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WELL DRAINED SOILS WITH A „DEGRADED" BT HORIZON IN LOESS DEPOSITS IN BELGIUM; RELATIONSHIP WITH PALEOPERIGLACIAL PROCESSES

Abstract

In Belgium the degradation of the Bt horizon in soils developed in loess is generally attributed to the presence of an intensively exploited oligotrophic vegetation. Detailed investigations, made by the authors through the loess belt, show that this correlation is not so valid as might be thought from the literature. It is observed that all degraded soils — icluding the well drained ones — do have a compact fragipan horizon in the transition zone between the A_2 and the Bt horizon. This fragipan is absent in the well drained non-degraded soils and has a somewhat different morphology from the one generally described for this horizon in loess deposits. It is also found that degradation of well drained soils coincides with the presence, below the loess, of a less permeable substratum. This correlation is still observed in plateau positions where the contact with the substratum is situated at several meters depth.

The presence of the fragipan helps to explain the association of the degradation of the soil and the permeability of the substratum. This is possible on basis of the hypothesis which links the fragipan development to ice segregation in permafrost aggrading in an environment with relatively high water supply from the subsoil. It is concluded that the degree of degradation, and its distribution in the landscape, can be explained in a much more satisfactory way by these processes associated with a periglacial climate than by the presence of a particular forest vegetation. The local coincidence between the land use and the degradation most probably is the consequence of the knowledge and the intelligence of the early settlers. These people started to deforest and to plow first those areas which did not present a compact layer at shallow depth.

Résumé des auteurs

En Belgique, la dégradation de l'horizon Bt dans les sols développés dans des loess, est généralement attribuée à la présence d'une végétation forestière oligotrophe intensivement exploitée. Des recherches détaillées, faites par les auteurs à travers la région des loess, montrent que cette corrélation n'est pas aussi valable qu'on pourrait le déduire des données de la litérature. Il est observé que tous les sols dégradés — y compris ceux qui sont bien drainés — ont un horizon fragipan, compact, dans la zone de transition entre l'horizon A_2 et le Bt. Ce fragipan est absent dans les sols non dégradés bien drainés et a une morphologie quelque peu différente de celle généralement décrite pour cet horizon dans des dépôts de loess. On trouve également que la dégradation des sols bien drainés coïncide avec la présence, sous le loess, d'un substrat moins perméable. Cette corrélation est encore observée dans des positions de plateau où le contact avec le substrat est situé à plusieurs mètres de profondeur.

La présence du fragipan permet de comprendre l'association entre la dégradation du sol et la perméabilité du substrat. Ceci est possible sur la base de l'hypothèse qui lie le fragipan à la ségrégation de glace dans un permafrost qui se développe dans un milieu avec une alimentation en eau relativement importante à partir du sous-sol. Il est conclu que le degré de dégradation, et sa distribution dans le paysage, peuvent-être expliqués d'une façon beaucoup plus satisfaisante par des processus associés à un climat périglaciaire, que par la présence d'une végétation forestière particulière. La coïncidence locale entre le type d'affection du sol et la dégradation est très probablement la conséquence de la connaissance et de l'intelligence des premiers cultivateurs. Ces gens ont commencé à déboiser et à labourer d'abord ces régions qui ne présentent pas d'horizon compact à faible profondeur.

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INTRODUCTION

In the loess belt of Belgium (Fig. 1) the upper meter(s) of eolian sediment have been deposited during the Vistula Pleniglacial B or Upper Vistula (e.g. HAESAERTS, VAN VLIET, 1974; PAEPE, VANHOORNE, 1976). The soils developed in these materials today have a textural B horizon (Bt horizon characterized by the accumulation of clay leached from the upper A_1 and A_2 horizons). The Belgian National Soil Survey (TAVERNIER, MARECHAL, 1962) has recognized three degrees of „degradation" of this Bt horizon: not-, slightly- and strongly degraded. The purpose of this paper is to investigate the origin of this „degradation". In order to keep constant a maximum of factors of soil genesis the research is focused on those soils which, following the legend of the Belgian soil maps, are „well drained". These soils, in the period of low evapotranspiration (fall + winter), do not present a ground water table which comes within a depth of less than 1.2 m from the soil surface (the term „well drained" however does not exclude the eventual presence of a temporary water table on a less permeable horizon within the profile itself).

The well drained non-degraded soils (Fig. 2A) have a dark yellowish brown (10YR 4/4 [1]) A_2 horizon with relatively low clay content (13—18%) and a uni-

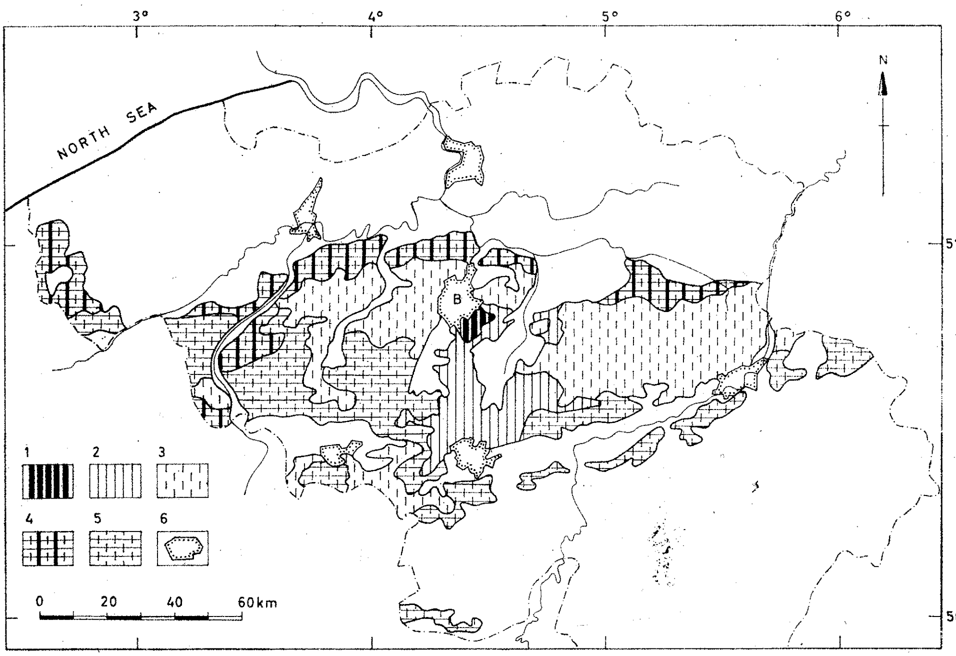

Fig. 1. Drainage and degree of degradation of the soils of Belgian loess belt

1. strongly degraded soils well drained; 2. slightly degraded soils — well drained; 3. non-degraded soils — well drained; 4. complex of strongly- and non-degraded soils — with drainage problems; 5. non-degraded soils — with drainage problems 6. towns (B — Brussels)

[1] Soil colours stated for moist conditions and using the Munsell Soil Color Charts.

form brown to dark brown (8YR 4/4) Bt horizon with 18—24% clay. In the well drained strongly degraded soils (Fig. 2B) the lower part of the A_2 horizon (A22g) has a lighter colour (pale brown — 10 YR 6/3) as consequence of a temporary perched water table situated at that level in the winter period.

An important feature of these soils is that this bleached A22g horizon tongues into the underlying Bt. These pockets may occupy as much as 30—50% of the upper half of the Bt horizon and the deepest ones reach a depth of about 1 m.

The slightly degraded soils have properties intermediate between those of the non — and of the strongly degraded soils.

In soil science the concept of „degraded" Bt horizon is associated to the irregular penetrations of the clay-impoverished and bleached A22g horizon into the brown, clay-enriched Bt. It is thought that originally the soil was non-degraded and that by a particular pedogenetic process clay became more mobile, or even has partly been destroyed, in the bleached pockets. From the morphology it is deduced that this process starts at the contact between the A_2 and the Bt horizons. It would gradually penetrate deeper into the latter horizon along those spots where relatively much water percolates. Such spots can correspond to old root channels and/or shrinkage cracks. For soils developed in loess detailed morphological and/or analytical studies of these properties have been made by Dudal (1953, 1955) and Louis (1955, 1969) in Belgium, by Jamagne (1972,

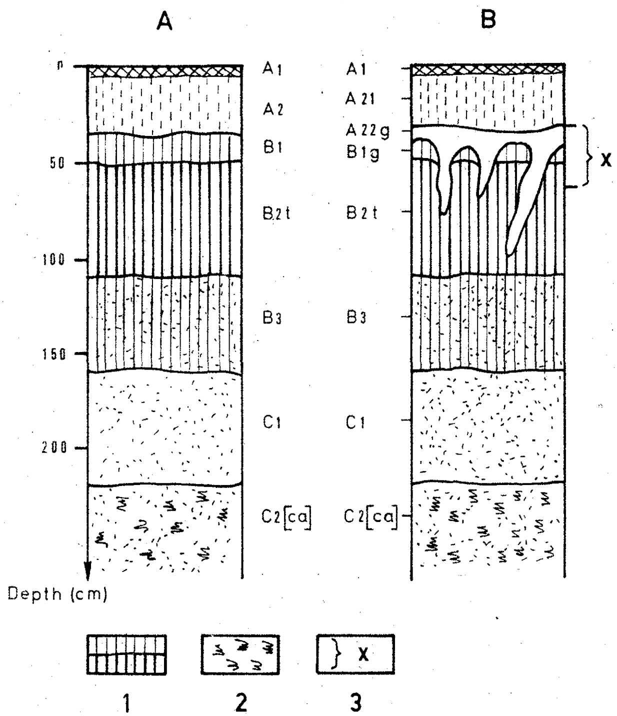

Fig. 2. Schematic representation of a non-degraded (A) and a strongly degraded (B) soil

1. clay illuviation; 2. $CaCO_3$ still present; 3. level of the compact fragipan horizon

1973) in France and by BOUMA *et al.* (1968, 1969) in the Netherlands. In non-loess deposits similar processes have been described, e.g. by FEDOROFF (1968) in France, DE CONINCK *et al.* in Belgium (1968) and France (1976) and by BULLOCK *et al.* (1974) in the United States.

THE CORRELATION BETWEEN LAND USE AND SOIL DEGRADATION

As to the factor responsible for the process of degradation, in Belgium a link has been found with the land use. From the systematic soil survey of the country it appeared that many strongly degraded soils occur in areas which today are still under forest whereas the non-degraded soils mostly are situated in regions which have been for many centuries (sometimes from before the Roman period) under cultivation. So a theory has emerged (DESENFANS, 1949; MANIL, 1951, 1958, 1959; DUDAL, 1952, 1953; GALOUX, 1953; LOUIS, 1955, 1971, TAVERNIER, LOUIS, 1971) which links the degradation to the presence of an intensively exploited forest vegetation. The soils would not have been degraded before the settlement of man (TAVERNIER, PÉCROT, 1957, p. 227). In those areas brought very early under agriculture, because of the application of fertilizers and the concomittant high base status of the soil, the clay colloids would have remained stable (flocculated or non-dispersed). Under forest, on the contrary, man did intensively harvest (wood, bark, litter, grazing of domestic animals) without any feed-back of the exported mineral elements. Thus there would have been a gradual impoverishment of the base status of such soils, favouring the dispersion and migration of the colloids. This process furthermore would be facilitated by the presence of an oligotrophic vegetation which generates a very acid litter and a more humus. Particularly beech trees (*Fagus silvatica* L.) are thought to accelerate soil degradation in this way. The same theory has been proposed by BONNEAU and DUCHAUFOUR (1960) for the explanation of some degraded soils in France. For the loess soils of Europe, JAMAGNE (1969) considers that either a long leaching period or an acidifying vegetation can produce a strong desaturation and a concomittant degradation.

NEW DATA ABOUT THE SOILS AND THEIR ENVIRONMENT

PROBLEMS ABOUT THE CORRELATION BETWEEN LAND USE AND SOIL DEGRADATION

Along numerous traverses through the loess belt the authors have observed that in many places the degree of soil degradation cannot be correlated to land use as it is explained in the previous chapter. Strongly degraded soils are observed in areas which have for many centuries been under agriculture and non-degraded soils are found in areas which never have been under agriculture. So it has to be concluded that the distribution of the soils can be explained by this correlation as long as one considers small scale maps. On passing to more detailed investigations, the correlation does not hold for many localities.

From these investigations it also appeared that those slightly degraded soils which are today under agriculture, often correspond to soils which were strongly degraded as long as they were under a forest vegetation. Since these soils have been plowed and fertilized the biological activity, particularly of earthworms, has increased tremendously. Consequently most traces of bleached tongues, associated with the degradation, have been largely effaced.

THE PRESENCE OF A FRAGIPAN

Field investigations in the last years have shown us that all the strongly degraded soils have a compact but non-cemented horizon in the contact zone between the A_2 and the Bt horizons (mostly between 35-60 cm depth). In our opinion this horizon is sufficiently thick, compact and continuous to be called a fragipan. The pedologists who surveyed the areas with degraded soils of the loess belt, mention that fragipans occur in the lower part of the Bt horizons of only some imperfectly or poorly drained soils situated in smooth upland depressions (Dudal, 1955, p. 75; Louis, 1969, p. 132). Dudal indicates that all transitions occur between latter soils and the well drained degraded soils without fragipan. Tavernier (1964) states that the strongly degraded soils often have a fragipan which may already start in the Bt horizon.

The fact that, up to now, the horizon which we consider to be a fragipan has not been generally described as such, can be attributed to two particular characteristics.

(1) The „typical" fragipans (Soil Survey Staff, 1975, p. 42) searched after by most soil scientists, have a characteristic pattern of vertical bleached streaks, 0.5—2.0 cm wide, which delimit a prismatic structure of 5—30 cm diameter. In the well drained degraded soils this property is lacking. Yet when examining the pattern of bleached tongues in a horizontal cut, it frequently appears that they are situated along large polygons of 40—80 cm diameter. This property is much less obvious than the previously described pattern of bleached streaks in „typical" fragipans.

(2) Fragipans are mostly described below or in the lower half of Bt horizons. In the well drained degraded soils, on the contrary, the compact horizon is situated in the upper transition zone of the Bt (Fig. 2B), more precisely at the level of the A22g, the B_1 and locally including the B21t; further down, the soil is very porous.

Thus this fragipan, versus the „typical" one, has a somewhat different morphology, is situated near the soil surface (upper boundary at 30—55 cm) and is relatively thin (15—30 cm). Yet the compaction and the continuity of the horizon is sufficient to cause in winter a periodic water saturation on top of the horizon and to largely impede root penetration. As a consequence of these properties large trees are frequently uprooted, a feature which is uncommon on the non-degraded soils.

THE CORRELATION WITH THE LITHOLOGY OF THE SUBSTRATUM OF THE LOESS

A study has been made on the possibility of correlating the distribution of the soils with various degrees of degradation and factors of the soil environment such as climate, landscape position, drainage class, vegetation, land use, lithology. This research showed that a clear correlation exists between the lithology of the substratum of the loess and the degradation of the surface soils. In the Belgian loess belt the substratum of the eolian sediments is composed of subhorizontally stratified Tertiary marine sediments with a clayey up to sandy texture and

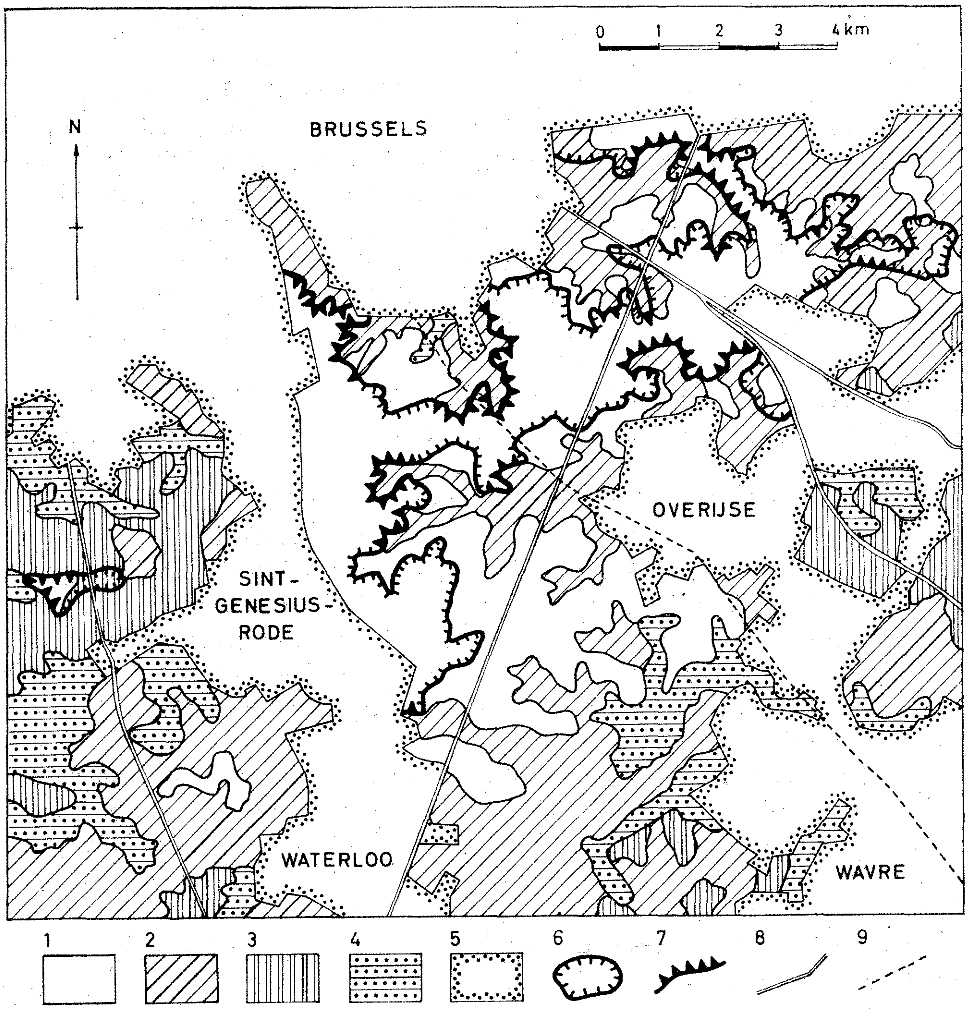

Fig. 3. The coincidence of the area of strongly degraded soils with the presence of a less permeable substratum below the loess

1. strongly degraded soils, in loess; 2. slightly degraded soils, in loess; 3. non-degraded soils, in loess; 4. other soils (sandy soils, alluvial soils); 5. urban area; 6. boundary of the less permeable Tertiary substratum; 7. area where the previous boundary coincides with the boundary between 1 and either 2 or 3; 8. roads; 9. railway

of Cretaceous chalk. The contact with the substratum is situated at variable depth, from more than 10 m up to outcrops of the older sediments (particularly on steep slopes). When considering the more or less flat uplands, this contact in general is situated at some 2—4 m.

It now appears that the well drained non-degraded soils occur in those areas where the substratum is composed of sands or chalk (eastern part of the loess belt, Fig.1) and that the degraded soils coincide with a less pervious substratum such as clays, sandy clays and clayey sands.

The region situated south of Brussels is a good illustration of this (Fig.3). Indeed, it is an area where non-degraded, slightly degraded and strongly degraded soils occur over short distances. Today nearly all the strongly degraded soils are situated in the forested zone. On the map the local coincidence of the soils boundary with the substrata boundary is evident (there is more than 30% of overlapping). In some areas the coincidence is not so clear; it however should be kept in mind that, while the soils distribution is derived from the detailed maps of the Belgian National Soil Survey (with an augering up to 125 cm depth every 75 m), the data concerning the geology come from reconnaissance maps made about one century ago on the basis of a survey at a scale of 1 : 40,000. So the boundaries of the latter maps are based on relatively few direct observations and mainly are the result of extrapolations.

DISCUSSION

The at least local overlapping of the well drained degraded soils with a less pervious substratum below the loess, and reciprocally the coincidence of the well drained non-degraded soils with a permeable substratum, is undeniable. From our field investigations throughout the loess belt it has to be concluded that this correlation is at least as frequent as the one mentioned about the land use (p. 206).

There still remains the question of the link between the degree of degradation of a well drained surface soil and the permeability of a substratum situated at several meters depth. The presence in the degraded soils of a fragipan, and the absence of this horizon in the non-degraded soils, helps to explain this correlation. Indeed, according to one of the theories about the genesis of the fragipan, this horizon would be associated to the former presence in the soil of permafrost (FitzPatrick, 1956, 1974). The compaction of the horizon would be the consequence of an important ice segregation as lenses in the upper part of that permafrost which aggrades in an environment with a relatively important water supply from the subsoil (Van Vliet, Langohr, 1980). The more important this supply, the more numerous the ice segregation bodies will be and the more the trapped earth between the successive ice lenses will be compacted. This compaction, after thawing of the permafrost, remains in the soil as long as no physical and/or chemical and/or biological processes alter it (Langohr, Van Vliet, 1979).

So if this hypothesis is correct, then it is logical that the fragipan is best developed in those soils where a less permeable substratum stores more water in the deeper loess layers. As the aggradation of permafrost is a slow process which lasts for many years, it is understandable that, although the contact with the substratum may be situated at several meters depth, a correlation is found between the properties of this substratum and the development of the pan near by the surface.

The association of the fragipan with the degradation of the soils — latter being expressed by the tonguing of the A22g horizon into the browner Bt horizon — can be explained by the compaction of the pan. As indicated by the bleaching of the A22g, a periodic fluctuating water table is present in winter on top of the pan. So at any place where latter horizon is interrupted, for example at those spots where once roots did penetrate deeper, relatively important quantities of water percolate down through the Bt horizon creating a particular morphology of vertical bleached tongues. The latter are frequently situated along a large polygonal pattern probably corresponding to the cracking of the soils at the time of permafrost development.

CONCLUSIONS

(1) The hypothesis of a causal relation between the degree of soil degradation and the type of land use, non-degraded soils being associated to old agricultural land and degraded soils being associated to intensively exploited forest land, frequently does not explain the soil distribution.

(2) The well drained degraded soils have a fragipan horizon which is situated in the transition zone between the A_2 and Bt horizon (A22g, B_1 and sometimes the B21t). This fragipan has a morphology which is somewhat different from the one commonly described in soils developed in loess (situation at the soil surface and absence of a marked polygonal pattern of bleached streaks).

(3) It is found that the boundary between the well drained non-degraded and the well drained degraded soils seems to coincide with the boundary between a permeable and a less permeable substratum below the loess. Such a coincidence is still observed for plateau positions in which the contact between the loess and the substratum is situated at several meters depth.

(4) The relation between the degradation of the soil and the perviousness of the substratum of the loess can be explained through the hypothesis which links the development of the fragipan to the process of ice segregation in the upper part of permafrost aggrading in an environment with relatively important water supply from the subsoil. A compact horizon remains in such soils after the thawing of the permafrost. From then on water will be periodically perched on this horizon and will mainly percolate further down along pockets corresponding to places where once roots did pass the pan. This explains the particular morphology of the degraded soils with tongues of bleached A22g horizon penetrating the lower Bt horizon. So it can be concluded that the degree of soil degradation

and its distribution, both recognized and surveyed by the pedologists, can be explained by processes which have been active in a periglacial environment.

(5) The local correlation between the degradation and the land use most probably is a translation of the intelligence and knowledge of the first settlers who started with agriculture in those areas which were well drained and which did not present a compact horizon at relatively shallow depth. This permits us to reverse the answer on the cause of this correlation by stating that „if man started to plow certain areas before others, it was just because the degradation, and the associated fragipan, did already exist in some soils and consequently the origin of latter properties must be searched for among pedogenetic processes active before the impact of man".

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