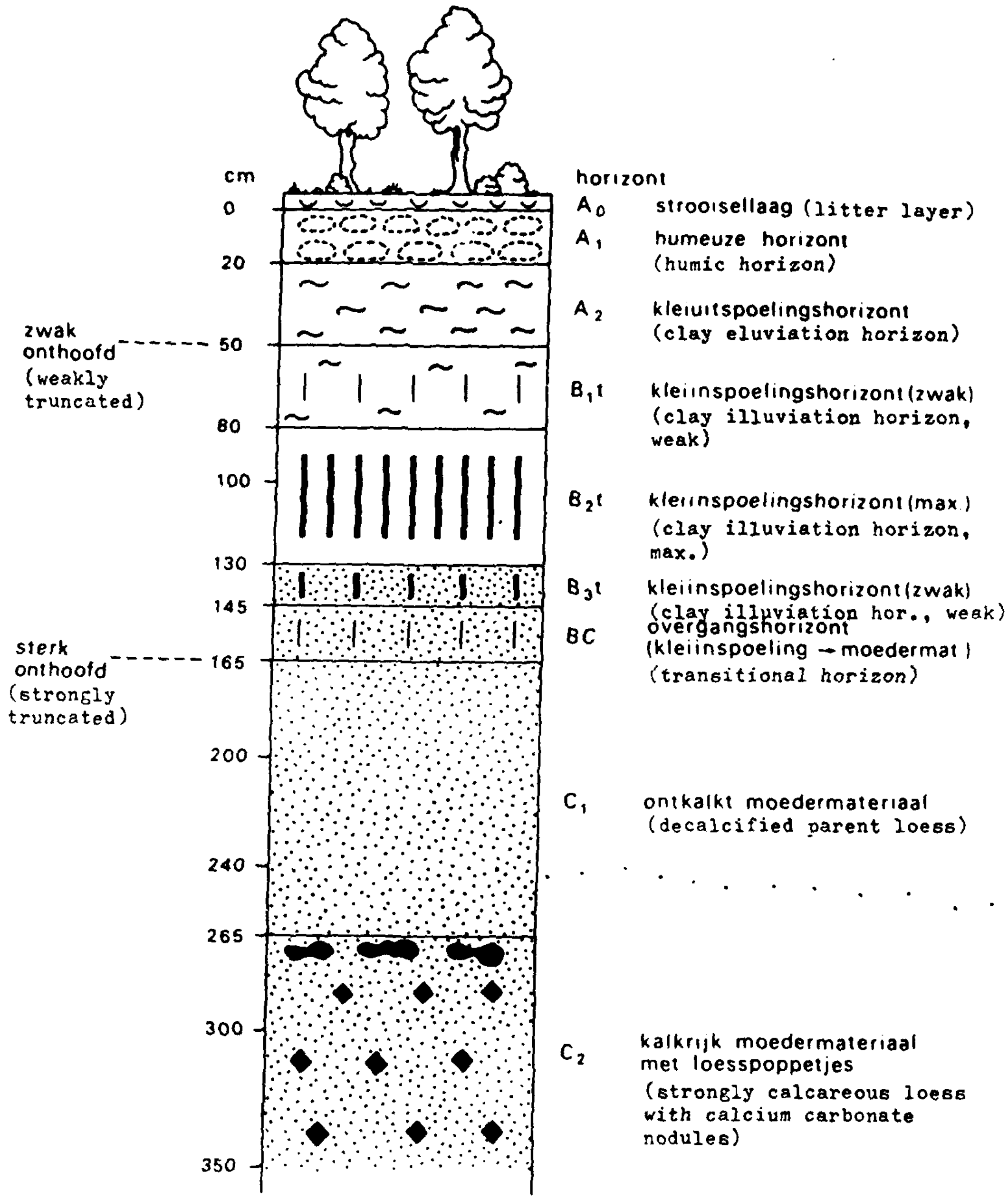


Fig.13. Een volledig ontwikkeld brikgrondprofiel in kalkrijke loess onder bos.
(Completely developed luvisol in calcareous loess under wood.)
K.N.A.G. Geografisch Tijdschrift VII (1973) Nr. 4 (Source: Fücher, 1973)

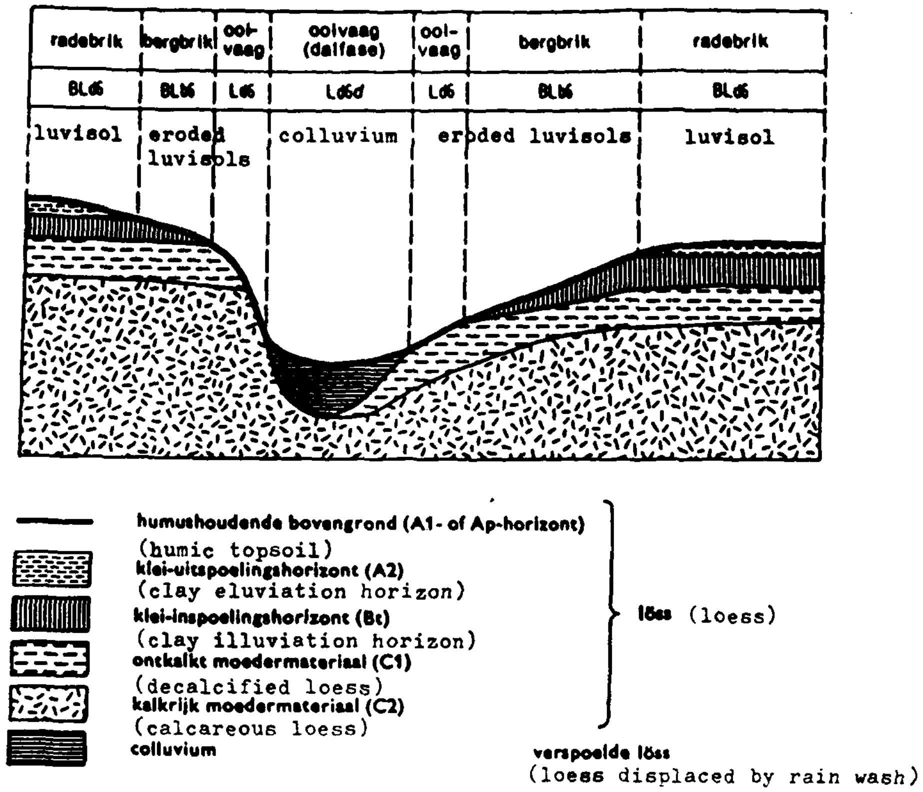
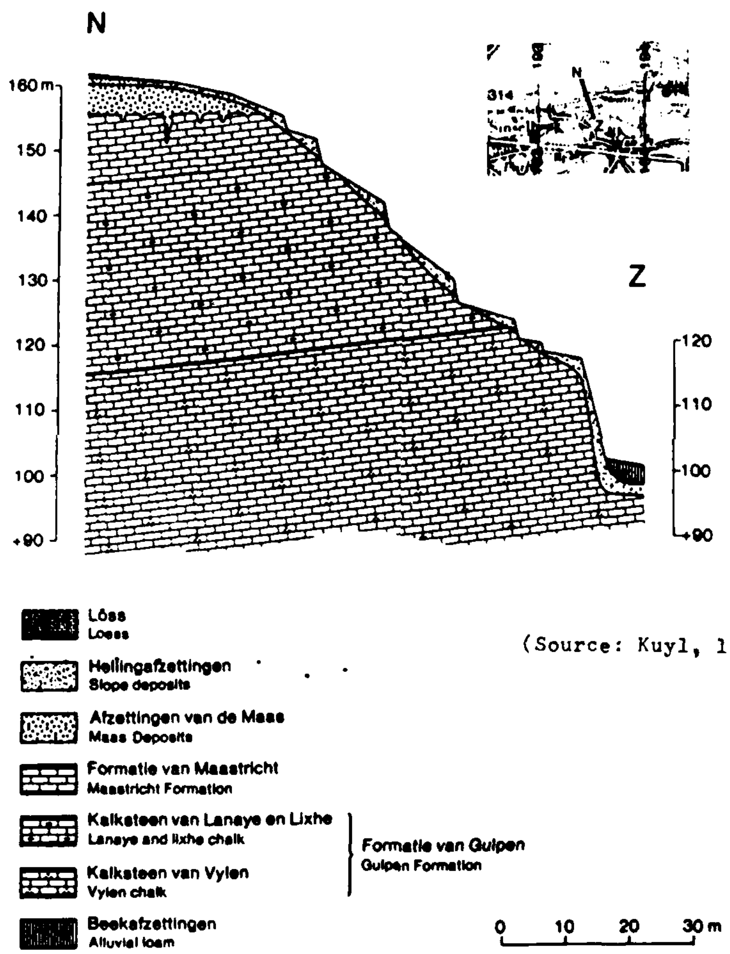


Fig.14. *Ligging van de bodemeenheden in en langs een asymmetrisch dal in het lössgebied, schematisch weergegeven* (Asymmetric dry valley with soil units)
(Source: Stiboka, 1970)



(Source: Kuyl, 1980)

Fig.15. *Profiel over grafien bij Wahlwiller.* (Slope with lynchets)
Section across 'escarpments' near Wahlwiller.

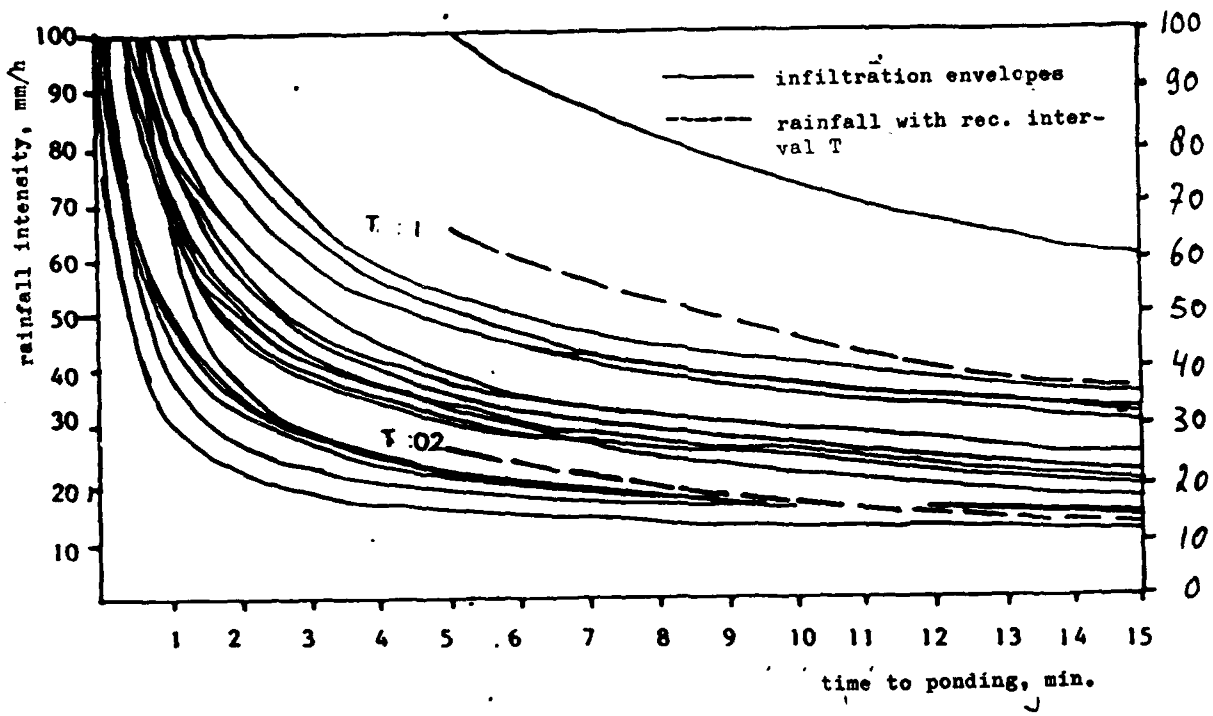
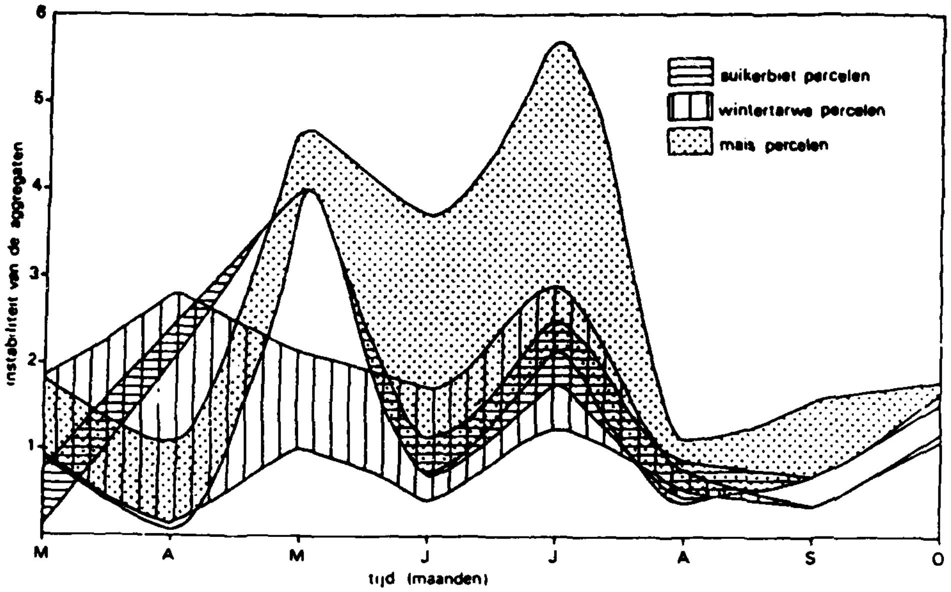


Fig.16. Examples of infiltration envelopes of loess soils in the "Ransdalerveld"- area. (From Van Eijsden, 1986)

. Maandelijkse gang van de instabiliteit van de aggregaten op verschillende landgebruikseenheden. Minimale en maximale waarden van de aggregaatstabiliteitsindex.

The maximum and minimum monthly aggregate stability values obtained for the different crops between March and October.



(Source: Van Eijsden and Imeson, 1985)

Fig. 17. Monthly values of aggregate stability under various crops (sugar beet, winter wheat, maize)

Fig. 18.

Location of sites with soil erosion, flooding and sedimentation in South-Limbourg.

- o sheet erosion
- ♦ linear erosion
- ■ colluviation
- ▲ flooding
- ▬ inundation areas of the rivers Maas and Geul

(Source: Province of Limbourg, 1987)

Tabel 1. Investeringskosten in kapitaalswerken ter preventie van water- en modderoverlast.

	huidige investering	jaarlijkse lasten	geplande investering
Gulpen	10.000	2.000	885.000
Nuth	400.000	80.000	2.000.000
Onderbanken	150.000	8.000	7.000.000
Schinnen	12.000	2.500	50.000
Valkenburg	1.500.000	200.000	2.000.000
Voerendaal	300.000	80.000	300.000
Wittem	4.000	2.000	24.000
Waterschap			
Roer en Overmaas	100.000	200.000	7.500.000
Landinrichtingsd.	ca. 225.000	?	ca. 4.000.000
Totaal	2.476.000	574.000	23.759.000

De jaarlijkse lasten, zoals rente, afschrijving en onderhoud, die gepaard gaan met een investering van meer dan 23 miljoen gulden, zullen waarschijnlijk tenminste 5 miljoen bedragen.
Uit tabel 2 blijkt dat de totale jaarlijkse uitgaven ter bestrijding van de gevolgen van bodemerosie en wateroverlast zwaar op het gemeentelijke budget voor het onderhoud van wegen, waterwegen en riolering drukken.

Tabel 2. Totale jaarlijkse uitgaven ten gevolge van erosie en wateroverlast van een vijftal gemeenten in Zuid-Limburg.

	kosten	% van het budget
Gulpen	f. 200.000 - f. 300.000	onbekend
Nuth	f. 100.000 - f. 150.000	ca. 15
Valkenburg	f. 400.000 - f. 500.000	10 - 15
Voerendaal	f. 100.000 - f. 150.000	5 - 10
Wittem	f. 100.000 - f. 200.000	30 - 40

Een schatting van de totale kosten die in Zuid-Limburg gemaakt worden ter bestrijding van de gevolgen van bodemerosie en wateroverlast en het voorkomen hiervan is niet te maken op basis van de hier gepresenteerde cijfers. De schade zal in werkelijkheid veel groter zijn dan de cijfers suggereren. In het onderzoek zijn slechts 5 van de 23 gemeenten in Zuid-Limburg betrokken. Veel schade aan privé-eigendommen wordt niet geregistreerd en de schadeposten in de agrarische sector zijn in het geheel niet in de berekening opgenomen. Op basis van het indicatieve cijfermateriaal kan de verwachting uitgesproken worden dat de jaarlijkse uitgaven van de gezamenlijke overheden in elke geval vele miljoenen guldens zullen bedragen.

(Costs of off-site damage in some of the municipalities which suffer from erosion and flooding)

(Source: Province of Limbourg, 1987)

Fig. 19. Off-site damage by soil erosion in South-Limbourg.

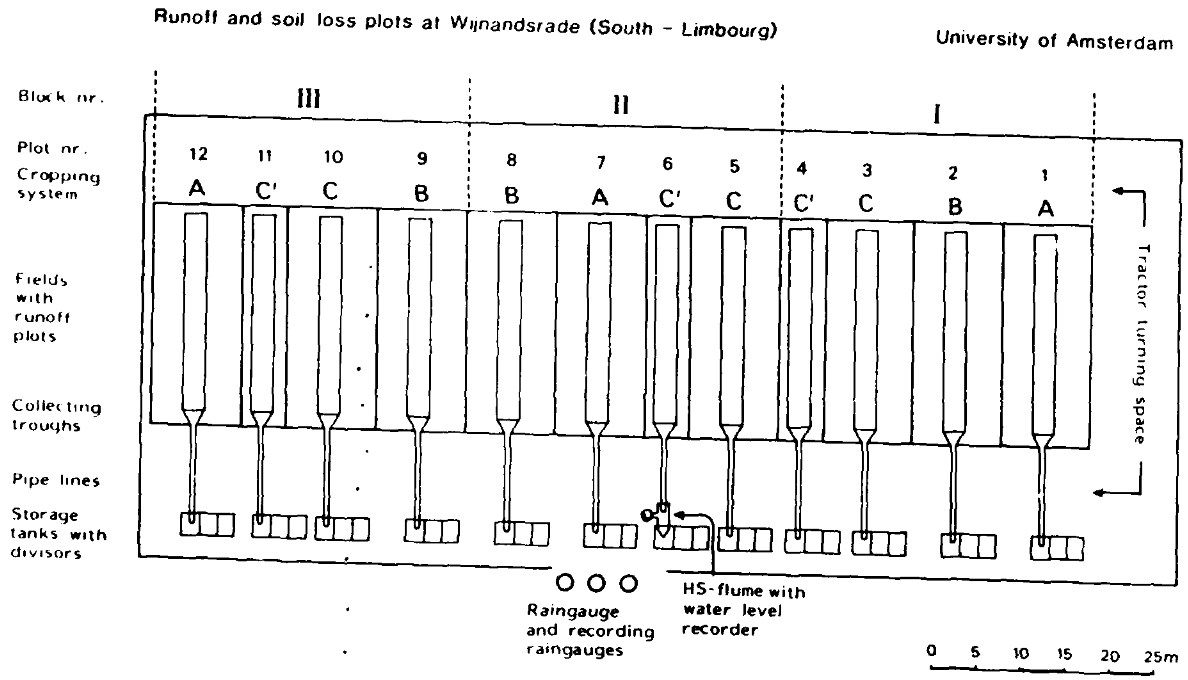


Fig. 20 Lay-out of experimental plots at Wijnandsrade

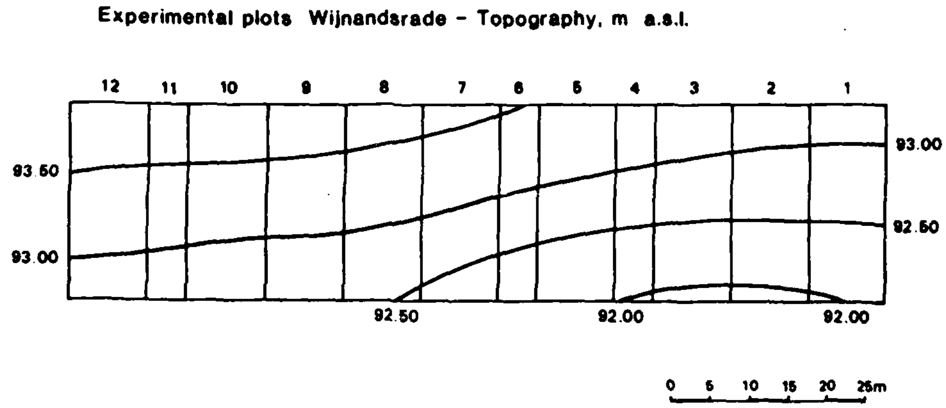


Fig. 21. Topography of experimental plots at Wijnandsrade.

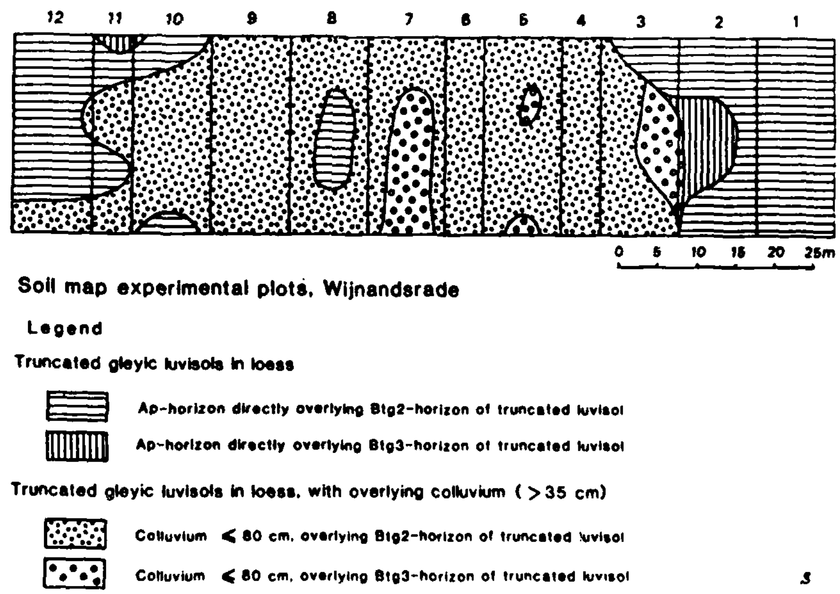


Fig. 22. Soils of experimental plots at Wijnandsrade.

FYSISCH GEOGRAFISCH EN BODEMKUNDIG LABORATORIUM

ONTKALKTE GRANULAIR (FRAKTIES IN % VAN DE MINERALE DELEN)
KWAAD

(Grain size analysis, organic carbon and pH of Ap-horizons of experimental plots, nrs. 1-12, at Wijnanderade)

VOLGNR.	1	2	3	4	5	6	7	8	9	10	11	12
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ORG. C	1.10	1.09	1.07	1.08	1.15	1.04	1.01	1.04	0.98	1.02	1.03	0.86
HUMUS	1.89	1.87	1.84	1.86	1.98	1.79	1.74	1.79	1.69	1.75	1.77	1.48
pH (H2O)	7.70	6.95	6.53	6.74	6.88	6.43	7.49	6.95	6.25	7.11	6.95	7.56
pH (CaCl2)	6.96	6.29	5.68	5.99	6.12	5.62	6.75	6.23	5.45	6.48	6.16	6.80
> 2000 mu	0.13	0.10	0.23	0.26	0.68	0.62	0.14	0.38	0.20	0.10	0.17	0.50
2000-500 mu	0.5	0.7	0.6	0.4	0.6	0.5	0.4	n.B.	0.4	0.3	0.2	0.3
500-150 mu	1.4	1.4	1.3	1.3	1.2	1.1	1.2	n.B.	1.1	1.0	0.8	0.9
150-105 mu	1.5	1.5	1.4	1.4	1.3	1.3	1.3	n.B.	1.1	1.0	0.9	0.9
105-50 mu	2.8	2.7	2.7	2.6	2.5	2.5	2.6	n.B.	2.5	2.6	2.4	2.2
50-16 mu	65.2	65.3	66.6	66.3	68.0	66.9	66.8	65.9	66.1	66.0	65.4	64.9
16-2 mu	14.8	15.2	14.9	15.2	14.6	15.1	15.4	15.3	15.5	15.5	15.3	13.9
<2 mu	13.8	13.3	12.6	12.7	11.8	12.5	12.3	12.8	13.4	13.7	15.0	16.9
ZAND	6.2	6.2	5.9	5.7	5.6	5.5	5.5	6.0	5.1	4.9	4.3	4.3
SILT	80.0	80.5	81.5	81.6	82.6	82.0	82.2	81.2	81.6	81.5	80.7	78.8
KLEI	13.8	13.3	12.6	12.7	11.8	12.5	12.3	12.8	13.4	13.7	15.0	16.9
SOM *)	101.0	100.5	101.4	101.5	105.7	100.9	101.6	100.0	101.6	100.2	101.8	101.3

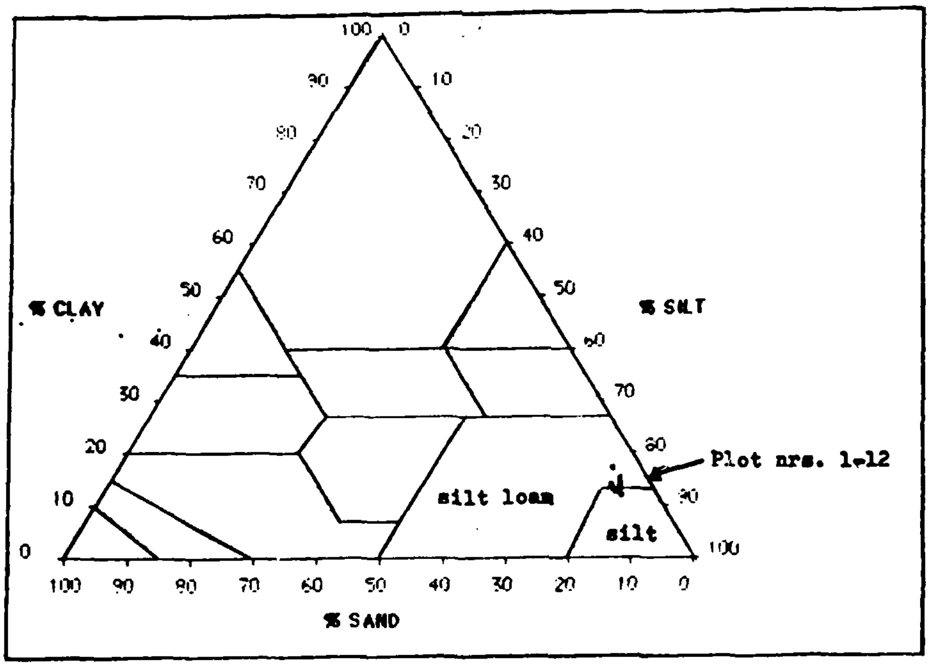


Fig. 23.
Texture of Ap-horizons of experimental plots at Wijnanderade
(Analysis by FGBL, University of Amsterdam)

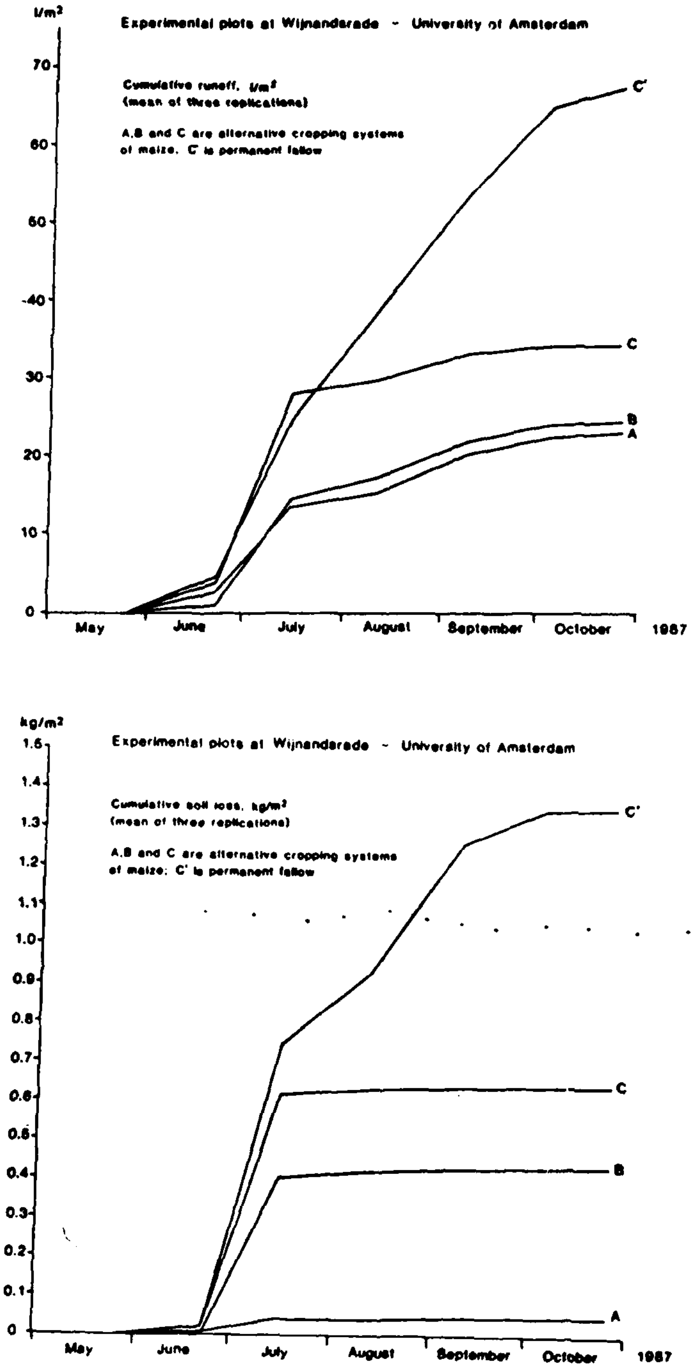


Fig. 24. Cumulative runoff and soil loss from experimental plots at Wijnandsrade during the growing season of 1987 (total rainfall 419.8 mm)

EXCURSION SOUTH-LIMBURG, 28-04-88, BENELUX COLLOQUIUM

MODELLING SOIL EROSION IN THE CATSOP WATERSHED

A. P. J. de Roo [1]

Introduction

On the löss-derived soils in South-Limburg (the Netherlands) soil erosion and the inconvenience of water are rising problems, causing damage not only to farmers, but mainly to civilians and the local government. Besides, ecological valuable areas are affected by penetrating amounts of polluted water. On long term the fertile löss-cover will locally disappear causing a substantial reduction of the agricultural potential.
Due to these problems, there is much interest at present in quantitative techniques to estimate the amount of runoff and soil erosion from watersheds, not only from the scientific world, but also from the regional and local government.
Information is needed by planners about the best possible locations for erosion control measures. One of the most useful tools that can be employed when planning control measures for soil erosion is an accurate, comprehensive watershed model capable of simulating all effects of proposed and/or applied control measures (Beasley, 1986).

Developments in erosion modelling

In modelling soil erosion there has been a shift from models calculating soil erosion on a single slope (such as the basic USLE) towards models estimating soil erosion and sedimentation within watersheds. Besides there is a shift from parametric models - such as the USLE and SLEMSA (Stocking, 1981) - towards deterministic models - such as CREAMS (Knisel, 1980) and ANSWERS (Beasley & Huggins, 1982).
Parametric or stochastic models, are based on a statistical analysis of important factors in the soil erosion process and yield only approximate and probable outcomes. Deterministic models try to describe the erosion proces with physical-mathematical relationships and yield precise and certain outcomes (Hammond & McCullagh, 1980).
The deterministic models are seperated in 'lumped' and 'distributed' models.
'Lumped' models, such as CREAMS, describe an overall or average response of the watershed (Beasley, 1986). Because of the spatial variability of the erosion process, these models often do a less than adequate job of describing the physical situation.
A distributed parameter model attempts to increase the ac-

[1] Institute of Geographical Research,
University of Utrecht, the Netherlands.

curacy of the resulting simulation by preserving and utilizing information concerning the areal distribution of all spatially variable, non-uniform processes incorporated into the model. These models have a potential for providing a more accurate simulation of natural catchment behaviour. They have an ability to simultaneously simulate conditions at all points within a watershed. In recent years, the distributed approach has become practicable as a result of the introduction of Geographical Information Systems and the continuing rapid improvements in the size, speed and general availability of modern computers.

The model ANSWERS

All processes and variables involved in soil erosion show more or less some spatial variation. This is the main reason why geographical information systems, with its tools such as creating digital elevation models (DEM's) resulting in altitude, slope and aspect maps, data storage and retreival in for example the Map Analysis Package (MAP), geostatistical interpolation techniques and display of spatial data, are very useful in erosion modelling (Burrough, 1986). Distributed parameter models cannot be optimally utilized without the presence of a well constructed GIS environment.
At present, the distributed parameter model ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation), developed by Beasley et al. (Beasley & Huggins, 1982), is used for modelling surface runoff and soil erosion.

The model ANSWERS is intended to simulate the bahaviour of watersheds having agriculture as their primary landuse, during and immediately following a rainfall event. Its primary application is planning and evaluating various strategies for controlling pollution from intensively cropped areas.

A watershed to be modelled is assumed to be composed of square elements. Values of variables are defined for each element:

- landform:	- slope;
	- aspect;
- soil:	- total porosity (percent volume);
	- field capacity (percent saturation);
	- antecedent soil moisture content;
	- steady state infiltration rate;
	- potential maximum infiltration rate;
	- infiltration control zone depth;
	- erodibility factor (USLE "K");
- landuse:	- percentage covered by crop;
	- potential interception capacity;
	- erosiveness factor (USLE "C"*"P" factor);
- surface:	- surface roughness coefficient;
	- maximum roughness height;
	- Manning's n;
- channels:	- width;
	- Manning's n;
- other:	- groundwater release fraction;
	- presence of Best Management Practices;
	- drainage coefficient for tile drains;

A rainfall event is simulated with increments of one minute. The continuity equation is used to accomplish the composite response of the single elements. The output of upslope elements becomes the input of downslope elements. Several physically-based mathematical relationships are used to describe interception, infiltration, surface retention, drainage, overland flow, channel flow, subsurface flow, detachment by rainfall and/or overland flow and sediment-transport by overland flow (interrill erosion). The global structure of the model is explained in the relational diagram (figure 1) and described below.

After rainfall begins, some is intercepted by the vegetal canopy until such time as the interception storage potential is met. When the rainfall rate exceeds the interception rate, infiltration into the soil begins. Since the infiltration rate decreases in an exponential manner as the soil water storage increases, a point may be reached when the rainfall rate exceeds the combined infiltration and interception rates. When this occurs, water begins to accumulate on the surface in micro-depressions.

Once surface retention exceeds the capacity of the micro-depressions, runoff begins. The accumulated water, when in excess of surface retention capacity, produces surface runoff and is termed surface detention. Subsurface drainage begins when the pressure potential of the groundwater surrounding a tile drain exceeds atmospheric potential. A steady-state infiltration rate may be reached if the duration and intensity of the rainfall event are sufficiently large.

When rainfall ceases, the surface detention storage begins to dissipate until surface runoff ceases altogether. However, infiltration continues until depressional water is no longer available. Subsurface drainage continues as long as there is excess soil water surrounding the drains. The long recession curve on the outflow hydrograph is then produced. Slowly falling recession limbs are also produced by interflow, the emergence of groundwater into the surface drainage network.

Soil detachment and transport can both be accomplished by either raindrop impact or overland flow. Detachment by rainfall occurs throughout a storm even though overland flow may not occur. Thus, most of the soil particles detached prior to flow initiation are deposited and to some extent, reattached. Detachment of soil particles by overland flow occurs when the shear stress at the surface is sufficient to overcome the gravitational and cohesive forces of the particles. Whether or not a detached soil particle moves, however, depends upon the sediment load in the flow and its capacity for sediment transport (Beasley & Huggins 1982).

When water and sediment reach an element with a channel, they are transported to the watershed outlet. Sedimentation within a channel appears when the transport capacity has been exceeded.

It is clear from the above description of the model that a lot of detailed information is needed for the simulation. A

large element-file is to be created with information of the single elements. The element-files for the simulations by Beasley et al. were created by hand. When the number of elements amounts several hundreds or even thousands, this is not only time consuming, but it is also not very user-friendly. When for instance the response of a watershed with a different kind of landuse is to be evaluated, the element-file has to be totally revised by hand.
With the introduction of Geographical Information Systems progress is made with the input and handling of spatial information (Burrough, 1986). Contour maps can be digitized and transformed to maps of slope, aspect, concavity/convexity and potential streamlines of runoff. Maps of soil, landuse, hydrology and planned measures can be digitized and stored in a map-database. With a package such as MAP it is possible to compare each map and to create overlays. At the University of Utrecht (the Netherlands) several computer programs have been written in which maps from the MAP-database are converted to an element-file used in the model ANSWERS. With the techniques available in GIS, it is possible to produce revised element-files, with for instance a different landuse or conservation measures, within a few hours. Besides it is possible to use very large element-files, so the watershed can be simulated with more detail.
Another advantage of using GIS are the possibilities of data display. Using a modified version of the ANSWERS model, developed at the University of Utrecht, several maps can be produced showing the spatial pattern of soil erosion, sedimentation and runoff at specified times. These maps can be compared by subtraction, resulting in maps of change of for instance erosion or sedimentation after the introduction of certain control measures within the watershed.

The Catsop watershed

Models of the type described above are of limited value until they have been validated using appropriate data. The validation of the ANSWERS model for löss-soils in the Netherlands is presently carried out.
In 1987, a study has been carried out in a watershed of 42.7 hectares near Catsop (Stein, Limburg, the Netherlands).
The Catsop research is meant to provide some information on possible erosion control measures. Besides it is meant to provide data for the validation of the ANSWERS-model. The validation of the model is carried out by measuring soil- and landuse-characteristics, precipitation, runoff and sediment-concentration in the runoff. The impact of possible erosion control measures was assessed by several simulations using data partly derived from several erosion-studies, partly carried out in Limburg (Daniels & Groeneveld 1986, Groeneveld & Daniels 1985, Bolline et al. 1978, De Ploey 1986).

The drainage area has a gently to moderately sloping topography with an average slope of 5.7 %. Approximately 0.5 % is steeper than 15 %. The soils are löss-derived and consist mainly of silt loam. 98.7 % of the landuse in the area consists of agriculture, with 10.7 % grasslands and 88.0 % row crops. The row crops consist of predominantly wheat (44

% in 1987), potatoes (20 %) and sugarbeets (12 %).
The watershed was modelled by constructing 4275 elements of 10 m. square (0.01 ha.). An element-file which described the topography of the watershed as it existed in march 1987 was constructed as a baseline condition. A Digital Elevation Model (DEM) was constructed by digitizing a contour map, which was rastered to 10 * 10 cells (figure 2). Maps of slope and aspect were derived from it. Data of soil, landuse, management and channel descriptions were entered. The landuse-map was digitized and rastered. Each cell was given an attribute. For the ease of simulation only 2 soil-types were defined: soils under row-crops and soils under grassland or forest. Channels and management-practices were also digitized and rastered. These maps were transformed to an ELEMENT-file of the ANSWERS-structure by a specially developed computer-program called TOELEMENT. Further data on soils and landuse were entered in the PREDATA-file.
The used data for the simulations are listed in table 1.

Table 1. Soil- and landuse-variables used for simulation.

variable	code	value for fallow	value for grassland	value for forest
total porosity (%)	TP	45	45	45
field capacity (%)	FP	60	60	60
antecedent soil moisture (%)	ASM	70	70	70
steady state infiltration (mm/h)	FC	7.0	30.0	30.0
maximum infiltration - FC (mm/h)	A	45.0	100.0	100.0
exponent in inf. equation (-)	P	0.65	0.65	0.65
infiltration control zone (mm)	DF	90	100	100
soil erodibility USLE "K" (-)	K	0.50	0.50	0.50
potential interception (mm)	PIT	0.0	0.4	2.0
crop coverage (%)	PER	0	95	90
roughness coefficient (-)	RC	0.40	0.50	0.55
maximum roughness height (mm)	HU	60	45	100
Manning's n · land-surface (-)	N	0.08	0.12	0.15
erosiveness (USLE C*P) (-)	C	0.76	0.01	0.01

The only available validation-data for the Catsop watershed prior to the simulations were from a rainfall-event in november 1984, when 28.5 mm fell in 36 hours. The measured runoff was 1700 m^3, against a runoff simulated by ANSWERS of 1578 m^3, a difference of 7.2 %. Measurements of soil-loss are much more difficult, but the simulated soil-loss of 300 kg/ha is realistic. In 1987, additional data were collected for the validation of the model. These data are presently handeled.
In order to evaluate some erosion control mesures, and determine the best possible locations for them, several land-use scenario's were developed. The following scenario's were used for the Catsop watershed:

1. BASELINE — Landuse and management as in march 1987. 88.0% of the surface is simulated as fallow with crop residuals, 10.7% as grassland and 0.5% as "graften", which are forrested terrace-borders on slopes.

2. FALLOW — The grassland is converted to fallow land with crop residuals, and the "graften" are removed.
3. GRASSLAND — All fallow land is converted to grassland.
4. CONTOURING — The fallow land is ploughed on the contour.
5. GRAFTEN — At several locations, graften are constructed as forrested flat terraces.
6. CONTOUR-GRASS-STRIPS Strips of grass, constructed on the contour, are left unploughed between bands of cropped land. This erosion control measure is a standard option in ANSWERS: the Best Management Practice no. 4).

The landuse in the scenario's is listed in table 2.

Table 2. Landuse within the different scenario's.

scenario	% fallow	% grassland	% graften	% other
BASELINE	88.0	10.7	0.5	0.8
FALLOW	100.0	0	0	0
GRASSLAND	0	98.7	0.5	0.8
CONTOURING	88.0	10.7	0.5	0.8
GRAFTEN	86.1	10.2	2.9	0.8
GRASS-STRIPS	83.8	14.9	0.5	0.8

The ANSWERS-model was runned several times with the following rainfall-events of different magnitude:

- 1: 28.5 mm rain within 36 hours (once a year);
- 2: 17.0 mm rain within 20 minutes (once in 5 years);
- 3: 19.9 mm rain within 20 minutes (once in 10 years);
- 4: 23.6 mm rain within 20 minutes (once in 25 years);
- 5: 26.8 mm rain within 20 minutes (once in 50 years);
- 6: 29.8 mm rain within 20 minutes (once in 100 years).

By simulating these rainfall-events it could be determined how the watershed possibly will react under normal and extreme conditions. The results of the simulations of the 28.5 mm event are summarized in table 3.

Table 3. Simulation results for several scenario's for the Catsop watershed for event no. 1.

scenario	runoff (m^3)	%	average soil loss (kg/ha)	%	max. runoff (l/s)	%
BASELINE	1300	-	194	-	92	-
FALLOW	1498	+15.2	316	+62.9	101	+ 9.5
GRASSLAND	813	-37.5	0	-100.0	5	-94.1
CONTOURING	*		160	-17.5	*	
GRAFTEN	1253	- 3.6	188	- 3.1	78	-15.4
GRASS-STRIPS	914	-29.7	56	-71.1	28	-69.2

The results for the simulations under more extreme conditions - a rainfall-event once in 25 years - are summarized in table 4.

Table 4. Simulation results for several scenario's for the Catsop watershed for event no. 4.

scenario	runoff (m^3)	runoff %	average soil loss (kg/ha)	average soil loss %	max. runoff (l/s)	max. runoff %
BASELINE	4083	-	1403	-	709	-
FALLOW	4518	+10.7	1899	+35.4	731	+ 3.1
GRASSLAND	1014	-75.2	2	-99.9	31	-95.7
CONTOURING	*		1061	-24.4	*	
GRAFTEN	3962	- 3.0	1352	- 3.6	*	
GRASS-STRIPS	3330	-18.4	728	-48.1	493	-30.5

From these results it can be concluded that the CONTOURING scenario is effective in reducing soil erosion, but it's effects on runoff are not clear from these simulations. The CONTOUR-GRASS-STRIPS scenario is effective both for runoff and soil erosion. Especially the maximum runoff is decreasing spectacular. Under extreme conditions, it's effectiviness is decreasing. The GRAFTEN-scenario is not as effective as expected, mainly due to the ineffective choice of the locations. The GRASSLAND scenario reduces soil erosion to zero and minimizes the surface runoff.

Using several GIS-tools, maps of soil erosion and sedimentation can be derived from the ANSWERS-model (figure 3 and 4). At the University of Utrecht a special version of the ANSWERS-model has been developed from which maps of surface runoff on several times during the simulation can be derived (figure 5 and 6). With this tool, it can be determined where, when and how many surface runoff appears within the watershed. Standard output of the model is the hydrograph (figure 7).

Conclusions

With the ANSWERS model it is possible to simulate surface runoff and soil erosion from watersheds having agriculture as their primary landuse.
Because the distributed character of the model, the use of Geographical Information Systems is very practicable.

ANSWERS has several advantages over older models such as the USLE. Some of these are:
- the potential increased accuracy of predicting runoff and erosion;
- the use of physically-based mathematical relationships;
- the capacity to incorporate new developed component relationships;
- the incorporation of the spatial variability of land characteristics;
- the ease of validation, compared with the USLE, because it deals with individual rainfall-events;

- the detailed spatial displayed output of the model, useful for planners because the effectiveness of potential control measures can be evaluated.

Disadvantages of ANSWERS are:
- the process of subsurface flow is not well defined;
- gully erosion is left out of the present version of the model, just like erosion in channels;
- the equation to describe infiltration needs some adaptation, specially the definition of the infiltration control zone depth;
- the quantity of necessary input-data and the related costs of data acquisition can possibly be a problem.

From the present available validation data it is concluded that the simulation-results from the ANSWERS model can be used quantitatively concerning runoff, but for now only qualitatively concerning soil erosion and sedimentation. The model can be helpfull to determine the best possible locations for erosion control measures.

The validation of the model is only possible when detailed measurements of the input-variables are carried out within the watershed. A rainfall event of about 20 mm or more is needed for validation in order to reduce the error of simulation. Only with detailed measurements of rainfall-intensity, runoff and sediment concentration, the output of the model can be validated properly. Since these events are not taking place frequently, the validation of this model for the löss-soils will take some years.

REFERENCES

BEASLEY, D.B. (1986), Distributed parameter hydrologic and water quality modelling.
In: GIORGINI, A. & F. ZINGALES (eds.) (1986), Agricultural Nonpoint Source Pollution: Model selection and application. Developments in Environmental Modelling 10. Elsevier Science Publishing Company Inc., Amsterdam New York.

BEASLEY, D.B. & L.F. HUGGINS (1982 ANSWERS - User's manual, Dept. of Agr., Eng., Purdue University, West Lafayette, In.

BOLLINE, A., G. HANOTIAUX & A. PISSART (1978), L'érosion en milieu agricole. Pédologie, vol. 28, no. 2, p 141-144.

BURROUGH, P.A. (1986), Principles of Geographical Information Systems for Land Resources Assessment.
Monographs on soil and resources survey no. 12, Clarendon Press, Oxford.

DANIELS, P.J.M. & D.A. GROENEVELD (1986), Simulaties van afstroming en erosie in löss-gebieden m.b.v. CREAMS.
Geografisch Instituut, Rijksuniversiteit Utrecht.

FERRARI, Th.J. (1978), Elements of system-dynamics simulation. Pudoc, Wageningen.

GROENEVELD, D.A. & P.J.M. DANIELS (1985), Korstvorming, doorlaatbaarheid en infiltratiecapaciteit bij lössbodems in Zuid-Limburg.
Geografisch Instituut, Rijksuniversiteit Utrecht.

HAMMOND, R. & P.S. MCCULLAGH (1980), Quantitative techniques in geography. An introduction. Second Edition.
Clarendon Press, Oxford.

KNISEL, W.G. (ed.) (1980), CREAMS: A field scale model for Chemicals Runoff and Erosion from Agricultural Management Systems. US. Dept. Agric., Conservation Research Report no. 26.

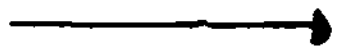
DE PLOEY, J. (1986), Bodemerosie in de lage landen. Een Europees milieuprobleem. Acco, Amersfoort.

STOCKING, M. (1981), A working model for the estimation of soil loss suitable for underdeveloped areas.
Development Studies Occasional Paper No. 15, University of East Anglia, UK.

WISCHMEIER, W.H. & D.D. SMITH (1978), Predicting rainfall erosion losses - A guide to conservation planning.
Agricultural Handbook 537. Science and Education Administration, USDA, Washington D.C.

Figure 1. Relational diagram of the ANSWERS model.

legend (after Ferrari, 1978):



Stream or flow and direction of an action by which the amount is changed.

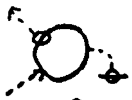
Storage; integral of the flow.

Valve which indicates that a decision takes place here.

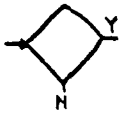
Source and sink of quantities whose content is not important.

Stream or flow and direction of information.

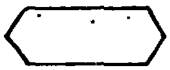
A constant or a parameter.



Auxillary equation, which is part of a decision function.



Decision.

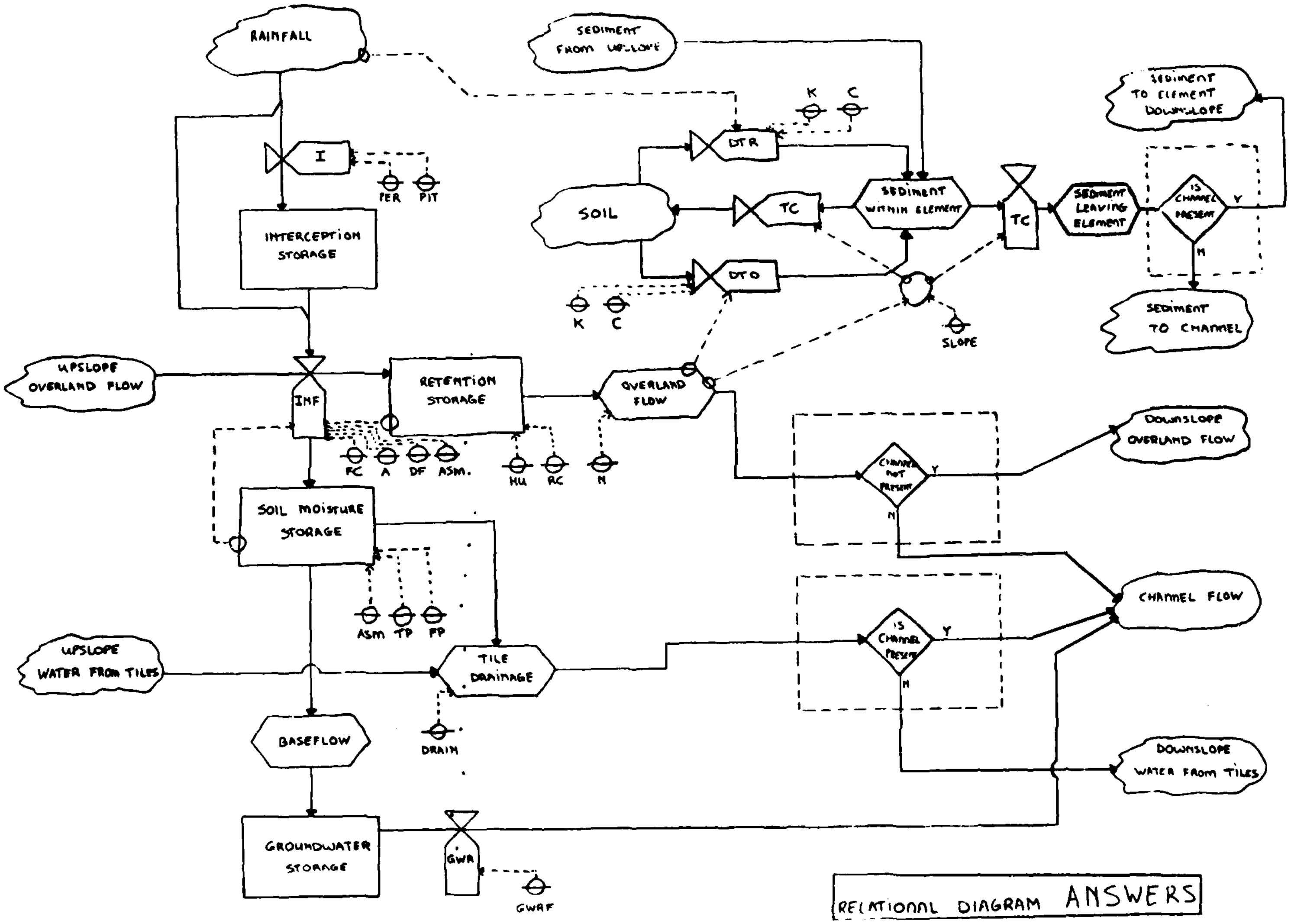


Quantity in transport.

TP = total porosity	PER = percentage cover
FP = field capacity	PIT = potential interception
FC = steady st. infiltration	C = erosiveness factor
A = maximum infiltration	RC = surface roughness coef.
DF = control zone depth	HU = max. roughness height
ASM = antecedent soil moist.	N = Manning's n
K = erodibility factor	

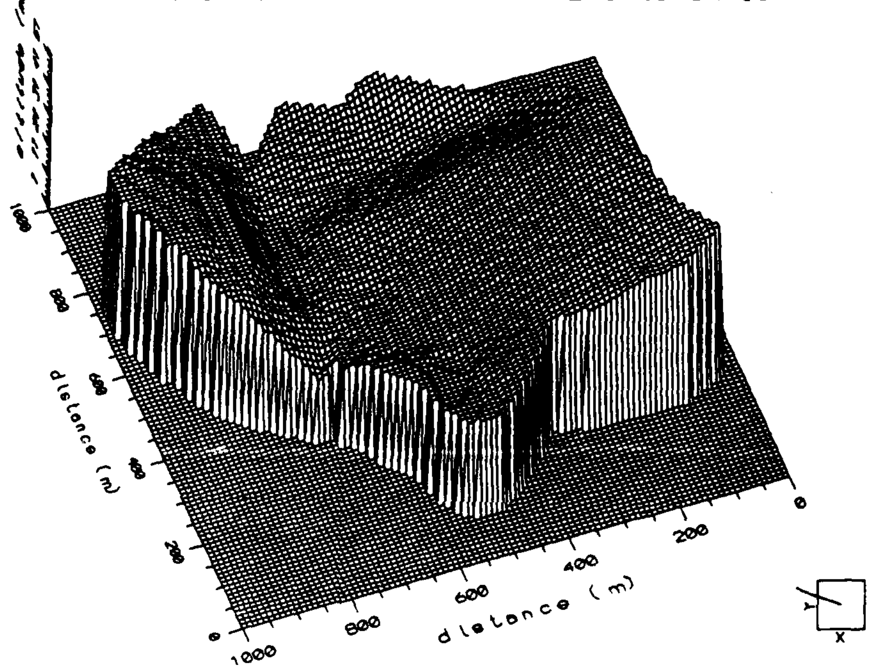
DRAIN= drainage coefficient for tile drains
GWRF = groundwater release fraction

DTO = detachment by overland flow
DTR = detachment by rainfall
I = interception
INF = infiltration
TC = transport capacity

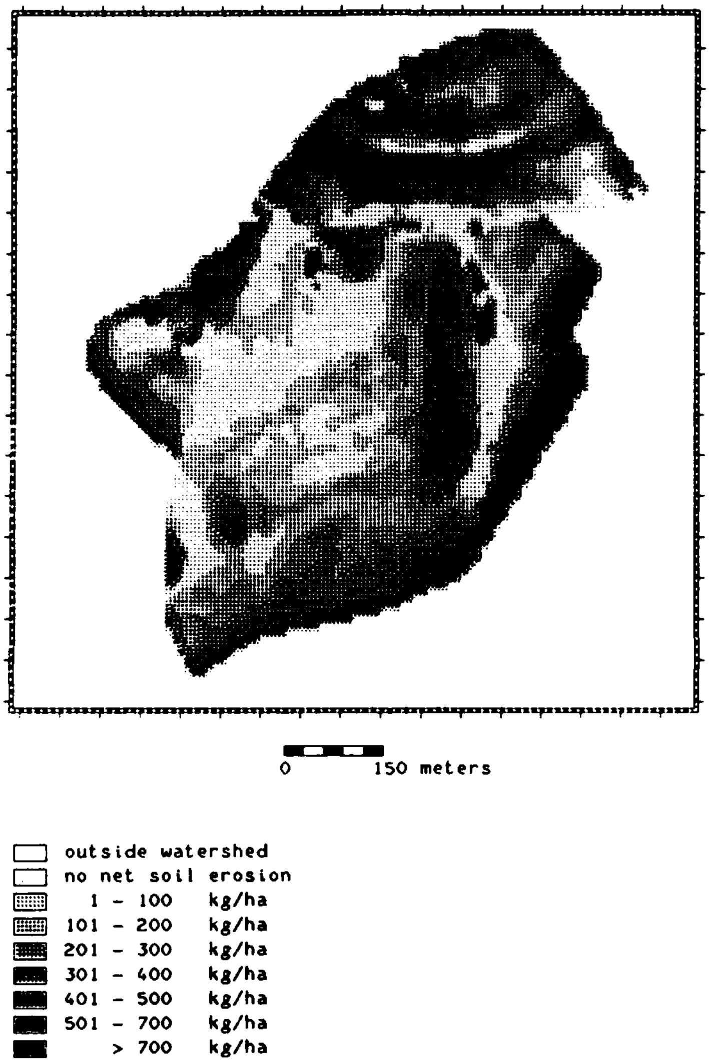


RELATIONAL DIAGRAM ANSWERS

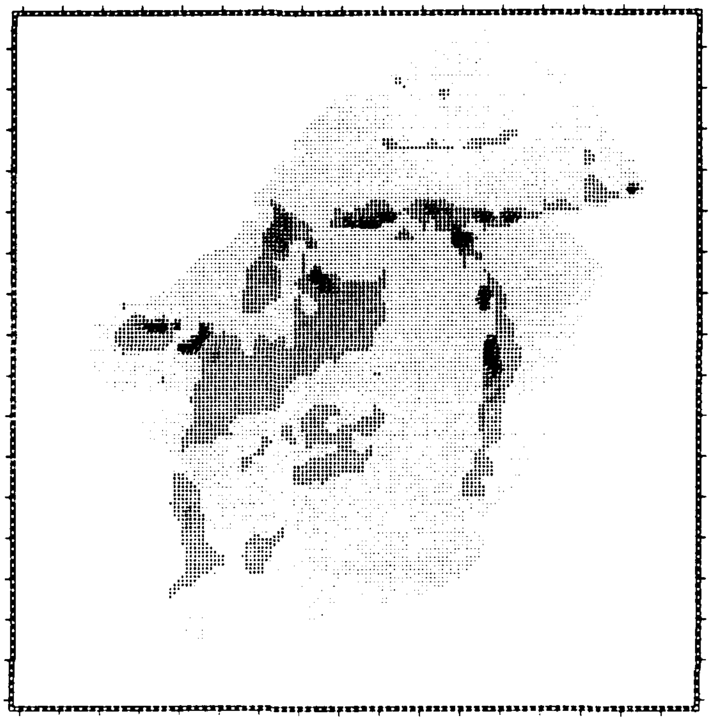
DIGITAL TERRAIN MODEL WATERSHED CATSOP



NET SOIL EROSION AFTER 20 MM. RAINFALL, CATSOP (LIMBURG)



NET SEDIMENTATION AFTER 20 MM. RAINFALL, CATSOP (LIMBURG)



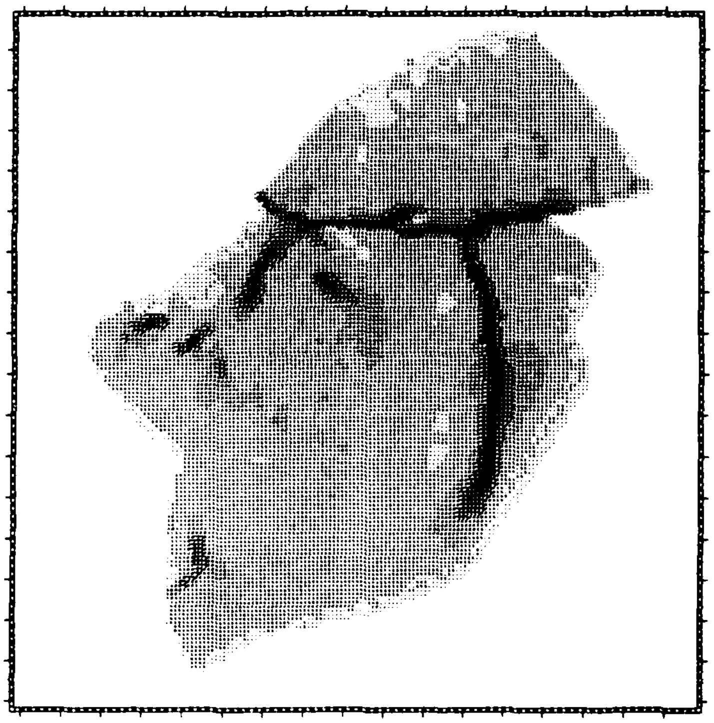
0 150 meters

- outside watershed
- no net sedimentation
- 0.0 - 0.5 ton/ha
- 0.5 - 1.0 ton/ha
- 1.0 - 1.5 ton/ha
- 1.5 - 2.0 ton/ha
- 2.0 - 2.5 ton/ha
- > 2.5 ton/ha

RUNOFF AFTER 25 MINUTES, CATSOP (LIMBURG)

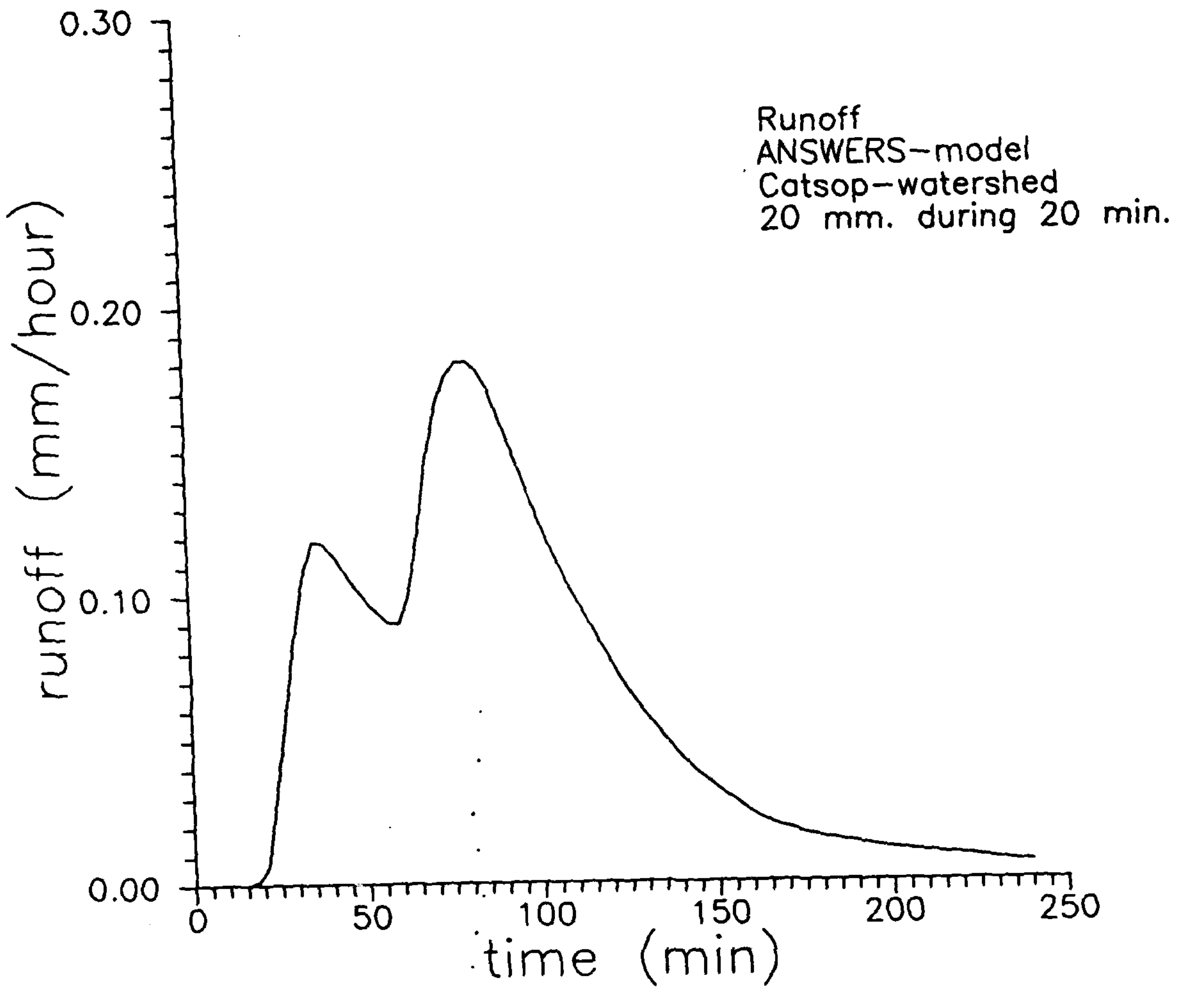
☐	outside watershed
☐	no runoff
▒	0.1 - 0.5 l/s
▒	0.6 - 1.0 l/s
▓	1.1 - 1.5 l/s
▓	1.6 - 2.0 l/s
█	2.1 - 3.0 l/s
█	3.1 - 4.0 l/s
█	> 4.0 l/s

RUNOFF AFTER 40 MINUTES, CATSOP (LIMBURG)



0 150 meters

	outside watershed
	no runoff
	0.1 - 0.5 l/s
	0.6 - 1.0 l/s
	1.1 - 1.5 l/s
	1.6 - 2.0 l/s
	2.1 - 3.0 l/s
	3.1 - 4.0 l/s
	> 4.0 l/s


Runoff
ANSWERS−model
Catsop−watershed
20 mm. during 20 min.
runoff (mm/hour)
0.30
0.20
0.10
0.00
0
50
100
150
200
250
time (min)

PRIMARY LOESS RIDGES IN HASPENGOUW

(Eastern Belgium)

by E. PAULISSEN
K.U.Leuven

South of the region the Kempen (Fr. La Campine),characterized by a continuous thin mantle of coversands, is situated the rolling topography of the Haspengouw region (Fr. La Hesbaye), mainly characterized by a continuous loess cover and a dense network of dry valleys, especially south of the river Jeker (Fr. Geer).

Haspengouw shows good exemples of linear topography (Figure .1) with ridges and valleys aligned with great regularity.
There are two systems with a linear topography/
AREA 1: a large area with a general S-N aligned system developed on a general topography dipping to the north.The aligned system is particularly developed south of the river Jeker. In this region,the loess is situated directly on cretaceous limestone and tertiary sands.
AREA 2: a relatively small area in the east with a general ENE-WSW alignment on a general topography also dipping to the north.

In Haspengouw, much attention is paid to the dry valleys especially concerning their asymmetry (a.o. Geukens,1947;Grimbérieux,1954) and their origin (a.o. Stevens,1934;Geukens,1947;Tavernier,1948).Generally these valleys are thought to be eroded by water erosion either before or after the loess under periglacvial circumstances. According to Grimbérieux(1954),the latter hypothesis was corraborated by the fact that dry valleys of area 1, south of teh Jeker are formed completely in the loess deposits (if so, only in their upstream sections - note of the writer). Pissart(1976) mentions a M.D. study by Planck who tested the hypothesis that teh linear alignment of teh dry valleys in area 1 could be the result from the primary deposition of loess,constructing the original topography resembling the "gredas" described by Rozycki (1967) in BUlgary and Central Europe.According to Pissart(1967) further studies were necessary to solve the problem. The hypothesis of an eolian origin of the linear topography in loess areas has been advocated already by Russell(1929,,by Lewis(1960) and by Bartkowski(1973).

Detailed geomorphological mapping in Haspengouw in the area north of the Jeker gave us the opportunity to study the influence of the loess deposits on the actual morphology.

In area 2(Fig. .1), with ridges and depressions aligned in a ENE-WSW direction, the loess deposits are thick(mean thickness estimated at 5m). In this area, situated immediately south of the continuous loess border, the loess deposits are situated on a substrate of different lithologies: on soft limestone (Cretaceous,to teh E of Tongeren),on Oligocene Sands and on gravel deposits of the river Maas(Fr. Meuse) develoepd in a large meander bend (west of Maastricht). IN this bend three terrace levels are distinguished (Halet,1932). These terraces are limited by scarps with a general S-N orientation. This original terrace landscape of teh Maas, generally dipping to the north, has been drastically changed by the loess:

- the S-N oriented terrace landscape became a ENE-WSW linear topography with two ridges and three depressions.
- all actual forms are build up entirely on loess deposits, except for the downstream valley ends near the Maas north of Maastricht;
- the main original landscape elements like the Southern meander border and and the terrace scarps remain however visible as gentle sloes on the individual ridges.

A complete ridge-depression catena had been studied on the youngest Maas terrace in this area(the Caberg-Pietersem Terrace, Paulissen1973).

Figure .2 summarizes the construction of this catena. The typical calcareous Brabantian loess(Gullentops,1954) forms the ridge and rests on on a small core of Hesbayan loess (both loess deposits are Weichselian in age).

From the field evidence we conclude for the existence of primary loess ridges or gredas in Haspengouw formed during the Late Weichselian. It is likely to consider these loess ridges as longitudinal forms constructed by ENE-winds (Paulissen,1981).

Since our study in Haspengouw, D. Gossens(1987) studied in detail the sedimentation of loess in a wind tunnel on scale models and compared these results with a detailed field survey south of Leuven where he demonstrated the presence of importent loess accumulations on a teriary substrate.

Figure .1 - Map of the drainage system in Haspengouw (Eastern belgium).

1. Rivers - 2. Axes of dry valleys
3. Terrace escarpments
4. Delimitation of area II, with a WSW-ENE drainage system. On the Maas terraces, this alignment is due to primary loess sedimentation. In the rest of area II with a tertiary and cretaceous substrate structural elemnts play a role in the WSW-ENE alignment of some valleys, but the loess accumulation accentuates the ridge topography.

Figure .2 - A ridge-depression catena of a primary loess ridge in Haspengouw(Veldwezelt,between lanaken and Maastricht; 5°38'45"E, 50°52'45"N).

1. truncated Holocene alfisol
2. Dark tongued horizon of the Kesselt soil(Gullentops,1954)
3. Anthropogenic colluvium
4. Lat-Weichselian silt and sand deposits,horiozntally bedded
5. Brabantian loess (Weichselian)
6. Hesbayen loess (Weichselian)
7. Gravel and coarse sands of the Maas terrace Caberg-Pietersem (Paulissen,1973)

The difference in heigth between ridge and depression is 6m, formed by a 2% slope.

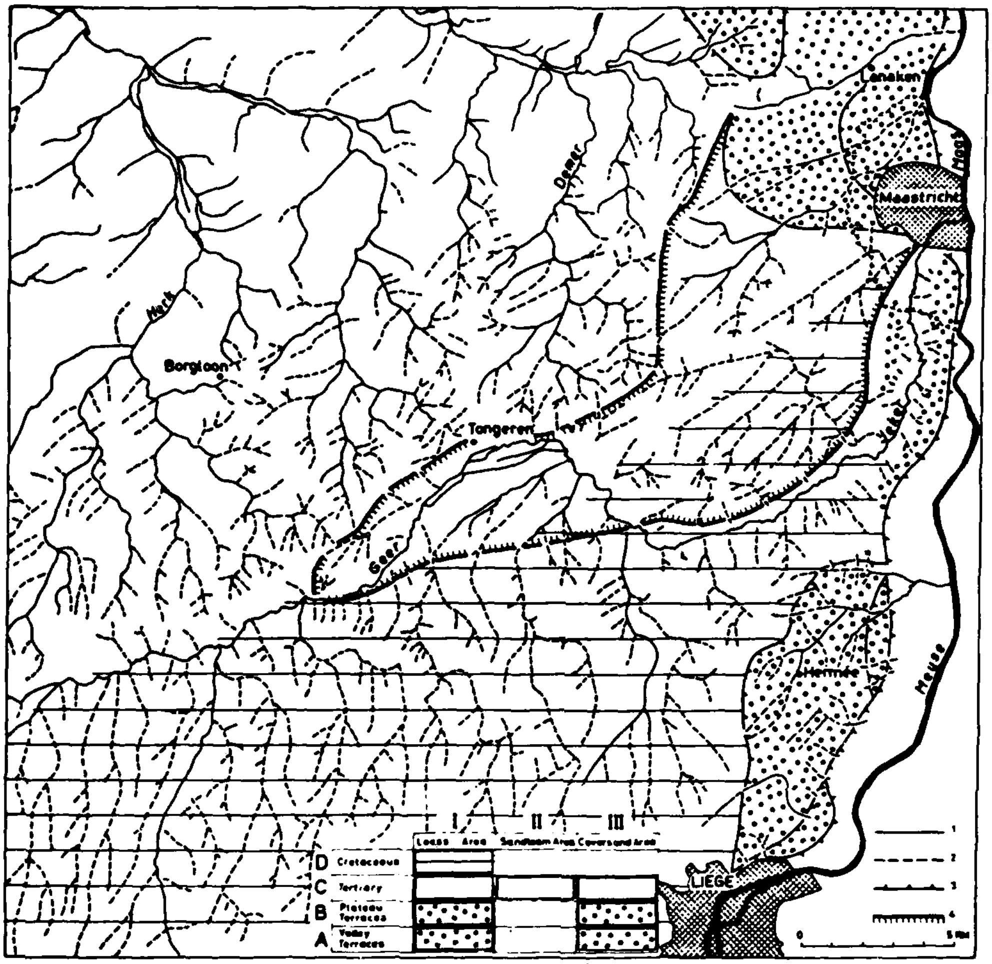

Lanaken
Maas
Maastricht
Demer
Herk
Borgloon
Tongeren
Geer
Meuse
LIEGE
I
II
III
Loess Area
Sandloam Area
Coversand Area
D Cretaceous
C Tertiary
B Plateau Terraces
A Valley Terraces
1
2
3
4
0
5 km

fig. 1

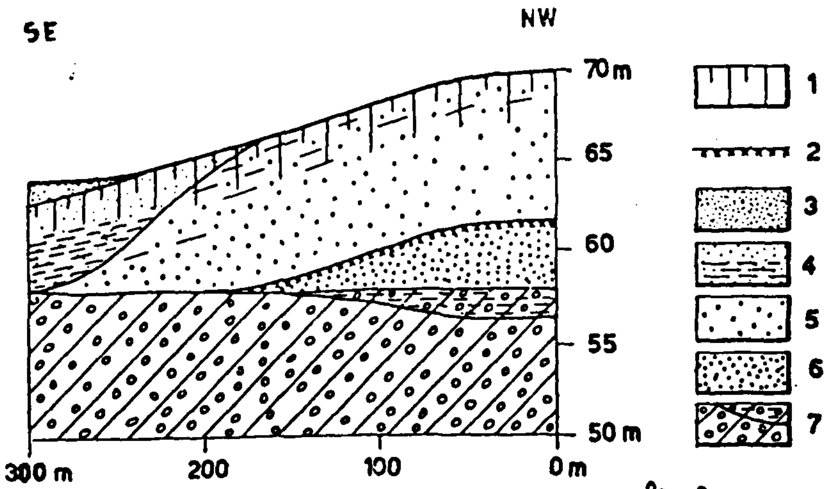
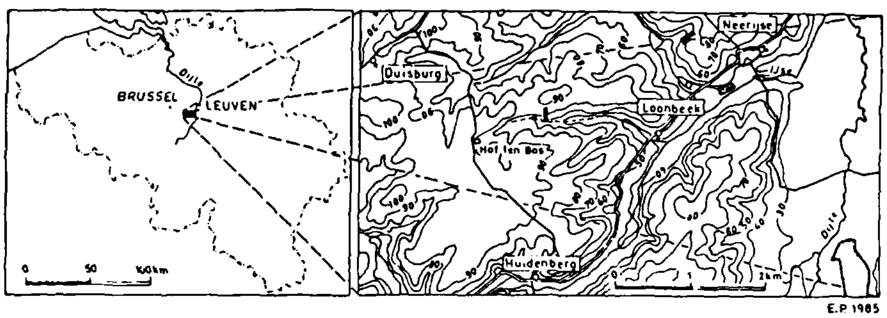

SE
NW
70 m
65
60
55
50 m
300 m
200
100
0 m
1
2
3
4
5
6
7

fig. 2

Benelux Colloquium
on
Geomorphological
Processes

Fig. 0.1 Situation of the Huldenberg area



GEOMORPHOLOGICAL PROCESSES AND SOIL

Excursion

Soil erosion and erosion control

Experiments in Brabant, Belgium

30th April 1988

0. INTRODUCTION

This excursion will focus attention on various aspects of present and historical soil erosion in the Belgian Loam Region. Three or four sites will be visited, which are all located SSW of Leuven, in the Dijle catchment (fig. 0.1). Some climatological data of this area are given in fig. 0.4. The excursion stops are :

- The Neerijse quarry (fig. 0.3) : historical erosion

- The Huldenberg experimental site (fig. 0.2) : actual and historical erosion processes

- The Moreels farm (situated 1 km NW of the Neerijse quarry): soil conservation

- Optionally, the Ormendael catchment : gully erosion and control

Several people collaborate in the field projects of the Laboratory of Experimental Geomorphology and will give explanations on their respective research subjects :

- Prof. J. De Ploey : general project leader, soil conservation
- Dr. H. Mücher (Amsterdam) : micromorphology
- Dr. E. Paulissen : historical erosion and colluviation
- Dr. J. Poesen : interrill erosion, gravel transport, gully control
- Dr. G. Govers : interrill erosion, rill erosion, soil conservation
- Drs. L. Van Elewyck : erosion by stemflow

Additional help in analysis and interpretation was provided by Prof. A. Munaut (Louvain la Neuve : pollen analysis) and Dr. B. Campbell (Sydney : ^{137}Cs datings). Technical assistance is provided by Eng. J. Meersmans and L. Cleeren.

G. Govers

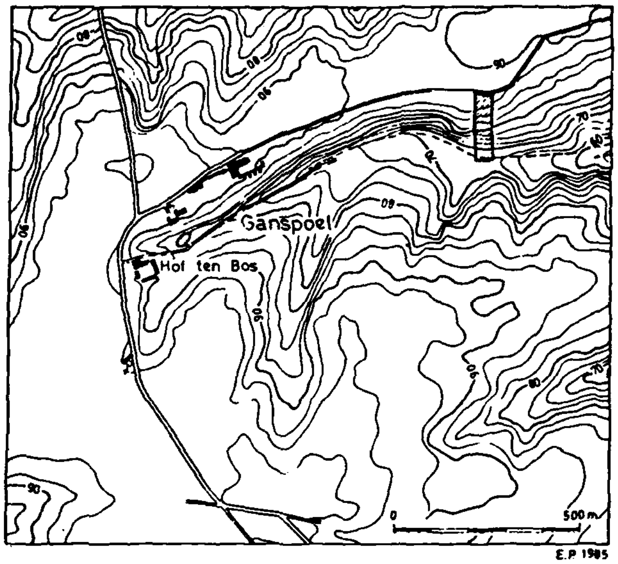


Fig. 0.2 Topography of the Ganspoel valley with the location of the Huldenberg experimental field

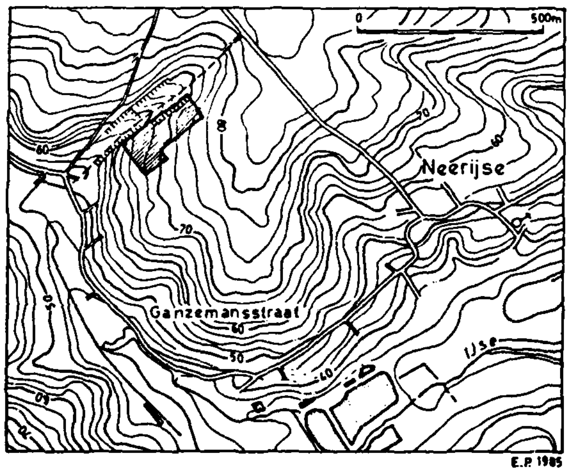


Fig. 0.3 Location of the Neerijse quarry

CLIMATE

-Air temperature (Ukkel Brussels)
- -yearly mean = 9.5°C
- -mean of coldest month (January) = 3.0 °C
- - mean of warmest month (July) = 17.0 °C

-Period without frost (Ukkel)
- - mean = 194 days/year
- - maximum = 236 days/year (1913)
- - minimum = 154 days/year (1928)

-Frost period (Ukkel)
- -frost starts on 05/11 (extremes : 06/10/12 and 06/12/13)
- -frost ends on 25/04 (extremes: 14/03/20 and 15/05/15)

-Wind
  see wind rose for Melsbroek (Brussel Nationaal)

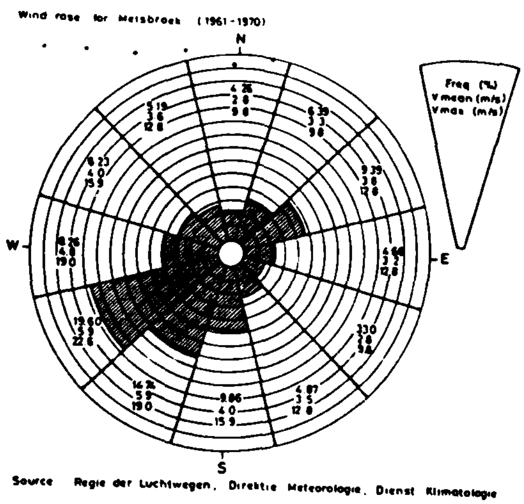
-Precipitation and rainfall erosivity
- -mean annual precipitation (P) and mean annual erosivity index (EI30):

Station	P(mm)	EI30 $(\frac{t\ m}{ha}\ \frac{cm}{h}\ 10^{-2})$
Overijse	822	67.5
Ukkel	796	64.9
Melsbroek	739	56.4
Heverlee	720	54.5

(after Bollinne 1982)

- - mean monthly precipitation (P) and mean monthly erosivity index (EI30): see figure

J.P. 1985



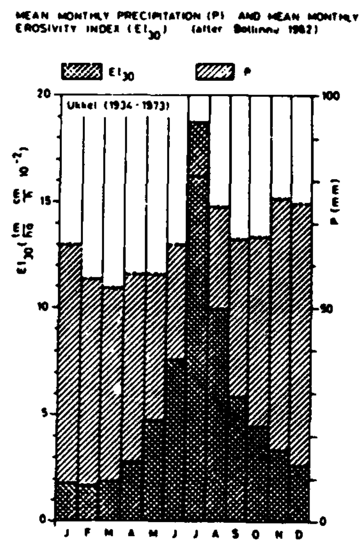


Fig. 0.4 Some climatological data for Middle Belgium

I. THE NEERIJSE QUARRY

(H. Mücher, E. Paulissen, J. Poesen)

1. Introduction

The section is situated in Poels valley, a first order catchment orientated from the NE towards the SW with a maximal depth of 35 m. Although there is no gully in the valley bottom, heavy showers may generate runoff in the thalweg. The studied section is situated in the middle of the valley at a height of 68 m parallel to the thalweg, close to the SE valley slope. A section of about 300 m parallel to the valley bottom was studied in the sandpit Poels. The section that is discussed here is the most complete. Most of the sandpit has been filled up after exploitation.

2. The deposits in the Poels valley (Fig. I.1)

Fig. I.1 shows one of the transverse sections throughout the valley, which was studied by borings. Four main units are distinguished :

- brown colluvial deposits of silt loam , thin on the valley slopes, but 6 m thick in the valley bottom. They contain some pebbles. Thin charcoal layers have been found till a depth of 5.2 m. These colluvial deposits fill a gully, 20 m wide and 6 m deep with steep walls eroded into :

- typical loess deposits, still calcareous at the base, with on top the B-horizon of a truncated alfisol. Thick loess deposits still cover the NW-slope, while they are nearly absent on the SE-slope.

- The substratum is formed by coarse Eocene sands. These sands are now very near to the surface on steep slopes and on the plateau convexities.

- A gravel lag is at the contact between the Tertiary and the Quaternary deposits. The well rounded pebbles are derived from marine gravels deposited during Tertiary transgressions and regressions. The very angular sandstone fragments were formed in situ within the Eocene sands.

3. Description of the cross-section (Fig. I.2)

In this guide only a schematic section not to scale, generalized from a section studied in detail, is presented. The position of the samples taken for micromorphological analysis is indicated on fig. I.2. From to to bottom, following units can be distinguished :

UNIT I C(olluvium) : coarse sandy loam (10 YR 4/4-5/4), rich in gravel. Boundary is clear and smooth.

UNIT II C : silt loam, grayish brown (10 YR 5/-5/6) with few rock and brickstone fragments and very few charcoal. The unit is massive and homogeneous but a sporadic horizontal

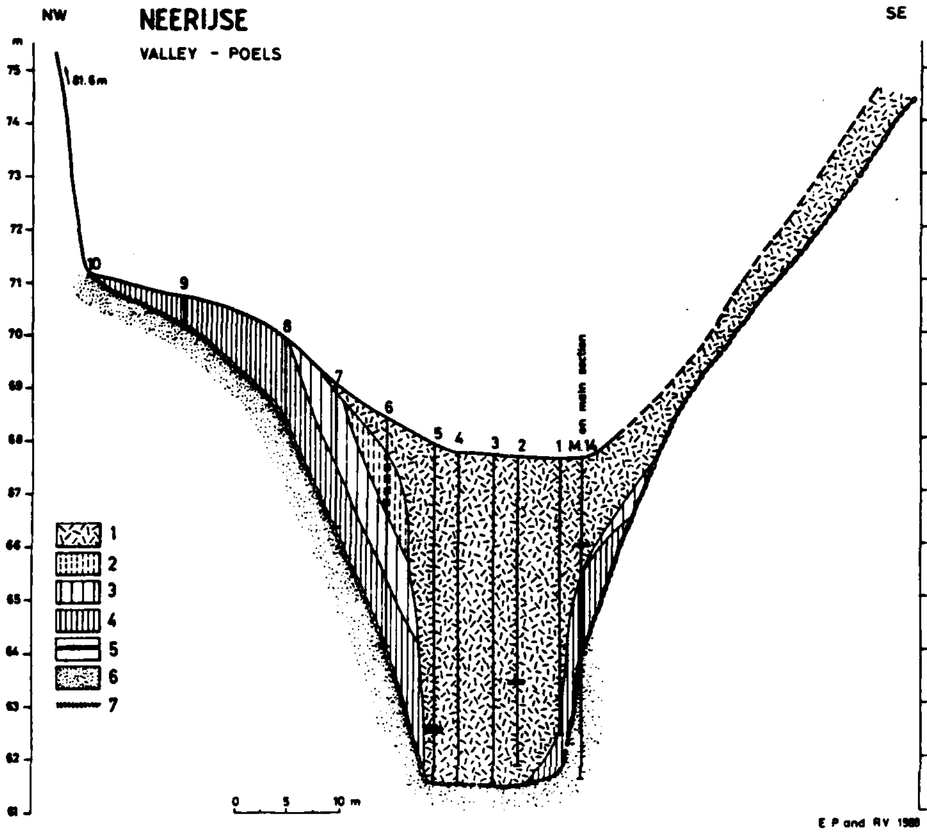


Figure I.1. Neerijse - Poels valley -transverse section

1. Colluvial deposits
2. B-horizon of truncated alfisol
3. Decalcified loessloam
4. calcareous loessloam
5. gravel lag
6. coarse Eocene sands
7. charcoal layer

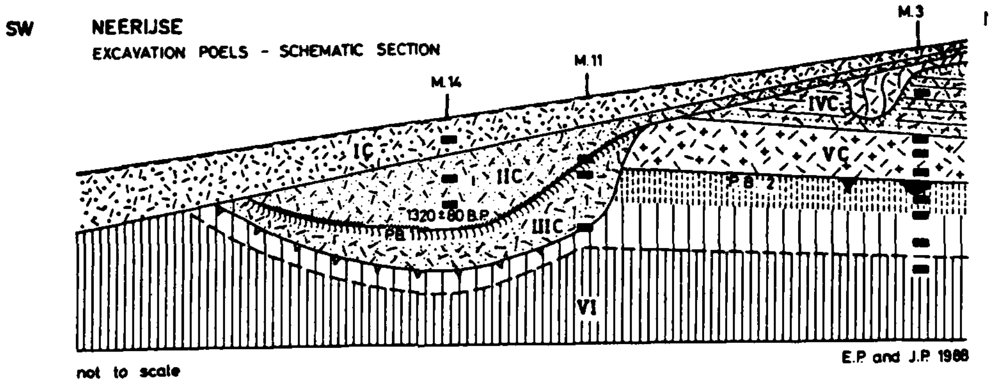


Figure I.2. Neerijse-Sand Pit Poels - Schematic section of main trench

Numbers refer to explanation in text.

For symbols see Fig.I.1.
The samples for micromorphological analyses are indicated.

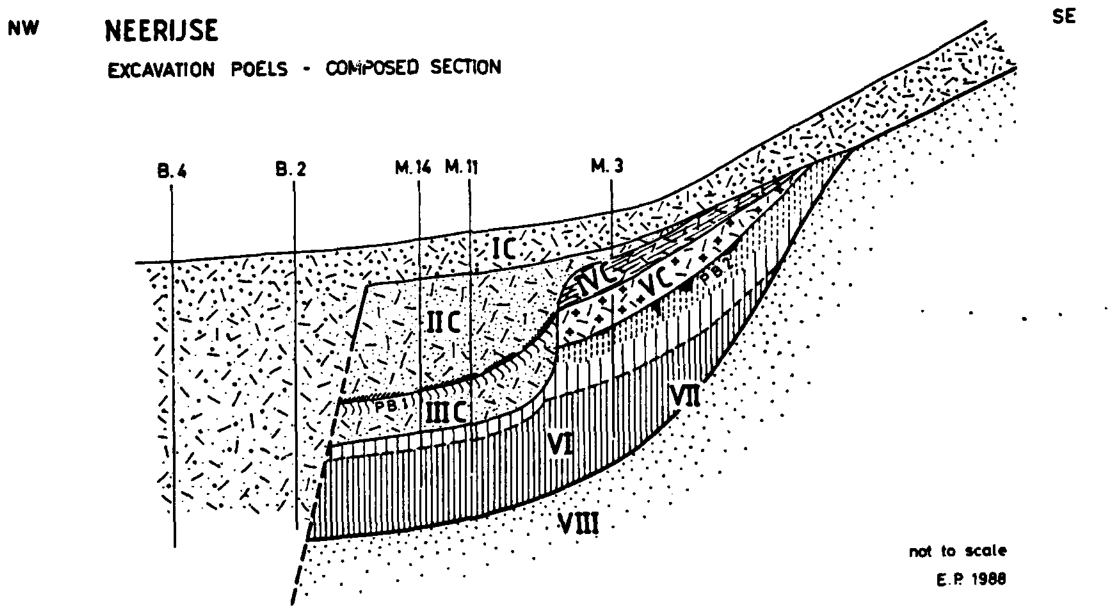


Figure I.3.Neerijse - Poels valley- Composed section of the different sedimentological units in their geomorphological context.

Numbers refer to explanation in tyext.

For symbols see Fig.I.1.

lamination is observed. The boundary is abrupt and smooth. At the lower boundary of IIC, a discontinuous layer of charcoal, 1 to 3 cm thick is found, locally burned in situ, but reworked in other places.

UNIT III C : silt loam, 10 YR 5/4, with some gravels and with at the base local rills filled with gravels in a silt loam matrix. Horizontal lamination is observed. A few ceramics were recovered.

UNIT IV C : stratified colluvial deposits with clear planar lamination : 10 YR 5/4 (darkest) till 10 YR 5/6 (brightest). The texture varies from a silt loam to a silty clay loam. The boundary is clear and smooth.

UNIT V C : is the first colluvial deposit consisting of silt loam 10 YR 5/6-4/6) with very few rock fragments, 2 cm in diameter. In the upper part, locally remnants of horizontal laminations are found. The top of this unit is a mottled silt loam deposit. The boundary is abrupt and smooth, locally wavy.

UNIT VI : Weichselian loess deposits with a buried paleosol on top (P.B. 2, truncated alfisol) :

- with the (truncated) B-horizon still conserved, upper part : 7.5 YR 6/4-6/6 - 10 YR 5/6). In the truncated top locally degradation pockets are found.

- a decalcified silt loam (10 YR 6/4) with no rock fragments and a horizontal lamination, even once a layer of pure sand. Decalcification is related to P.B. 2. Boundary is abrupt and smooth.

- a calcareous silt loam (10 YR 6/6) with very few rock fragments. Horizontal lamination is less than 0.5 cm.

UNIT VII : quaternary gravel lag of reworked well rounded marine flint pebbles and angular Eocene rock fragments.

UNIT VIII : coarse Eocene sands with several sandstone units formed in situ in the lower part . Actual water table is about 10 m below the valley bottom.

4. Distribution of the different units on the SE-slope (Fig. I.3)

The distribution of the various units is very variable :

Unit VI and P.B. 2 are limited tot the basal part of the slope

Units V and IV, the oldest colluvial deposits, form a continuous deposit in the basal part. They truncate unit VI and P.B. 2.

Unit III is limited to an incision about 10 m large and 1.5 m deep, eroded into units IV, V and VI.

P.B. 1 is best developed on unit III, but an iron pan, related to this soil, is on top of unit IV.

Unit II is best developed in the same incision as unit III, but occurs also as a 10 cm thick layer in the basal part of the valley slope

Unit I has the largest extension ans forms the top layer all over the valley slope. This unit covers an important erosion surface. A transverse section (Fig. I.3) was composed to relate all units to their geomorphological context.

5. The sand and rock fragment content of units I to VI (fig. I.4 and I.5)

Detailed grain size analyses learned that the sand content is a diagnostic criterium to distinguish between the different units. The sand fraction will inform us wether the material is derived from the loess deposits (unit VI) only or that also Eocene sands were eroded.

Colluvial deposits II, III, IV and V have sand contents similar to the sand content of unit VI (Fig. I.4). We assume that during these phases very few Tertiary sands were eroded. In colluvial unit I (profiles M1 and M3) the sand content amounts to 50 % or more (Fig. I.4).

As for the sand content, the rock fragment content in unit I is high and amounts to 10 % (Fig. I.5). In unit I C the mean intermediate axis of the largest rock fragments found equalled 4.2 cm (n= 7) compared to 3.5 cm (n = 6) for unit II C.

6. An important gully formation posterior to unit IIC ?

In figures I.2 and I.3 we suggested an important erosion phase between the silt loam derived colluvium II C and the sandy colluvium I C in the valley bottom. The latter is studied only by borings. Unit II C with its low sand content can not be prolonged in the valley bottom, where on the same level the sand content is high. In the valley bottom, an increase of the sand content of the sediments from a depth of 4 m upwards is striking. The sand content in the top part is similar to that of the studied section.

7. The chronology

1. The charcoal layer between unit IIC and P.B. 1 is radiocarbon dated at 1320 +/- 80 BP (LV-11). In calendar years, after calibration, this means 650-780 A.D..

2. The ceramics found in unit IIIC are dated sometime in the first century B.C. to the third century A.D. (determination by Prof. Mertens and Prof. Van Doorslaer, K.U.L.).

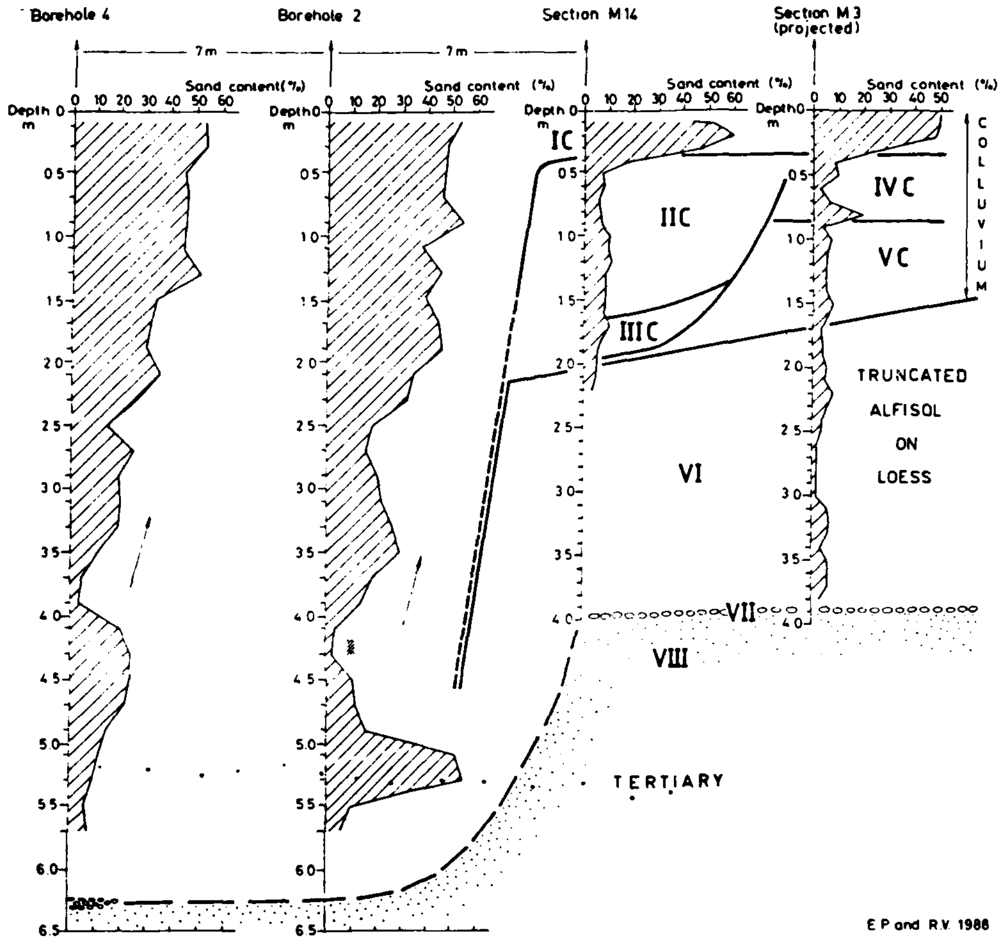


Figure I.4. Neerijse - Poels valley- The sand content on different sites.

Compare to Fig. I.4.

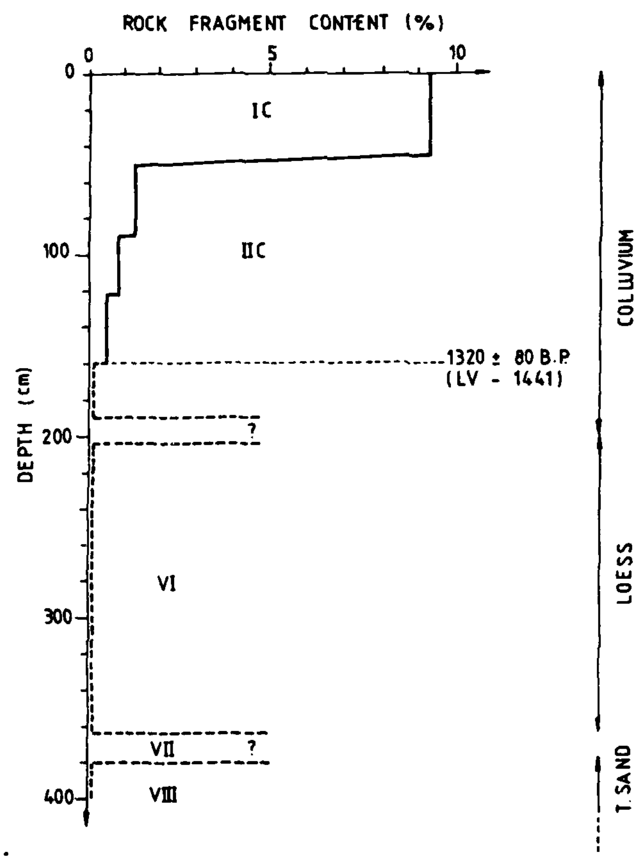


Fig. I.5. Neerijse - Sand Pit Poels - The rock fragment content in units IC and IIC of M 14 in the main section(see Fig.I.2.)

8. Micromorphological results of units I to VI

The cross-section in the pit shows an upperslope with profile M.3 and a valley infilling in the lower part, profiles M.14 & M.11. Undisturbed soil samples are taken from the various units and soil horizons for thin sectioning. The study of the thin section is focussed on the sedimentary characteristics of the units and the soil formation after deposition.

a. Micromorphological results of the upper slope, profile M.3 (thin sections 0.620-0.628).

In profile M.3 are sampled, from below to above, the following units: VI (thin sections 0.628-0.624), V (0.623-0.622), IV (0.621) and III (0.620).

UNIT VI: from below in upward direction thin sections 0.628-0.624.

Depositional characteristics

This unit shows mainly in the lowest part (0.628) a clear, but coarse, laminated fabric, which decreases in upward direction. Thin section 0.627 shows only a weak lamination. The remaining part of unit VI contains incidentally only remnants of laminae (0.626-0.624). The parent material is a mainly loess-derived slope deposit, calcareous in the lowest part (0.628) and non-calcareous in the remaining part (0.627-0.624), locally polluted with lithorelicts (e.g. pedorelicts of an older soil formation) and sharply bounded ferric nodules.

The indivudual laminae are mainly badly sorted, suggesting deposition by rainwash. Formation of well sorted laminae with sharp boundaries is very restricted, suggesting that deposition by afterflow was of minor importance in the past. The local occurrence of mud crust fragments, indicate short stable periods of non-deposition during the sedimentation of the unit. The mainly unlaminated material in the upper part could be the result of transport by splash action. The relatively high bioturbation on one hand, and the local occurence of remnants of laminae, on the other hand, could indicate disappearance of a former laminated structure by biological activity.

Postdepositional features and soil formation

With exception of the lowest part the unit is decalcified. Only the calcareous lower part (0.628) is still characterized by dissolution of primary carbonates, transformations and precipitation of carbonates, giving rise to the local formation of intercalary crustals, crystal sheets, crystal chambers, calcareous nodules and common neocalcitane around pores.

A relatively high biological activity is observed throughout the unit, with formation of channels, fecal pellets and common pedotubules (e.g. tubular infillings of biopores). The biological activity was followed by illuviation of clay (e.g. yellowish brown (few) and common dirty brown ferriargillans), increasing in upward direction.

Hydromorphic features, such as ferrans and diffusely bounded ferric nodules are very rare, indicating that soil formation occured mainly under well-drained conditions.

The soil formation in unit VI is truncated. After examination of the thin sections of this buried soil PB.2 following horizon designation is proposed:

VI Bt 2.1 (0.625) - VI Bt2.2 (0.626) - VI Bt3 (0.627) - VI BC (0.628)

In the pit, locally pockets infilled with A or E horizon material are observed in the truncated surface of this buried paleosol PB.2. Thin section 0.624 derived from this pocket, shows an undifferentiated silt loam with little clay, and common sharply bounded ferric and manganese nodules, and few rounded soil nodules, however without organic material. The infilling consists probably of transported E horizon material. Deposition, probably by splash, was followed by soil formation, giving rise to the development of channesl (but no pedotubules), and locally of yellowish brown and dirty brown illuviation ferriargillans. The illuviation phenomena are regarded as illuviation features belonging to the soil formation above it.

<u>UNIT V</u> (thin sections 0.623, 0.622 and 0.621)

<u>Depositional characteristics</u>

The lower part of unit V is a mainly loess-derived slope deposit, locally mixed with weathered sandstone fragments, coarse sand grains (in the upper part concentrated in one layer) and rounded sharply bounded ferric nodules. In thin section 0.622 three zones occur with mud crust formation. The upper part is partly laminated, probably formed by rainwash. This unit is deposited at least in three different stages.

The top part of unit V (thin section 0.621) is a weakly laminated, almost pure loess-derived slope deposit, with only few sharply bounded ferric nodules, and without coarser, non-loessic relicts. In total 4 phases of mud crust formation could be recognized, alternating with unistral, argillaceous areas and areas rich in silt-sized particles and poor in fine clayey components, suggesting deposition by repeated rainwash and afterflow conditions.

Postdepositional features and soil formation

In the two lower thin sections, 0.623 and 0.622, pedological features are mainly channels and common to many pedotubules, increasing in upward direction. Illuviation ferriargillans (mostly the dirty brown type) are very rare throughout the unit. Few, diffusely bounded, ferric nodules are only observed in the bottom part. This formation of ferric nodules in situ suggests a slightly impeded drainage in the lower part of the unit during soil formation.

In the top part of unit V, pedological phenomena are very limited and occur mainly in the lower part of the thin section 0.621. They consist of a few channels and pedotubules, followed by a weak clay illuviation. There is a contradiction between the relatively high degree of disorder in the thin section on one hand andare only observed in the bottom part. This formation of ferric nodules in situ suggests a slightly impeded drainage in the lower part of the unit during soil formation.

In the top part of unit V, pedological phenomena are very limited and occur mainly in the lower part of the thin section 0.621. They consist of a few channels and pedotubules, followed by a weak clay illuviation. There is a contradiction between the relatively high degree of disorder in the thin section on one hand and a relatively low bioturbation on the other hand. A tentative explanation could be a relatively high impact of frost action in this unit, due to the differences in clay content of the individual laminae. A tentative explanation could be a relatively high impact of frost action in this unit, due to the differences in clay content of the individual laminae.

UNIT IV (thin section 0.620).

Depositional characteristics

Unit IV is a horizontal banded, almost pure, loess-derived, slope deposit. The individual bands, 1.5-3 cm thick, consist of weakly laminated material, mainly silt-sized particles (poor in argillaceous material) with on top of it a fine laminated argillaceous deposti (the argillaceous laminae are enriched with micas parallel to the surface, and/or opaque minerals). This suggests that the silty part is formed by rainwash and the top deposit by afterflow. Locally, mud crust fragments and sharply bounded ferric nodules are found.

Postdepositional features and soil formation

Pedological features are mainly pedotubules occurring in three main stages, starting from the argillaceous upper parts of the bands going in downward direction. This was followed only by a weak illuviation of dirty clay and a very weak formation of yellowish brown illuviation ferriargillans. This pattern could indicate a relatively slow colluviation alternating with periods of soil formation.

In units IV to VI of profile M.3 no artefacts were found, such as coals, pottery fragments, etd., indicating human influence during formation of the deposits.

b. Micromorphological results of the valley infilling, profiles M.11 and M.14 (from below to the surface thin sections 0.634-0.629).

In profile M.11 the following units are sampled for thin sectioning, from below to above : VI (lower part of thin section 0.63), III (upper part of 0.63, 0.633, and lower part of 0.632), and unit II (upper part of 0.632).

In profile M.14 undisturbed samples are taken for thin sectioning, from below to above, in the units: II (0.631 and 0.630) and I (0.629).

UNIT VI (0.634, lower part).

Depositional characterisitcs

In the top of unit VI only remnants of badly sorted laminae are recognized in combination with some coarse sand grains and sharply bounded ferric nodules, suggesting deposition by rainwash, slightly polluted during transportation of loess-derived material.

Postdepositional features and soil formation

Indications for soil formation are very limited, and consist of irregular voids (so-called vughs), channels and pedotubules, formation of few dirty brown illuviation ferriargillans and diffusely bounded ferric nodules, which are formed in situ. The pedotubules are most well developed near the upper boundary of unit VI. Taking into account the observed hydromorphic features and the weak clay illuviation, is suggested as pedological horizon designation : VI BCg.

UNIT III (upper part of 0.634, 0.633, and lower part of 0.632).

Depositional characteristics

Unit III is a loess-derived slope deposit, containing additionaly lithorelicts, such as sandstone fragments, sharply bounded ferric nodules, coarse sand grains, and soil nodules. Remnants of laminae occur only very locally (upper part of 0.63 and in 0.633). These remnants consist mostly of badly sorted fine silt. They occur in combination with mud crust fragments. Taking into account the relatively low bioturbation in this unit, it could be formed by rainwash, in combination with transportation b. splash action.

Post-depositional features and soil formation

After deposition of unit III followed bioturbation (with the formation of mainly pedotubules and less channels), formation of hydromorphic features, such as diffusely bounded ferric nodules, reduction of matrix material, oxydation of matrix material around biopores and pedotubules. Illuviation of clay is very limited in this unit. Few yellowish brown illuviation ferriargillans are only observed in 0.63 (upper part) and in 0.633. Biological activity increases in upward direction, and is most prominent in 0.633 and 0.632 (lower part).

Striking in this unit is the sequence of events concerning biological activity and hydromorphic features. In 0.633 occured firstly biological activity, followed, secondly, above all by reduction and only locally by oxydation around biopores. In 0.632 (lower part) first a high hydromorphism with dominantly reduction in the upper part of unit III and iron segregation in the bottom part of 0.632 developed. It was followed by bioturbation, in which pedotubules crossed the iron segregation.

In the top of unit III occurs a band of elongated, thin, charcoal fragments, probably derived from burned grass blades. Elsewhere in the profile thick charcoal fragments from wood are frequent. The charcoal was dated by the C1-method 1320 ± 80 B.P.. These thin charcoal fragments are also incorporated in the pedotubules below this band, witnessing of continued pedoturbation after burning of the vegetation.

After examination of the thin section following horizon designation is proposed: III BCg (upper part 0.63) - III Bg (0.633) - III ABg (lower part of 0.6321).

UNIT II (upper part of 0.632, 0.631 and 0.630).

Depositional characteristics

Unit II is an unlaminated loess-derived slope deposit containing in addition lithorelicts, such as weathered and unweathered sandstone fragments, mediam and coarse sand grains (locally in clusters (0.631) or in vertical bands, 0.630), sharply bounded ferric nodules, mud crust fragments, and few pieces of charcoal. In comparison with unit III the pollution of the loess-derived slope deposit has increased.

The absence of lamination and the occurence of mud crust fragments suggests periods of deposition by splash, alternating with mud crust formation. The possibility that the unit was originally well-laminated but disappeared by subsequent bioturbation is unlikely, due to a relatively low biological activity as has been observed in the upper part of 0.632 and in 0.631. Bioturbation is only more prominent in 0.630.

Post-depositional features and soil formation

Indications for soil formation are very limited, among others: common vughs, few channels and pedotubules (these are only common in 0.630), very locally yellowish brown and dirty brown illuviation ferri-argillans, and formation of diffusely bounded ferric nodules (0.631). In common unit II is well drained, in contrast with the unit III below.

UNIT I (0.629)

Depositional characteristics

Unit I is an, only very locally, laminated (enclosed silty layers) sandy loam to loamy sand with common sand grains (locally occurring in clusters), weathered and unweathered sandstone fragments (up to gravel-size), and with common charcoal fragments. If this slope deposit was laminated originally than this structure disappeared by ploughing above 20 cm, and by biological activity in the zone deeper than 20 cm of depth.

Postdepositional features and soil formation

Recognizable pedological features are again very limited. The upper part of 0.629 is relatively compact, without biopores, but with root remnants in living position. Below 20 cm of depth common channels and pedotubules occur and is consequently porous. Illuviation phenomena are not observed in this unit.

The following pedological horizon designation is suggested for unit I: I A(0-6 cm) - I Ap (6-20 cm) - I C1 (20-32 cm).

The occurence of charcoal in the top of unit V and in the units II and I suggests that the formation of profile M.14 at least is influenced by human activity since 1320 $\pm$ 80 B.P.

9. Conclusions and discussion

The onset of colluviation in this valley is not dated. Units V C and IV C are mainly loess-derived slope deposits on a truncated surface. No human artefacts were found. The micromorphological analysis suggests that the lamination in the top part of unit V C should be formed mainly by rainsplash, while the horizontal banding of IV C should be due to rainwash followed by afterflow.

The colluviation of units V C and IV C was followed by an incision of the valley of at least 2 m by concentrated runoff. Rills containing rock fragments were also observed.

These erosion forms were colluviated first by unit III C, later by unit II C. Unit III C is a loess-derived slope deposit. It could be formed by rainwash in combination with splash. This unit is dated by ceramics in a period between 1 century B.C. and 3 centuries A.D..

The age of the hydromorphic soil P.B. 1 on top of this unit is rather well fixed as it is younger than the ceramics and older than the charcoal on top (650-780 A.D.) and covers the Merovingian period. This period is known as period of decline, abandonment of arable land and exentension of forest areas. To our knowledge, it is the first time that a soil of this period is des-ribed in Belgium. The soil is probably formed due to local wet conditions related to an increased throughflow on top of an impeding horizon (B-horizon of P.B. 2 ?) under forest. A relation with the main aquifer is indeed excluded as ther are not general reduction phenomen below P.B. 1..

The charcoal layer forms a key in the stratigraphy and marks the final deforestation by man somewhere between 650 and 780 A.D., at the beginning of the Carolingian period. The micromorphological analyses indicate that the formation of the hydromorphic soil still continued for a very short period of time and was soon recovered by the colluvium II C, which has the typical colour of anthropogenic colluvium in the area.

Unit II C is mostly homogeneous, but some sporadic horizontal laminations have been observed. The origin of this unit is not clear. The micromorphological analyses suggest deposition by splash with mud crust formation. But how then to explain the thickness of II C, the presence of rock fragments (1%) and what about the effects of cultivation practices by man on the fabric of the colluvium ?

An important period of slope erosion - unfortunately not dated - truncates all former deposits and forms a clear planar disconformity covered with the coarse colluvia of unit I C. Detailed bore sections make us to believe that during this period an important gully has been formed in the valley bottom. It is during this stage that most of the valley slope has been uncovered from loamy deposits (a process that is still in progress). The most recent colluvial deposits I C contain more coarse rock fragments that the older colluvia II C (Fig. I.5). This can be attributed either to the fact that more and more rock fragments have become available at the upland soil surface for subsequent evacuation, or that the frequency of rilling and the competence of rill flow has increased.

II. THE HULDENBERG EXPERIMENTAL FIELD AND THE HOF TEN BOSCH CATCHMENT

(J. De Ploey, G. Govers, H. Mücher, E. Paulissen, J. Poesen, L. Van Elewyck)

1. Introduction

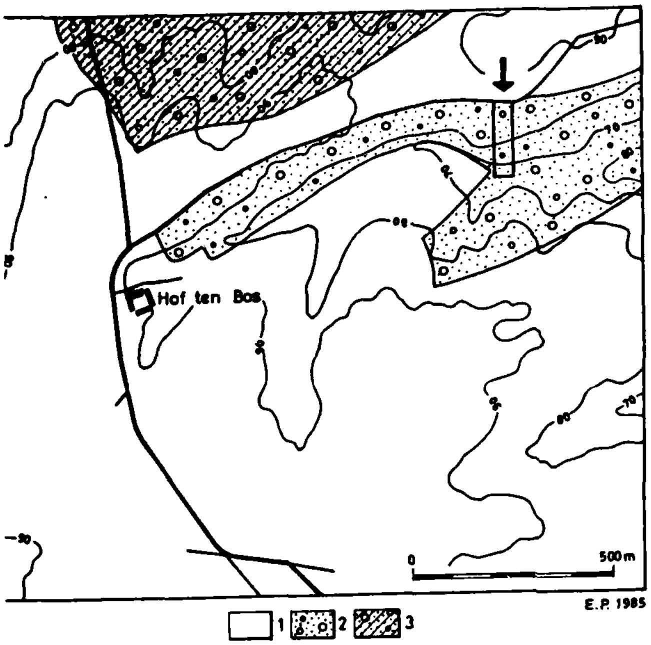
The original aim of the observations on the Huldenberg field site (fig. 0.2) was to obtain as much and as detailed information as possible on the hillslope erosion processes as they occur in the Belgian Loam Belt. This required not only erosion measurements but also the collection of information on hillslope hydrology and on the static and dynamic soil characteristics influencing both hydrology and erosion. By doing so, it was hoped to gain insight in the sediment transfer system, taking into account the interrelationships between the various subprocesses. Furthermore, investigations of the properties of the historic deposits at the base of the slope and in the cathment allowed to situate the current phenomena in an historical framework.

Observations on the slope and in the cathcment are carried out since november 1982. Splash transport measurements took place from 1/03/83 till 01/06/83. The evolution of the rill and gully system and splash detachment were intensively monitored from 15/11/83 till 03/10/84. Interrill wash erosion and runoff was measured from 02/10/84 till 28/12/84. From 20/10/86 till present additional observations are carried out on runoff production on interrill areas.

2. Surficial deposits

The characteristics of the surficial deposits of the experimental slope are highly variable. On the western part of the steepest slope section a thick loam cover is present, while on other parts of the field the Tertiary sands are near to the surface, sometimes covered with an early Quaternary gravel deposit (fig. II.3, II.4 and II.5). Gravel deposits are cropping out over a limited surface (fig. II.4). Actually, gravel is found in the topsoil on a considerable distance downslope from the outcrop (fig. II.5). As there is no gravel present in the underlying loess, vertical migration of the pebbles has to be excluded so that it can be stated that rock fragment migration has taken place over the surface. The basal concavity consists of a thick colluvial deposit.

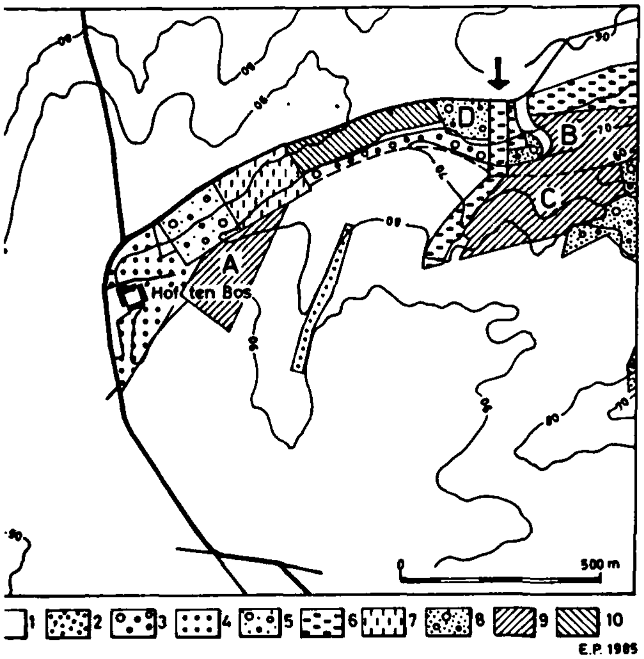
This variability is reflected in the surface soil properties : clay content of the topsoil is very variable (fig. II.6) the USLE K-value varies within the field from 0.28 to 0.55 (fig. II.7). This questions the feasibility of erosion risk surveys based on USLE criteria.



times till 1850.

1. Arable lands. In the Ganspoel valley, these lands belongs to the Hof ten Bos farm, mentioned already in the early 1300.
2. Forest area till 1850. This forest had already an identical surface in 1526, the oldest precise document.
3. Forest area in 1806, arable land in 1850.

ig. II.1 Land use in the Hof ten Bos area in Late Mediaeval times till 1850



1. Old arable land.
2. Arable land from 1865, forest since 1908 at least.
3. Forest
4. Orchards
5. Park
6. Arable lands in 1865. The experimental field belongs to this unit.
7. Deforested in 1865, meadow since 1920 at least.
8. Arable lands in 1865, forest since about 1935.
9. Meadow since 1920 at least. Arable land since 1950 for A, since 1954 for B and since 1979 for C.
10. Arable land in 1855 till 1954, meadow till 1974 and afterwards arable land.

Fig. II.2 Land use in the Hof ten Bos area since 1865

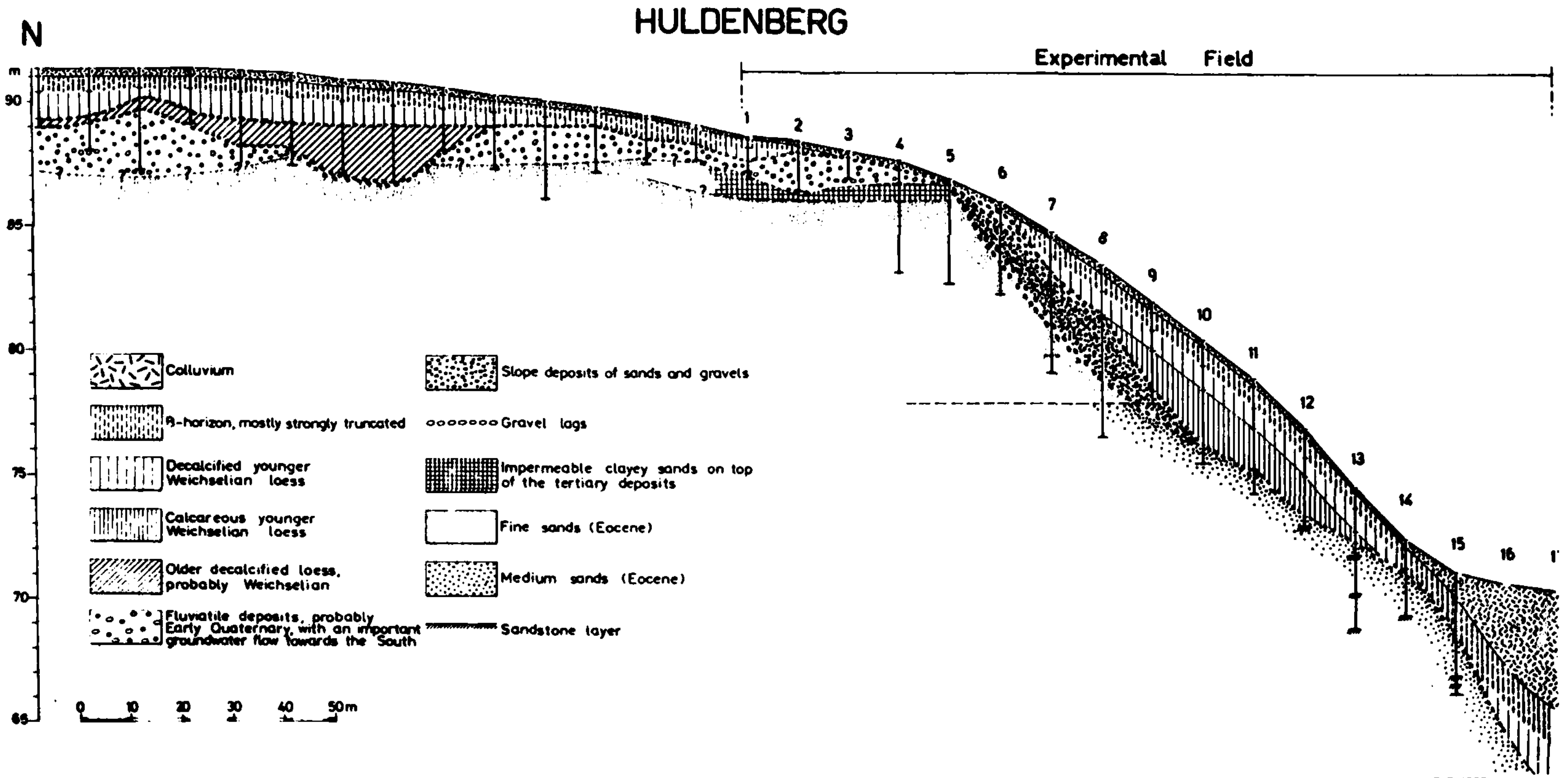


Fig. 11.3 Section through the steep northern slope of the Genspoel valley

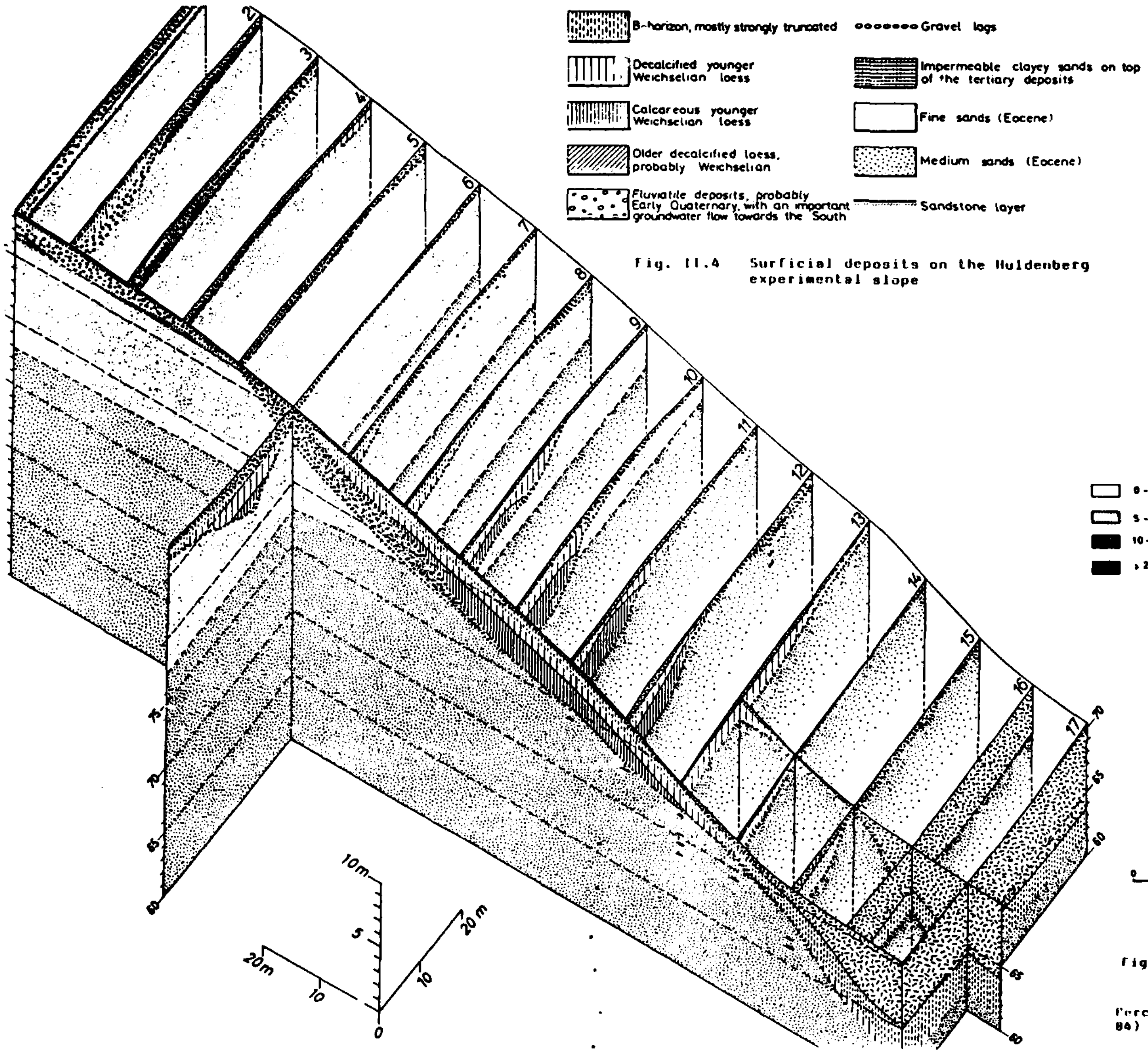


Fig. 11.4 Surficial deposits on the Huldenberg experimental slope

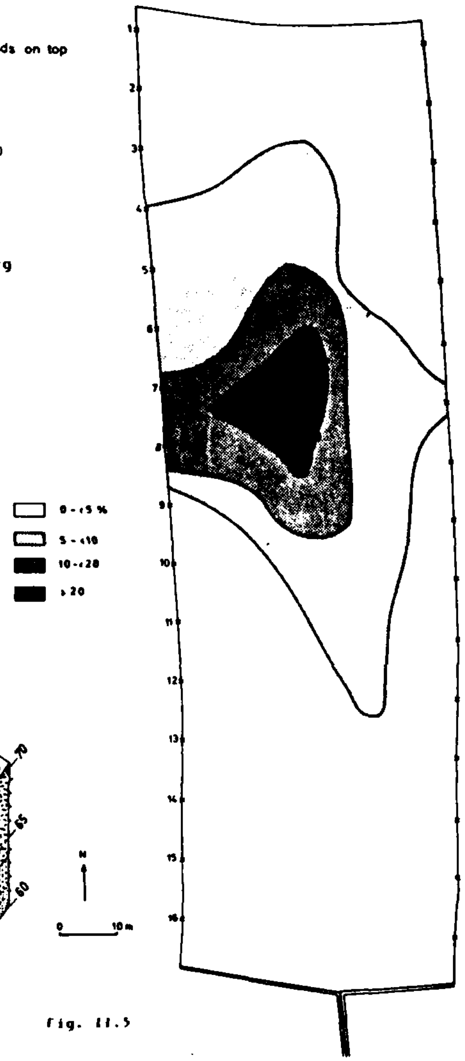
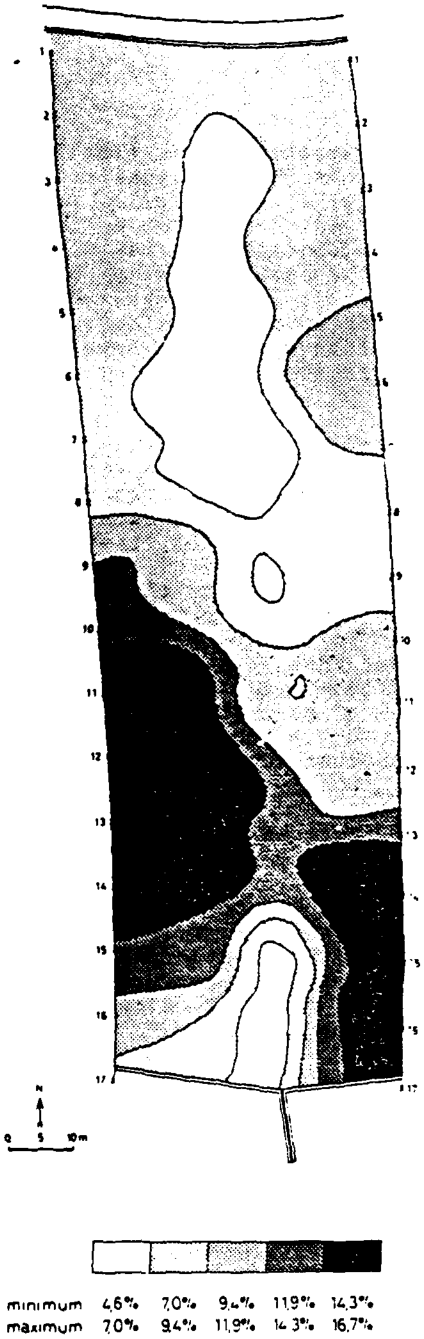


Fig. 11.5

Percentage of topsoil covered with gravel (Ju[n] 86)



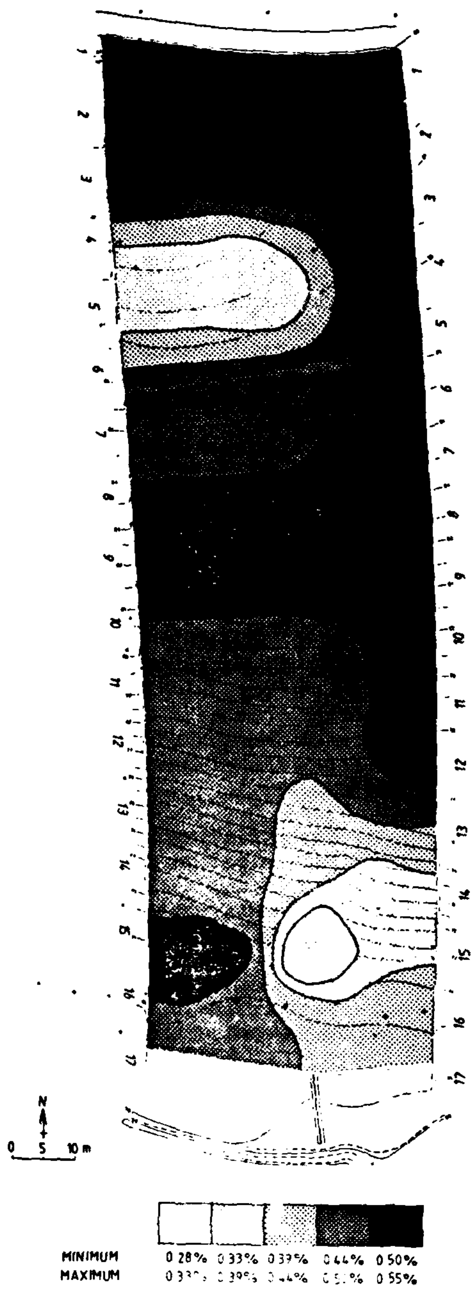


Fig. II.7 Spatial variability of the estimated K-value

Fig. II.6 Spatial variability of the clay content of the plow layer

3. Hillslope hydrology

On the slope, a pronounced spatial variability of runoff yield was observed, with maximum amounts on the flattest parts (fig. II.8). Measurements of soil cohesion on interrill areas suggested that these variations could be related to slope-dependent crust development (fig. II.9). The latter is believed to be caused by a combination of various mechanisms : on steeper slopes, surface seal development will be obstructed by the intense erosion and furthermore, complete saturation of the top layer is very unlikely to occur so that aggregate breakdown and sealing might be retarded.

However, these observations did not allow to conclude that there was a definite slope and/or soil effect as soil properties varied together with slope. Therefore, a new series of plot measurements was set up, whereby the surface soil of small interrill plots was exchanged : on the plateau, plots were set up with the topsoil found on the slope and vice versa. Comparison of the results of these plots with the results of plots on which the original topsoil remained in place allowed to distinguish between soil and slope effects. The results showed that in the first period after cultivation soil effects were the most important (tab. II.1). After ca. 150 mm of rain, the slope effect became dominant. It may be concluded that both slope and topsoil characteristics have an influence on runoff production.

On continually crusted low sloping interrill areas runoff yield per unit surface was generally independent of slope length (tab. II.2). However, due to the differentiation of crust properties as a function of length, runoff yield increases with slope length during minor runoff events. On the steep slope, runoff yield decreased with slope length, probably not only because of the better structural characteristics of the soil but also because of slope effects (erosion of surface seal on longer plots ?).

During dry periods runoff generation is clearly Hortonian. However, tensiometer recordings indicate frequent saturation of the plow layer during wet periods so that saturation overland flow may occur (fig. II.10). Lateral migration of the water takes place through macropores as well as through pipes formed by animal activity or by tillage operations.

4. Interrill erosion

Raindrop impact can be considered to be the major detachment agent on interrill areas. Spatial variability of absolute splash amounts is reasonably well predicted by an erodibility index resulting from laboratory experiments by Verhaegen (fig. II.11 and II.12).

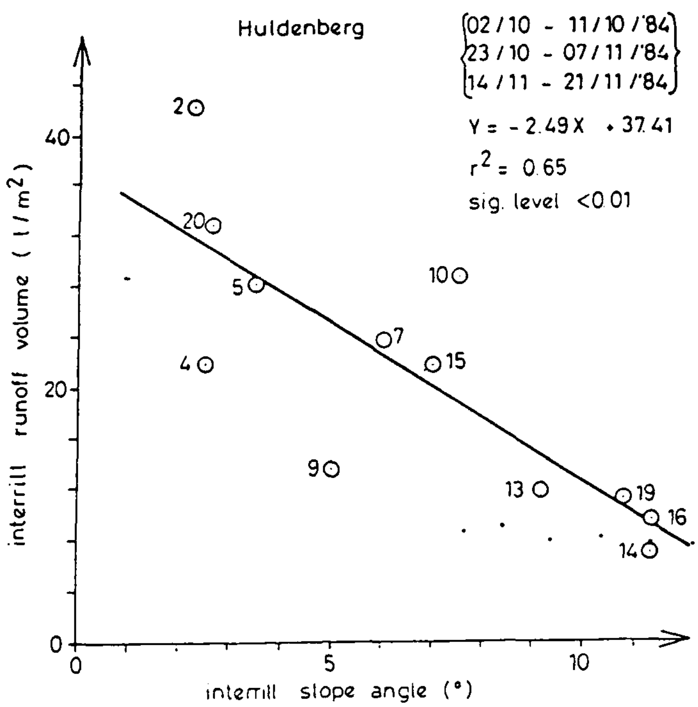


Fig. II.8 Runoff yield on interrill plots as a function of slope

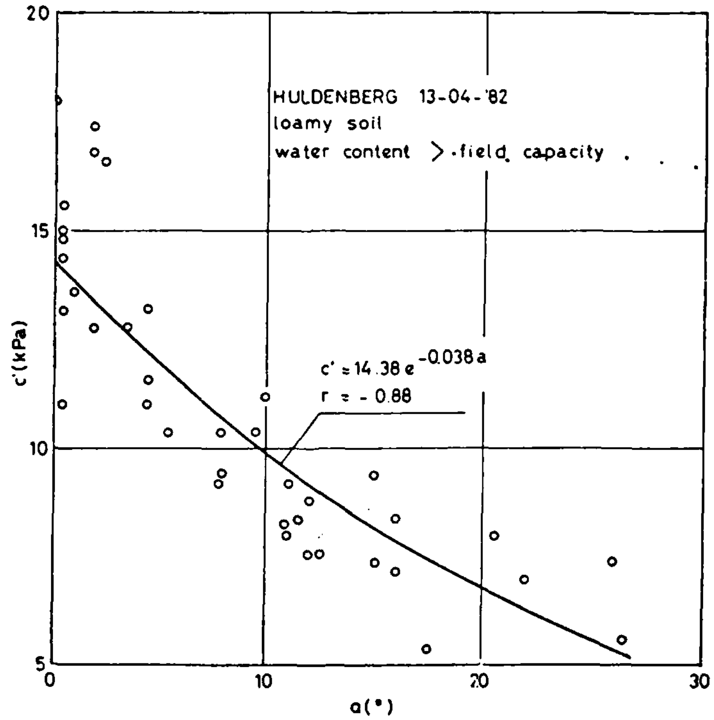


Fig. II.9 Apparent cohesion of interrill surfaces as a function of slope

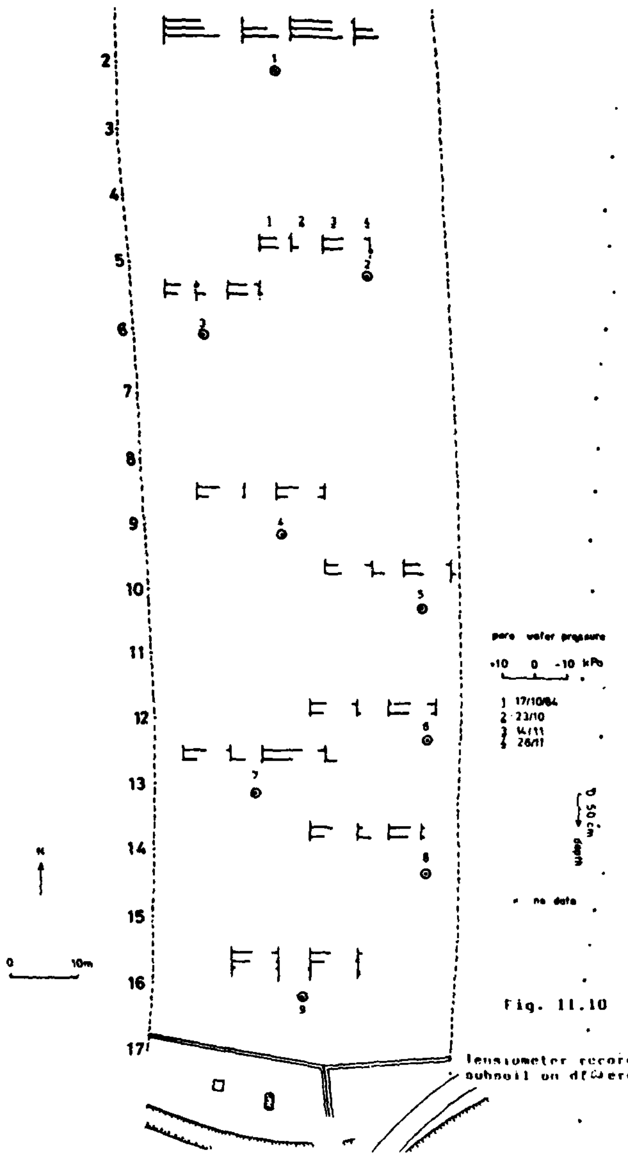


Fig. 11.10 Tensiometer recordings in the plow layer and the subsoil on different dates

Period	Plateau P-soil (mm)	Plateau Sl-soil (mm)	Slope P-soil (mm)	Slope Sl-soil (mm)	Slope-effect	Soil-effect	P (mm)
20/10/86-22/11/86	70.1	20.9	46.7	10.6	Ps : 0 Ss : 0	P : 1 S : 1	144
22/11/86-31/12/86	52.3	23.7	43.9	7.6	Ps : 0 Ss : 0	P : 0 S : 1	100
31/12/86-06/03/97	51.8	33.0	42.9	8.8	Ps : 0 Ss : 1	P : 0 S : 1	124
06/03/87-25/06/87	44.8	32.6	12.1	3.7	Ps : 1 Ss : 1	P : 0 S : 0	280
25/06/87-28/08/87	88.1	74.5	48.3	26.8	Ps : 1 Ss : 1	P : 0 S : 1	202
28/08/87-28/10/87	31.0	29.5	16.2	12.0	Ps : 1 Ss : 1	P : 0 S : 0	118
28/10/87-11/01/88	83.3	68.2	46.4	28.3	Ps : 1 Ss : 1	P : 0 S : 0	195

Tab. 11.1 Influence of slope and soil type on interrill runoff generation (Slope-effect and Soil-effect column report the results of analysis of variance, 0 : no significant effect, 1 : significant effect (5% level), Ps : plateau soil, Ss : slope soil, P : plateau, S : slope)

Period	Plateau 0.8 m	Plateau 2.5 m	Plateau 7.5 m	Slope 0.8 m	Slope 2.5 m	Slope 7.5 m
I	100	71.4	69.7	100	83.5	33.6
II	100	72.3	102.3	100	21.3	94.7
III	100	112.3	91.7	100	148.8	115.9
IV	100	122.0	195.2	100	147.5	46.5
V	100	84.0	102.1	100	83.3	77.0
VI	100	129.2	137.4	100	93.3	61.3
VII	100	105.2	105.0	100	75.6	46.3
Total	100	96.2	107.2	100	85.9	65.0

Tab. 11.2 Influence of slope length on interrill runoff generation (runoff per unit area expressed as percentage of runoff per unit area on shortest plots)

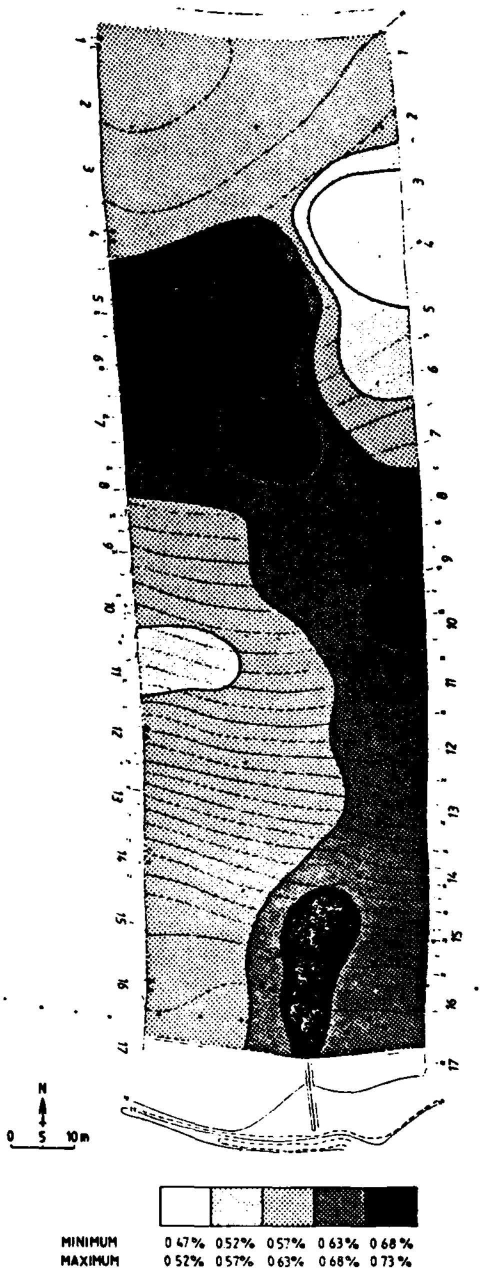


Fig. II.11

Spatial variability of Verhaegen's interrill erodibility index

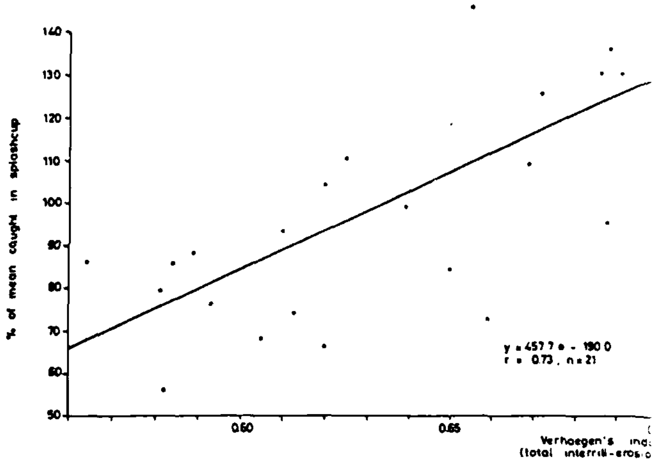


Fig. II.12 Relative amount of splash detachment in function of Verhaegen's interrill erodibility index

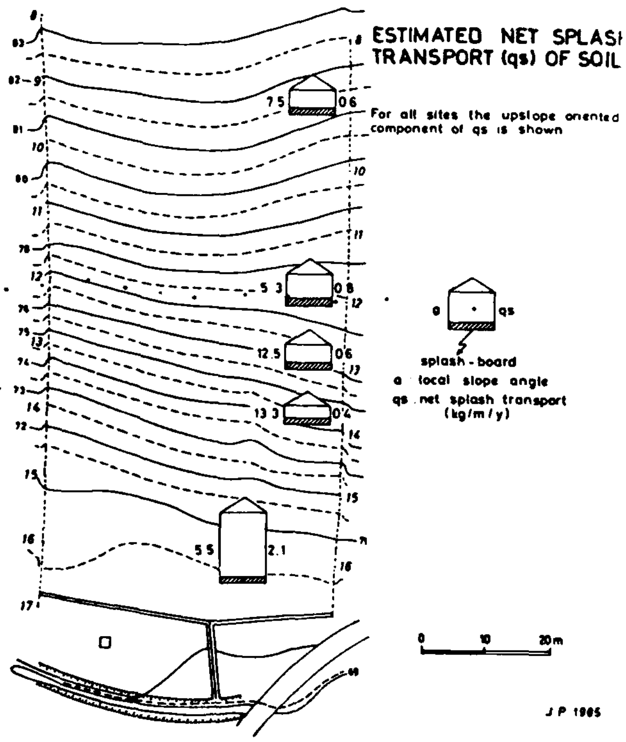


Fig. II.13 Estimated net splash transport of soil

Net splash transport is well predicted by a laboratory model. Verification on the field showed that net transport on a south-facing slope is often directed upslope due to the influence of southwesterly winds (fig. II.13). However, the direct contribution of splash transport to soil loss is of minor importance and amounts to some tens of kg per ha and per year at a maximum.

Splash amounts during higher magnitude events are underestimated if rainfall kinetic energy is used as a measure of rainfall erosivity. Better results are obtained if the sum of the squared momenta is used (fig. II.14a-b).

Sediment transport from interrill areas mainly occurs by interrill wash. The delivery-ratio, being the proportion of the detached sediment that is actually evacuated by wash, is near unity for freshly tilled surfaces (provided that there are sufficient amounts of runoff) (fig. II.15a). The delivery-ratio appears to be slope-dependent for crusted interrill areas. This migth be due to the formation of a coarse lag deposit on lower slopes (fig. II.15b).

For the Huldenberg field site, it was estimated that about 34 tons of sediment were evacuated by interrill wash during a one year period. Direct insplash into the rill and gully system caused a loss of approximately 2.4 tons in the same period (tab. II.5) and is therefore of negligible importance compared to interrill wash.

5. Rill and gully erosion

The evolution of the rill and gully system was monitored by periodic mapping whereby the position, depth and width of each rill were noted on 15 transects each 10 m downslope (fig. II.16 and II.17). This allowed the monitoring of temporal and of spatial variability of rill and gully erosion (fig. II.18 and II.19).

To analyse and describe rill development, it was necessary to make a distinction between hydraulic rill erosion, mass wasting on rill sidewalls and gully erosion as different factors influenced these subprocesses.

Hydraulic rill erosion was defined as the amount of rill erosion directly caused by flowing water. It occurs mainly during higher magnitude runoff events (fig. II.20) : ca. 70% of total hydraulic erosion was caused by three higher magnitude events on 03/02/8,06/02/8 and 25/08/84 with rainfall amounts of 8,13 and 36 mm and intensities of 50,50 and 80 mm/h respectively, while total precipitation during the observation period was 721 mm. However, comparison of hydraulic rill erosion with total transporting capacity of the flow indicated that the ratio erosion/transporting capacity does not increase considerably during extreme events (tab. II.3). Transporting capacity relationships may

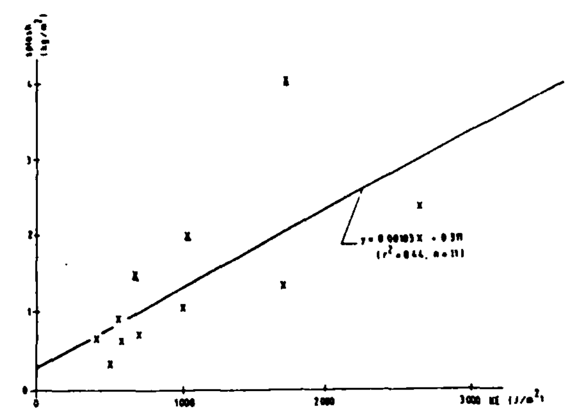


Fig. II.14a Splash detachment in function of rainfall kinetic energy

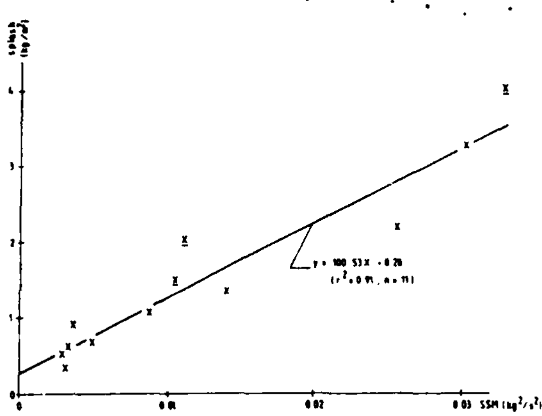
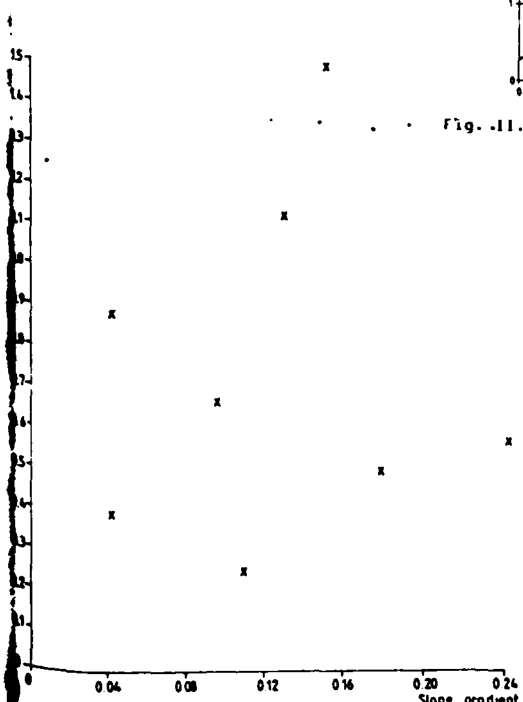


Fig. II.14b Splash detachment in function of rainfall sum of sqared momentum



11.15a

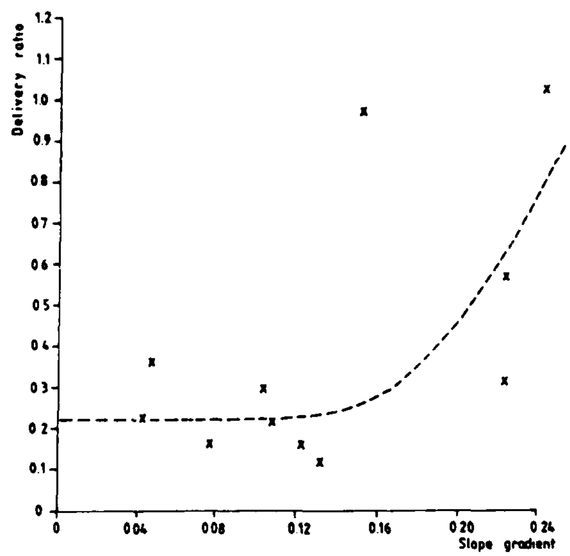


Fig. 11.15b

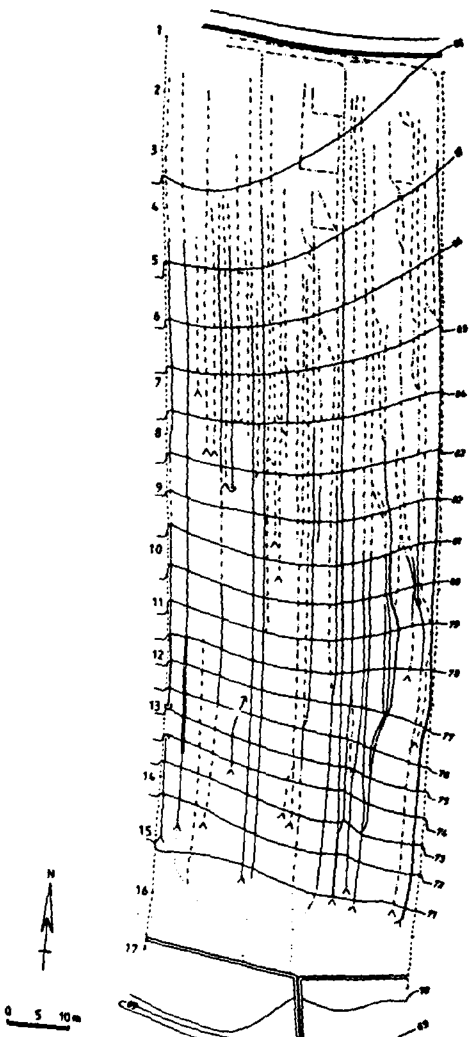


Fig. 11.16 Map of the rill system on 30/01/84

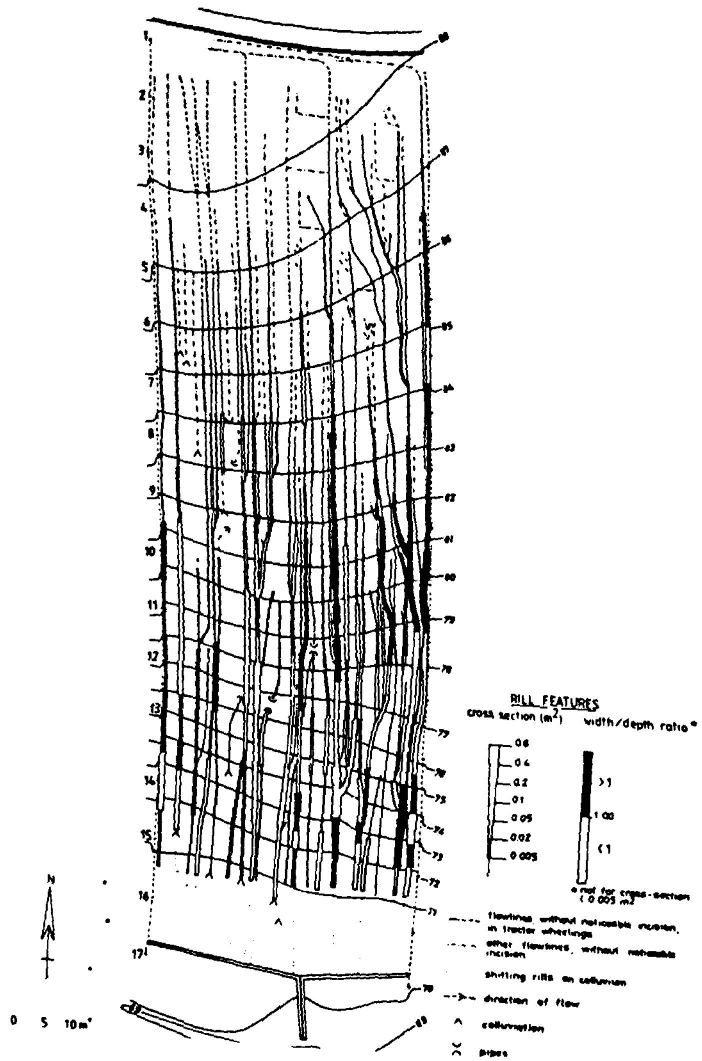


Fig. 11.17 Map of the rill system on 05/10/84

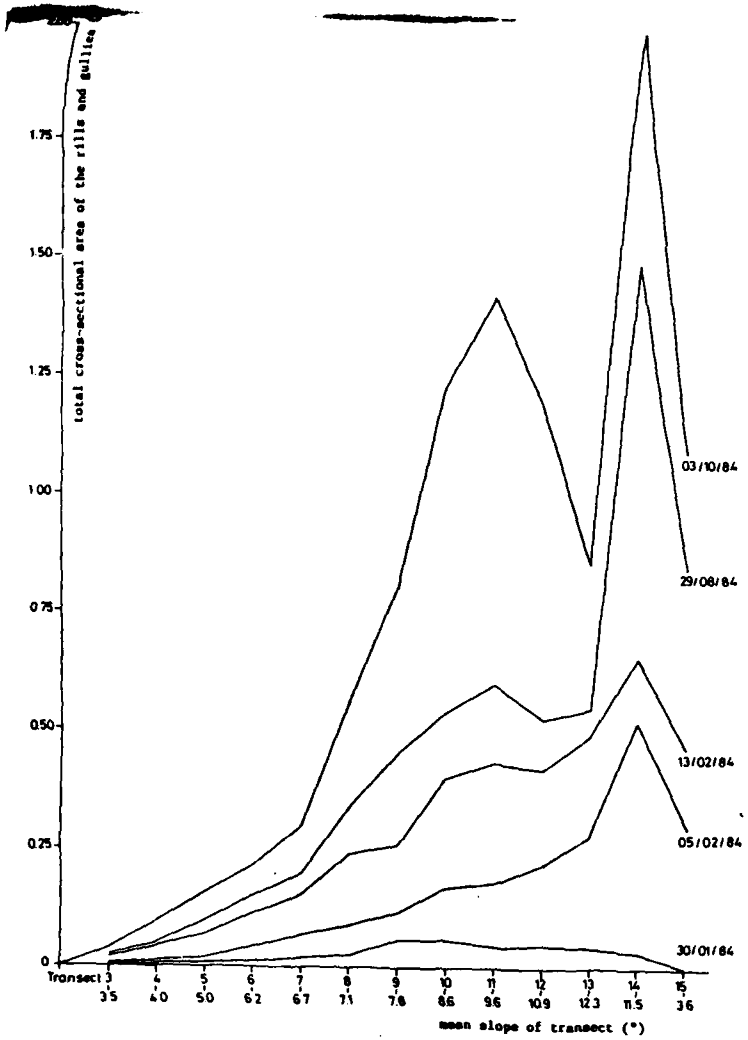


Fig. II.18 Total cross-sectional area of the rills and gullies per transect on different dates

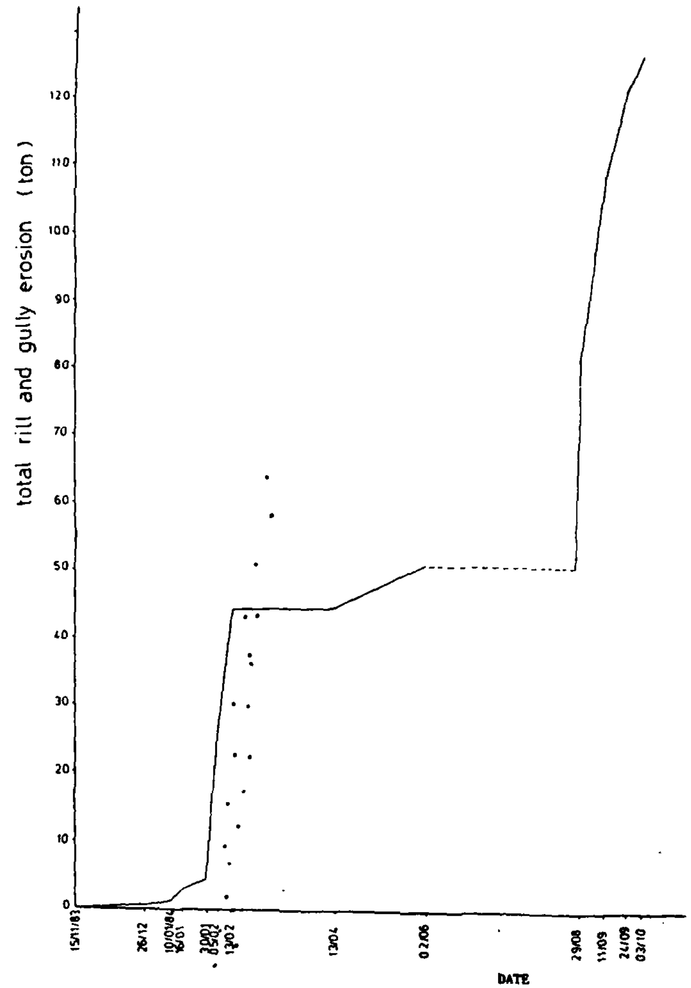


Fig. II.19 Temporal evolution of total rill and gully erosion

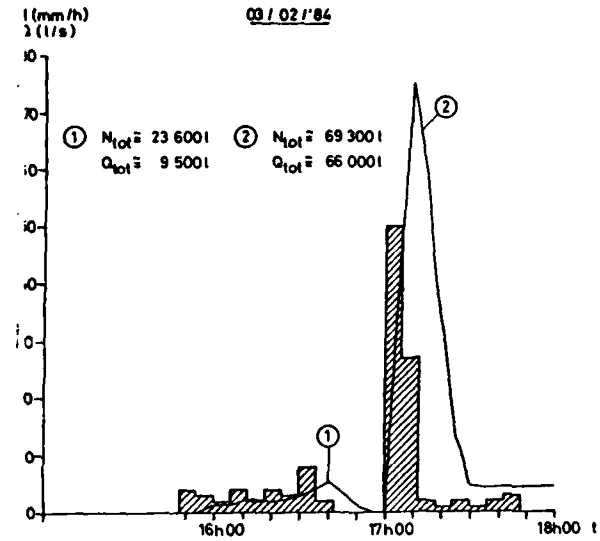
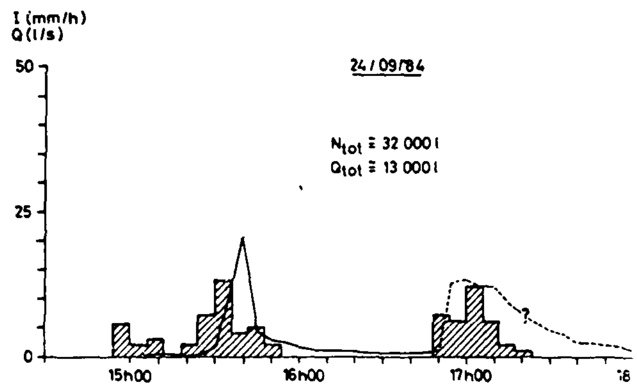
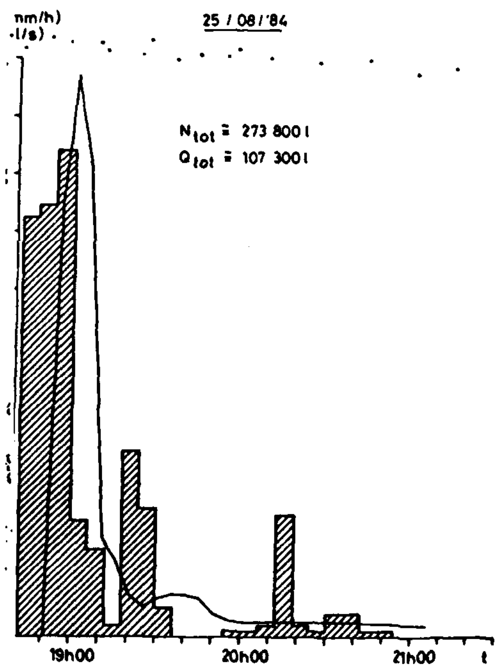


Fig. II.20 Some typical runoff events





Period	Hydraulic Rill Erosion (ton)	Total Transport Capacity (ton)	%
15/11/'83-30/01/84	4.4	21.7	20.2
30/01/84 05/02/84	16.7	79.7	20.9
02/06/84 30/08/84	18.2	91.4	[illegible].9
30/08/84 03/10/84	14.4	175.3	8.2

Tab. II.3 Comparison of transporting capacity and hydraulic rill erosion for different observ periods therefore be useful tools in making a first estimate of the erosion potential of a given runoff event.

Hydraulic rill erosion is well related to topographical factors, at least if runoff generation is general (fig. II.21). Rills generated when the slope of the field exceeded 4-5%. This is in agreement with laboratory data and earlier literature data and is explained by the fact that the start of incision is related to a critical grain shear velocity. If both slope and slope length are included in a regression equation, it appears that slope and length exponents are far from constant. This is mainly caused by the fact that hydraulic rill erosion rate on the concave base of the slope (transect 15) increases less rapidly as hydraulic rill erosion on the convex part of the slope

Mass wasting on the contrary is mainly determined by the hydrological and soil mechanical properties of the soil profile. At the Huldenberg site, it was most active on the eastern half of the mid-slope section (fig. II.18), where a sandy plow layer overlaid an impervious subsoil. Sidewalls of rills formed in loamy material proved to be more stable, despite the occurence of positive pore water pressures (fig. II.10). Mass wasting produced 37 % of total sediment output from the rill and gully system during the observation period. 62 % of total sediment production by mass wasting occured during the last month of the observation period, after considerable deepening of the rills by an higher magnitude event on 25/08/84.

On the eastern part of the steepest slope section gully erosion occurred (fig. II.17). As the Brusselian sand was very near to the surface in this area, a headcut was formed when the rill beds reached the sand. This headcut moved rapidly upslope during extreme runoff events. Gully sidewalls were most vulnerable during summer and spring as drying caused the sand to loose all its cohesion (fig. II.22). Backward migration of the headcut was limited to major runoff events. The occurrence of these gullies illustrates very well the fact that the erodibility of a given soil profile is dependent on its position in the landscape. The vulnerability of a soil with a sandy subsoil in a given location will depend on the local slope and on the potential of concentrating considerable amounts of runoff.

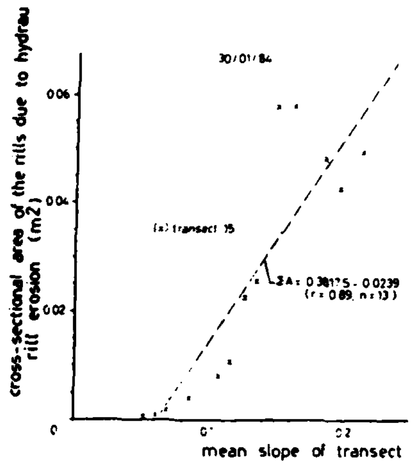
A sediment budget was constructed as a synthesis of the measurements (tab. II.5). One of the most interesting results was that, although the field site was very heavily rilled, interrill erosion was relatively important in total sediment production : 22 % of total soil loss came from interrill areas. Of course, the relative importance of the various processes varies in time and in space : in the beginning of the observation period, 40 % of total erosion was interrill erosion. Interrill erosion is also much more

Date	Slope	Length	r^2
30/01/84	0.45	2.00	0.956
05/02/84	0.26	2.09	0.987
13/02/84	0.29	1.34	0.984
29/08/84	0.45	1.21	0.957
03/10/84	0.46	1.06	0.963

Regression equation :

Cross-section = A log(S-S_{cr}) + B log(L) + C
with A,B,C = regression coefficients
S = slope
S_{cr} = critical slope for rill initiation (set equal to 0.04)
L = distance from transect to upslope field boundary

Tab. 11.4 Slope and slope length exponents resulting from multiple (logartihmic) regression of hydraulic rill erosion on topographical factors



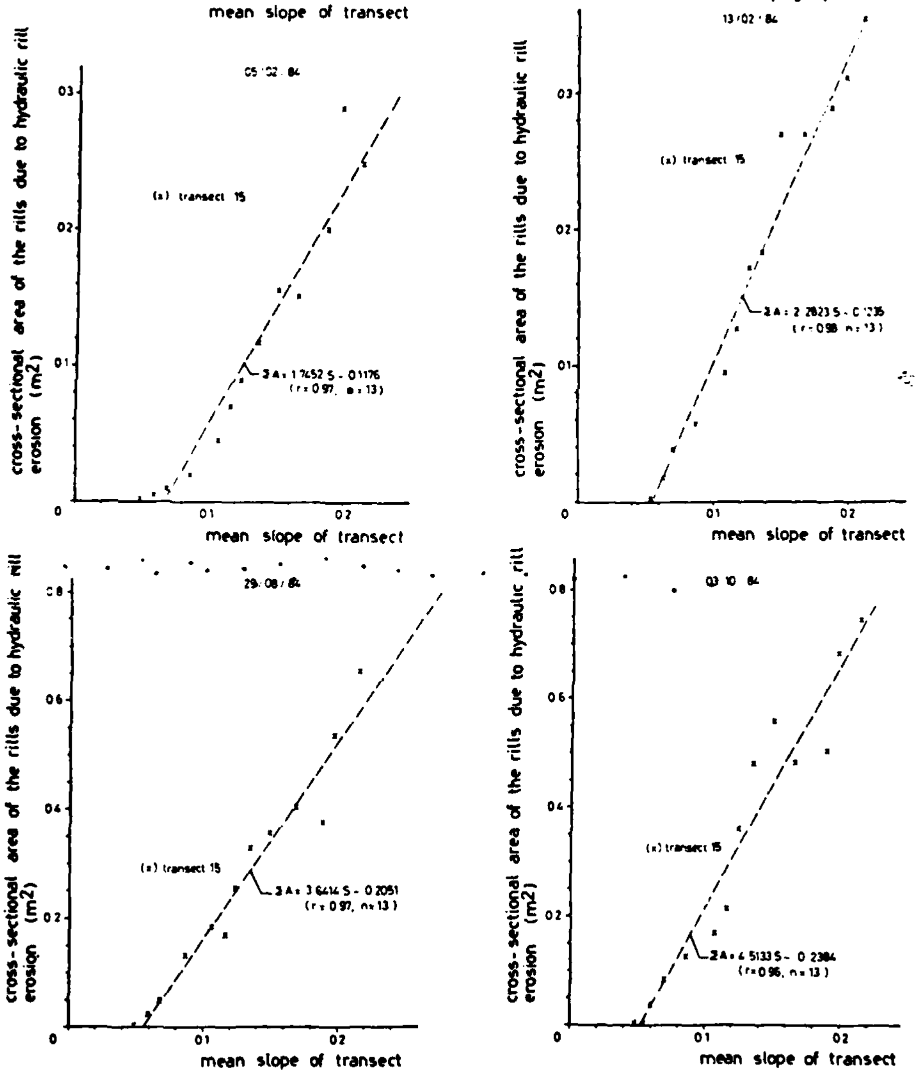


Fig. 11.21 The relation between hydraulic rill erosion and slope on different dates

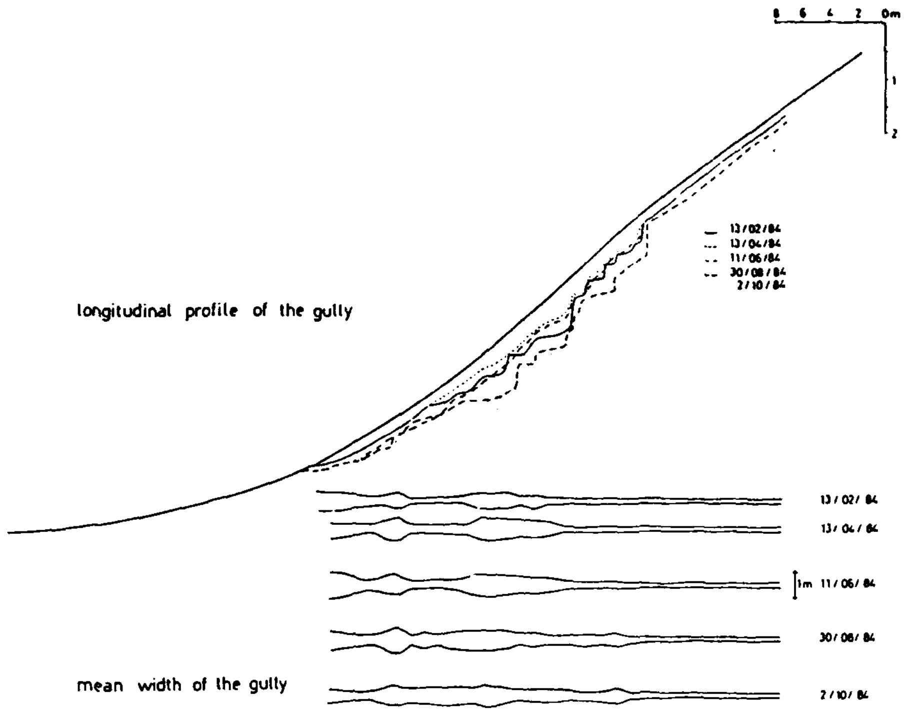


Fig. 11.22 Evolution of the longitudinal profile and the *mean width of a gully*

	15/11/83	30/01/84	03/02/84	06/02/84	29/08/84	03/10/84
RSP	0	0.1 (1.3)	0.3 (0.7)	0.6 (1.0)	2.0 (1.8)	2.4 (1.5)
IRW	0	3.1 (39)	9.9 (27)	14.6 (24)	29.2 (26)	34.1 (20)
TIRE	0	3.2 (41)	10.2 (29)	15.2 (25)	31.2 (28)	36.5 (22)
HRE	0	4.4 (56)	21.5 (59)	34.9 (58)	51.8 (46)	65.8 (39)
RSW	0	0.3 (3.8)	2.7 (7.4)	5.4 (9.0)	18.4 (16)	47.9 (29)
GE	0	0.0 (0.0)	2.3 (6.3)	4.4 (7.3)	11.6 (10)	16.7 (10)
TRGE	0	4.7 (59)	26.5 (72)	44.7 (75)	81.8 (72)	130.5 (78)
Total	0	7.9 (100)	36.7 (100)	59.9 (100)	113.0 (100)	167.0 (100)
P	0	178	208	259	559	721

Tab. 11.5

Sediment budget of the Huldenberg experimental field for different dates : RSP : direct insplash into the rill and gully system, IRW : interrill wash, TIRE : total interrill erosion, HRE : hydraulic rill erosion, RSW : rill sidewall processes, GE : gully erosion, TRGE : total rill and gully erosion)

	30/01/84				03/10/84			
Transect	RSP	IRW	HRE	RSW	RSP	IRW	HRE	RSW
1	0.0	0.07	0.0	0.0	0.0	0.71	0.0	0.0
2	0.002	0.21	0.006	0.0	0.037	1.42	0.062	0.0
3	0.002	0.14	0.009	0.0	0.056	1.35	0.52	0.05
4	0.002	0.13	0.022	0.0	0.059	1.14	1.36	0.55
5	0.004	0.20	0.047	0.0	0.14	1.77	1.74	0.67
6	0.006	0.24	0.10	0.0	0.18	1.87	2.33	0.75
7	0.007	0.28	0.13	0.0	0.23	2.01	2.94	1.59
8	0.006	0.32	0.27	0.0	0.25	2.11	4.96	2.83
9	0.005	0.25	0.31	0.035	0.22	1.72	6.59	7.74
10	0.005	0.23	0.70	0.084	0.24	2.38	7.67	9.55
11	0.004	0.18	0.70	0.042	0.18	2.65	6.60	7.66
12	0.006	0.23	0.58	0.047	0.23	3.94	6.90	6.45
13	0.006	0.21	0.60	0.0	0.21	4.65	10.26	5.19
14	0.005	0.22	0.54	0.052	0.21	4.64	9.40	3.70
15	0.005	0.22	0.44	0.019	0.20	1.70	4.46	1.07

Tab. 11.6 Contribution of various processes to total erosion transect on two different dates

important on the upper part of the slope (tab. II.6) : this implies that on normally cultivated fields, which have generally a lower maximum slope and are bare for a much shorter period, the relative importance of interrill erosion may well be above 50 %.

Rill flow, generated during moderate runoff events can be identified as the most important process leading to the downslope movement of *rock fragments* on upland areas in the Belgian Loam Region. Incipient motion conditions for single or clustered rock fragments on relatively flat rill beds coincide with a mean Shields entrainment parameter (θ_c) of 0.012, which is much smaller than the generally accepted θ_c for channel flow (fig. II.24). Laboratory data show that this can be explained by the relative steep bed gradients and the low angle of repose

Transport of rock fragments by rill flow is relatively aselective (fig. II.23a-b and II.25). This is partly explained by the stochastic nature of rock fragment entrainment and partly by the traps occuring in the rill bed : also, it is possible that larger fragments are set in motion by the impact of moving smaller fragments. This means that the gravel size as an indicator of flow competence is very limited.

<u>6. Considerations on the shape of rills as related to hydraulic conditions and the length of a convex slope L (J. De Ploey)</u>

- On the convex, bare slope section of Huldenberg, slope S, in percentage, is linearly related to slope length L, in meters:

$$S = 0.22\ L \qquad (1)$$

- Where the rills start S is about 4 % and further downslope

$$S = 4 + 0.22\ L \qquad (2)$$

- Remarkable is the fact that there is also a linear relationship between the depth D (meters) of the rills and slope length L:

For the different rills the function varies :

$$D = 0.0025\ L \qquad (3)$$

to :

$$D = 0.0050\ L \qquad (4)$$

- At the first incision, over a distance of 20-30 m, width W definitely exceeds depth D. The rills start in more sandy, gravelous material. But downslope, where there is entrenching in the clayey Bt-horizon W becomes equal to D:

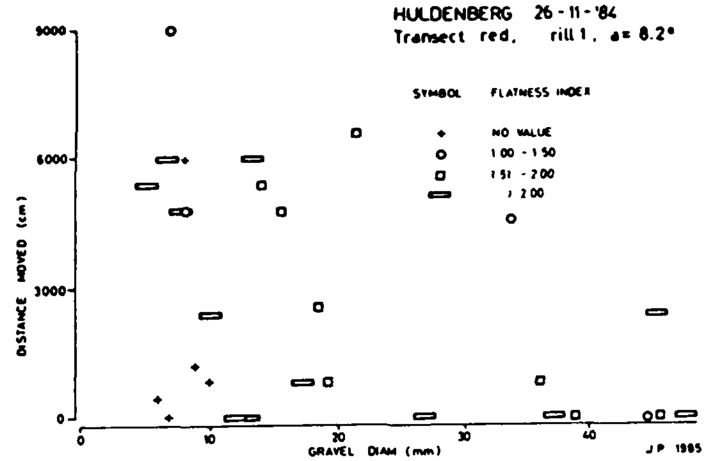


Fig. 11.23 Distance moved in function of gravel diameter for transect red

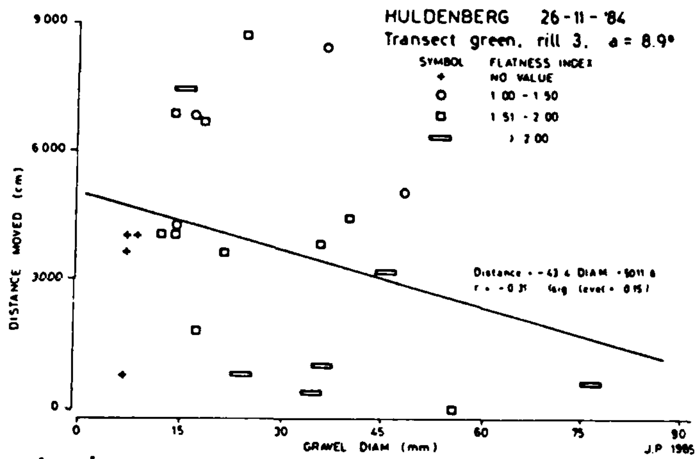


Fig. 11.23b

Distance moved in function of gravel diamete for transect green

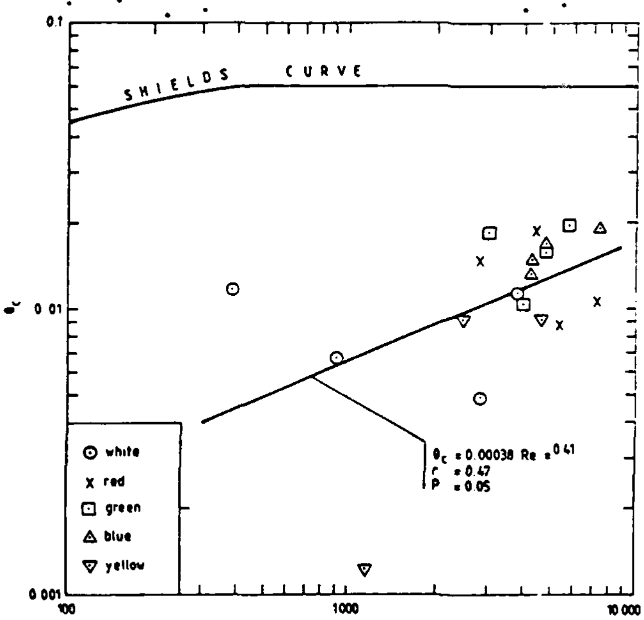


Fig. 11.24

Shields entrainment parameter in function of shear velocity grain Reynolds number for large pebbles moved

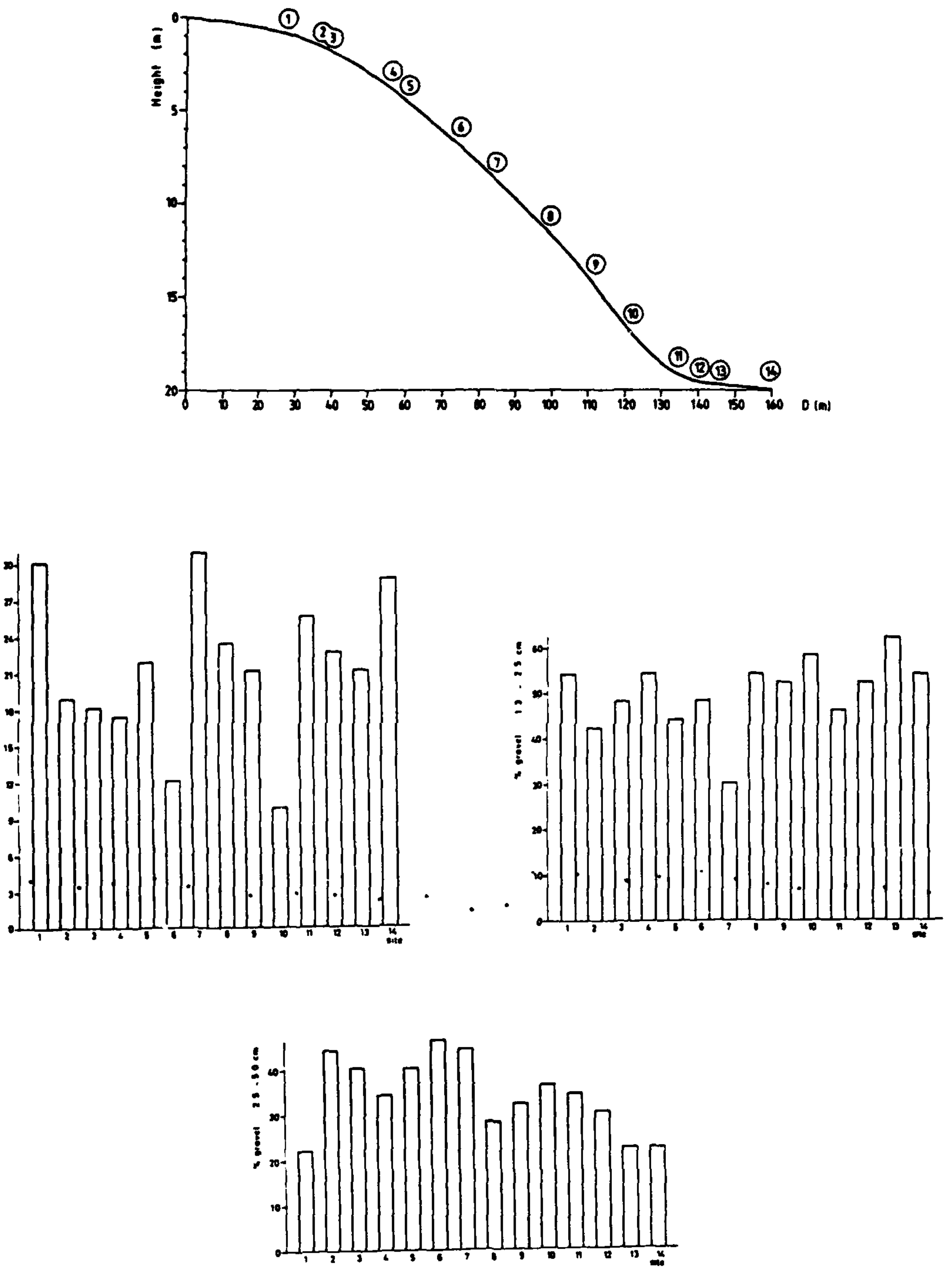


Fig. II.25 Grain size distribution of gravel deposits on different sites in a rill

$$W = D \quad (5)$$

- Thus, the volume V eroded per unit length, corresponds to

$$V = D \times W/2 \times 1 = D^2/2 \quad (6)$$

which means, taking into account (3) and (4):

$$V \sim L^2 \quad (7)$$

- Interesting is a consideration on the relationship between the shear stress s of the flow and its evolution along the slope L:

According to Darcy-Weisbach :

$$\bar{u} = (8gRS/f)^{1/2} \quad (8)$$

where :

- $\bar{u}$ = the mean velocity of the flow
- g = acceleration due to gravity
- R = the hydraulic radius
- S = the slope
- f = the friction factor

For flows in a rough channel GOVERS and RAUWS (1986) propose to split up the friction factor f:

$$f = f' + f'' \quad (9)$$

whereby f' is the grain roughness friction factor, f" is the form friction factor related i.a. to the pool successions within the channel bed. Based on literature data and on experimental research, it can be stated that the erosivity as well as the transporting capacity of the flow are not controlled by total shear stress, but by the grain shear stress, which is the shear stress exerted on the (transportable) grains :

$$s' = d_w . g . R' . S \quad (10)$$

or :

$$s' = 1/8 \, f' \rho \, \bar{u}^2 \quad (11)$$

where :

- d_w = density of water
- R' = the hydraulic radius attributed to the grain roughness
- s' = the grain shear stress

It is reasonable to consider f and f' as nearly constant within the rills. In fact, measurements show that the number of pools per unit length, and therefore also their size, is fairly constant so that :

$$f = 8\ g\ R\ S/\bar{u}^2$$

and $$f = 8\ g\ R\bar{u}\ S/\bar{u}^3 \qquad (12)$$

so that, with $R\bar{u} = q$:

$$\bar{u} = (8\ g/f)^{1/3}\ q^{1/3}\ S^{1/3} \qquad (13)$$

where q = the unit discharge

Thus, within (13), the factor $(8\ g/f)^{1/3}$ can be considered as constant, with a value C^{te}.

Finally expression (11) of shear stress s becomes:

$$s' = C^{te}.q^{2/3}.S^{2/3} \qquad (14)$$

Now : $$q \sim L^{1.0} \qquad (15)$$

according the rational formula, $Q = C.Ir.A$, where :

C = the runoff coefficient
Ir = rainfall intensity and
A = the size of the rill catchment,
proportional to $L^{1.0}$ and, taking into account (4):

$$S \sim L^{1.0}$$

which means for (14) : $$s' \sim L^{4/3} \qquad (16)$$

The transporting capacity T of the flows is related to a power funciton of s, with maximum values defined recently by GOVERS (in press):

for silty loams : $T \sim s'^{5.0}$ (17)

for sandy sediments : $T \sim s'^{2.5}$ (18)

and the combination of (16), (17) and (18) permits to link T with L, for material that may loamy to sandy:

$$T \sim L^{3.0 \text{ to } 4.0} \qquad (19)$$

Proportionally (7) expresses erosion E in the rills and shows that E $L^{2.0}$. So it becomes clear that transporting capacity T far ex-ceeds erosion E.

Summarized:

$$S \sim L^{1.0}$$

$$D = W \ L^{1.0}$$

$$s' \sim L^{4/3}$$

$$Y \sim L^{2.0}$$

$$T \sim L^{3.0 \text{ to } 4.0}$$

$$E << T$$

These relationships concern a convex slope section which corres-ponds to an arc of circle. The proportionality D $L^{1.0}$ can be com-pared to the one on rectilinear slope section where the exponent of L takes values inferior to 1.0 (oral communication RAUWS and GOVERS)

7. Vegetation and erosion

a. Erosion by stemflow on corn

Stemflow measurements on corn showed that a corn plant can yearly produce up to 20 l of stemflow. When corn plants are fully grown, stemflow can amount to 45 % of total precipitation. This stemflow water reaches the soil at the base of the corn plant and can activate rill erosion if the slope is sufficiently steep. These rills may develop along the plant rows or between them (fig. II.26) and may continue to grow even if the plant cover is nearly 100 % (tab. II.7).

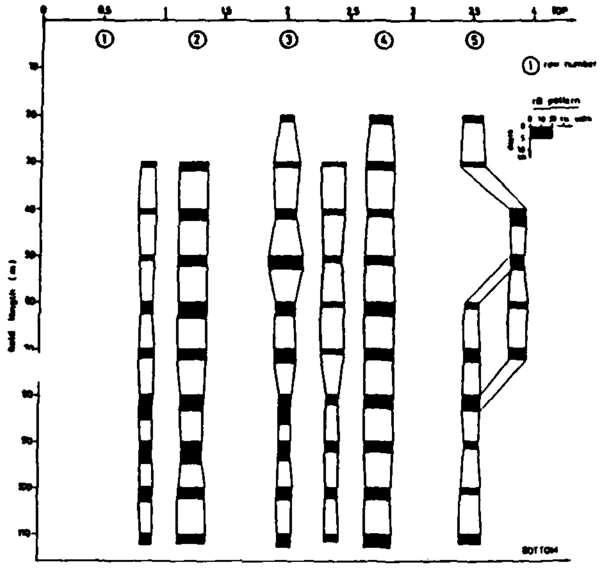
b. Recent gullying on the experimental slope covered by grass (J. De Ploey, G. Govers)

Following sequence of events was observed in the gullies formed on the vegetated part of the slope, after planting of the grass in the fall 1986 :

- Incision of the rills and gullies started between the rows

- Lateral erosion is impeded as long as entrenching is within the top layer with the root mat

- When incision goes down through the root mat erosion accelerates as a lot of lateral sapping occurs. Sidewalls are undercut and slide into the gully with the grass sods on top. The lower part of these blocks is eroded by the flow, but the top layer with the sods is resistant.



g. II.26a Rill erosion in a corn field (20/08/84)

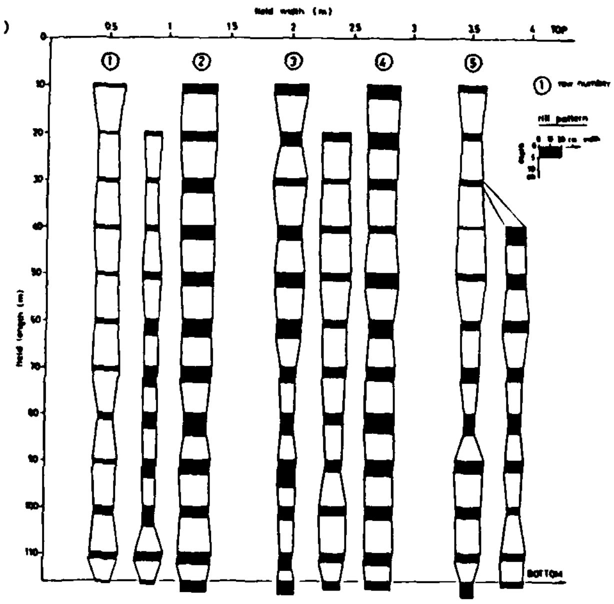


Fig. II.26b Rill erosion in a corn field (14/10/84)

Table : Stemflow and erosion measurements at Huldenberg.

.an slope: 7°
Soil material: sand loam
Length of slope: 120m

Total eroded volume by rills at end of season: $198m^3$/ha = 1,98cm

For period august-oktober (2 months, dry period):

eroded volume by rills: $79m^3$/ha = 0,79cm
rainfall : 48,5mm = 485000l/ha
stemflow : 140760l/ha (average of 1,65l/plant)
==> ± 30% of rainfall = stemflow
(for wet period ± 45% of rainfall = stemflow)

Tab. II.7 Some data on stemflow on corn

- These residual blocks act as large roughness elements which promote the unilateral shift of the flow and sapping of opposite gully walls. This effect raises the question wether or not vegetation is not indirectly promoting and accelerating the erosion in the deeper gully sections compared to their development on bare soils.

Of course, other effects are also involved :

- Colonization of the channel and gully walls by the grass is poor.

- The global roughness of the channels is superior to the roughness of the channels developed on bare surfaces.

- The net balance will also be determined by the increase of infiltration under the grass cover, which, in turn, can activate subsurface flow, pipeflow and pipe erosion.

8. The colluvium

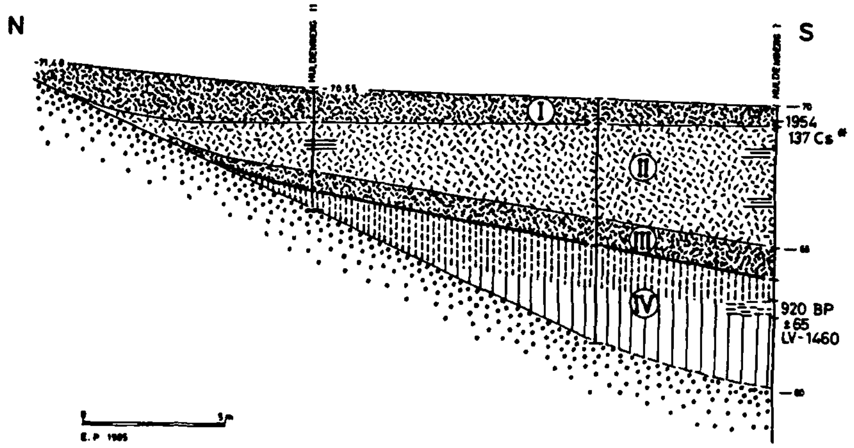
Two borings in the colluvium (fig. II.27) have been sampled each 10 cm for grain size analysis (tab. II.8). In a pit located near boring I additional samples were taken for micromorpholigical analysis and for Caesium-137 dating.

The colluvium can be subdivided in three units : a sandy silt colluvium at the base (III), a main middle unit of silt colluvia (II) and a sandy colluvium at the top (I).

The sandy silt colluvia (III and I) are considered to originate from the experimental field. The lower slope colluvium (III) is dated between the 10th to the 12th century (^{14}C-date) and 1526 when a coppice occupied already the steep slope of the experimental field. These colluvia, about 1 m thick are deposited on a slope of .20 %.

The upper sandy silt colluvium (I), about 1 m thick, showing only very locally lamination, is partly a fan-like deposit on a flat valley-bottom. Most of these deposits are ^{137}Cs dated to be younger than 1954 (by B. Campbell, Australian Atomic Energy Comission, see tab. II.9).

The main sedimentological characteristics of the middle silt colluvium unit (II), more than 4 m thick, is its horizontal and inclined lamination. These deposits fill up the valley bottom and are considered to originate from the Hof ten Bosch catchment. Only the upper part of this unit shows clear micromorphological evidence of a stable vegetation. This observation is corroborated by palynological investigations (by A.V. Munaut, Université Catholique de Louvain, Belgium). The local environment during the deposition of the lower and middle colluvia is dominated by Dyopteris, grasses and Composites, practically without Cereals, and a coppice vegetation.



I. Sandy silt colluvium originating from the experimental field and mostly deposited since 1950 (137 Cs-date, Atomic Energy Comission)

II. Silt colluvium originated from the experimental field as well as from other fields in the Hof ten Bosch catchment

III. Sandy silt colluvium originated from the experimental field. The base is dated at 920 BP ± 65

IV. Weichselian silt deposits with truncated Holocene soil on top

Fig. II.27 Section of the colluvium at the base of the experimental field

Unit	Provenance	Median (um)		Sand content (%)	
		boring 1	boring 2	boring 1	boring 2
I	Exp. field	20.9	24.9	15.1	21.7
II	Exp. field + catchment	15.4	18.0	3.4	2.5
III	Exp. field	22.0	24.6	12.9	25.9

Tab. II.8 Grain size characteristics of the colluvium

Sample depth	^{137}Cs (millibequerels per gram)
0-5	6.7 ± 0.5
5-10	5.9 ± 0.4
10-15	5.4 ± 0.6
15-20	5.9 ± 0.4
20-25	6.0 ± 0.4
25-30	5.6 ± 0.4
35-40	9.4 ± 0.6
40-45	9.0 ± 0.6
45-50	8.2 ± 0.6
50-55	6.1 ± 0.5
55-60	2.0 ± 0.3
60-65	0.4 ± 0.4
65-70	0.0 ± 0.3
70-75	0.0 ± 0.4

Analytical uncertainties cover the range 0-1 mBq/g and therefore reak measured ^{137}Cs is present in soil down to 60 cm

In stable soil profiles ^{137}Cs is distributed exponentially from the the surface down to about 10 cm. Therefore the layer from 50 to 60 cm should be regarded as the original ground surface before receiving the modern colluvium. There is therefore a layer of modern colluvial sediments 50 cm thick.

Tab. II.9 ^{137}Cs activity as a function of depth in the colluvium

The top part of unit II, situated at a depth of about 60 cm, is considered to be the surface of the coppice, where pasture was a common phenomenon. This coppice has occupied the area till 1850, as indicated on historical maps. These observations indicate that colluviation on the experimental field was extremely limited in the period 1850-1950 in spite of the fact that it was continuously arable land since 1860. Since about 1950 soil erosion increased dramatically on this parcel.

The results of the micromorphological study of the upper 1.5 m of the colluvium are synthesized in fig. II.28.

The deposit can be divided into an upper (0-54 cm), almost unlaminated deposit I, and a lower (54-150 cm), mainly well or diffusely laminated deposit II. According to ^{137}Cs measurements the upper 54 cm were deposited after 1954. The difference in sedimentary structure might indicate a different mode of formation of the deposit after 1954, or that the original structure, identical with that of the lower part, has largely disappeared during the last 30 years as a result of different management.

The lamination in the lower part II is horizontal or inclined (16-27°). The inclined lamination could belong to deposits of detrital loessic material of buried alluvial fans, as formed mainly by rain-wash today at the end of gullies or rills.

The horizontal lamination suggests on the contrary that deposition is mainly by afterflow in a more calm environment, alternating with periods of nondeposition. The in situ mud-crust fragment in thin section 0.521 is in agreement with this hypothesis.

Soil development in deposit I is very weak, showing Fluvisol-like soils, with little biological activity and almost no illuviation phenomena. Field characteristics in combination with the observed sedimentary and pedological features suggest two main Fluvisol-like soil formations, consisting of a soil with Ap- C1- C2 horizons, and a soil with a Ap horizon, respectively.

The lower deposit II shows in comparison with deposit I stronger soil formation. Mainly based on the alternation of horizons with clear and diffuse lamination, biological activity and illuviation phenomena the deposit could be divided in three main periods of Cambisol-like soil formations, each composed of an Ap and (B) horizon. The most upper one is most strongly developed, showing even some normal yellow illuviation ferriargillans, characteristic of a Bt horizon of Chromic Luvisol formed in a temperate climate under deciduous forest.

Deposit I resembles in structure ard soil formation largely

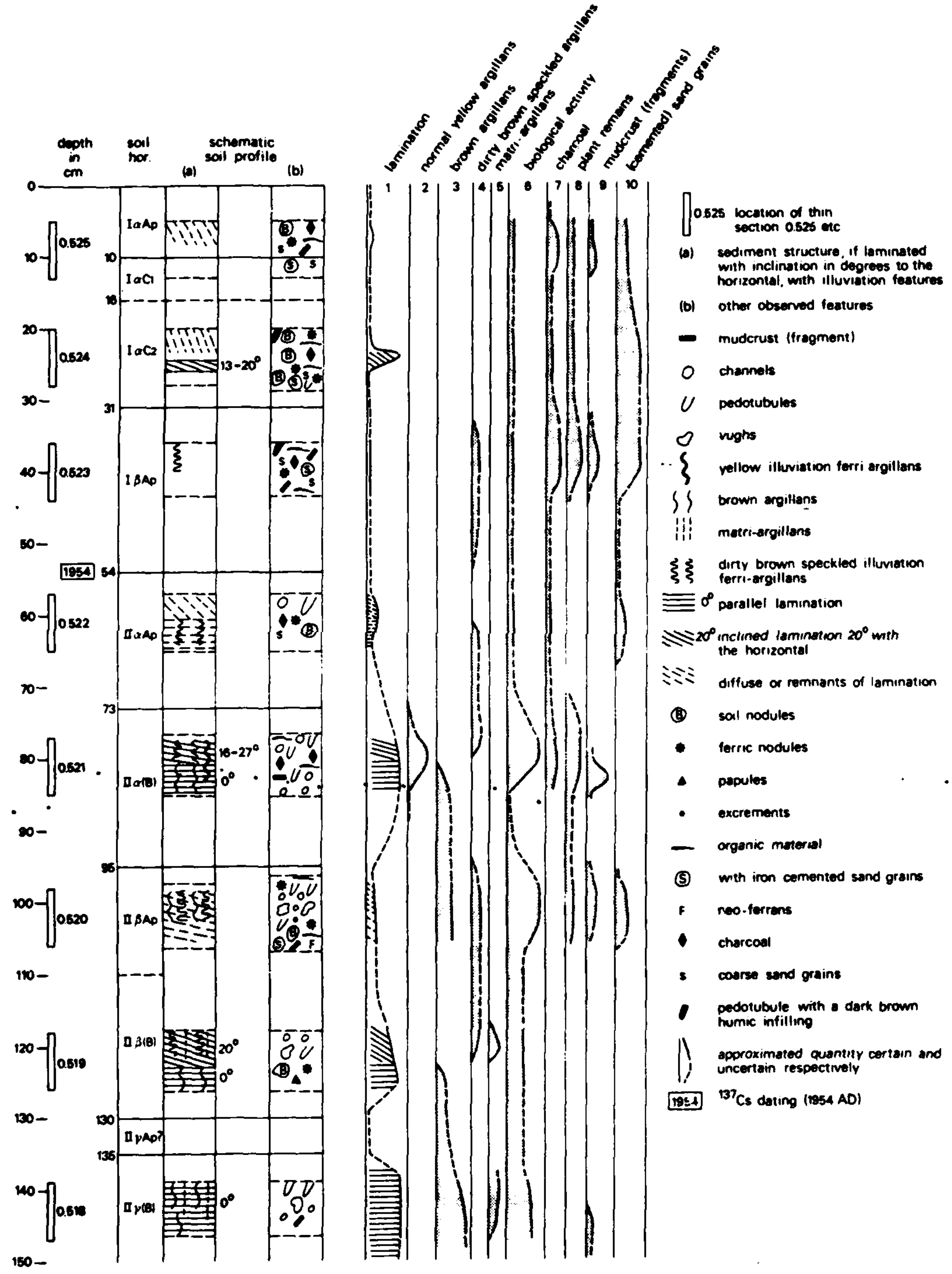


Fig. II.28 Visual approximation of the frequency of micromorphological features in anthropogenic colluvia at the Huldenberg experimental plot, Belgium.

H.M. 1985

HULDENBERG - CATCHMENT

Estimation of total erosion and colluviation since agricultural practices

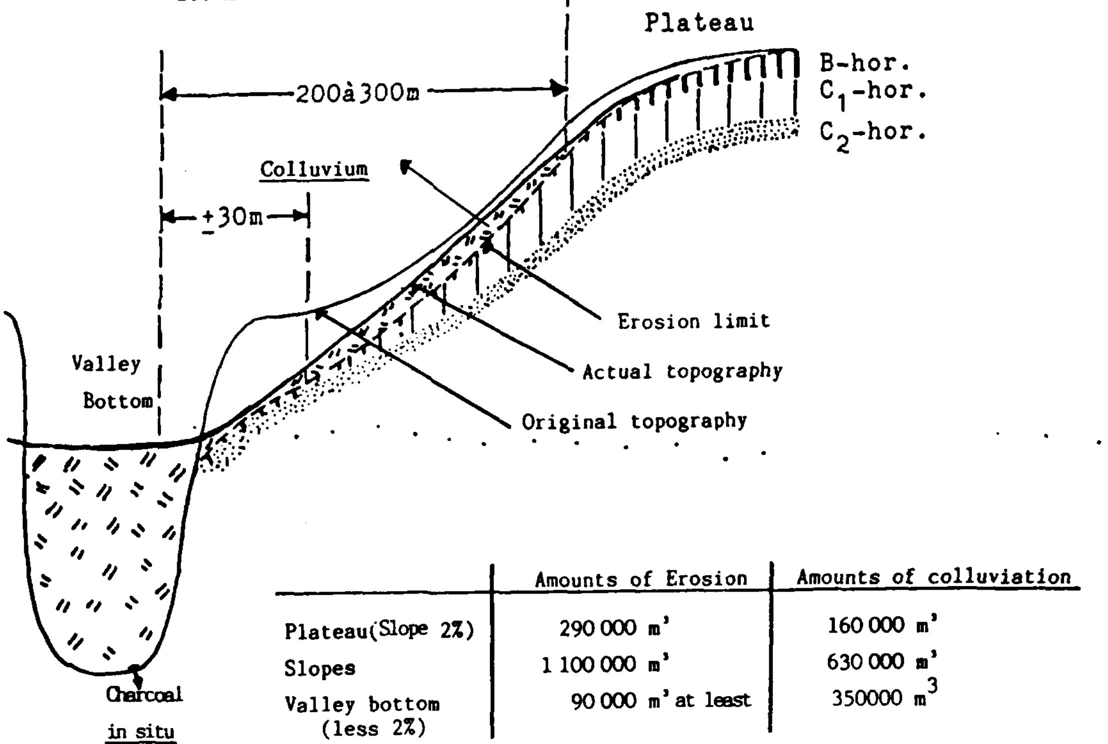
E. PAULISSEN AND P. DESMET

DRAINAGE BASIN AREA: 1.1 km²

DEFORESTATION TIME : in the period 1020-1190 AD (C-14 : 920 ± 65 BP)

GENERAL SLOPE CHARACTERISTICS SINCE AGRICULTURAL PRACTICES

Erosion and colluviation amounts are based on truncated soil horizons
Top of calcareous loess under Holocene soil is situated at a depth of 2.6 m



	Amounts of Erosion	Amounts of colluviation
Plateau(Slope 2%)	290 000 m³	160 000 m³
Slopes	1 100 000 m³	630 000 m³
Valley bottom (less 2%)	90 000 m³ at least	350000 m³

DELIVERY RATIOS SINCE AGRICULTURAL PRACTICES in the Huldenberg catchment:

Plateau and slopes: 40-45 %

the catchment : 20-25 %

Fig. II.29 Sediment budget of the Hof ten Bosch catchment the "recent" loess-derived anthropogenic colluvia in Dutch southern Limbourg, whereas deposit II shows a large resemblance only pedogenetically with the "old" loess-derived anthropogenic colluvia in The Netherlands, in which distinct laminations are almost lacking.

9. Historical erosion and colluviation in the Hof ten Bosch catchment

a. General characteristics of the catchment

- drainage area : 1.1 km^2

- assymetrical cover of loess : thick loess cover on the north-facing slopes, thin cover on the south-facing slopes, variable on the plateau remnants.

- Soil type : gray-brown podzolic soil, or alfisol.
  Typical soils on loess : hapludalf
  Degraded soils on loess : glossidalf

- Top of calcareous loess is at 2.6 m depth on non-eroded sites

- Calculation of erosion and colluviation budgets are based on about 450 borings, arranged in catenas. All sections were leveled. The thickness of colluvial deposits was measured directly. The amount of total erosion was calculated by comparing the actual truncated soil profile with the thickness of the different horizons of the original soil profile. The top of the calcareous loess was considered to be a reference level.

b. Age of deforestation

Charcoal from a layer burned in situ at the very base of a 6 m thick colluvial deposit was radiocarbon dated at 920 BP +/- 65. This means that deforestation has to be placed somewhere in the period 1020-1190 AD. Colluvial deposits, prior tot this deforestation were not recovered in the Hof ten Bosch catchment.

c. Historical evolution of land use

The historical evolution of the land use in this catchment is well documented as nearly all the land belonged to the Hof ten Bosch farm. Precise maps exist from 1526 on. The main information is presented in fig. II.1 and II.2. Since 1526 the steep south-facing slopes as well as the slope opposite to the experimental field were covered with forest for three centuries or more. The rest of the land was probably permanently arable land since deforestation.

d. Valley bottom morphology

The bore data prove that a deep incision occured in the valley bottom before deforestation. A hydromorphic soil in the bottom of this incision indicates a humid environment. The larger valleys in the forests of Middle Belgium have still the same characteristics.

e. Total erosion and colluviation since deforestation

Main observations and conclusions are given in fig. II.29. Generally total erosion rate increases from the plateau towards the valley bottom. In the basal concavities, erosion down to the calcareous loess (which means more than 2.6 m), is not rare. Mean depths of erosion are :

- on the plateau spurs : 0.9 m
- on the slopes : 1.7 m
- in the valley bottom : not evaluated due to the absence of reference points

Averaging over the basin, the mean erosion depth is calculated as 1.3 m. The mean thickness of colluvial deposits, which are always on top of truncated soil horizons, is 2.9 m in the valley, 1.0 m on the slopes and 0.5 m on the plateau spurs. Colluvial deposits on the slopes are widespread and were even observed on slopes of 15 %. Further attention has to be paid to the role of man. Indeed, man may have induced colluviation to recover exposed gravel deposits with silt loam.

III. THE MOREELS FARM : EROSION CONTROL BY NO-TILLAGE
(J. De Ploey, G. Govers, H. Mücher, J. Poesen)

1. Perspectives for erosion control. An option for no-tillage.

There is no feasible planning possible in this field without taking into account the whole complexity of physical, technical and socio-economic constraints which govern modern agriculture.

It is clear that reforestation could largely eliminate soil erosion in northwestern Europe on several hundred thousands of ha with critical slope angles above 4-5 %. But such an operation seems rather unfeasible from a socio-economic point of view, considering also the high natural fertility of the loess loam areas.

Efficient erosion control would also result from turning critical arable landinto pasture. A rough estimate learns that such a change in land use in Belgium would already involve at least 100000 ha. It would also increase the overproduction of meat and dairy products within the EEC which costs the Community more than overproduction of cereals or sugar beets. To be efficient, grass-land should be established on critical slope segments, sometimes far from the farmstead, whereas today it is concentrated in house pastures. The whole operation would be opposite to the evolution of the last decade in which there was a decrease in the loamy belt of permanent pasture land but an increase of cattle-density (Van Hecke, 1976). The operation would imply an important investment for farmers who have always concentrated on agriculture and who will not decide spontaneously to change.

As explained, rill erosion is very imminent on fields with a maximum slope angle exceeding 4-5 %, as indicated by a regional survey whereby 90 fields were visited yearly during springtime for three years (fig. III.1). They develop over very short distances. Fairly rapidly they may become heavily loaded and colluviation can start as soon as the transport capacity of the flow is locally reduced. Therefore one may be very sceptical about the efficiency of strip cropping or the introduction of grassed waterways: the closely grown, erosion-resistant strips will be quickly buried under colluvial deposits. On the other hand it is not certain that slope segmentation will significantly reduce erosion rates on the tilled areas : no clear relationship exists between field length and the mean rill erosion rate (fig. III.2). Moreover these systems may hamper tillage and may imply an evolution toward mixed farming, posing financial problems for farmers and for the EEC.

One may also consider different mechanical interventions. It may be benefical to prepare seedbeds as coarsely as

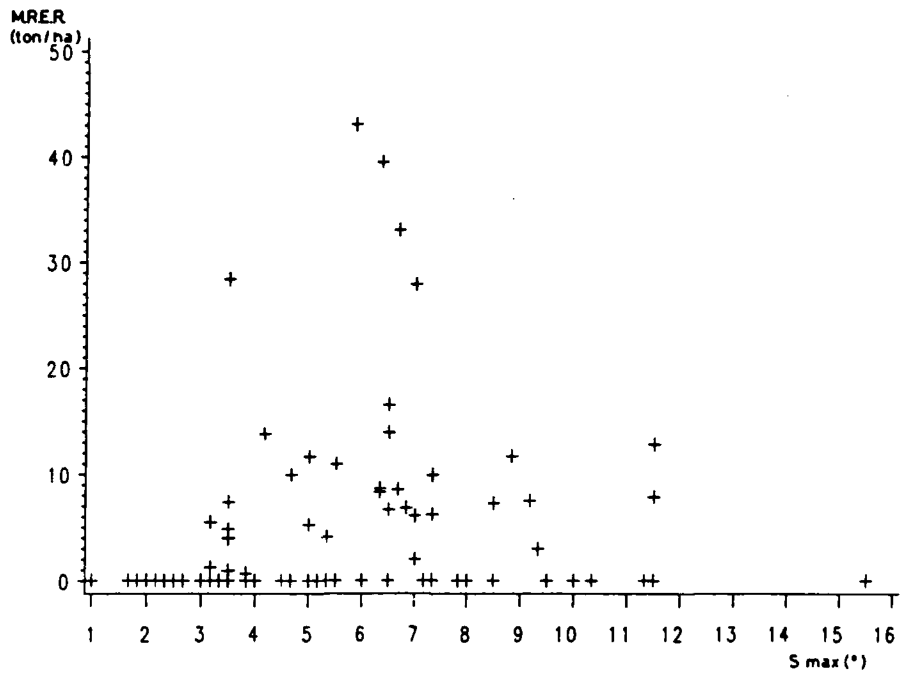


Fig. III.1 Relationship between mean rill erosion rate and maximum slope angle of the field

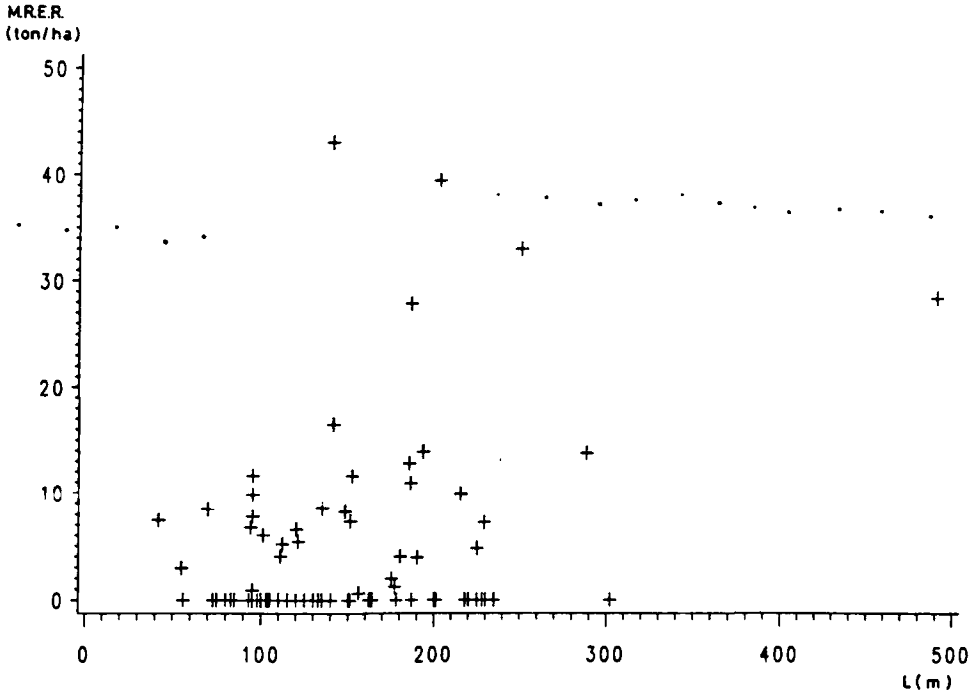


Fig. III.2 Relationship between mean rill erosion rate and field length possible in order to retard sealing and crusting (Moldenhauer, 1970). However, the crustability of most loamy topsoils in northwestern Europe is so high that runoff (and erosion) can occur even one or two months after seeding (De Ploey, 1981).

Contour tillage is an effective measure on slopes below 4 %. But it is a risky technique on steeper slopes where it may promote gullying as water, after spilling from degraded furrows, is concentrated along a few slope lines. Striking examples of this phenomenon have been observed at the pilot farm in Huldenberg, near Brussels.

The remaining colluvial terraces in the loess belts have ambivalent effects with respect to erosion control. Special attention will have to be paid to processes of pipe-erosion which have been underestimated hitherto and which are currently activated by high runoff production on adjoining fields, the length (and slope) of which increased often during the last decades. For the same reasons the erosion resistance of new terraces, constructed with highly erodible silt loams, is questionable. They also may hamper tillage operations.

It is clear that erosion control can be promoted by increasing infiltration rates of the soils and reducing runoff yields. However, structural stability of most topsoils in this region is at present very low and far insufficient to prevent runoff generation (fig. III.3). On only very few fields, aggregate stability is high enough to prevent runoff generation and rilling. Thus, aggregate stability of the topsoil would have to be (re)established by applying organic manure provided they really contribute to a strong structurization of topsoils. It is questionable whether this can be achieved without turning the land into pasture, at least for a certain period.

Most encouraging are the reports about conservation tillage for erosion control in the United States (Moldenhauer et al., 1983). If, during the next decades, cropping patterns and crop rotations remain the same in the European loess areas then it would be worthwhile to devote experiments to these practices, including no-till. No-tillage has the advantage of combining the beneficial effects of a partial vegetation cover with an increased erosion resistance due to soil compaction. Survey data on rill erosion rates in this region show that fields are efficiently protected during wintertime if the near-ground vegetation cover exceeds 40 % (fig. III.4). Furhtermore, the results showed that rill erosion rates were significantly lower on maize and chicory fields, which remained compact after harvest than on winter wheat fields (tab. III.2).

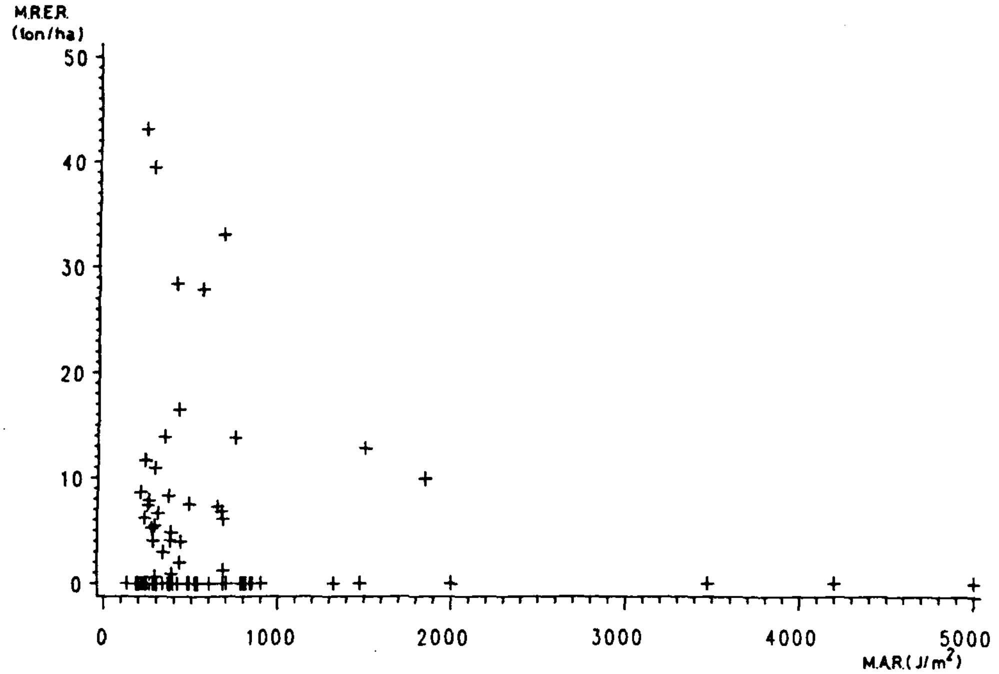


Fig. III.3 Influence of aggregate resistance on rill erosion

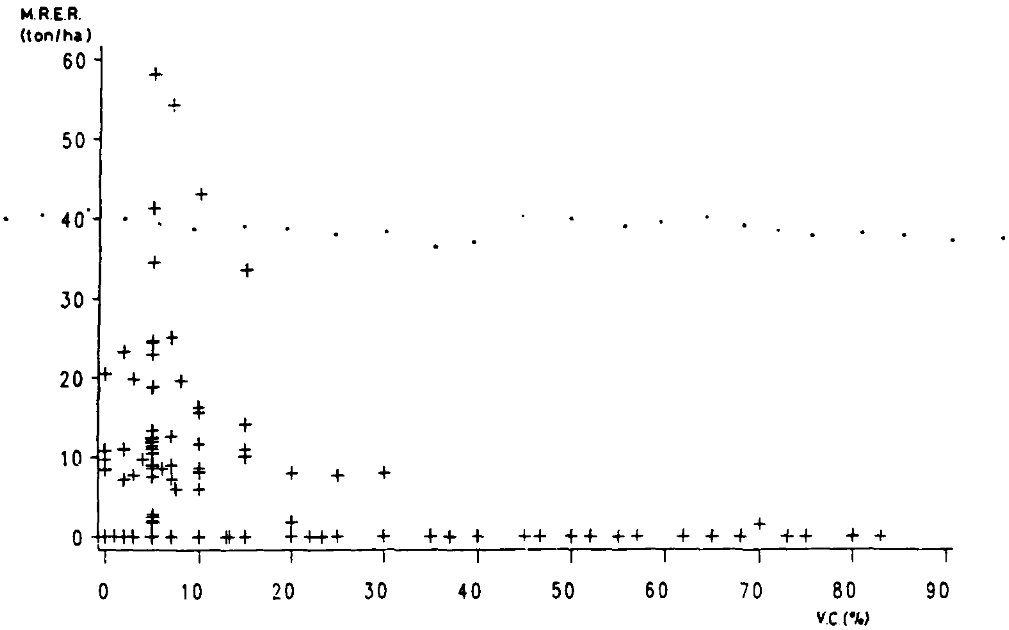


Fig. III.4 Relationship between rill erosion rate and vegetation cover

Year	Winter barley	Winter wheat
1982	14.7	6.6
1983	36.7	10.8
1984	47.8	8.6
1985	9.3	3.3

ıb. III.1 Vegetation cover percentage on winter barley and winter wheat fields in different years (situation in march)

	Bulk density** (g/cm^3)	Slope ( )	Vegetation cover (%)	Rill erosion rate (ton/ha)*
Winter wheat or barley	1.35	5.6	8.9	8.23
Fallow	1.49	6.2	8.0	3.36

** : significantly different at the 0.2 % level
* : significantly different at the 1 % level

Tab. III.2 Comparison of rill erosion rates on non-compacted winter wheat and barley fields with rill erosion rates on compacted fallow fields

OBSERVATION PERIOD / RAINFALL VOLUME (mm)	CONVENTIONAL TILLAGE		NO-TILLAGE FIRST YEAR	NO-TILLAGE SECOND YEAR	BARE AND COMPACTED PLOT (*) FIRST YEAR	BARE AND COMPACTED PLOT (*) SECOND YEAR
08/10/86 - 24/10/86	0.94	(**)	0.54	0.01	-	0.62
± 84	(0.48,n=10)	(***)	(0.19,n=8)	(n=2)		(0.50,n=3)
24/10/86 - 24/11/86	0.26		0.32	0.16	0.85	0.44
± 73	(0.07,n=9)		(0.12,n=9)	(n=2)	(0.2,n=5)	(0.16,n=3)
24/11/86 - 11/02/87	0.62		0.36	0.17	1.28	0.41
± 158	(0.26,n=7)		(0.16,n=9)	(n=1)	(0.59,n=4)	(0.07,n=3)
11/02/87 - 25/04/87	0.32		0.29	-	0.97	-
± 164	(0.10,n=10)		(0.11,n=8)		(0.53,n=5)	

(*) : = clipped plots located in the no-till fields:
(**) : data are corrected for cup diameter effect and are expressed in kg m^{-2} ;
(***) : standard deviation and number of observations respectively.

Tab. III.3 Influence of NT on splash erosion

	Peeters '86 CT	Peeters '86 NT	Peeters '87 CT	Peeters '87 NT	Moreels '87 CT	Moreels '87 NT	Verstappen '88 CT	Verstappen '88 NT	Van Geel '88 CT	Van Geel '88 NT	De Bontr. '88 CT	De Bontr. '88 NT	Moreels '88 CT	Moreels '88 NT	Vd. Veken '88 CT	Vd. Veken '88 NT
rills	40	0	0	0	15	0	10	0	0	0	0	0	0	0	3	0
thalweg erosion	-	0	35	-	40	-	15	0	15	0	-	0	-	0	-	0

Tab. III.4 Effect of no-tillage on rill erosion and on thalweg erosion. Figures indicate maximum recorded depth, - : not relevant, CT : conventional tillage, NT : no-tillage

FINALLY COMBATING STRUCTURAL DEGRADATION AND SOIL LOSS MUST REST ON TWO PILLARS

1. improvement and stabilization of the aggregate structure of the topsoil

2. better and continuous soil coverage, by mulching and by the use of minimal tillage technique. Future experiments will have to demonstrate the degree to which these techniques are efficient and acceptable by farmers. Moreover, suppose a limited production loss occurs. This would reduce the production of surplusses. It means that financial compensation could be released from the EC in order to compensate for a supposed decreased production, resulting from a conservation technique.

The application of a new technique must satisfy at least two conditions: it must be equally attractive economically and it must be psychologically reconciliable with the value system of the farmer. The involvement of innovative farmers is the key for success.

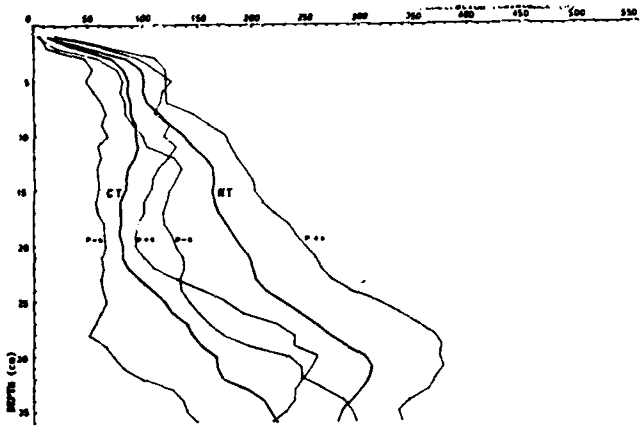
Reduced tillage is a proven method of greatly reducing erosion problems. This is certainly the case for NO-TILL which lowers considerably the erodibility of the topsoil which remains fairly compact and protected by stubble. A first prototype of no-till planter, adapted to the very silty loams, and since 1987 a second prototype have been conceived in collaboration whith the VVV-factory in Vossem-Tervuren.

The first experiment on a 100 ha farm in Huldenberg was realized in 1985-86. Last year 3 farmers applied no-till on 2.6 ha. Last October 5 farmers planted winter barley directly into the winter wheat stubble of the foregoing harvest. For this year we are expecting no-till results on about 10 ha.

Although concerning a limited number of tests the results yet obtained are fairly promising :

1. On the no-till parcels rill erosion is nearly completely eliminated (tab. III.4). The protective effect of no-tillage is great enough to protect also thalwegs of small zero-order cathments. Splash detachment also decreases (fig. III.3), mainly due to the mulch effect and to a lesser extent due to compaction.

2. No-tillage has also some hydrological effects : soil moisture content variations and amounts are similar under no-till and conventional till conditions (fig. III.6). However, throughflow in the plow layer can correspond to several hundreds of liters per meter and per year on a conventionally tilled field, but it is virtually absent under no-tillage (fig. III.7 and III.8). The scarce data on



g. III.5a

>arison of penetration resistance of no-till
conventionally tilled field (04/12/85)

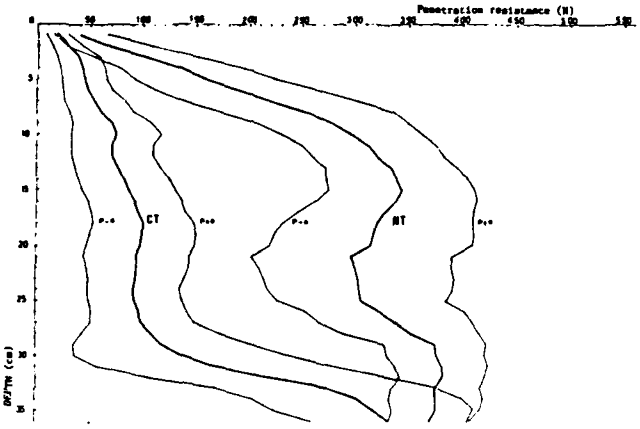


Fig. III.5b Comparison of penetration resistance of no-till and conventionally tilled field (06/04/86)

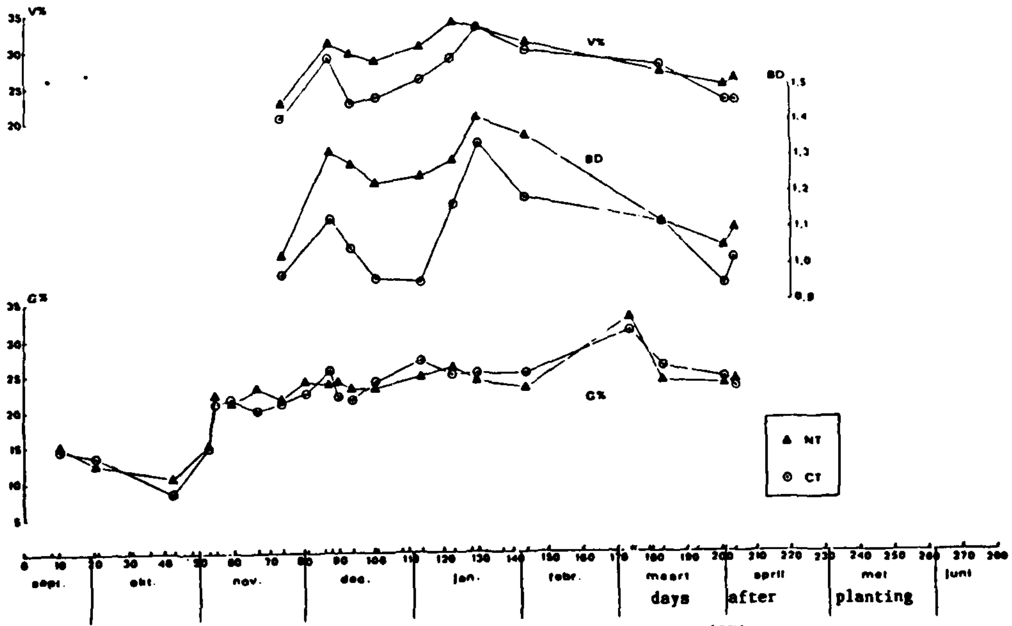


Fig. III.6 Evolution of gravimetric moisture content (G%), volumetric moisture content (V%) and bulk density (BD) of the plow layer on a no-till and runoff generation indicate that runoff production on no-till is of the same order of magnitude than on conventional till.

3. Soil physical properties do change significantly : bulk density and penetration resistance in the plow layer is significantly higher on no-till, especially just after planting (fig. III.5a-b and III.6). Differences diminish considerably during winter time (freeze-thaw cycles). There are clear differences in total porosity as well as in pore types between no-tillage and conventional tillage (see text below).

4. Cereal production was equal or superior to the one on reference parcels with conventional tillage.

5. Hitherto there have been no indications of specific diseases. Weed control with herbicides was the same as for conventional tillage.

It has to be stressed that during heavy rainstorms runoff production on the no-till parcels is important. So we may expect a downstream (linear) concentration of erosive flows if one day no-tillage would break through. But in that case water control works on the roads and in the villages would become meaningful for s lting up would still be much less catastrophic than it is today.

2. Micromorphological comparison of the c/f related distribution and porosity under conventianal tillage (C.T.) and no-tillage (N.T.), after one year

a. Introduction

To compare the structural development under C.T. and N.T. after one year undisturbed samples for thin sectioning were taken in the middle of the Ap horizon, at a depth between ca. 11 and 17 cm, and from the transitional zone between the Ap horizon and the substratum (silt loam colluvium) at a depth of ca. 26-32 cm.

The experimental plots are located in the loess region near Huldenberg, Belgium. The N.T.-plot has been used as conventionally tilled farm land in the past.

The concept of the c/f related distribution has been used to characterise the composition of soil materials. The c/f concept stands for "coarse versus finer". In this case the limit between coarse and fine material is situated at 20 μm. Stoops and Jongerius (1975) defined it as follows : "The c/f related distribution expresses the distribution of individual particles in relation to fine material and associated voids not included in the particles".

Field experiments over a relatively long period (21 years) showed that between years 1 and 5 total porosity (> 50 μm)

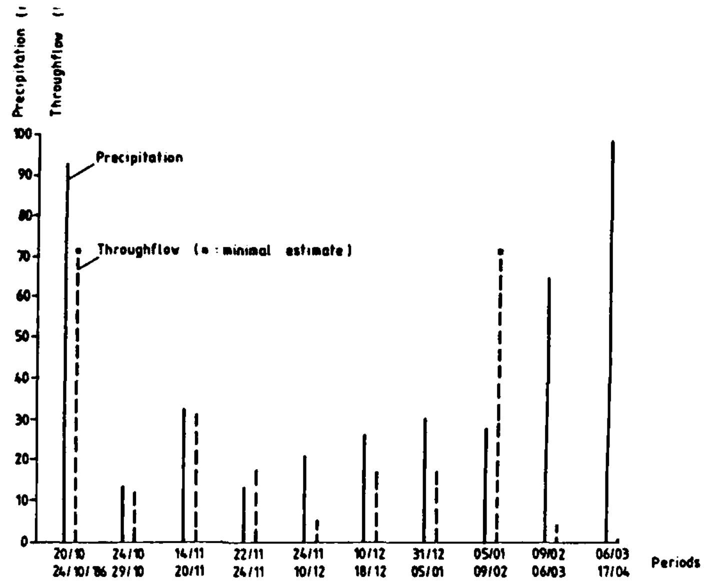


Fig. III.7 Throughflow amounts registered on a conventionally tilled field

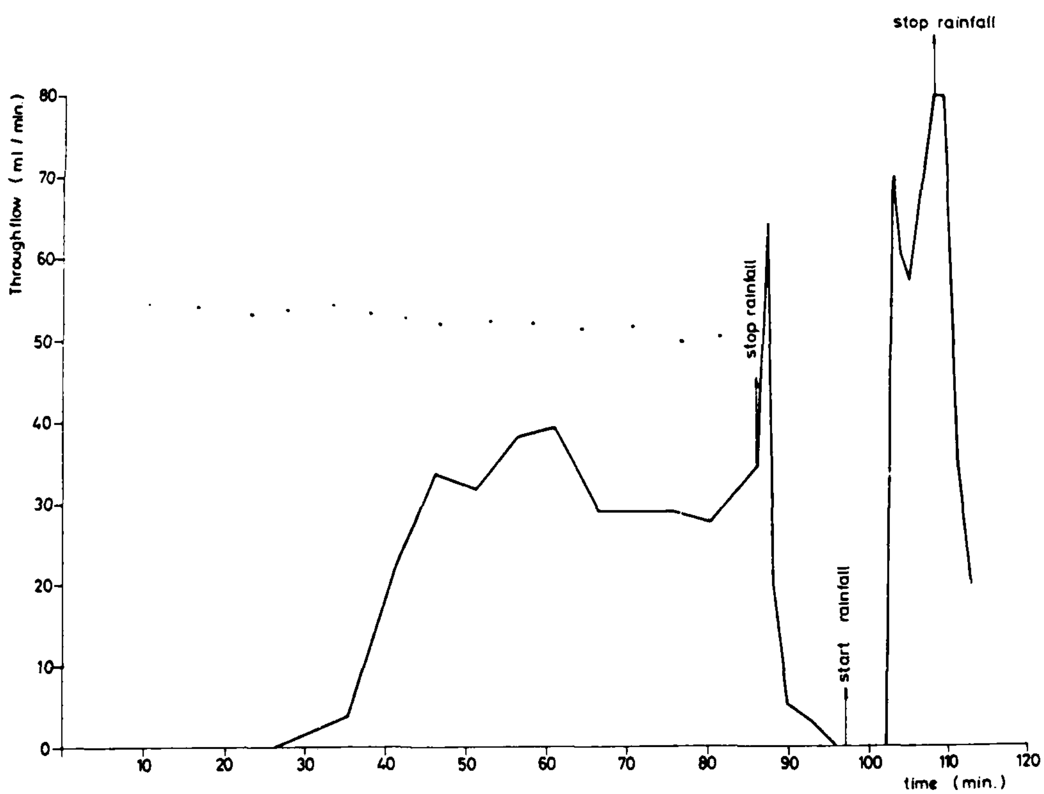


Fig. III.8 Throughflow rate generated by the application of a 50 mm/h rainfall on a 0.6 m^2 surface decreased under N.T. and then increased rapidly between years 5 to 9, and remained somewhat constant afterwards, in comparison with C.T (Norton and Schroeder, 1987).

Shipitalo and Protz (1987) reported that the macroporosity (> 200 µm) in Ap horizons is ca. 50 % lower in N.T. plots than in C.T. plots. At the same time the bioporosity increased more in the N.T. soil than in the C.T. pedon (Norton and Schroeder, 1987, Shipitalo and Protz, 1987).

Micromorphometric analyses of Paglai et al. (1983) indicated that total porosity was significantly higher at all sampling times in C.T. plots than in N.T. plots. However, the proportion of pores ranging from 30-500 µm, which they considered as the most important, both in soil-water-plant relationships as in maintaining a good soil structure, was higher in N.T. plots. Paglai et al. (1983) ascribed the occurrence of this pore size class to a higher faunal activity in the N.T. plots.

In the light of the preceding the micromorphological investigations are focussed on the comparison of total porosity, pore size distribution (classes : micropores < 100 µm, mesopores 100-500 µm and macropores > 500 µm) and void types (vughs, channels and planes). Channels are rounded pores caused by faunal and floral activity. Vughs are mostly irregular voids. Their mode of formation is not clear. They are the result of a complex packing of compound particles. The nature of this packing is conditioned by the degree of adhesion and attraction between particles (Brewer, 196). One type, so-called mammilated vughs, is the direct result of faunal activity. They consist of relativley sharp protuberances. Planes or cracks origninate through shrinking and swelling during wetting and drying. However, this type of voids is relatively rare in silt loam deposits.

The various components of the soils are estimated in percentages by volume with a polarization microscope by point counting in thin sections, usin a Leitz-Blaschke ocular. In each thin section 200 points are conted on six horizontla lines. The distance with depth between the lines is approximately 12 mm. The counted lineds are indicated in the figures by horizontal dashes on the vertical.

b.Results

The c/f_{20} related distribution shows after one year of no-tillage only minor differences (Fig. III.9 a and b). Total porosity (> 20 µm) under N.T. is slightly increased in the the middle part of the Ap horizon and in the zone around the weakly developed plough pan in comparison with the C.T. plot.

The distribution with depth of channels and vughs shows larger differences between N.T. and C.T. (Fig. II.10). The runoff generation indicate that runoff production on no-till is of the same order of magnitude than on conventional till.

3. Soil physical properties do change significantly : bulk density and penetration resistance in the plow layer is significantly higher on no-till, especially just after planting (fig. III.5a-b and III.6). Differences diminish considerably during winter time (freeze-thaw cycles). There are clear differences in total porosity as well as in pore types between no-tillage and conventional tillage (see text below).

4. Cereal production was *equal or superior* to the one on reference parcels with conventional tillage.

5. Hitherto there have been no indications of specific diseases. Weed control with herbicides was the same as for conventional tillage.

It has to be stressed that during heavy rainstorms runoff production on the *no-till* parcels is important. So we may expect a downstream (linear) concentration of erosive flows if one day no-tillage would break through. But in that case water control works on the roads and in the villages would become meaningful for silting up would still be much less catastrophic than it is today.

<u>2. Micromorphological comparison of the c/f related distribution and porosity under conventianal tillage (C.T.) and *no*-tillage (N.T.), after one year</u>

<u>a. Introduction</u>

To compare the structural development under C.T. and N.T. after one year undisturbed samples for thin sectioning were taken in the middle of the Ap horizon, at a depth between ca. 11 and 17 cm, and from the transitional zone between the Ap horizon and the substratum (silt loam colluvium) at a depth of ca. 26-32 cm.

The experimental plots are located in the loess region near Huldenberg, Belgium. The N.T.-plot has been used as conventionally tilled farm land in the past.

The concept of the c/f related distribution has been used to characterise the composition of soil materials. The c/f concept stands for "coarse versus finer". In this case the limit between coarse and fine material is situated at 20 µm. Stoops and Jongerius (1975) defined it as follows : "The c/f related distribution expresses the distribution of individual particles in relation to fine material and associated voids not included in the particles".

Field experiments over a relatively long period (21 years) showed that between years 1 and 5 total porosity (> 50 µm)

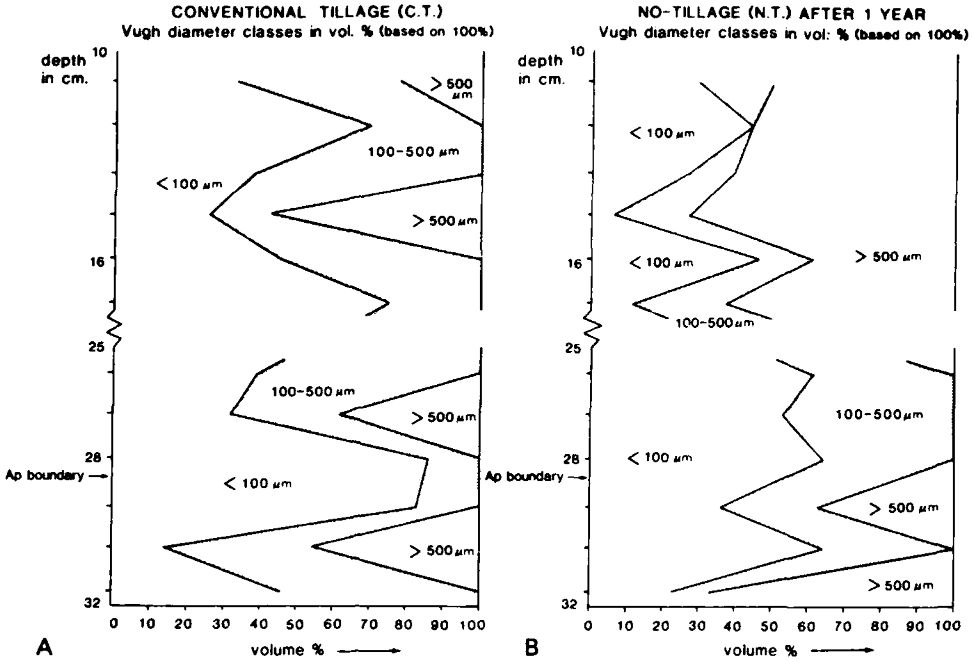


Fig. III.11 Size distribution of vughs into three classes (micro, meso, and macro pores) in conventionally tilled plots (a) and in no-tilled plots (b), after one year, based on 100 %.

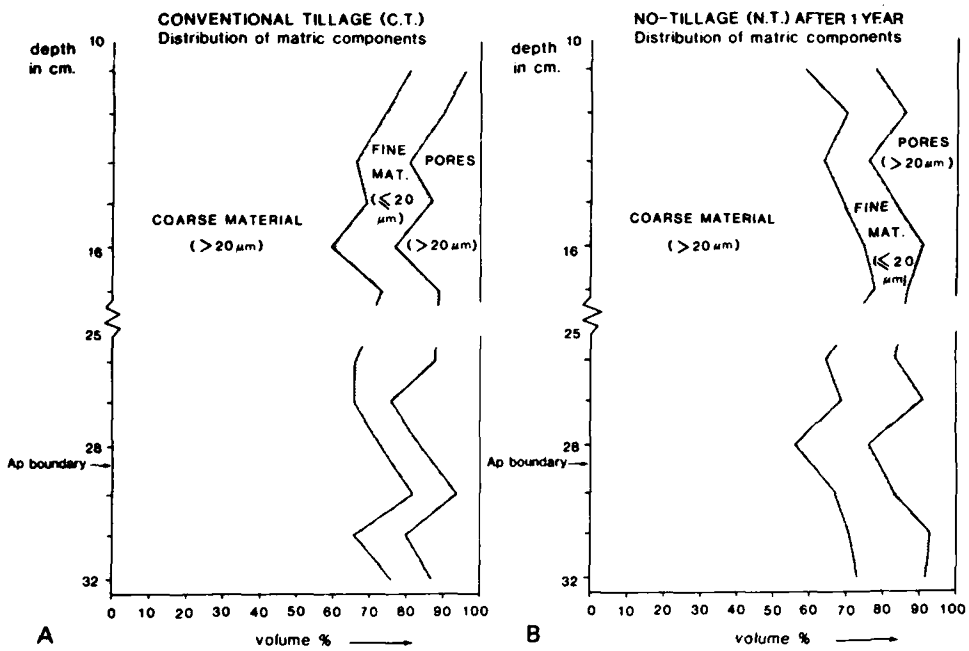


Fig. III.9 The c/f_{20}related distribution of conventional tillage (a) and no-tillage (b) agter one year

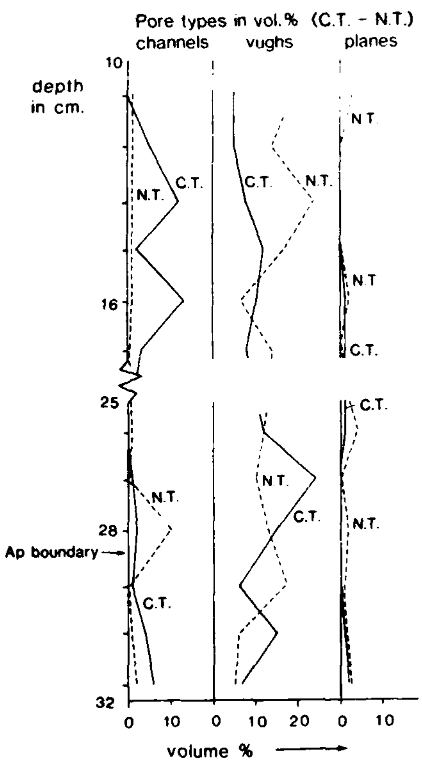


Fig. III.10 Distrubution of channels, vughs and planes with depth in conventionally tilled soils and in no-till soils after one year

Bresson and M.A. Courty (eds.), Soil Micromorphology, Ass. pour lètude du sol,

Pagliai, M., La Marca, M., Lucamante, G., 1983 : Micromorphometric and micromorphological investigations of a clay loam soil in viticulture under zero and conventional tillage. Journal of Soil Science, 34 : 391-403.

Shipitalo, M.M., Protz, R., 1987 : Comparison of morphology and porosity of a soil under conventional and zero tillage. Can. J. Soil Sci., 67 : 45-456.

Stoops, G., Jongerius, A., 1975 : Proposal for a micromorphological classification of soil materials. I. A classification of the related distributions of fine and coarse particles. Geoderma, 13 : 189-199.

IV. THE ORMENDAEL CATCHMENT
(J. Poesen)

In the Belgian Loam Region, gully headcuts often form near sunken roads or abrupts where overland flow tends to concentrate (fig. IV.1). A limited survey and inquiry among farmes indicates that piping due to animal activity is an important factor in their genesis. At Ormendael (Korbeek-Dijle), a gully head has recently been selected for testing conservation measures : i.e. a porous check dam, constructed using loose rock (angular sandstone of from the Neerijse quarry) and willow staking.

Ap horizon contains under C.T. more channels than under N.T., with exception of the zone above the plough pan, where the biological activity is higher under N.T.

The percentages of vughs are higher in the Ap horizon of the N.T. plot than in the C.T. plot, which is partly due to the occurrence of mammilated vughs. The percentages by volume of planes are only sligthly higher in the N.T. than in the C.T. plots, but are in common very low (< 4 %).

The channel diameter in N.T. plots falls mainly in these of the meso pores (100-500 microns) whereas in C.T. plots besides meso channels occcasionally also macro channels are observed in the Ap horizon. The percentages of meso and macro channels are higher in C.T. than in N.T.. This is not in agreement with the results of e.g. Paglai et al. (1983).

The size distribution of vughs into three size classes is based on 100 % and illustrated in Fig. III.11, which shows that under N.T. mainly the micro vughs decreased in the Ap horizon and secondly the meso vughs in comparison with the C.T. plot, whereas the macro vughs under N.T. are increased after one year, mainly in the middle part of the Ap horizon. This increase in macro vughs under N.T. is mainly the result of the occurrence of faunal mammillated vughs in the Ap horizon.

c. Conclusions

1. The porosity under N.T. after one year has been increased only slightly in the middle part of the Ap horizon and in the top of the substratum material, which is mainly due to an increase of (mammillated vughs).

2. In N.T. plots, macro channels are almost absent after one year.

3. In N.T. plots the increase in macro vughs is mainly due to faunal activity. The devrease in micro and meso vughs is probably the result of compaction by structural collapse and settling.

4. The weakly developed plough pan characterised by a domination of micro vughs in C.T. plots is reduced under N.T. after one year by the increase of channels, (mammillated) vughs and planes.

d. References

Brewer, R., 1964 : Fabric and Mineral Analysis of Soils, Wiley, N.Y., 470 p.

Norton, L.D. and Schroeder, S.L., 1987 : "The effect of varous cultivation methods on soil loss : a micromorhological approach", in : N.Fedoroff, L.M.

Related publications

De Ploey, J., 1986 : 'Naar een strategie voor bodemerosiebestrijding op leemgronden', Tijdschrift van de Belgische Vereniging voor Aardrijkskundige studies', 55, 33-43.

De Ploey, J., 1986 : Bodemerosie in de Lage Landen - een Europees milieuprobleem. Acco, Leuven, 108 p.

De Ploey, J., Paulissen, E., 1988 : 'Processus géomorphologiques, formes du relief et interprétations des paleo-environnements quaternaires', Bull. Assoc. Géogr. Franc, 1988-1, 65-78

Govers, G., 1987 : 'A regional study of rill patterns in the Flemish Loam and Sand Loam Region', Tijdschrift van de Belgische Vereniging voor Aardrijkskundige Studies, 56, 75-89.

Govers, G., 1987 : 'Spatial and temporal variability in rill development processes at the Huldenberg experimental site', in R.B. Bryan (ed.), Rill Erosion : Processes and Significance, Catena Supp. 8, 17-34.

Govers, G., Poesen, J., 1986 : A field-scale study of surface sealing and compaction on loam and sandy loam soils [illegible] Spatial variability of soil surface sealing and [illegible] in F. Callebaut, D. Gabriëls, M. De [illegible] Assessment of soil surface sealing [illegible] Proceedings of the Symposium held [illegible] Belgium, 1985, 171-181.

Poesen, J., 1986 : 'Field measurements of splash erosion to validate a splash transport model', Z. Geom. Supp. Bd. 55 81-91.

Poesen, J., 1987 : [illegible] of rock fragments by rill flow - a field study', in R.B. Bryan (ed.), Rill Erosion : Processes and Significance, Catena Supp. 8, 35-54.

Poesen, J., Govers, G. [illegible] A field-scale study of surface sealing [illegible] on loam and sandy loam soils. [illegible] surface sealing and compaction [illegible] processes', in F. Callebaut, [illegible] M. De Boodt (eds.), Assessment of soil surface sealing and crusting, Proceedings of the Symposium held in Ghent, Belgium, 1985, 18[illegible]-19[illegible].

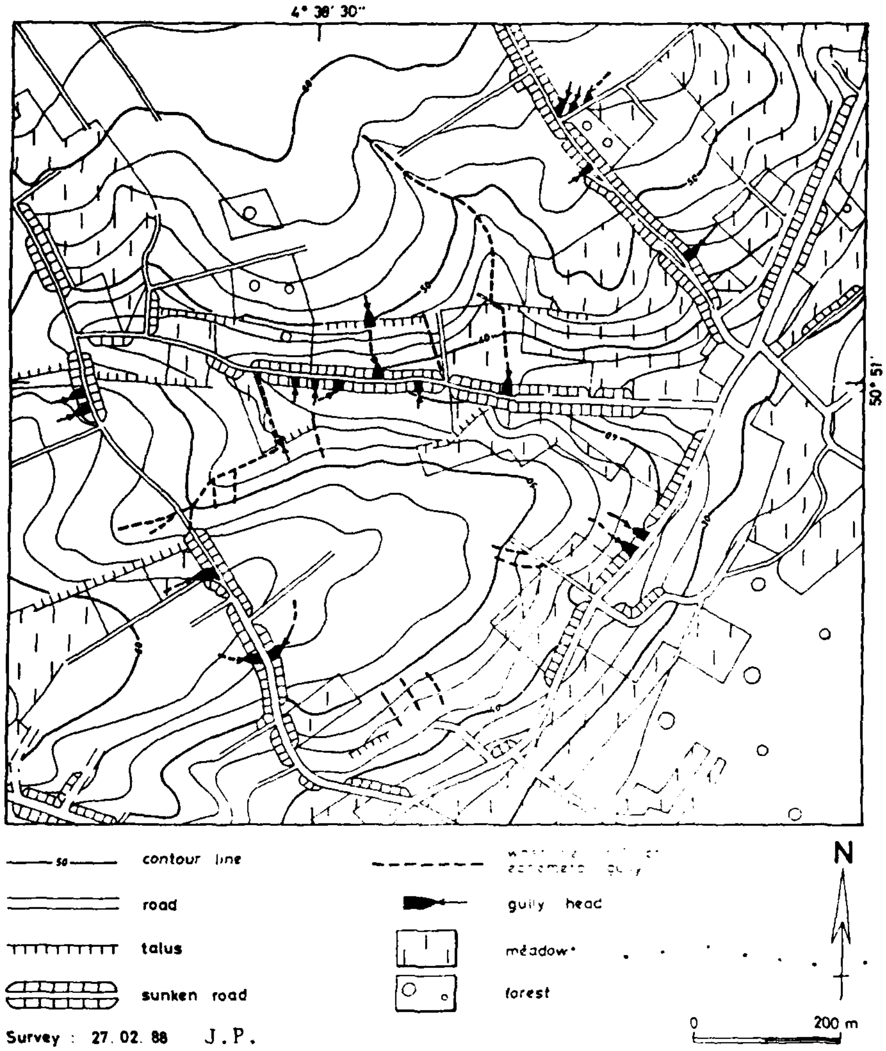


Fig. IV.1 Location of gully heads in the [illegible]mendael area

Part 4: Luxembourg

LUXEMBOURG EXCURSION - 1st May 1988

I. General information

The field excursion site is situated in the centre of Luxembourg, between Diekirch and Larochette, directly south of the Sure river, which is a tributary of the Mosel (see fig. 1). The research area is called "Gutland"; it is known for its relatively good farming soils.

In this area research has been carried out by the University of Amsterdam since the 1970's, and resulted in many reports and papers (see list).

The geology of the area is dominated by sedimentary Mesozoic strata, gently dipping to the S and belonging to the Paris Basin. Three main formations can be distinguished in the area: the Keuper Formation, the Psilonoten Marl Formation, both Triassic, and the Luxembourg Sandstone Formation (Jurassic) the latter forming a distinct cuesta all over the area at the border of its occurrence (see fig. 2). It is in the upper series of the Keuper: the Steinmergel Keuper area, where the excursion site is situated. This formation occupies a large area and has a rolling topography with broad flat watersheds and gentle slopes of up to 5-10°, except for the river incisions which can be much steeper.

The Steinmergel Keuper strata are formed by variegated soft marls with intercalations of thin stony banks of marls and dolomites. Outcrops only occur at the stream incisions. Almost no deep percolation of water occurs and atmospheric water is drained by subsurface flow or saturated overland flow in the streams and artificial ditches, and has a very short residence time in the soil.

Luxembourg has a humid temperate climate with rain all through the year, with a mean annual precipitation of 785 mm.

Figure 1

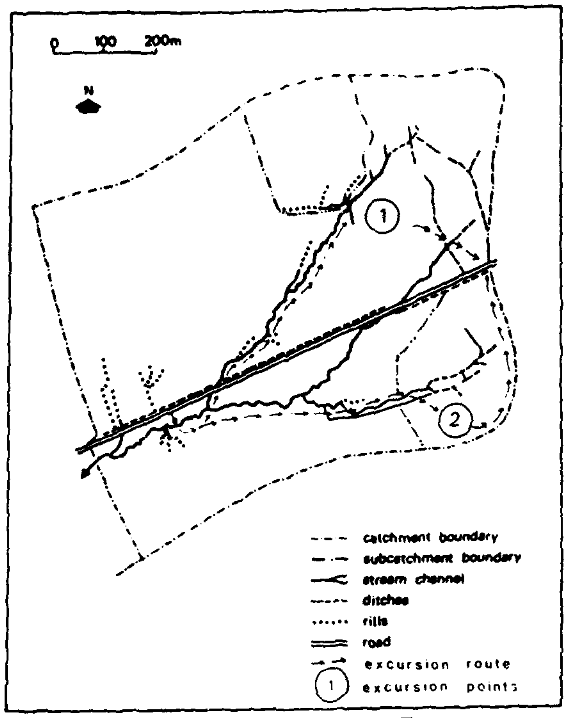


Fig. 1B. Drainage pattern of the Schrondweilerbaach catchment with excursion routes. For location see fig. 1.

Table 1. Lithostratigraphical column through the Rhaetien and Keuper in Luxembourg (after Lucius, 1948)

chronostratigraphy		lithostratigraphy	
JURA	Lias		
TRIAS	Rhaetien	Rote Tone	: claystone
TRIAS	Rhaetien	Rhätformation	: sandstone/marl
TRIAS	Keuper	Steinmergel formation	: marl
TRIAS	Keuper	Rote Gips f.	: marl
TRIAS	Keuper	Schilfsandstein f.	: sandstone
TRIAS	Keuper	Pseudomorfosen f.	: marl/conglomerates
TRIAS	Muschelkalk		
TRIAS	Buntsandstein		

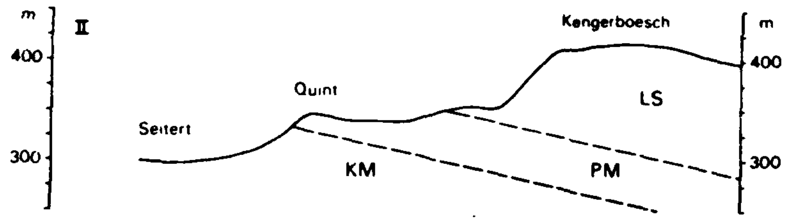


Figure 2.

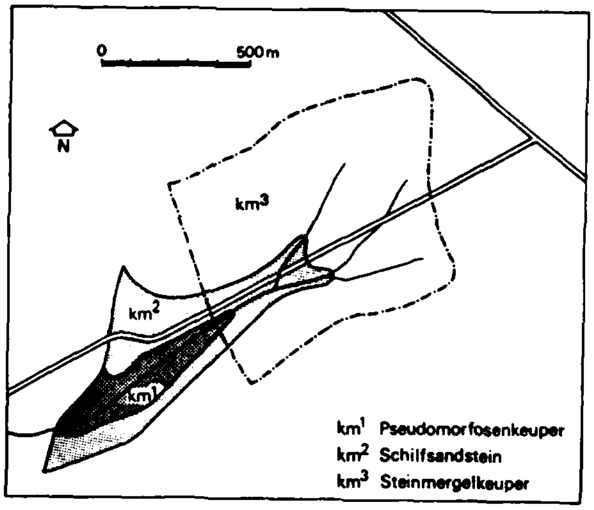


Fig. 3. Geological map of the research catchment
(based on map sheet 6, Diekirch,
Service Géologique de Luxembourg, 1949)

1. <u>Holocene landscape evolution in the research catchment</u>

The Keuper landscape is characterised by slightly convex hillslopes and deeply incised valleys with meandering streams. As a result if differential weathering and slope processes, valley slope angles differ somewhat according to the lithology. Slope angles range from 1°-5° for slopes in the Steinmergelkeuper and from 2°-8° for slopes in the other two geological series. The slopes are slightly convex, often with concave lower ends and exhibit a micro-topography of shallow depressions up to 15 m in diameter and ridges with differences in altitude of at the most 1 to 2 metres. These depressions play an important role in runoff generation and sediment production. At the lower end of the valley slopes colluvial deposits are present. The lateral extent of these deposits is limited to about 5-15 m while their maximum thickness is about 0.8 m. This means that the total volume of deposited material is rather small, which is in agreement with the fact that no truncation of the soil profile has been observed upslope. It may then be assumed that soil development and soil erosion are more or less in equilibrium.

Poeteray et al. (1984) calculated the rates of surface lowering of Steinmergelkeuper-underlain areas from "Mardell-trapped material during the Sub-Atlanticum".(Mardels are common oval or round closed depressions on the broad watersheds of the Keuper regions). From palynological studies of the trapped sediments (see fig. 4) in the depressions they concluded that the accumulation rates varied between 0.4 to 3.3 mm/yr (see table 2). Considering the shape of the depressions they calculated the surface lowering (table 3 and fig. 5). They also concluded that the variations they observed more likely were related to human activity (increase of agricultural activities) than to natural changes in the environment.

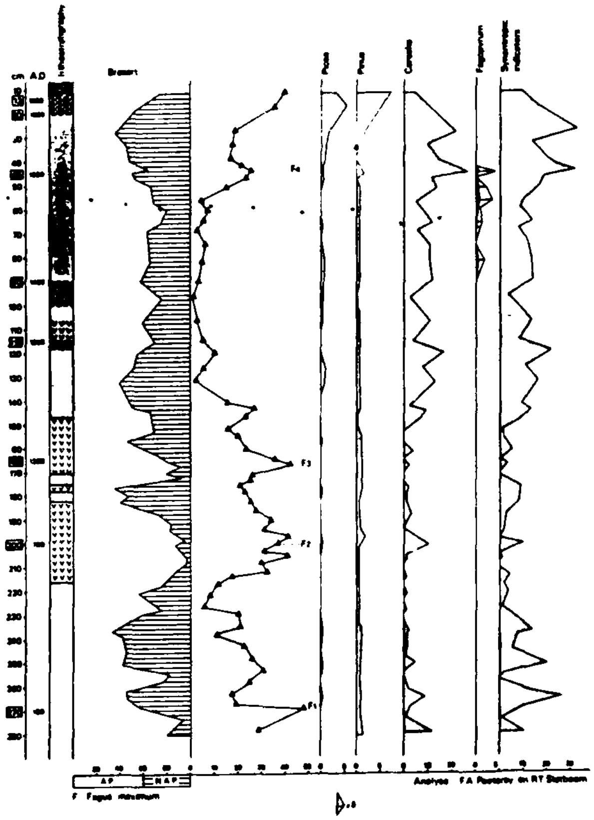


Fig. 4. Simplified pollen-diagram from the deposit in the Brasert mardel.

Table 2. Accumulation rates in the four mardels

Mardel	Period of time	Type of vegetation	Accumulation rate
Kalefeld	1350–1460	forest	0.9 mm/yr^{-1}
	1460–1600	forest/open vegetation	1.4 mm/yr^{-1}
	1600–1800	forest/open vegetation	1.0 mm/yr^{-1}
	1800–1980	forest/open vegetation	0.7 mm/yr^{-1}
	1350–1980		1.0 mm/yr^{-1}
Masselter	1200–1350	open vegetation	1.7 mm/yr^{-1}
	1350–1460	forest/open vegetation	2.7 mm/yr^{-1}
	1460–1600	open vegetation/forest	0.4 mm/yr^{-1}
	1600–1800	open vegetation/forest	0.6 mm/yr^{-1}
	1800–1980	forest	0.4 mm/yr^{-1}
	1200–1980		1.0 mm/yr^{-1}
Gebrannte Boesch	1200–1350	open vegetation	1.3 mm/yr^{-1}
	1350–1460	forest	2.7 mm/yr^{-1}
	1460–1600	forest	1.4 mm/yr^{-1}
	1200–1600		1.8 mm/yr^{-1}
Brasert	100– 700	forest/open	1.2 mm/yr^{-1}
	700–1200	forest/open	0.8 mm/yr^{-1}
	1200–1350	forest/open	3.3 mm/yr^{-1}
	1350–1460	forest	2.3 mm/yr^{-1}
	1460–1600	forest	3.2 mm/yr^{-1}
	1600–1800	forest/open	1.2 mm/yr^{-1}
	1800–1980	open/forest	1.0 mm/yr^{-1}
	100–1980		1.4 mm/yr^{-1}

Table 3. Calculated maximum and minimum rates of surface lowering (MaSL and MiSL) in periods of increasing duration in the feeding area of the Brasert mardel

Period of time	MaV → MaSL	MiV → MiSL
1980– 100 A.D.	163.7 m^3 → 87 mm/1000 yr^{-1}	62.6 m^3 → 33 mm/1000 yr^{-1}
1800– 100 A.D.	154.0 m^3 → 91 mm/1000 yr^{-1}	59.1 m^3 → 35 mm/1000 yr^{-1}
1600– 100 A.D.	122.7 m^3 → 82 mm/1000 yr^{-1}	48.1 m^3 → 32 mm/1000 yr^{-1}
1460– 100 A.D.	83.5 m^3 → 61 mm/1000 yr^{-1}	34.1 m^3 → 25 mm/1000 yr^{-1}
1350– 100 A.D.	63.5 m^3 → 51 mm/1000 yr^{-1}	26.4 m^3 → 21 mm/1000 yr^{-1}
1200– 100 A.D.	31.3 m^3 → 28 mm/1000 yr^{-1}	13.5 m^3 → 12 mm/1000 yr^{-1}
700– 100 A.D.	16.4 m^3 → 27 mm/1000 yr^{-1}	7.0 m^3 → 12 mm/1000 yr^{-1}

Table 5 MaSL and MiSL values calculated for the separate time intervals I up to and including VII in the Brasert feeding area.

Time interval		MaV → MaSL	MiV → MiSL
VII	1980–1800 A.D.	9.7 m^3 → 54 mm/1000 yr^{-1}	3.6 m^3 → 20 mm/1000 yr^{-1}
VI	1800–1600 A.D.	31.3 m^3 → 156 mm/1000 yr^{-1}	11.0 m^3 → 55 mm/1000 yr^{-1}
V	1600–1460 A.D.	39.2 m^3 → 279 mm/1000 yr^{-1}	14.0 m^3 → 100 mm/1000 yr^{-1}
IV	1460–1350 A.D.	20.0 m^3 → 182 mm/1000 yr^{-1}	7.7 m^3 → 70 mm/1000 yr^{-1}
III	1350–1200 A.D.	32.2 m^3 → 215 mm/1000 yr^{-1}	12.9 m^3 → 86 mm/1000 yr^{-1}
II	1200– 700 A.D.	14.8 m^3 → 30 mm/1000 yr^{-1}	6.6 m^3 → 13 mm/1000 yr^{-1}
I	700– 100 A. D.	16.4 m^3 → 27 mm/1000 yr^{-1}	7.0 m^3 → 12 mm/1000 yr^{-1}

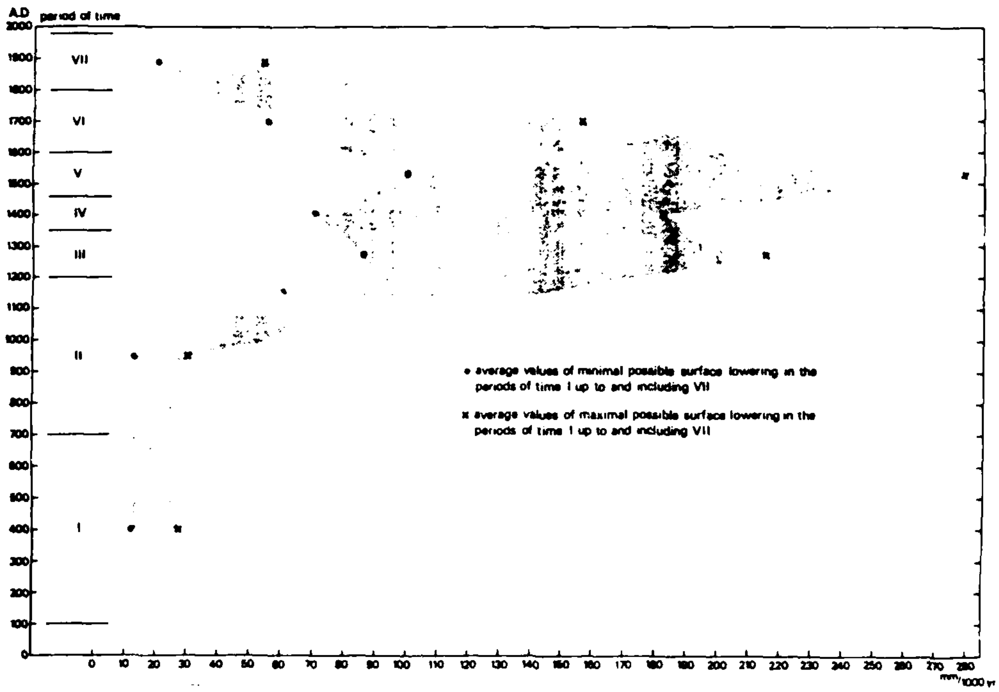


Figure 5

Investigations of Kwaad (1977) in a forested catchment in Northern Luxembourg showed that splashed material and colluvium had both more clay and silt and less gravel and stones than the surface soil. As in the catchment studied by Kwaad overland flow was never observed or likely to occur, it was assumed that the colluvial deposits were supplied by the combined. action of splash erosion and burrowing animals (Imeson et al., 1980).

Imeson and Vis (1984) investigated the seasonal variations in soil erodibility under different land-use types in Luxembourg on Steinmergel-keuper soils in a nearby catchment. In winter and (early) spring erodibility showed to be at a maximum (see tables 5 and 6 and fig. 6). The forest soil is then covered with litter and therefore the amount of splashed material will be largest during times of exposion of the mineral soil (approx. 40% of total surface). Consequently the amount of splashed material will be highest during summer and autumn.

Table 4. Soil texture properties related to soil erodibility (n = 5)

		Lias Sandstone	Lias Marls	Keuper Marls	row average
a average clay content	exposed surface (cf. worm casts)	8.3	32.1	35.3	25.2
	surface horizon	7.8	28.5	33.7	23.3
	subsurface hor. (cf. mole hills)	4.9	29.2	39.1	24.4
	column average	7.0	29.9	36.0	24.3
b average silt + very fine sand content (%)	exposed surface (cf. worm casts)	30.0	58.2	58.1	48.8
	surface horizon	14.7	54.3	58.3	42.4
	subsurface hor. (cf. mole hills)	13.4	55.3	53.6	40.8
	column average	19.4	55.9	56.7	44.0
c average organic matter content (%)	exposed surface (cf. worm casts)	7.2	22.4	11.0	13.5
	surface horizon	9.1	14.9	9.5	11.2
	subsurf. horizon (cf. mole hills)	2.7	6.7	4.3	4.6
	column average	6.4	14.7	8.3	9.8

Table 5. Average amount of material caught in splash board traps (a in g:b in mg/mm rainfall)

Collection date	Site 1 forest (colluvium)		Site 2 pasture		Site 3 forest (A1)	
	a	b	a	b	a	b
6.v.1978	4.7	70	0.2	4	5.3	79
31.v.1978	4.0	80	0.2	4	2.8	57
22.vi.1978	2.0	40	0.08	2	0.8	17
29.vii.1978	2.9	29	0.07	1	2.1	21
29.viii.1978	0.8	31	0.07	3	0.4	17
19.ix.1978	0.5	22	0.04	2	0.3	11
20.x.1978	0.3	7	0.05	1	0.9	21
19.xi.1978	0.2	57	0.1	30	0.09	24
16.xii.1978	0.9	15	0	0	0.4	7
9.ii.1979	4.3	35	0.09	1	2.8	22
6.iii.1979	1.6	62	0.07	3	0.4	16

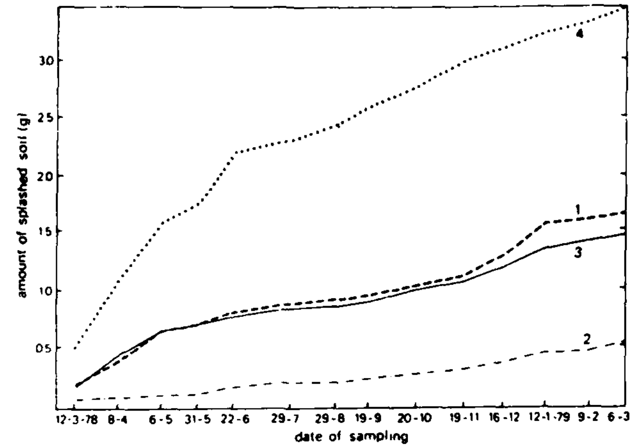


Fig. 6. Cumulative amount of soil splashed from undisturbed soil samples during laboratory experiments.
1. forest (colluvium)
2. pasture
3. forest (A1)
4. arable farmland

Table 6. Months of the year when erodibility is at a maximum, minimum, or approximately its average value (a = rainfall simulation experiment; b = aggregate stability; * = no value approximating average)

		Maximum	Minimum	Average
Site 1 (forest)	a	Dec. to May	Aug., Sept.	*
	b	April, June, July, Oct.	Aug., Sept.	Oct., Dec.
Site 2 (pasture)	a	Dec. to May	April to June, Sept.	March, Sept.
	b	Dec., Jan.	May to Aug.	Sept., Nov.
Site 3 (forest)	a	Dec. to May	Aug., Sept.	May, Dec.
	b	March, Oct., Feb.	Aug., Sept.	June, July, Dec., Feb., March
Site 4 (arable)	a	March to May	July, Aug., Feb.	June, Nov.
	b	No clear trend	Aug., Sept.	Nov. to Jan.

Jungerius and Van Zon (1984) investigated the sources of soil erodibility in wooded drainage basins in Luxembourg. They concluded that "erodibility is, at last for a significant part, modified by faunal activity". Differences between landscape units are decreasing by the faunal activity. Moles and worms reduce by homogenisation differences in erodibility between landscape units, although conflicting tendencies occur: moles bring subsurface material with low organic content to the surface, increasing the availability of material susceptible to erosion and, at the other side, worms which enrich the organic matter content of the soil, improving the soil structure and reducing the soil erodibility (Table 4).

In the Schrondweilerbaach catchment the close relationship between characteristics of the colluvium and the topsoil higher upslope implies that besides splash erosion also another process controls the supply of the colluvial material. Probably overland flow plays a dominant role in this respect, because it was observed that during intense rainstorms overland flow transported surface soil aggregates up to about 3 mm. This is confirmed by the observation of aggregates in micromorphological samples.

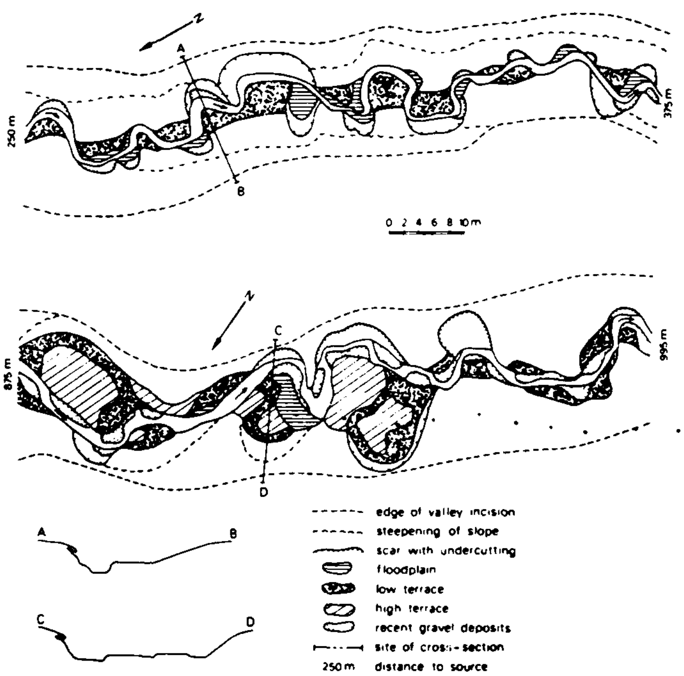


Fig. 7. Two channel reaches of the Schrondweilerbaach (main branch) and their characteristic cross-sections

The valley incisions may in general be considered as the most dynamic zone in the catchment: besides erosional and depositional processes in the channel itself, the incision also acts as a transport route for material eroded by a variety of slope processes elsewhere in the catchment. The complexity of the interrelations between channel characteristics and varying in- and throughputs of sediment in the channel is reflected in its form.

Channel bed topography in the research catchment is rather irregular (fig. 8) and strongly dependent upon contributory catchment area and bed lithology (outcrops of more resitant conglomerate layers). Organic debris dams may locally cause distinct steps in the longitudinal profile due to aggregation upstream and intense bed scour downstream of the dam. Bed gradient in general varies between 0.5° and 5.0°. Depth and width of the incision show an increase in a downstream direction and vary respectively from 0.5-5.0 m and from 1.5-20 m. Streambank gradients generally are in between 30° and 50°. Schematic representation of channel planform and cross-section is given in fig. 7 for two reaches, the upstream part incised in the Steinmergelkeuper and the downstream part in the Schilfsandstein. Two terrace levels may be distinguished (fig. 6) from which may be concluded that downward channel erosion has been active or is still active today. Considerable erosion has probably occurred since 1930, when drainage of the catchment was improved by the construction of a system of narrow and shallow ditches on the surrounding slopes. The improved drainage conditions

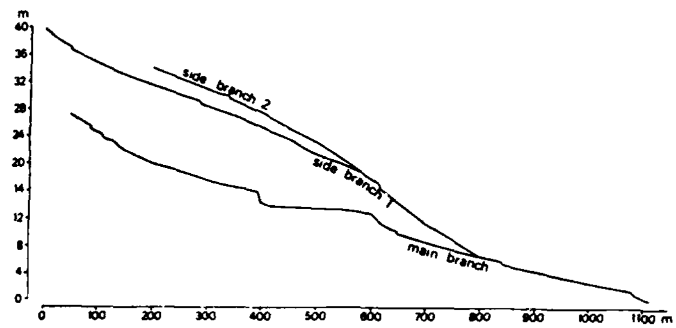


Fig. 8. Longitudinal profile of the Schrondweilerbaach

will have resulted in a faster response of runoff to precipitation and higher peak flows with consequent erosion of the channel. One of the abovementioned terrace levels may thus represent the 1930 channel bed. In contrast to the deepening of the river incision in the past 50 years, the headward extension of the channel network on the slopes has proceeded slowly; most of the ditches excavated in the catchment headwater area show only limited features of accelerated erosional activity. Only where they join the main channel, headward erosion has occurred over a distance varying from about 1-5 m.

2. Vegetation and land use

The Schrondweilerbaach catchment is almost completely (99.2%) covered with forest. The non-wooded part is formed by the road which crosses the catchment from NE to SW. The forests in the study area of the oak-hornbeam association with predominantly oak (Quercus cf, robur, L), hornbeam (Carpinus betulus, L) and beech (Fagus sylvatica, L). According to Hazelhoff et al. (1981) these three species form about 90% of the trees. The trees have a maximum age of about 120 years and are up to 30 m high. Locally a shrub layer is well developed, which consists of mainly hawthorn (Crataegus laevigata) and beech. The largest shrubs are about 10 years old.

A comparison of the present land use with that in 1777, as inferred from the maps of the "Comte de Ferraris" (re-issued 1965-1970 at scale 1:25000) shows nearly no shift in the forest boundaries. Most of the area now covered with mixed deciduous forest was also forested about 200 years ago. However, the similarity in land use between now and 200 years ago does not imply similarity in land utilisation. Up to about 1865 (Administration des Eaux et Forêts, 1971) successive parts of the forest were totally cleared in a cyclic way for firewood. During the clear-cutting phases and in the years thereafter, considerable erosion might have taken place at the stripped sites. Today only the younger trees are cut down every 25 to 30 years and the older trees, when they have an age of about 120-140 years for beech and hornbeam and 140-200 years for oak.

3. Zoological aspects

The importance of animal activity in erosion studies rests mainly on its effects on the rate of exposure of soil material to erosional processes and on the physical and biochemical changes brought about in the topsoil. The spatial and temporal variations in the exposure of soil material can easily be observed in the field. In the forests of the study area, extensive areas of the forest floor are litter-free or covered with wormcasts during many months of the year.

The low permeability and fine texture of the Steinmergelkeuper soils provide a favourable environment for earthworms and moles. Hazelhoff et al. (1981) suggested the importance of the earthworm species Lumbricus terrestris L. in removing the protecting litter layer by pulling leaves from the surface into their burrows (Satchell and Lowe, 1967).

In fig. 9 a blockdiagram is given from a bare soil surface with burrows of Lumbricus terrestris with gathered litter, and a crack where coarse litter remains are concentrated. In tables 7 and 8 relations between depth of perched water table and groups of plots respectively, and relation between tree species and earthworm (burrow) density are given. Groups are distinguished with respect to the mean maximum percentage of bare soil during the measuring period (1978/1979). Group I mean maximum: 31-50%; Group II mean maximum: 11-31%; Group III mean maximum: 0-10%. It is shown that areas where Fagus sylvatica and Carpinus betulus prevail, the Lumbricus terrestris is less active, as the activity of this worm accounts for 99% of the occurrence of bare soil surface. The spatial distribution of bare soil patches om a broad nearby watershed is shown in fig. 10. Table 9 gives the several tree and shrub species occurring in this area, which is characteristic for the Steinmergelkeuper areas. The seasonal variation is shown for several sampling plots on this watershed, showing increase of bare surfaces and moss growth during spring, summer and early autumn. Soil moisture is lowest during late summer, due to the large evapotranspiration of the vegetation in the warm season.

In this way, earthworm activity results in the creation of bare surfaces which are susceptible for splash erosion or erosion by overland flow. The amount of exposed soil ranges from zero during winter, when leaves have fallen onto the forest floor and earthworms are relatively dormant, to about 25-40% at the end of summer (Hazelhoff et al., 1981; Jungerius and Van Zon, 1982; van Hooff, 1983). Maximum effects (up to 90% litter-free surface) are observed in the microtopographic depressions of a few hundred square metres which are damper than the immediate surroundings.

Only the moderately well-drained sandy loam to sandy clay loam soils of the Schilfsandstein- and Pseudomorfosen-series the activity of the worm species Allolobophora nocturna, Sav. and Allolobophora longa, Ude, was recognised. These worms produce casts which can almost completely cover the litter (Hazelhoff et al., 1981). No specific pattern in the activity of the Allolobophora species was observed.

Representative soil profile from the Laangen Haedboesch, described according to the FAO-guidelines (FAO, 1977)

0—4 cm	A11	10YR 3/2 silty clay loam; strong medium granular; friable; few fine pores; few fine roots; abrupt smooth boundary.
4—10 cm	A12	10 YR 3/2 silt loam; moderate and strong medium subangular blocky; firm; common fine pores; common very fine; fine and medium roots; abrupt smooth boundary
10—34 cm	Bg2	10YR 5/8 and 7.5Y 4/1 medium prominent sharp mottles; slightly gravelly silty clay; strong medium angular blocky; firm; patchy moderately thick cutans on rock fragments; many very fine and fine pores; few medium and coarse roots; clear boundary
34—100+cm	C	2.5Y 5/2 gravelly silty clay loam

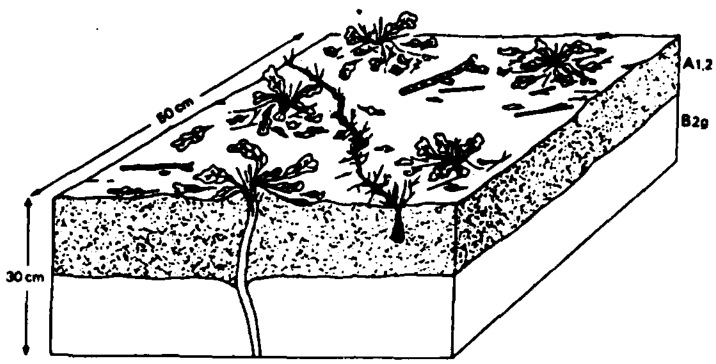


Fig. 9. Schematic block diagram of a site with burrows of Lumbricus terrestris and a crack where coarse litter remains are concentrated (see also Hazelhoff et al., 1981).

Table 7.

Comparison of six plots with respect to depths of the perched water tables

Plot	Group	Position on slope	Average depth (cm)	Level of significance
1	I	Upper slope	20	0.001
11	III		40	
10	II	Middle slope	17	0.001
2	III		61	
3	II	Lower slope	15	0.02
9	III		25	

Comparison of groups with respect to the numbers of earthworms and species composition of the tree layers

	Groups			Levels of significance		
	I	II	III	I/II	I/III	II/III
Total earthworms/0.25 m^2	67	50	27	+	*	+
Burrows/m^2	14	10	4	+	*	+
Quercus robur (%)	56	46	30	+	+	+
Acer campestre (%)	28	16	3	+	*	+
Fagus sylvatica (%)	7	10	25	+	*	*
Carpinus betulus (%)	8	14	43	+	*	*

+significance between 0.15 and 0.10.
*significance between 0.10 and 0.05.

Table 8. **Comparison of the three groups with respect to mean moisture contents of the A12 and the B2g horizons (in each row the figures are significantly different (α = 0.05), except where italicized)**

	Group: I	II	III
Mean maxima of bare soil 1978 (%):	50.4	20.5	9.8
Mean maxima of bare soil 1979 (%):	34.0	11.6	4.7
*Mean soil moisture contents A (%)	*52*	41	*50*
*Mean soil moisture contents B (%)	*35*	28	*32*

*In both 1978 and 1979.

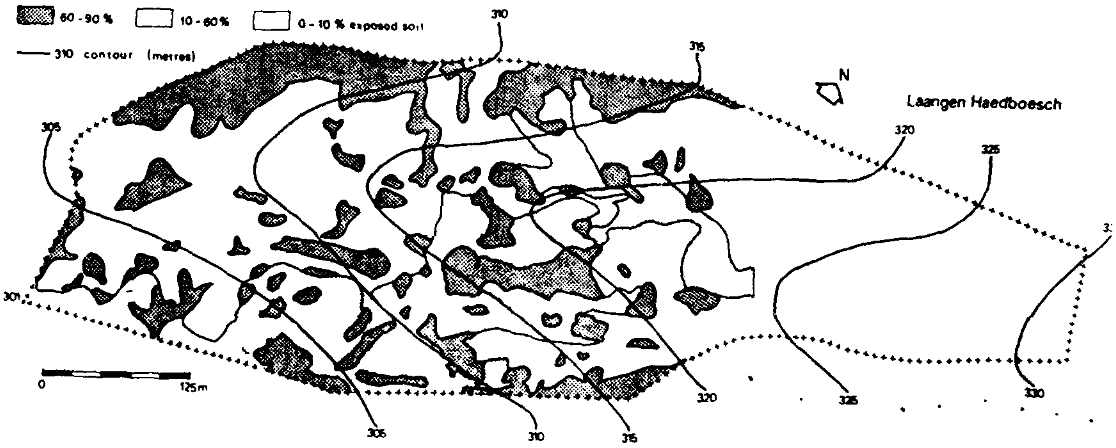


Fig. 10. The distribution of exposed soil in the Laangen Haedboesch during July 1978

Table 9. Composition of the tree and shrub layers in the Laangen Haedboesch

		Approx. %
Tree species:	*Fagus sylvatica, L.* (beech)	30
	Quercus cf. robur, L. (oak)	30
	Carpinus betulus, L. (hornbeam)	30
	Acer compestre, L. (maple)	5
	Acer pseudoplatanus, L. (sycamore)	5
Shrub layer:	*Crataegus laevigata,* (Poir.) DC (hawthorn)	80
	Fagus sylvatica, L. (beech)	15
	Corylus avellana, L. (hazel)	2
	Acer compestre, L. (maple)	3

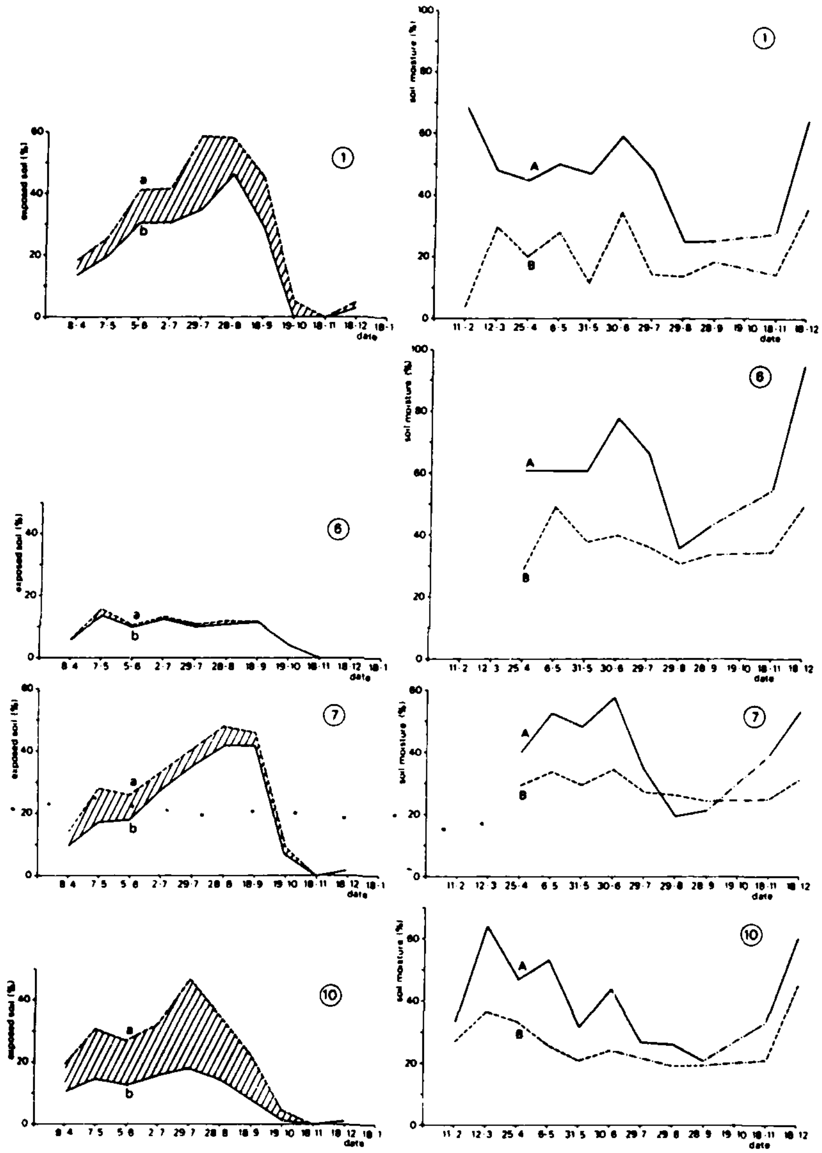


Fig. 11. Left: percentage of the plot surface formed by the exposed soil (b) and exposed soil and moss .a).
Right: soil moisture (gravimetric) content in (A) and (B) the B horizon. The encir⁻led number indicates the plot number.

Besides influencing soil erosion in a direct way, the activity of earthworms and moles increases the permeability of the topsoil and favours throughflow and lateral eluviation of this topsoil.

Disturbance of the forest floor caused by deer and wild pigs is limited to the occasionally scraping away of the soil surface, but this is of limited importance for sediment production from the valley slopes. Occasionally pig activity can result in high sediment concentration in surface flow if freshly remoulded surface material is entrained during heavy thunderstorms. This led to sediment concentrations as high as 7700 mg/l in the river during a peak discharge in september 1987.

4. Hydrological characteristics

The Schrondweilerbaach is a first order tributary of the Alzette River. The latter drains about 25% of the Grand Duchy of Luxembourg and forms part of the drainage basin of the River Rhine. The total length of the stream channel system in the Schrondweilerbaach catchment is about 2250 m. To this should be added about 1400 m of narrow (about 0.5 m wide) drainage ditches dug by man. Runoff in the upstream part of the main stem and side branches of the channel system and in the drainage ditches is intermittent. In the downstream reaches runoff is practically continuous throughout the year.

During the winter a perched watertable develops above the BEg-horizon and usually remains within 0.3 m of the surface, except in zones close to the divide and close to the channel incision. Runoff is generated by overland flow from various micro-topographic depressions on the valley slopes (Bonell et al., 1984) and by rapid subsurface flow through channels and pipes in the AEh- and EAhg-horizons. The runoff produced collects in rills and ditches and supplies most of the water in the stream channel. As a result the headwater streams in the Steinmergelkeuper respond rapidly to rainfall and the runoff coefficient and proportion of storm runoff by quickflow are both high (Bonell et al., 1984). Most runoff is generated during the winter, although extremely heavy thunderstorms during summer occasionally produce very high amounts of runoff. In fact, the highest discharge registrated during 1978 and 1979 occurred during such a thunderstorm, when 39.5 mm of rainfall fell in 45 minutes and resulted in a maximum discharge of about 500 l/s^{-1} at the catchment outlet. The processes of runoff generation on the valley slopes will be discussed in more detail especially with respect to their role in soil erosion and sediment transport.

A less important part of the catchment runoff is the interflow which emerges quantitatively on the channel banks. It is only of importance in the channel reach through the Schilfsandstein- and Pseudomorfosenseries. Another special aspect in the hydrological response of the catchment is formed by the road which crosses the catchment from the divide to the lower boundary. Precipitation on the road (800 m long and 8 m wide, inclusive verges) is collected into ditches which enter the main stream channel at several places.

Runoff measurements carried out over a period of three years (1978-1980) in a neighbouring forested catchment show that 26-29% of precipitation leaves the catchment as surface runoff (Imeson and Vis, 1984). Investigations of Einsele et al. (1983) into the water budget of a forested catchment on Keuper marls close to Tübingen (FRG) reveal a similar value for runoff output: 30%.

Suspended catchment concentration at the catchment outlet is very variable as it is strongly dependent upon seasonal catchment conditions and rainfall intensities (Imeson et al., 1984). It varies in general between 1 and 500 mg/l^{-1}. The maximum concentration observed during the study period amounted 2300 mg/l^{-1} and was measured during a summer thunderstorm.

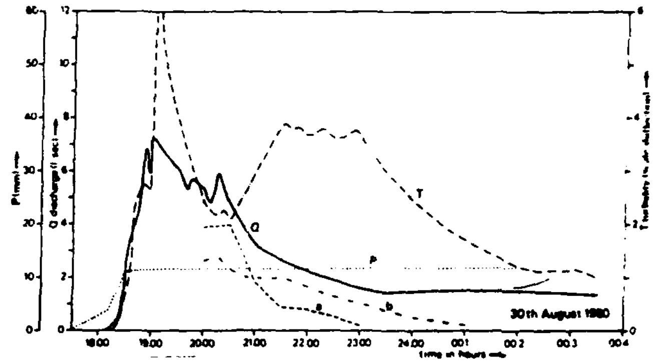


Figure 12. The turbidity (T) and discharge (Q) of the Schrondweilerbaach resulting from the rainfall on the 29th August 1980. (P is the precipitation, a the quickflow hydrograph and b the discharge of turbid water from the topographic depressions)

The contribution of sediment from different sources can sometimes be recognised in the turbidity of a discharge peak. A first turbidity peak is generated by the uptake of surface material in the river water and a second peak can be explained by the arrival of subsurface material originally transported by subsurface flow (pipe erosion, lateral eluviation of dispersed clay).

Electrical conductivity of the streamwater which reflects total concentration of solutes shows, in contrast to the wide fluctuations in suspended sediment concentration, a much smaller range: 65-850 μ S cm^{-1}. The lower and upper value are determined by the electrical conductivity of respectively throughfall (during peak flow conditions) and interflow in the rocks of the Schilfsandstein and Pseudomorfosenkeuper (during baseflow conditions).

Within the sub-catchment where the current research is carried out relatively large differences are present with respect to hydrological and morphological aspects. If we look at subsurface flow we see 2 important pathways of water through the solum: a general lateral water movement on the clayey B-horizon through the more silty and very porous A-horizon (bulk density between 0.7 to 1.1 g/cm^3). The macroporosity of this topsoil is the second very important factor in water movement. The latter factor is influenced by a) shrink and swell of clays, in the topsoil as well as in the B-horizon and the colluvial deposits in the lowest part of the subcatchment. This process is very sensitive to soil moisture conditions and leads to a general presence of polygonal crack systems. Fig. 13 shows the seasonal variation in the width of cracks reaching a maximum in autumn. Fig. 14 shows the spatial development of a spot with many cracks;
b) activity of soil animals like worms, moles etc., burying smaller and larger partly continuous pore systems in the soil. During heavy rain showers it was observed that water powerfully streamed out of macropores leading to local overland flow and finally infiltration of the same water in the subsoil again.

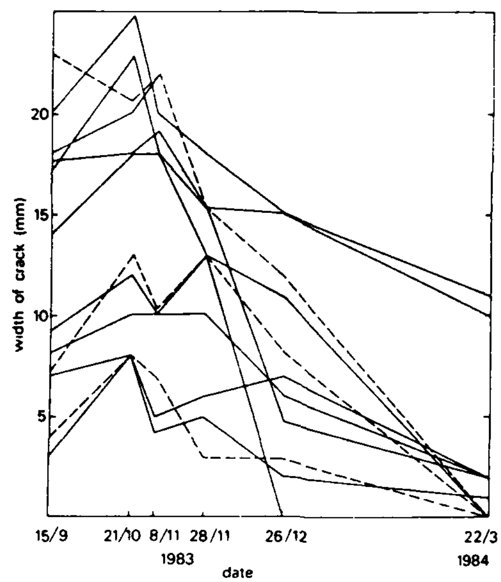


Fig. 13. Average width of cracks measured on experimental plots between September 1983 and March 1084, in the Schrondweilerbaach drainage basin, Luxembourg.

Macropore systems vary during the season, due to (continuous) bioturbation, animal activity, freeze-thaw cycles, pipe erosion, splash erosion, slaking of cracks at the soil surface, changing soil moisture condition, perched groundwater table (see fig. 15), and vegetational effects. Due to this high macroporosity the reaction factor of the catchment is very high. In adjacent pasture areas the reaction factor is lower due to the less prominent presence of macroporosity. From the foregoing it will be clear that the hydraulic conductivity will change during the season.

From a morphological point of view there are differences within the catchment between the areas with Keuper substratum and colluvial deposits in the shallow valley bottom. Perched groundwater tables are lower on the footslopes, where colluvium is present indicating larger porosity. Wet areas are often found in depressions. Elongated depressions are connected with pipes draining into the ditches. In the depressions, the Lumbricus terrestris is more active and crack systems are more prominent. In places where small stept occur on the slopes, probably due to mass wasting, also differences in soil moisture regimes are present, indicating perched groundwater steps.

5. Streambank contribution to the sediment budget

Our primary aim was the construction of a sediment budget for a small forested catchment, special emphasis being given to the contribution of streambank erosion. The study area forms part of the Keuper region of Central Luxembourg, where forested drainage basins are characterised by gentle slopes and deeply incised valleys with meandering streams. In this area the drainage basin of the Schrondweilerbaach (60.8 ha) was selected for detailed investigations. The study was carried out between November 1979 and November 1981.

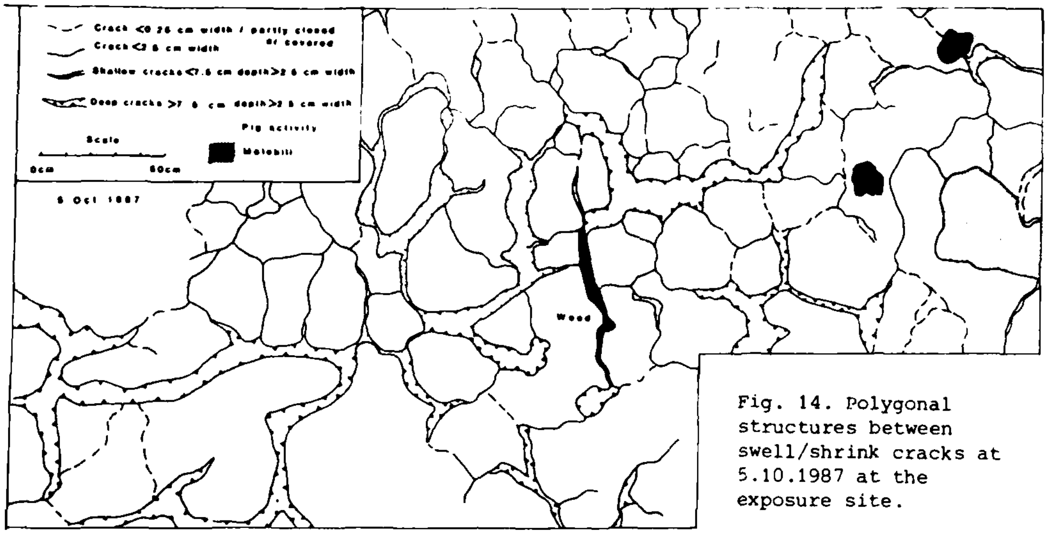


Fig. 14. Polygonal structures between swell/shrink cracks at 5.10.1987 at the exposure site.

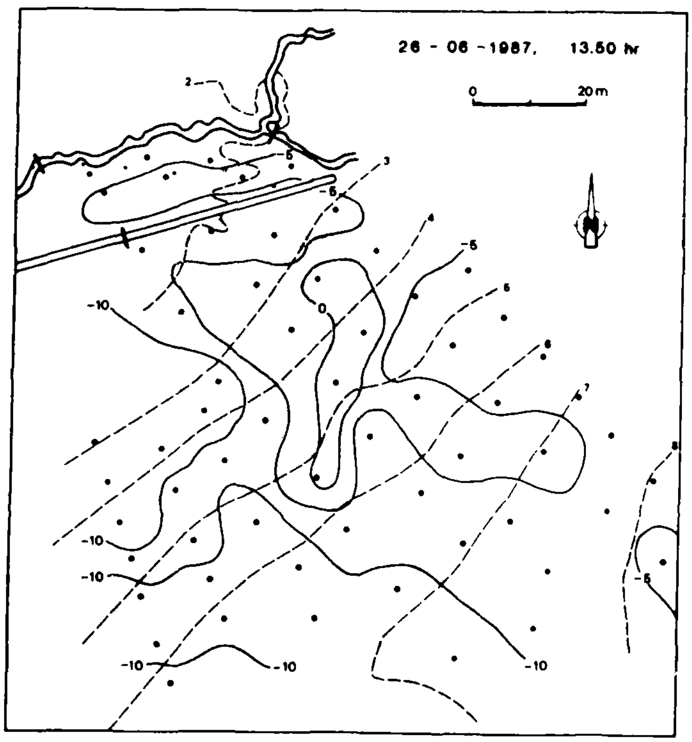


Fig. 15. Perched watertable level at the experimental slope after a heavy rai:.-storm.

The lithology of the drainage basin is dominated by the marls of the Steinmergelkeuper, which weather into heavy clay soils. Soils are poorly drained and shallow, leading to the development of a perched watertable above the subsoil and to extensive conditions of overland flow during periods with prolonged rainfall or snowmelt. Mean annual rainfall in the period of investigations was about 1050 mm, generating about 300 mm of runoff. The forest in the drainage basin predominantly consists of oak, beech and hornbeam with a maximum age of about 120 years.

The sediment budget of the Schrondweilerbaach catchment was divided into three main parts: sediment transfer from the stream banks, sediment transfer from the valley slopes and sediment output from the drainage basi

Six processes were found to be active in streambank erosion: lateral corrasion, bank failures, soil fall, creep, rainsplash, and overland flow. Programmes to measure these processes were carried out in three sample areas comprising the variations in bank material characteristics and channel morphology. After the processes had been measured for two years, statistical relationships were established between the monthly amount of eroded material and a number of bank parameters (morphological variables and bank erodibility indices). In 1981 the channel was surveyed and the essential parameters were then used to calculate the total sediment supply by each of the bank processes.

The streambanks contributed 53.3% to the total supply of sediment with lateral corrasion and subsoil fall being the main bank processes contributing respectively 22.9% and 21.0%. Bank failures, rainsplash erosion and soil creep transferred respectively 7.6%, 1.4% and 0.4%. The sediment transfer by overland flow was left out of the budget as it was observed that overland flow predominantly acted as a transport medium for material detached by other processes; consequently the transferred amount was already included in the results for these processes.

The activity of each of these processes was restricted to a particular part of the bank and to specific hydro/meteorological conditions. Maximum rates of lateral corrasion and splash erosion were generally encountered during summer thunderstorms, while the highest rates of subsoil fall were measured during frost periods. High rates of soil creep could largely be attributed to the effect of biological activity (summer) and to a lesser extent to the effect of frost action.

The spatial trend in sediment supply from the streambanks showed a general increase with increasing catchment area. However, the highest rates of bank recession were encountered in the upstream part of the main river. These were due to various indirect effects of distinct breaks in the longitudinal profile, especially related to the presence of organic debris dams.

Splash detachment and subsequent transport of detached material by overland flow appeared to be the dominant mechanism of soil erosion on the valley slopes, contributing 42.2% to the total sediment supply. Both the rate of splash detachment and storm runoff generation were influenced to a large degree by the forest ecology; apart from the canopy effects on the erosivity of rainfall, the rate of splash detachment was related to the spatial and temporal variations in the occurrence of exposed soil. Most of the exposures of bare soil were caused by the consumption of leaves by earthworms. In addition, the combination of clayey soils and a rich soil fauna led to a high content of biopores and pipes above the seasonally saturated subsoil, causing rapid draining of the topsoil. Widespread conditions of overland flow on the valley slopes occurred at least once a year, during which up to 75% of the catchment contributed to the stream hydrograph. Throughflow through biopores and pipes supplied sediment originating from the subsoil. This sediment transfer dominantly occurred during baseflow conditions and contributed 4.5% to the total sediment supply.

Sediment transfer out of the drainage basin dominantly occurred as suspended load (93%), while bedload contributed only 7%. Both transport modes showed highest output rates during summer thunderstorms. Grainsize analysis of the sediment supplied by the various streambank and valley slope processes revealed that bedload was largely made available by lateral corrasion, subsoil fall and bank failures. On the other hand, hillslope processes wete the main contributor to suspended load.

The results from the sediment budget showed that during the study period sediment production from streambanks and valley slopes was about equal to sediment output from the drainage basin, implying a present state of dynamic equilibrium in sediment transfer. When viewing the results from the 1979-1981 period within a wider time scale (about 50 years), the present-day activity of the erosion processes reflects adjustment to channel changes (in)directly caused by the drainage operations carried out between 1928 and 1930. Insufficient data were available for further extrapolation in time in order to calculate the virtual age of the channel incision.

The results of the channel surveys and observations of bank processes are summarised in a descriptive model for the widening of valley incisions in the study area.

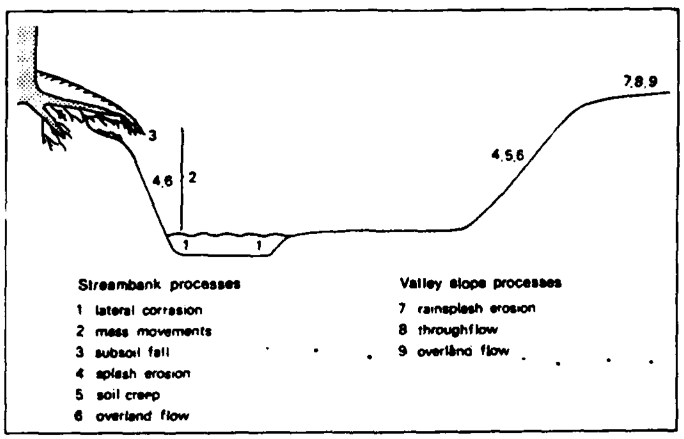


Fig. 16. Schematic representation of valley cross-section showing the active zones of the erosion processes

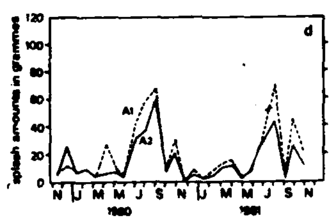


Fig. 17. Splash loss

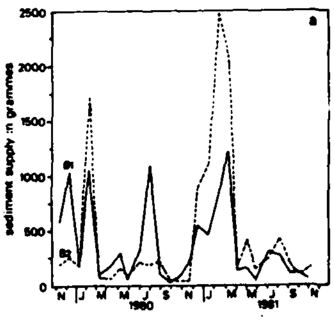


Fig. 18. Monthly variation in sediment supply by subsoil fall.
a. Steinmergelkeuper series.

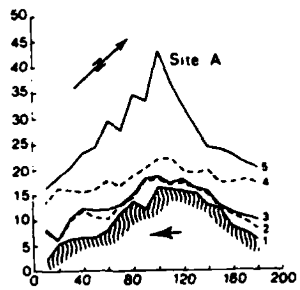


Fig. 19. Plots showing the subsequent positions of the bank face with respect to the reference bar. Arrow show direction of streamflow.
1 = Nov. 1979; 2 = May 1980; 3 = Nov. 1980;
4 = March 1981; 5 = Nov. 1981.

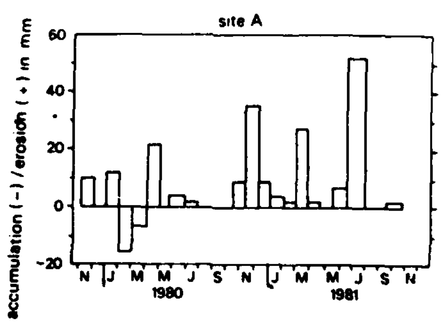


Fig. 20. Temporal variation in lateral corrasion, November 1979 - November 1981.

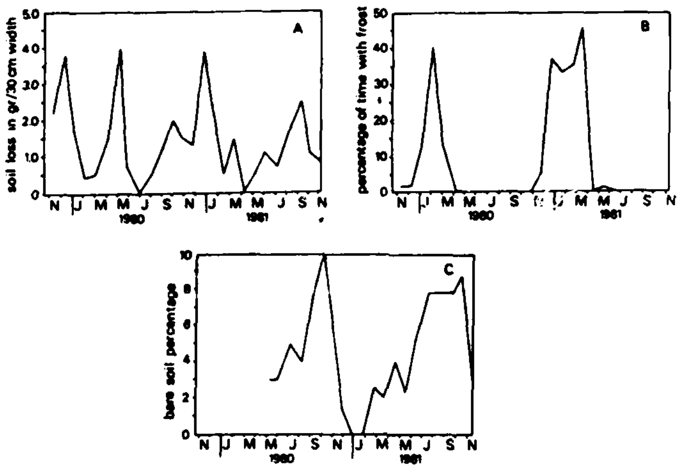


Fig. 21. A. Mean soil creep (sites A, C and E)
B. Occurrence of frost
C. Temporal variation in bare soil percentage

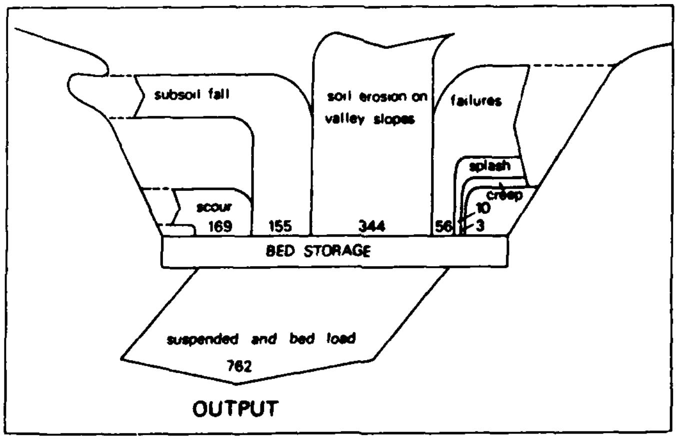


Fig. 22. Sediment budget for the Schrondweilerbaach catchment 1979-1981. Numbers are in $kg.ha^{-1}.yr^{-1}$.

Fig. 23. Spatial variation in sediment supply from banks.

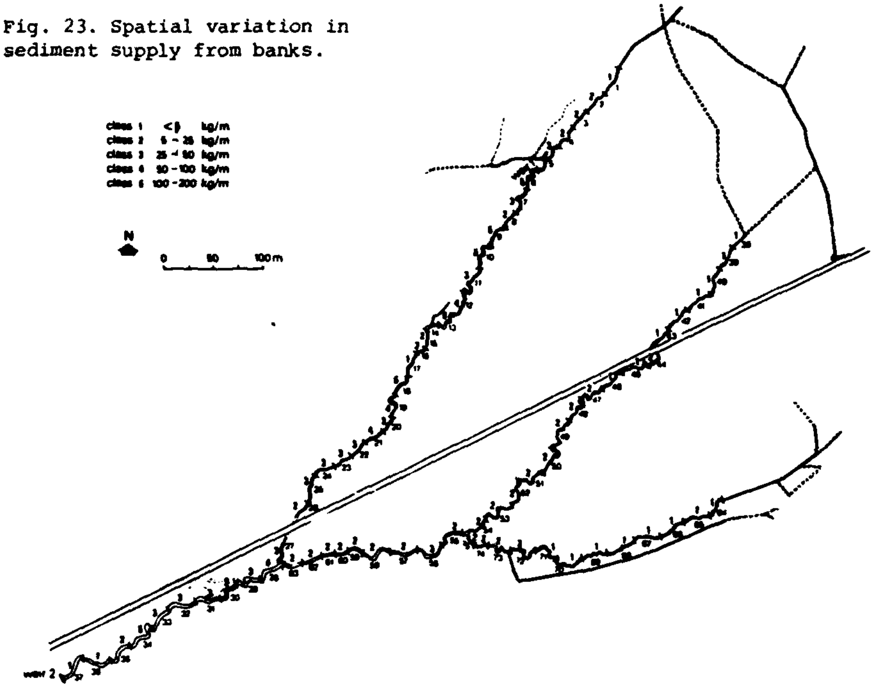


Table 10. Sediment budget for the Schrondweilerbaach catchment (0.61 km²), November 1979 - November 1981.

		process	sediment supply kg/ 2 years	%
INPUT	STREAMBANKS	lateral corrasion	20650	22.9
		subsoil fall	18860	21.0
		mass movements	6850	7.6
		rainsplash erosion	1240	1.4
		soil creep	400	0.4
		overland flow	-	
		streambank total	48000	53.3
	VALLEY SLOPES	splash detachment + overland flow transport	38000	42.2
		throughflow	4000	4.5
		slopes total	42000	46.7
		total sediment input	90000	
OUTPUT		suspended load	86300	92.8
		bed load	6700	7.2
		total sediment output	93000	
		net dissolved output	180400	

REFERENCES

Bonell, M., M.R.Hendriks, A.C.Imeson and L.Hazelhoff, 1984. The generation of storm runoff in forested clayey drainage basin in Luxembourg. J. of Hydr. 71, 53-77.

Cammeraat, L.H. and A.C.Imeson (in prep.). The discontinuity of geomorphological processes in a uniformly forested drainage basin. Catena.

Duysings, J.J.H.M., 1985. Streambank contribution to the sediment budget of a forest stream. Publ. FGBL, UvA, nr. 40.

Duysings, J.J.H.M., 1987. A sediment budget for a forested catchment in Luxembourg and its implications for channel development. Earth Surf. Proc. and Landf., Vol. 12, 173-184.

Hazelhoff, L., P.van Hooff, A.C.Imeson and F.J.P.M.Kwaad, 1981. The exposure of forest soil to erosion by earthworms. Earth Surf. Proc. and Landf., Vol. 6, 235-250.

Hooff, P.van, 1983. Earthworm activity as a cause of splash erosion in a Luxembourg forest. Geoderma 31, 195-204.

Imeson, A.C., 1977. Splash erosion, animal activity and sediment supply in a small forested Luxembourg catchment. Earth Surf. Proc., Vol. 2, 153-160.

Imeson, A.C., 1986. Investigation of volumetric changes in clayey soils related to subsurface water movement and piping. Z.Geomorph. N.F., Suppl. Band 60, 115-130.

Imeson, A.C. and P.D.Jungerius, 1977. The widening of valley incisions by soil fall in a forested Keuper area, Luxembourg. Earth Surf. Proc., Vol. 2, 141-152.

Imeson, A.C. and M.Vis, 1984. Seasonal variations in soil erodibility under different land-use types in Luxembourg. J. of Soil Sci., Vol. 35, 323-331.

Imeson, A.C., M.Vis and J.J.H.M.Duysings, 1984. Surface and subsurface sources of suspended solids in forested drainage basins in the Keuper region of Luxembourg. In: Catchment experiments in fluvial geomorphology. Ed. T.P.Burt and D.E.Walling. GeoBooks, Norwich.

Jungerius, P.D. and H.J.M.van Zon, 1982. The formation of the Lias cuesta in the light of present-day erosion processes operating on forest soils. Geogr. Ann. 64A, 3-4, 127-140.

Jungerius, P.D. and H.J.M.van Zon, 1984. Sources of variation of soil erodibility in wooded drainage basins in Luxembourg. In: Catchment Experiment in Fluvial Geomorphology. Ed. T.P.Burt and D.E.Walling. GeoBooks, Norwich.

Poeteray, F.A., P.A.Riezebos and R.T.Slotboom, 1984. Rates of Subatlantic surface lowering, calculated from mardel-trapped material (Gutland, Luxembourg). Z.f.Geomorph. N.F., 28-4, 467-481.

II. PEDOGENESIS ON FORESTED SLOPES OF THE KEUPER MARLS: CLAY DISPERSION AND THE FORMATION OF AN ABRUPT TEXTURE

Introduction

Certain areas in the world have a soil type of which the abrupt texture contrast between the light textured surface horizon snd the clayey subsurface horizon is one of the most eye-catching characteristics.

The textural change in the subsurface horizon can be of pedogenic as well as of non-pedogenic origin. Soils which are developed on lithologic discontinuities can be found everywhere, e.g. in the Sydney Basin in Australia. Here, coarse-grained material has been moved downslope on top of a fine-textured surface layer, forming a duplex soil (Bishop et al., 1980).

Besides the non-pedogenic character of the abrupt textural changes, the texture contrast in the subsurface horizon is often caused by one or more soil forming processes.

In the context of the parent material, the specific soil type (see Table 11) and the field situation described in the introduction to the excursion guide, it can be reasonably assumed that a soil forming process and not a lithological discontinuity is responsible for the abrupt texture contrast. Therefore, this study is focussed on clay dispersion related to the abrupt texture contrast between A and B horizon.

Chemical dispersion and flocculation of clay minerals is ruled by the electrolyte and its concentration in the soil solution, the saturation of the exchange complex, and the type of clay mineral. Hence attention is paid to the chemical conditions of:
- the soil material of A and B horizon, reflecting the potential dispersibility;
- the chemical conditions of the soil solution;
- the chemical conditions of the lateral subsurface flow and clay transport over the contact between A and B horizon.

Methods

To gather information about the dynamics in the conditions of the soil moisture and lateral subsurface flow, a regular sampling scheme has been carried out:
- Soil moisture has been sampled by porous cups which are installed at the contact between A and B horizon. This soil moisture has been chemically analysed.
- Subsurface flow running over the clayey, massive B-horizon during and after rainfall, has been sampled by means of polyethyleen plates, installed at the contact between A and B horizon. This flow is also analysed.
- Dispersed fine material in streamwater and subsurface flow is sampled. This material is flocculated and used for X-ray analysis.

To characterise the chemical parameters of the soil, standard soil analyses for the whole profile were carried out. The clay mineralogy has been determined, and thin sections of A and B horizon prepared.

The measured chemical characteristics of soil moisture and soil material are linked to the observed subsurface flow containing dispersed material, by laboratory experiments:

- By means of a dispersion experiment, the dispersibility of clay fractions of A and B horizons has been determined, as well as the influence of several parameters on dispersion.
- Using a test, flocculation values of clay fractions of the Bg horizon have been determined.

Results

Profile characteristics:

With regard to clay dispersion and the abrupt texture contrast, the next properties are important:
- the texture contrast between A and B horizon, the increase in the ratio fine/total clay from A to B horizon, and the more or less constant ratio throughout the B and C horizon (see fig. 24);
- the high base saturation due to Ca and Mg; the low Ca/Mg ratio of the exchange complex (especially the B horizon); the almost complete absence of monovalent and trivalent ions at the complex (see table 11);
- no clay illuviation is observed in thin sections of the B horizon.

Soil moisture characteristics

The spatial variability of the chemical conditions of the soil moisture is enormous. The difference in e.g. Mg^{2+} concentration between porous cups is often larger than the ranges at one cup during the sampling period (see fig. 25). It seems that a dry or a wet period, ruling the length of the interaction time of the water with the soil matrix, does not really influence the chemical conditions of the soil moisture. For dry as well as wet periods the electrolyte concentration and EC(25) are very low.

Subsurface flow

The plates are draining the slope approximately 30 minutes after the start of the rain, even before the complete slope is water-saturated. Subsurface water is transported laterally in pores, cracks and pipes over the B horizon ("bypass flow").

The chemical conditions of the subsurface flow do not differ much for periods of rain with low or high discharges. The EC(25) and electrolyte concentration are again very low (see fig. 26). These are in the same order of magnitude as in the soil moisture in the porous cups.

Dispersed material collected in streamwater and subsurface flow

The amount and colour (organic matter) of dispersed material is very variable in time. A great deal of the dispersed material in the throughflow is fine clay (<0.2μm).

Dispersion experiment

In fig. 27 the relationship between soil/water ratios and dispersion is shown by turbidity. (The turbidity values of the two clay fractions may not be compared). With an increasing soil/water ratio the turbidity also increases. This implies that both fractions are dispersed at the used soil/water ratios with their belonging electrolyte concentration, due to water soluble salts.

The Bg horizon shows a much higher turbidity than the AEh horizon, because of its higher (fine) clay content.

Although the saturation with Mg^{2+} shows a higher turbidity for both fractions compared to Ca^{2+}, the effect is not as much as was expected from literature.

Flocculation test

From fig. 28 the flocculation value of the two clay fractions for the Bg horizon can be deduced. Flocculation takes place at an EC(25) of 200-250 µS/cm, and at a concentration of divalent ions (Ca^{2+} and Mg^{2+}) of 0.8-1 mmol/l.

Conclusions

The pedogenesis on the forested slopes of the Keuper marks is ruled by several factors. The soil material is easy to disperse. The presence of easily swelling and dispersible smectite in the fine clay fraction, and the relatively high pH, together with a complex saturation of just divalent cations (no active Al^{3+}), are responsible for the potential instability.

The electrolyte concentration of the soil solution or subsurface flow at almost any soil moisture condition, appears to be below the flocculation value of the clay which is dispersed and transported.

The clayey, massive B horizon is impermeable, due to its swelling nature. A perched watertable is formed in wet periods, and the high lateral porosity in the surface horizon is responsible for a subsurface flow containing dispersed fine clay.

Table 11. Description of the reference profile.

REFERENCE PROFILE

Date of description: 24/03/1987
Author: Theo van den Broek

Classification :
- Aquic Eutrochrept, fine silty, mixed, over clayey, mixed, mesic (Soil Survey Staf, 1975)
- (Abruptic) Eutric Gleysol (FAO-Unesco, 1974)
- Pélosol brunifié (CPCS, 1967)

Location	:	2 km NE of Schrondweiler , in the forest at the middle of the slope 49°49'16'' N 6°10'50'' W
Altitude	:	325 m
Relief	:	Gently undulating macro-relief
Slope	:	4°
Aspect	:	North facing
Drainage	:	Poorly to imperfectly drained
Vegetation	:	Oak (Quercus cf, robor, L), hornbeam (Carpinus betulus, L) and beech (Fagus sylvatica, L)

All colors are for moist soil, according to the Munsell scale

AEh	0-10 cm:	Dark brown (10 YR-3/4) wet silt loam with few, fine, faint, diffuse mottles; moderate fine to medium crumb; slightly sticky, non-plastic; many fine, common medium and a few coarse pores; very frequent fine and common medium roots; gradual, wavy boundary to
EAh	10-20 cm:	Dark brown (10 YR-3/4) wet silt loam with few, fine, faint diffuse mottles; moderate medium crumb; sampleslightly sticky, non-plastic; many fine, common medium pores; frequent, fine and common, medium roots; abrupt, smooth boundary to
Bg	20-34 cm:	Brownish gray (10 YR-5/1) wet clay with many, medium, distinct, clear yellowish brown (10 YR-5/8) mottles; strong, medium/coarse angular blocky; slightly sticky, very plastic; few, very fine pores; few, very fine and very few medium roots; gradual boundary to
Bw	34-50 cm:	Brownish gray (10 YR-6/1) wet silty clay loam with common, fine, distinct, diffuse brown (10 YR-4/4) mottles; moderate, medium sub-angular blocky; slightly sticky, plastic; few very fine pores; few, very fine and very few medium roots, clear, irregular boundary to
C1	50-58 cm:	Dark reddish brown (5 YR-3/4) wet silt loam, no mottles; moderate, medium sub-angular blocky; lightly sticky, plastic; very few, very fine pores; no roots; clear, irregularer boundary to
C2	58-75 cm:	Grayish yellow (2.5 Y-6/2) wet silt loam, no mottles; medium sub-angular blocky; slightly sticky, plastic, no pores; no roots; few weathered Keuper marl flakes; clear irregular boundary to
C3	75 + cm:	Grayish yellow (2.5 Y-6/2) wet silt loam, no mottles; medium sub-angular blocky; slightly sticky, plastic, no pores; no roots; weathered Keuper marl flakes

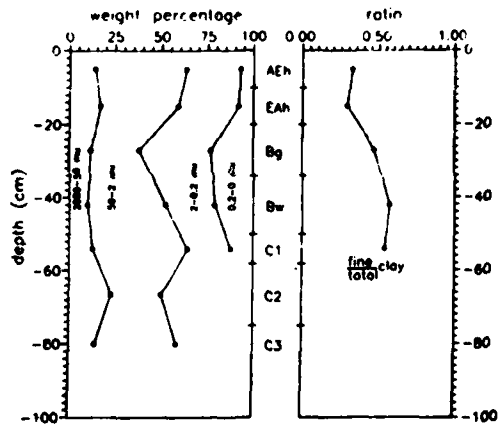


Fig. 24. The texture classes and the fine/total clay ratio of the refence profile.

Table 12. A summary of horizon characteristics of the reference profile

Horizon	AEh	EAh	Bg	Bw	C1
Depth (cm)	0-10	10-20	20-34	34-50	50-58
pH(H2O)	5.87	5.75	6.20	6.48	7.14
pH(CaCl2)	5.44	5.14	5.51	5.83	6.57
% Org. C	3.68	1.89	0.57	0.40	0.28
CEC (meq/100 g)	12.61	10.49	20.55	27.75	27.41
base saturation	89.59	80.16	84.89	89.06	94.57
Ca2+ (meq/100 g	8.00	5.43	10.28	15.30	17.04
Mg2+ "	2.73	2.63	6.53	8.68	8.08
K+ "	0.52	0.30	0.58	0.66	0.71
Na+ "	0.05	0.05	0.05	0.07	0.09
Ca/Mg ratio	2.93	2.06	1.57	1.76	2.11
%Fe2O3	1.25	1.67	2.38	1.48	1.70
coarse clay					
16 Å	-	-	-	(+)	(+)
14 Å	++	++	++	++	++
10 Å	++	++	++	++(+)	++(+)
fine clay					
16 Å	+(+)	+(+)	++	++(+)	++(+)
14 Å	-	-	-	-	-
10 Å	++(+)	++(+)	++(+)	++	++

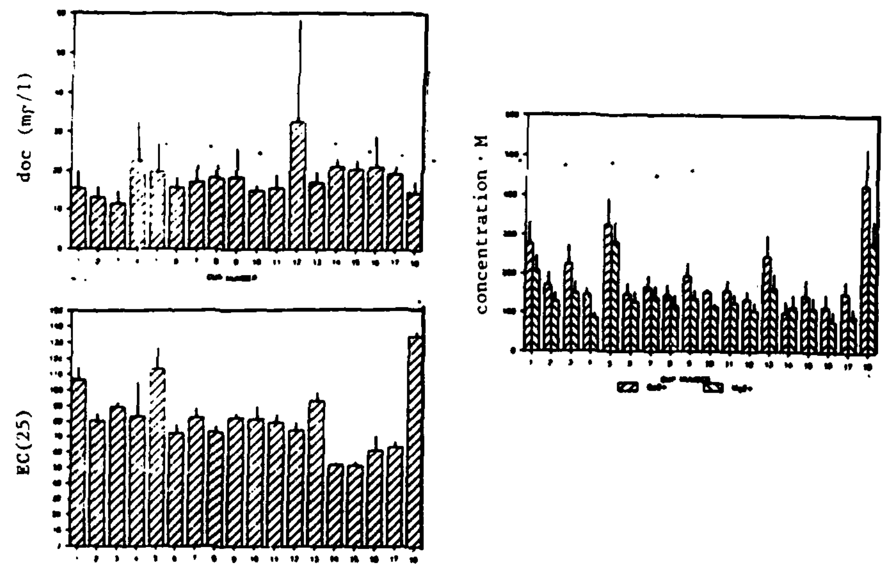


Fig. 25. Average and standard deviation of EC(25), Dissolved Organic Carbon (DOC), and Ca^{2+} and Mg^{2+} concentration of the soil moisture sampled by the porous cups in the period April-December 1987.

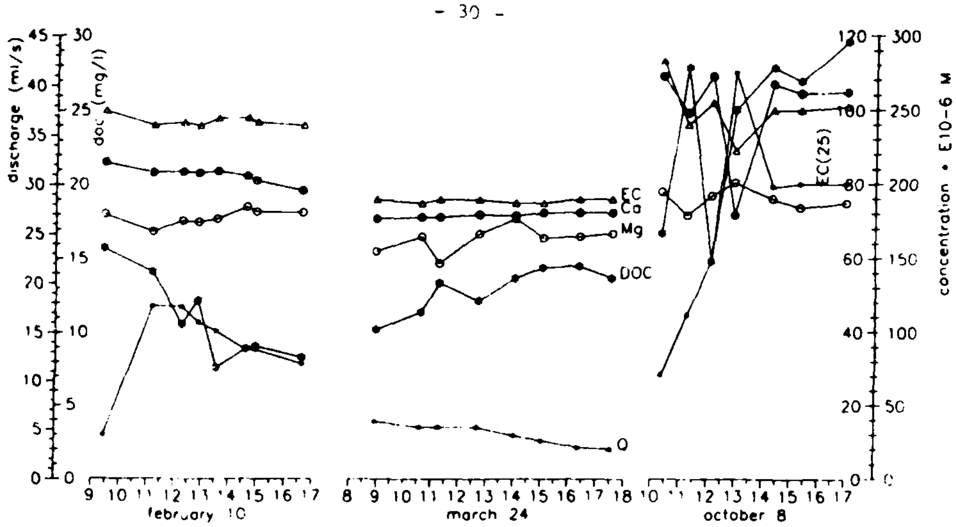


Fig. 26. The relation between time and discharge, EC(25), Dissolved Organic Carbon (DOC), and Ca^{2+} and Mg^{2+} concentration on 3 days in 1987 of the lateral sub-surface flow sampled by the gutter.

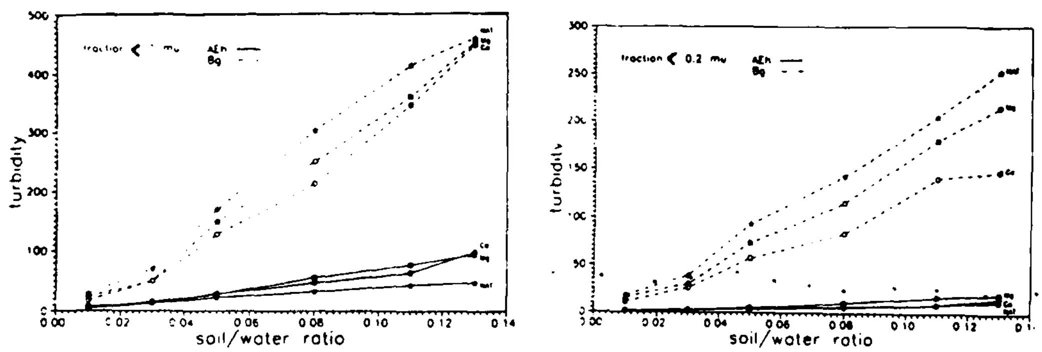


Fig. 27. The relationship between soil/water ratios and turbidity for the AEh and Bg horizon. Ca - exchange complex saturated with Ca^{2+}; Mg - exchange complex saturated with Mg^{2+}; NAT - exchange complex in its original state.

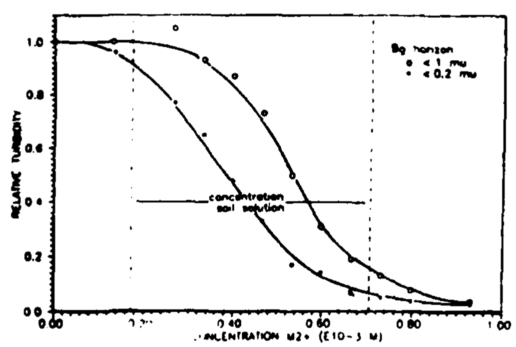


Fig. 28. The relationship between increasing electrolyte concentration and relative turbidity of a sample with a soil/water ratio of 0.08 of the Bg horizon. Shown is also the range of the M2+ ions in the soil solution.

III. ACIDIFICATION OF A FOREST KEUPER ECOSYSTEM

General

Acidification of terrestrial forest ecosystems, or one of their compartments, and the relation to (potentially) acidifying atmospheric deposition, are major topics in the studies of these ecosystems (Driscoll and Likens, 1982; van Breemen et al., 1984; Verstraten et al., 1988).

The term acidification, with respect to a (forest) ecosystem, consists of three major aspects:
1. rate of acidification
2. state of acidification
3. pH (of the liquid phase)

ad 1. The rate of acidification is defined as the rate of decrease in Acid Neutralizing Capacity (ANC) and equals the storage decrease of excess cations (except H^+):

$$\Delta ANC = \Delta S_{cations} - \Delta S_{anions}$$

ad 2. The state of acidification is the actual, pH-dependent, ANC throughout the studied system. As a (small) part of the total (potential) ANC, the ANCfast can be distinguished. This ANCfast is formed by substances such as fine granular calcite, amorphous metals and basic cations at the adsorption complex, that have a fast response time in proton buffering.

ad 3. The pH of the liquid phase in the ecosystem is an important ecological parameter which reflects, to a large extent, the value of the ANCfast of the (solid) phase.

If in a forest ecosystem steady state conditions are assumed for the total biomass (vegetation and forest floor), the rate of ecosystem acidification equals the rate of soil acidification.

The impact of external proton sources ("acid deposition") to the total proton production within an ecosystem is defined as the sum of net ammonium input, net nitrage leaching and net proton input (free acidity).

Methods

For the Schrondweilerbaach Forest Ecosystem (SFE) the rate of soil acidification was determined using solute input and output. As the SFE is a "watertight" catchment, atmospheric input and streamwater output are the only relevant fluxes into and out of the system, respectively. Atmospheric input of chemical elements was calculated from atmospheric precipitation and throughfall/stemflow data, assuming the increase of K and Mn to be caused by canopy leaching and compensated by an equivalent uptake of NH_4^+. The increase of the other elements was associated with canopy interception of atmospheric elements. Discharge concentration rating curves and a contunuous registration of discharge at the catchment outlet formed the information to calculate the output of solutes by streamwater.

The ANC of the soil was calculated from the chemical characteristics (elemental composition, pH, cation distribution at the adsorption complex etc.) of several representative soil profiles.

Results and discussion

The proton cycle for the SFE is presented in table 12. External proton sources account for only 15% of the total proton production, implying the importance of CO_2 dissociation, an internal proton source.

The (high) rate of ecosystem acidification, using the retention and release figures of table 11, is $(4.6\text{-}8.6)*10^2$ keq km^{-2} yr^{-1}. This variation is caused by the speciation of nitrogen, retained in the vegetation, when released and exported out of the ecosystem. Organic nitrogen released as NH_4^+ can be nitrified within the system, producing two protons per atom nitrogen.

If the above values for ecosystem acidification rates, ignoring the retention figures, are used for soil acidification rates, it should be noticed that an aggrading ecosystem like the SFE normally undergoes a net accumulation of excess cations, resulting in a higher soil acidification rate. The ecosystem acidification rates are in fact minimum values for soil acidification rates. The current high (minimum) rate of soil acidification in the SFE for the year 1980-1981 thus calculated, is $6.5*10^2$ keq km^{-2} yr^{-1}.

The ANC- and pH values of a representative soil profile are given in figure 29. All values show a (strong) decrease towards the surface. The low ANC values (and subsequent low pH values) of the (sub)surface horizons can be ascribed to the relatively high rates of soil acidification and the selective export of base-rich (fine) clay particles (see elsewhere in this hand-out).

Literature

Breemen, N.van, C.T.Driscoll and J.Mulder, 1984. Acidic deposition and internal proton sources in acidification of soils and water. Nature, 307, 599-604.

Driscoll, C.T. and G.E.Likens, 1982. Hydrogen ion output of an aggrading forest ecosystem. Tellus, 34, 283-292.

Verstraten, J.M., J.C.R.Dopheide, J.J.H.M.Duysings, A.Tietema and W.Bouten, 1988. Hydrochemical budget of forest ecosystems in the Netherlands: II. The proton cycle and its implications for soil acidification. Submitted to Journal of Ecology.

Table 12. The proton cycle (keq km^{-2} yr^{-1}) for the Schrondweiler-baach Forest Ecosystem (1980-1981).

factor	proton production	proton consumption
free acidity	90	
bound acidity	41	
retention		
NH_4-N	110	
Mn	0.3	
NO_3-N		87
SO_4-S		4.6
ortho-P		1.0
release		
K		7.5
Na		8.8
Ca		180*
Mg		470
M^{3+} (Al + Fe)	0.2	
Cl	11	
CO_2 (+org. acids) diss.	690	
Σ	$7.6*10^2$	$7.6*10^2$

* all Ca derived from Calcite

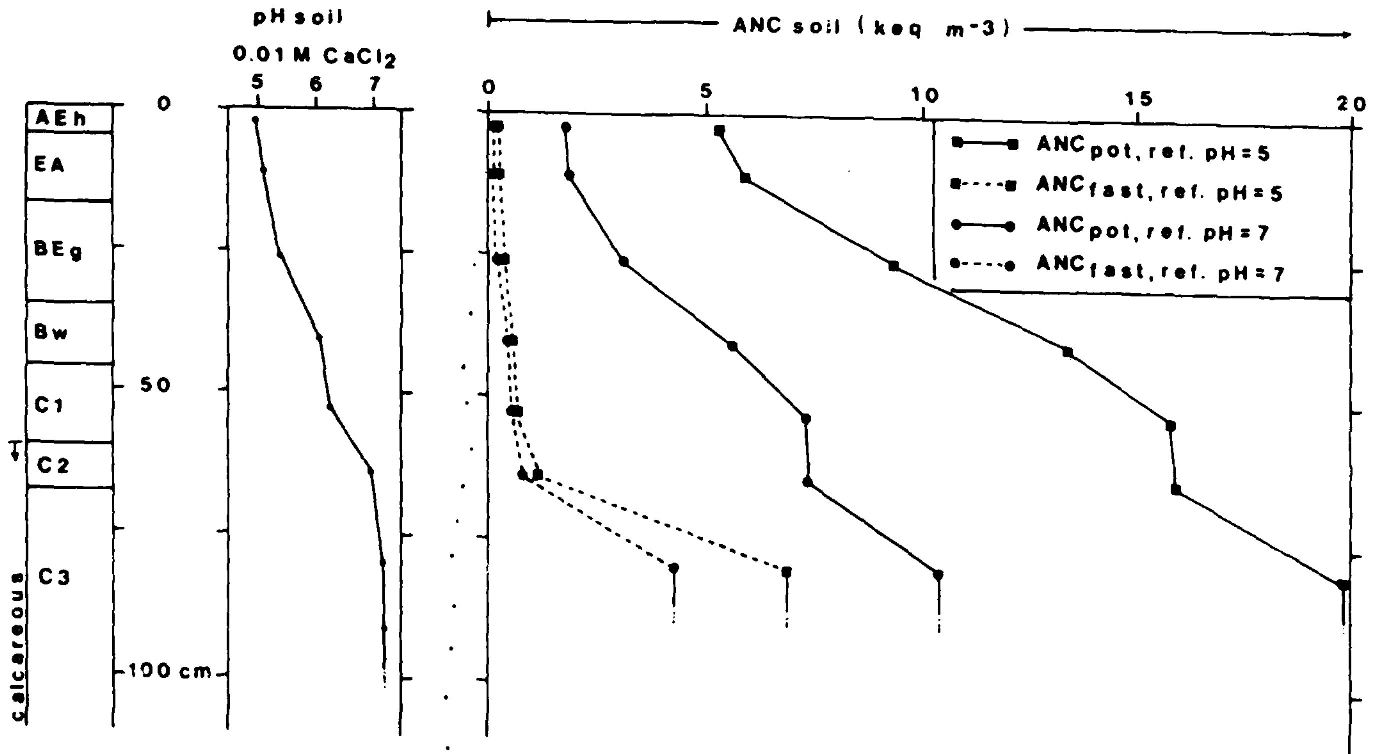


Fig. 29. pH and ANC of a representative soil profile in the Schrondweilerbaach Forest Ecosystem

IV. THE EFFECTS OF BIOTIC ACTIVITY

The effects of the biotic factor on soil and landscape development in Luxembourg are manifold and have been introduced by Dr. A.C.Imeson as a major research theme of the Laboratory of Physical Geography and Soil Science in the early seventies. A leading part in the biotic factor is played by earthworms (mainly Lumbricus terrestris and Allolobophora longa). They are significant in two respects.

In the first place it appears that earthworms are responsible for much of the bioturbation in the surface soil. In this way they contribute to the contrast between the surface soil and subsoil, which is of decisive importance for landscape forming processes on the Keuper Formation. In the second place they are responsible for removing litter, which results in the forest floor being exposed to splash.

To investigate the long-term effects of these two earthworm activities, two research projects were set up in Luxembourg. The first of these started in 1981 and investigated the extent of forest floor exposed at the end of the summer on different parent materials: Luxembourg sandstone, Psilonoten marls and Keuper marls. The research was carried out along five sections across the Lias cuesta (fig. 30). In these sections, the Luxembourg sandstone forms the main escarpment, whereas the Psilonoten marls form a secondary step (fig. 31). There are 15 sampling lines of 400 m length, one for each of the parent materials in each of the five sections. Each year estimates of soil cover were made in squares of 4 m², 10 m apart, numbering 600 in total.

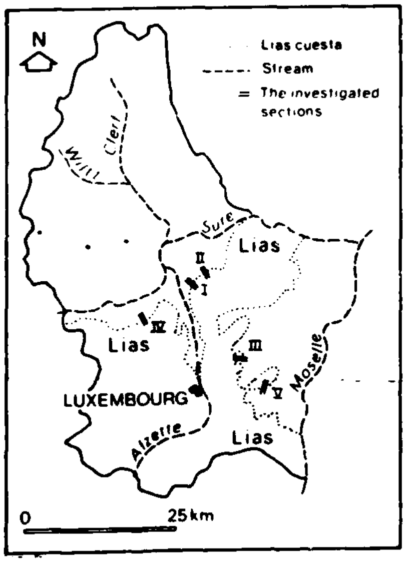


Fig. 30. The location of the five investigated sections.

To characterise the substratum, a number of soil properties were recorded for each sampling line:
- soil profile description;
- grain size distribution, pH, organic carbon content and calcium carbonate content
- sensitivity to splash
- dispersion

To study the cause of the variability of surface protection by litter, two approaches are ussed:

- differences in leaf production were deduced from the circumference of 40 trees; measured at breast height, at 10 m intervals along each of the 15 sampling lines;
- agents responsible for the exposure of soil material are recorded for each of the 600 squares mentioned above. Apart from earthworms these are moles and voles, game (wild boar, roe, deer) and stemflow.

Since 1985 the state of vitality of the trees is yearly determined at each of the 600 squares, using a modification of the vitality inventarisation of the State Forestry Service (Staatsbosbeheer) in the Netherlands.

Some of the results so far:

1) Worms and moles reduce by homogenisation differences in erodibility between landscape units (Jungerius and van Zon, 1984). Moles enhance erodibility by bringing material to the surface which is poor in organic matter, whereas worms reduce erodibility by improving the structure and increasing the organic matter content.
2) The relief configuration of the Lias cuesta area cannot be accounted for by lithological differences between the underlying rock types, but appears to be due to differential soil erosion under natural conditions (Jungerius and van Zon, 1982). Due to a much larger exposed surface, especially during summer, th e Keuper soils are more subject to splash than the Psilonoten soils, whereas the soils of the Luxembourg sandstone remain protected by a litter layer throughout the year. Leaf consumption by earthworms is the principal cause of the observed differences. The ecological conditions of the Keuper soils are most favourable for these organisms.

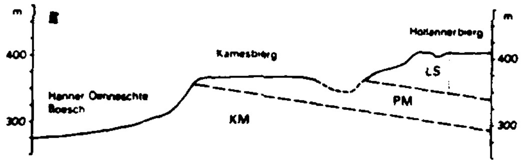


Fig. 31. One of the investigated sections. The names refer to the topographical map 1:20.000, Administration du Cadastre de G.D. de Luxembourg.
LS = Luxembourg sandstone, PM = Psilonoten marls,
KM = Keuper marls

The second project was devised to study bioturbation in the surface horizon of forest soils on the Keuper Formation. Two approaches are used.

On the Pseudomorfosenkeuper in the eastern part of Luxembourg, where the textural difference between the surface soil and the subsoil is particularly well developed, five soil pits were dug along a catenary transect. Samples were taken for micromorphological analysis. No results of this research are available yet.

In the Schrondweilerbaach forest, a creep experiment is being carried out according to the method of Young. At five localities along a catenary transect (plateau, upper slope, middle slope, lower slope and bottom) small boreholes 50 cm deep and 2 cm in diameter, were filled with sand in 1982. At each of the five localities, two boreholes were made in a depression with poorly drained soils, and two boreholes in a higher position where soils are better drained. It was the aim of this research to deduct downward creep of the surface soil from dislocation of the sand column. Two columns dug up after one year showed definite bending in their upper parts. However, bioturbation since then has been so intensive that the sand of the columns can no longer be detected in the surface horizon.

LITERATURE

Jungerius, P.D. and H.J.M.van Zon, 1982. The formation of the Lias cuesta (Luxembourg) in the light of present-day erosion processes operating on forest soils. Geogr. Annaler 64A, 3-4, 127-140.

Jungerius, P.D. and H.J.M.van Zon, 1984. Sources of variation of soil erodibility in wooded drainage basins in Luxembourg. In: T.P.Burt and D.E.Walling (Eds.): Catchment experiments in fluvial geomorphology. GeoBooks, Norwich, 235-246.