Fertility and classification of Limburg soils (Netherlands) based on morphological, chemical and clay-mineral characteristics

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1. Introduction

In recent years the chemistry and clay-mineral properties of soils have been increasingly examined for the light they may throw on soil morphology and classification and for the information they can provide on soil fertility and its potential productivity. As a soil type is a "correlative complex" (PIJLS, 1959), there is a relationship between morphological, chemical and clay-mineral characteristics.
Thus rendzinas and terra fusca soils are rich in Ca, Mg and P as a result of their organogenic origin; moreover their high montmorillonite content renders them sticky. On the other hand, latosols are deficient in plant nutrients; they contain kaolinite or halloysite. They can, however, have a high productivity when they are deeply rooted and the rainfall is sufficient (or when they are irrigated and fertilized).
Practical experiments have shown that there will be good agreement, even in less extreme examples, between the identification of a soil type according to its morphological, chemical and clay-mineral characteristics, and its potential to produce crops.
This paper describes the main morphological features of the soils over some 200.000 hectares in the province of Limburg together with chemical characteristics and the clay mineralogy. It links these with the fertility (physical and chemical) requirements of agricultural crops and it sets out to show some of the difficulties in evaluating the potential productivity of these soils for cultivated annual crops.

2. Morphological characteristics

FIG. 1 shows the occurrence of the dominant soil groups in Limburg. They have been distinguished by their morphological characteristics based on type of profile development, difference in origin and lithology of the geological sediment (BROEK and MAREL, 1962). The parent material is the main factor governing the development of the soil profile.
As the climate of this region is humid with a DE MARTONNE (1926) climatic index of $P/T + 10 = 35$, podzolization is the main process occuring in these soils.
In the south are found old geological formations of Senonian age, consisting of limestones and glauconite clays. The former give rise to rendzina soils (1) when weathered to a shallow depth; where they are leached more deeply the soils are of the Terra Fusca type (2), *i.e.* they consist of a sticky, non-calcareous clay about 60 cm thick overlying unweathered limestone. Flint containing limestones have been

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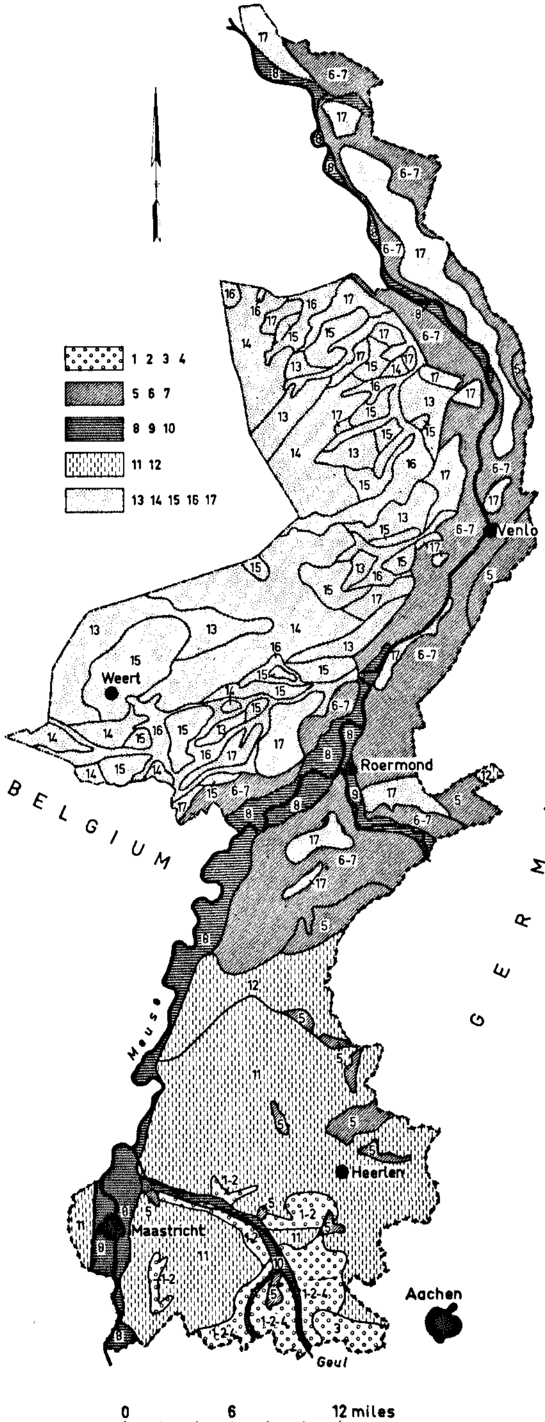


FIG. 1.
Dominant soil groups in Limburg (S.E. Netherlands)

Soils on limestone and glauconitic sediments

1 Rendzina soils: shallow soils consisting of humic or humic clayey layer on unweathered limestone.
2 Terra fusca soils: Soils of sticky, non calcareous and swelling clay derived from limestones by dissolving of $CaCO_3$.
3 Podzolized flint soils: Soils of intensively leached flint-containing limestone rocks.
4 Glauconite soils: Soils in differing stages of weathering and erosion predominantly with Gray Brown Podzolic profile development.

Fluviatile river terrace soils

5 High Terrace soils: Brown Podzolic and Podzolic soils on strongly weathered sandy and gravelly old Pleistocene river sediments.
6 Loamy Low Terrace soils: Gray Brown Podzolic soils on late Pleistocene river sediments.
7 Sandy Low Terrace soils: Brown Podzolic soils on late Pleistocene river sediments.

Recent Alluvial soils

8 Meuse Alluvial soils.
9 Roer Alluvial soils.
10 Geul Alluvial soils.

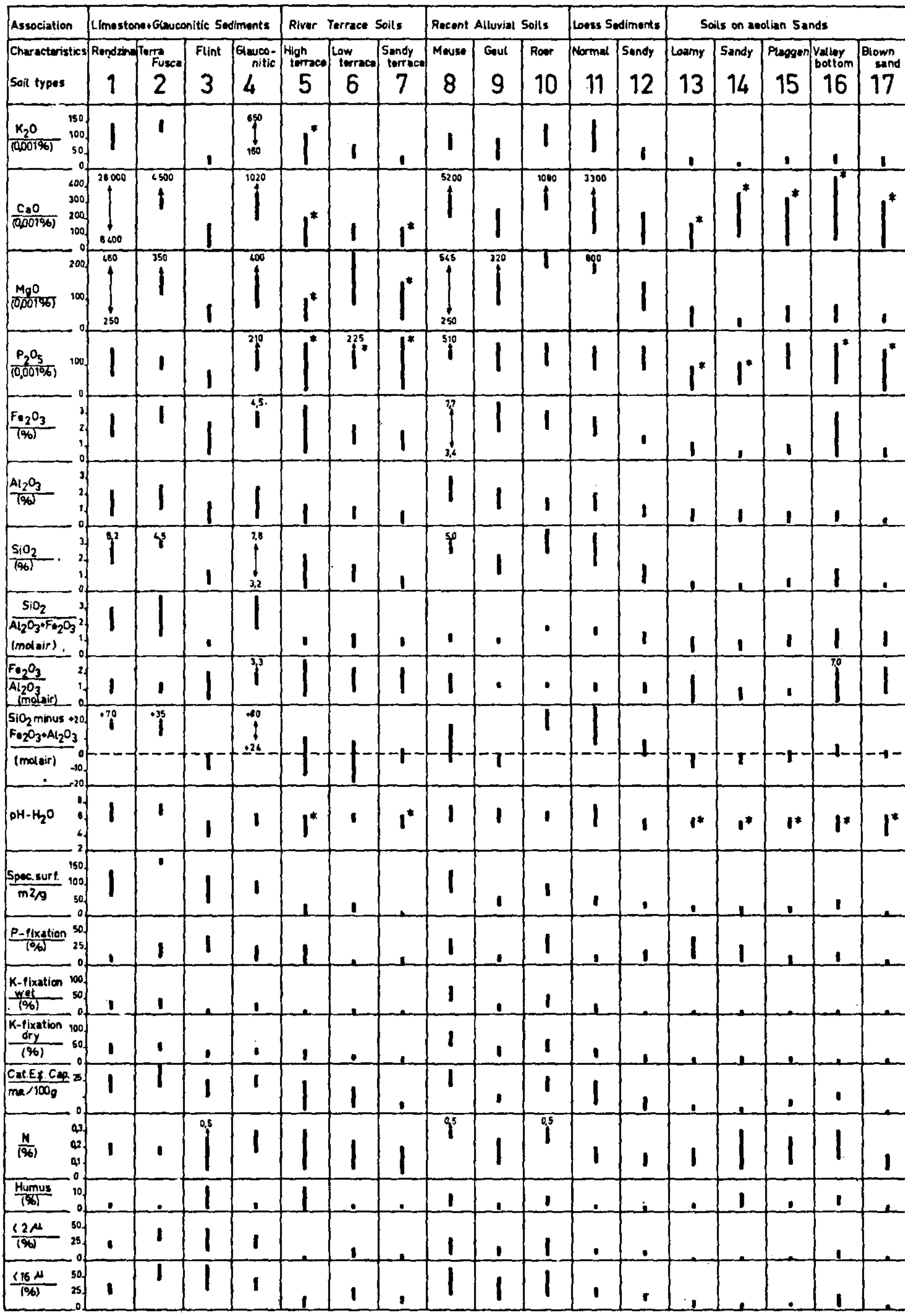
Loess soils

11 Normal loess soils: Gray Brown Podzolic Soils, partly eroded.
12 Sandy loess soils: Gray Brown Podzolic and Brown Podzolic soils.

Cover-sand soils

13 Loamy Cover-sand soils: with Brown Podzolic and shallow Podzol soils.
14 Sandy Cover-sand soils: strongly weathered and leached Cover-sands with Podzol profile development.
15 Plaggen soils: soils with thick humic toplayer originating from long continued manuring by human activity.
16 Valley bottom soils: sandy soils of brook valleys partly with thin clayey toplayer or peat development.
17 Blown sand soils: Recently built up land dunes of loose sands without soil profile development.

FIG. 2. Chemical characteristics of various soils in Limburg



* Large spreading caused by manuring.

severely leached with heavy rainfall and yielded highly weathered soils with podzol development (3). In glauconitic sediments the soils (4) show clay movement with development of a textural B-horizon of Gray Brown Podzolic soils; where not eroded these soils are moderately weathered. These Senonian sediments are overlain by Tertiary and Quaternary deposits in the centre and north of the province. The Old Pleistocene river terraces (High terraces) consist of sand and gravel (5); usually the soils are highly weathered as a result of their coarse texture and have Brown Podzolic profile features, partly with shallow podzol at the top.
The younger, Late Pleistocene river terraces (Low terraces) are more finely textured and have well-developed Gray Brown Podzolic profiles (6) in very fine textured deposits about 1 to 1,5 m thick overlying coarse sand; in sandy, Late Pleistocene fluviatile sediments Brown Podzolic soils (7) have formed, often with prominent fibers of clay and iron in the subsoil.
The Recent alluvial soils differ according to their rivers of origin, *viz.* the Meuse (8), Roer (9) and Geul (10). The soils show no profile development, but vary with the deposits laid down by the respective rivers (BROEK and MAREL, 1963).
The loess soils in the southern part of the country, originating from glacial Pleistocene environments, have a very uniform granulometric composition; a zone with sandy loess is only found along the northern border of the loess belt. The normal loess (11) is only slightly weathered, showing the Gray Brown Podzolic soil-profile development; along the slopes of the hilly, southern part of Limburg these soils are subject to moderate erosion. The sandy loess soils (12) show the Gray Brown Podzolic type, grading into Brown Podzolic soil which becomes the more dominant soil profile as the loess becomes sandier; weathering is more extensive in these soils than in the non-sandy, normal loess soils.
The soils on Cover-sand occur in the areas west of the Meuse. They also are of glacial Pleistocene origin. Like the loess soils they are wind-borne, but they show some more variation in silt content (fraction $< 50\,\mu$). Their clay content however is practically negligible. The loamy Cover-sand soils (13) with 20 to 50 % of silt normally carry shallow podzols and Brown Podzolic soils in hydrographically elevated soils. Like the sandy Cover-sand soils (14) they are very acid in origin and are fairly strongly weathered. The sandy Cover-sand soils, which contain up to 20 % of silt are characterized by very pronounced podzol development. When the ground-water tables are high these soils are also peaty.
"Plaggen" soils (15) have been cultivated lands for centuries and this has given them a humic topsoil about 40 to 100 cm thick originating from farmyard manure mixed with sand and sod compost.
The broad drainage ways in the Cover-sand area carry valley-bottom soils (16). These are low-lying, mainly wet soils of varying textural composition with sandy or clayey topsoils and are peaty in places.
Recently redistributed sands occur throughout the northern part of the country; the blown-sand soils (17) are very poor, practically without clay or silt fractions and with hardly any profile development. They occur as dry, high sand dunes.

3. Chemical characteristics

FIG. 2 shows that there are considerable differences in the chemical composition of the various soil types. Thus, the Aeolian sands, the High-terrace soils and the flint soils are very deficient in the plant nutrients K_2O, CaO, MgO and P_2O_5. They are also the most acid. In contrast, the rendzina, terra fusca and glauconite soils are the richest. The sandy loess is more deficient than the normal loess. There is less difference between the loamy and sandy terrace soils. The former have fairly high MgO contents compared to K_2O and CaO. This is due to the chlorite found as a component in the clay fraction.

Calcite and calcite + dolomite contents of loess soils are related (FIG. 3). Thus, 100 parts of calcite to 31 parts of dolomite are found. There is some increase in dolomite, which compared to calcite is the most insoluble component, when weathering occurs.

According to HISSINK (1935, 1952) and MASCHHAUPT (1950, 1952), about 1 % $CaCO_3$ is washed out from the alluvial marine topsoils (0—20, 0—25 cm) in the Netherlands over periods of 50 and 25 years respectively. EDELMAN and DE SMET (1951) arrived at a figure of 65 to 90 years. LÜTTMER (1952) found 1 % over 100 years for clay soils in Germany and TOVBORG JENSEN (1952) 1 % $CaCO_3$ for 20 years for the 32 tons $CaCO_3$/ha limed plot of an experimental field laid down for 13 years on an acid sandy soil in Denmark.

The Limburg loess soils have lost their original carbonates (up to ca 15 % by weight) to a depth of 2,5 to 3 m during the 12.500—25.000 years that have elapsed since their deposition (ANDERSEN *et al.*, 1960). This would give a loss of 1 % carbonates in 110 to 160 years for a layer of 0—20 (25) cm. But the Dutch marine alluvial soils contain less dolomite (calcite/dolomite ratio = 1,15 to 1,20) and unlike the Danish soil they are not acid.

The magnesium and potassium contents of loess are related as a result of the weathering of biotite. Other soils containing this mineral, *e.g.* the rhyolite soils of the N.E. coast of Sumatra also show a correlation (FIG. 4). The quotient found for the loess soils (0,37) is lower than that for the Sumatra soils (0,68). This depends on the composition of the original biotite and its present stage of weathering in the soils. Compared to other K-bearing minerals (K-feldspar, leucite, muscovite) biotite weathers readily. Plant roots may even break down biotite to vermiculite (MORTLAND *et al.*, 1956), so that its occurrence in soils is very valuable to plant nutrition, especially in wet and hot climates (MAREL, 1947).

The relative increase of Mg in the loess as compared to K and Ca (biotite, calcite and dolomite contain more Ca and K than Mg) is caused by the more covalent and hence less ionogenic nature of the first atom (electronegativity: Mg = 1,2 eV, Ca = 1,0 eV and K = 0,8 eV) (PAULING, 1944; HAISSINSKY, 1946).

Humus percentage may be highest (up to 15 %) in flint, Aeolian sand, "plaggen", valley-bottom and occasionally in certain Recent alluvial soils. Humus-nitrogen ratios are also highest in this case (up to 40). Organic P_2O_5 and humus contents of the soil are related but the percentage of organic P_2O_5 in the humus fraction decreases with increasing percentages of humus (BROEK and MAREL, 1963). Organic P_2O_5 is an important factor in the P-nutrition of plants where it is present in high amounts (NEU BAUER, 1933; MAREL, 1935, 1936, 1947; BERTRAMSON and STEPHENSON, 1942; PIERRE, 1948; PICCI, 1954; ULRICH and BENZLER, 1955; DIEST and BLACK, 1959). This is especially true of tropical soils (MAREL, 1947; EID *et al.*, 1951).

Potassium is firmly fixed in the alluvial Meuse and Geul river soils (wet method = 60—85 %, dry method = 75—95 %). The alluvial Roer sediments and the rendzina and terra fusca soils also fix appreciable amounts.

Cation-exchange is closely related to specific surface. On an average 1 cation occu-

FIG. 3. $CaCO_3$ (10 % acetic acid) and $CaMg(CO_3)_2$ + $CaCO_3$ (10 % HCl) in %

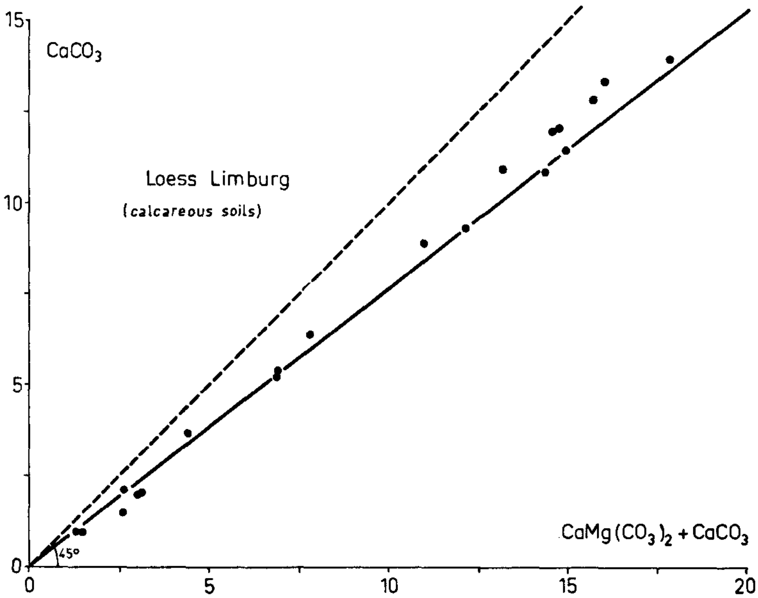


FIG. 4. K_2O and MgO (in 0,001 %) extracted by 25 % HCl during 1 hr at 110° C from loess soils in Limburg (Netherlands) and from rhyolite soils in N. Sumatra

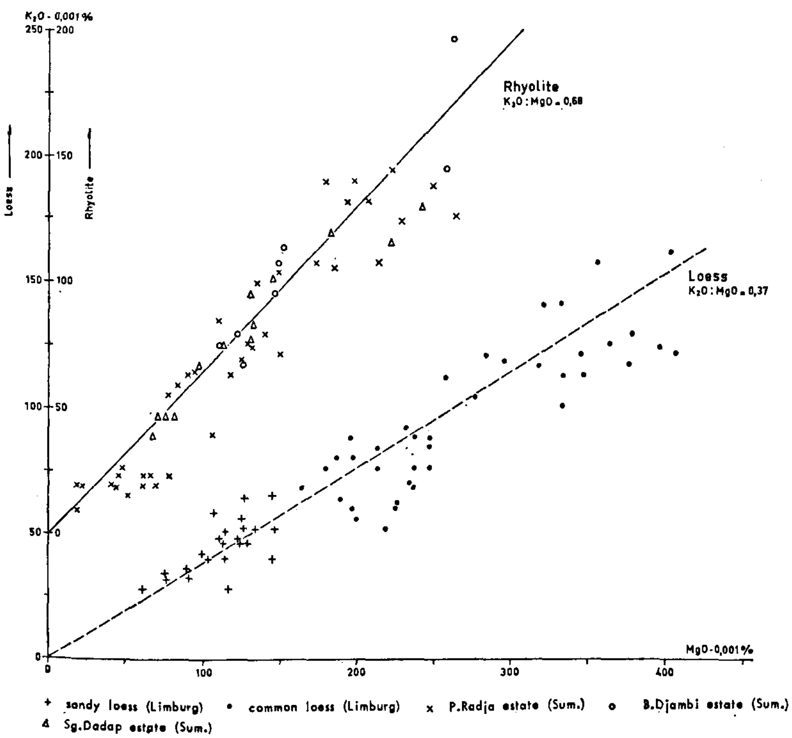
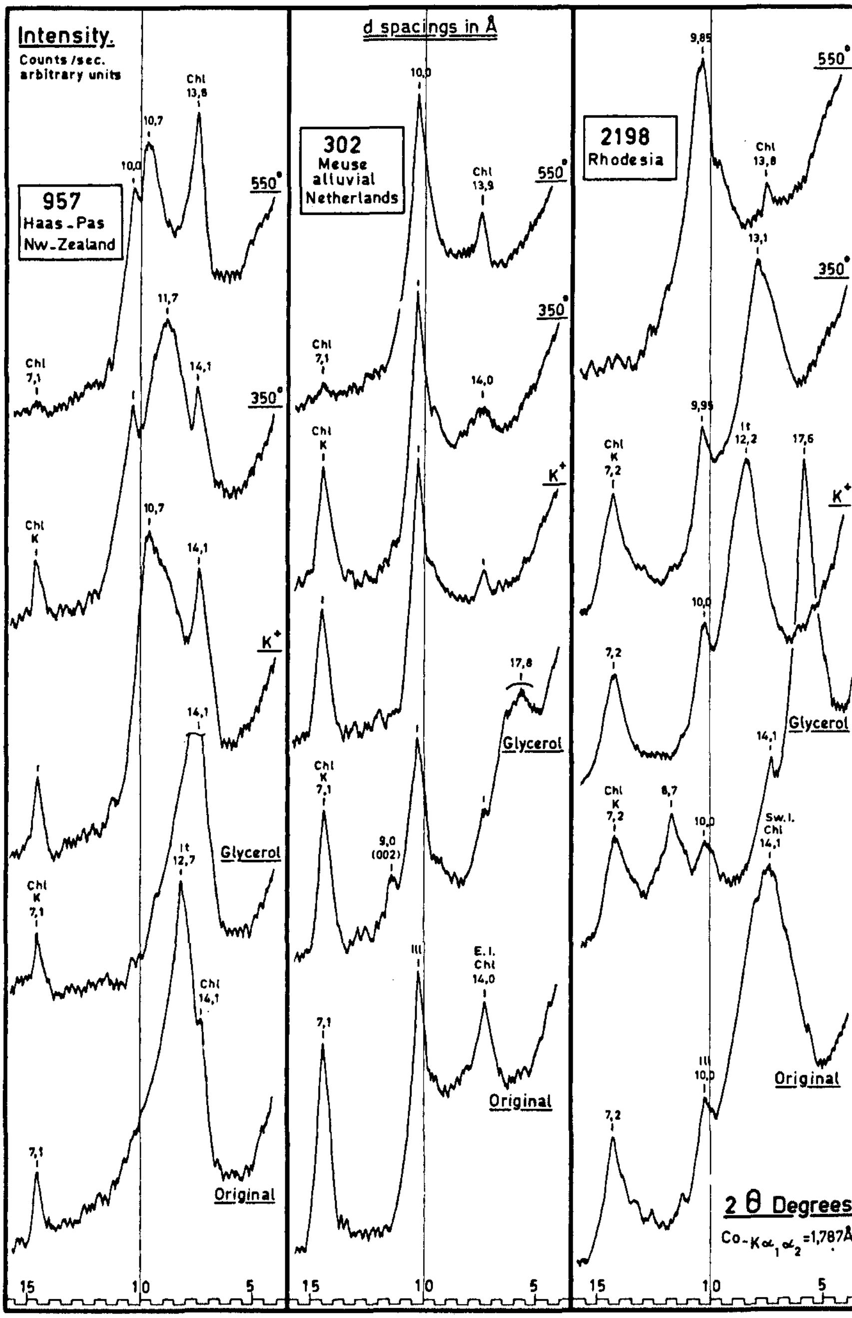


FIG. 5. X-ray diffraction spectra of the separate < 2 μ treated on several ways of K-fixating soils with illite-expanded illite intermadiate (957), expanded illite (302) and swelling illite (2198)



K = kaolinite, Chl = chlorite, Ill = illite, It = intermediate, E. I. = expanded illite, Sw. I. = swelling illite.

pies about 72 Å^2 (PLAISANCE and MAREL, 1961; BEUTELSPACHER and MAREL, 1962; MAREL, 1962; BROEK and MAREL, 1963).
Iron, aluminium and silica contents are smallest in the coarse textured High-terrace, Aeolian and flint soils.
The SiO_2 : (Fe_2O_3 + Al_2O_3) ratio (molar) is very useful for distinguishing the various soil types, *viz.* glauconite (1,7/3,7), rendzina (1,6/3,1), terra fusca (1,3/3,8), flint (0,6/1,0), common loess (1,3/1,8), sandy loess (0,8/1,5), Meuse (0,9/1,3), Roer (0,8/1,0), Geul (1,6/1,9), High and Low-terrace soils (0,5/1,4), Aeolian sands (0,2/1,7).
The amounts of SiO_2 — Fe_2O_3 + Al_2O_3 (mol.) are also useful characteristics, *viz.* rendzina (+15/+70), terra fusca (+12/+35), flint soils (0/—10), normal loess (+5/+29), sandy loess (+8/—2), Meuse (+18/—6), Roer (+14/+27), Geul (0/—9), High and Low terrace soils (+10/—18), Aeolian sands (+5/—9). In heavily manured regions such as western Europa, K, Mg, P and Ca characteristics bear little relation to other soil features and to classification. Potash-fixation as determined by the dry method is however useful as this value is only slightly influenced by fertilizers, unless vast amounts, *e.g.* 1000 kg K_2O/ha annually, are applied (for instance in orchards). In this case the subsoil should be analysed.

4. Clay mineral characteristics

Clay minerals are the result of weathering conditions and the type of parent rock. Thus under hot tropical conditions when a wet period is followed by a dry one kaolinite will predominate in deeply drained soils derived from basic or acidic parent rocks and halloysite will predominate when the wet period is short. Vice versa Mg-rich rocks (serpentines) may supply saponite and saponite-like minerals in temperate climates, whereas the same sediments will supply kaolinite and halloysite in the tropics, etc.
The clays of the 17 dominant soil groups which have been distinguished in Limburg on their morphological characteristics, have been produced both under influence of climatic conditions and from different parent rocks.
The amount of clay (particles $< 2\,\mu$) in the Aeolion sands is very small (1—5 %); only the valley-bottom soils contain up to 15 %. Characteristic of this group, which includes loamy and sandy Cover-sand soils, valley-bottom soils and blown sands, is their high quartz content, *viz.* 40—50 %. In the well-developed podzols, which are commonly found on the loamy and especially the more sandy parent materials, the clay fraction of the topsoil contains only quartz. The clay fraction of the "plaggen" soils may also contain very large amounts of quartz. Other components of the clay separate of these soils are 0—15 % kaolinite, 15—20 % illite, 15—20 % chlorite.
The clay fraction in the loess soils (9—18 %) contains 10—15 % kaolinite, 15—25 % quartz, 30—40 % illite, 10—15 % chlorite and 15—25 % intermediate + expanded illite. The latter mineral causes K-fixation.
The Recent alluvial soils of the rivers Meuse, Roer and Geul contain 8—35 % clay, consisting of 10—15 % kaolinite, 10—15 % quartz, 15—25 % illite, 5—15 % chlorite, 5—10 % feldspar and 20—45 % expanded illite. FIG. 5 shows the X-ray spectra of this illitic mineral from various countries when pretreated in several ways, including a treatment with KCl. In this case the lattices are contracted from 14 Å to 10 Å.
Unlike vermiculite, expanded illite (illite ouverte, aufweitbarer Illit) and swelling illite, (illite gonflante, quellender Illit), are acid-resistant, *e.g.* when heated with 25 % HCl for one hour at 100° C.

Both illitic minerals have been found in many countries, *e.g.* U.S.A., New Zealand, Belgium, W. Germany, Netherlands (TALVENHEIMO, 1951; TEMME and VAN DER MAREL, 1952; KUNZE, 1952; KUNZE and JEFFRIES, 1953; ROLFE and JEFFRIES, 1953; BROWN, 1954; ROLFE, 1954; FIELDES and SWINDALE, 1954; MAREL, 1954 and 1959; SCHROEDER, 1955; RICH and OBENSHAIN, 1955; DEKEYSER *et al.*, 1955; WHITE *et al.*, 1957; SWINDALE, 1957; SCHWERTMANN and POLITZ, 1961; KURON *et al.*, 1961; RIVIÈRE *et al.*, 1961). It has also been referred to in literature under different names, *viz.* vermiculite clay, soil vermiculite, dioctahedral vermiculite, hydromuscovite gonflante, montmorillonite, clay vermiculite with expandable layers, expanding mineral of the montmorillonite type, etc.

The river-terrace soils contain 2—8 % (High terrace and sandy Low terrace) and 6—20 % (loamy Low terrace) clay respectivily. This fraction contains 30—40 % quartz (the coarser types have the highest amount), 10—15 % kaolinite, 10—25 % illite, 20—30 % chlorite. The latter is the cause of the relatively large amounts of 25 % HCl-soluble MgO on this soil type compared to K_2O and CaO. When a well-defined podzol has developed on the High terrace deposits, the clay fraction of the topsoil contains only quartz.

The rendzinas and the closely related terra fusca soils contain 20—50 % clay. In addition to some quartz, illite, kaolinite and calcite (in rendzinas 10—15 % of each mineral), these soils mainly contain soil-montmorillonite. Owing to its moderate K-fixing power the kind of montmorillonite prevailing in this soil type still has some charge left between its layers resulting from Al/Si-subsitution in the tetrahedra.

The more strongly weathered (stony) flint soils contain 15—50 % clay composed of 45—55 % quartz, 25—30 % kaolinite and 20—25 % illite. Here also where a podzol has developed on this parent material the clay fraction of the topsoil only contains quartz and some kaolinite.

The clay particles (20—40 %) of the glauconite soils mainly consist of glauconite. Other components are some quartz (5—10 %) and kaolinite (5—10 %). Where, as very often happens, the glauconite clay soils occur associated with rendzinas and terra fuscas they also contain montmorillonite.

The foregoing has shown that clay-mineral analysis may be a very useful aid for soil classification. Also, where the soils contain large amounts of clay particles, *i.e.* > 20—25 %, the composition of the latter also has an important bearing on the physical behaviour of the soil (terra fusca and rendzina) or on plant nutrition (illite (K), chlorite (Mg), glauconite (K, Mg, P)).

5. Fertility

Generally speaking, the coarse textured soil types of Limburg, especially those with a deep water table, are the least productive, *i.e.* the loamy and sandy members of the Cover-sand soils, sandy Low-terrace soils and High-terrace soils.

These soils are very little suited for such crops as flax, wheat and sugar beet. They can only hold about 30 mm water in between field capacity and wilting point (pF 2,0—4,5) to a depth of 30 cm and about 50 mm to a depth of 60 cm. Rye, oats and potatoes, which need less moisture and plant nutrients, are the usual crops grown on these soils. This is the reason why blown sands and flint soils, in which the condition for plant growth are even less favourable are practically alle wooded.

Their capacity to produce crops and grass is considerably better where the water table is high enough in dry seasons. The close relationship between water conditions

FIG. 7. K, Ca and Mg (molair) of *potato* leaves in % of total K + Ca + Mg for some soil types in Limburg; variety Bintje

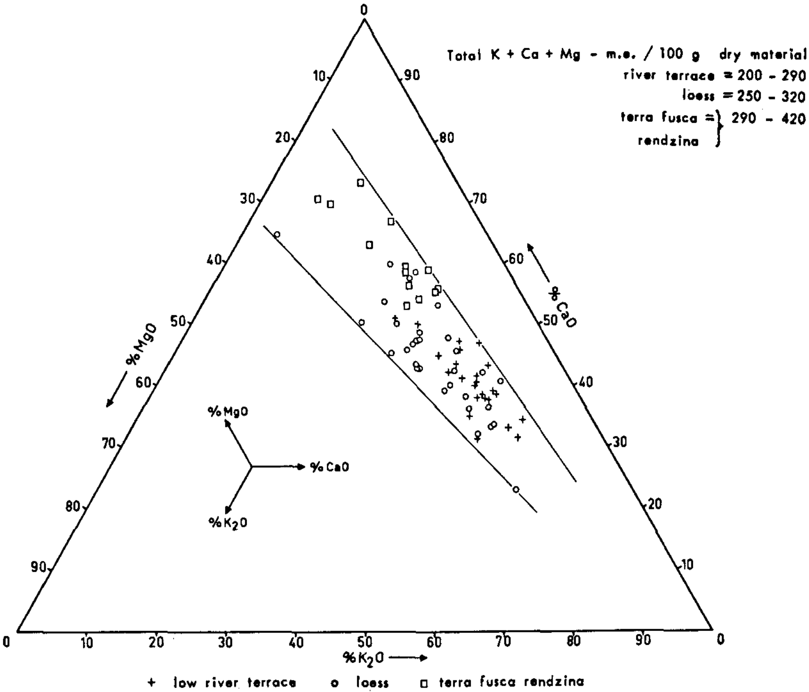
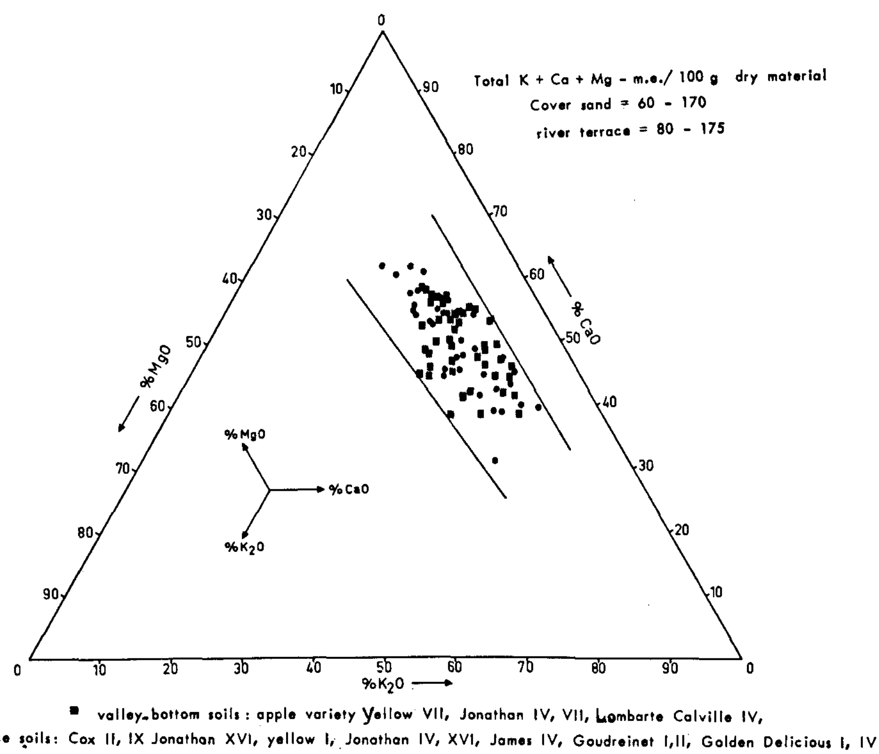


FIG. 8. K, Ca and Mg (molair) of *apple* leaves in % of total K + Ca + Mg for some soil types in Limburg



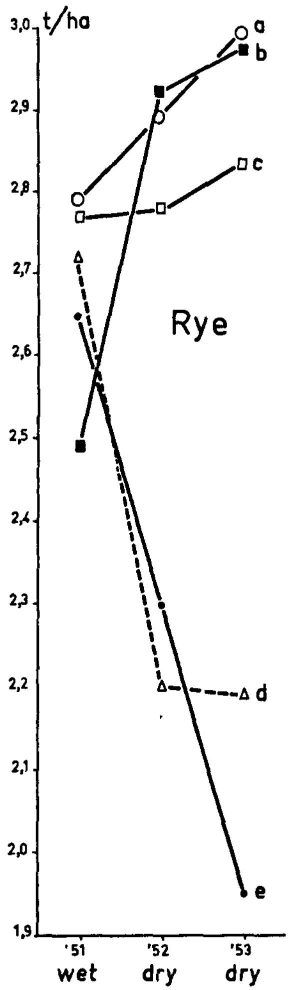


FIG. 6.
Yields of rye on several Cover-sand soils as an average of ca 25 practice fields in the years 1951, 1952 and 1953 (from unpublished investigations of J. PAPE)

a Plaggen soils (15)
b Loamy Cover-sand soils (13)
c Sandy Cover-sand soils (14) with moderately high groundwater level
d Sandy Cover-sand soils (14) with deep groundwater level
e Blown sand soils (17)

and yields on these soils is clearly demonstrated in FIG. 6. The average yields of rye on the various Cover-sand soils fluctuates considerably and this depends mostly on whether spring conditions are wet or dry. All the summers mentioned in this figure were normal. The sandy soils in particular give low yields, when no additional ground water is available to the plants roots. On the other hand the loamy Cover-sand soils, "plaggen" soils and even the sandy Cover-sand soils with a high water table give higher yields in dry springs than in wet ones. Generally speaking, however, these soils are less productive than the more heavy textured ones.

Of these last the loess soils retain 70 and 130 mm in the first 30 and 60 cm respectivily between field capacity and wilting point (pF 2,0—4,5), the terra fusca 70 and 140 mm, the plaggen soils 60 and 120 mm and the alluvial Meuse, Geul and Roer soils 70 and 120 mm. Rendzinas having a top layer with a maximum thickness of only 25 cm may hold about 50 mm, depending on humus content. Wheat and sugar beet are grown on all these soil types and they are also suitable for pasture. The latter also yield higher than in the sandy soil types mentioned previously. In some years the Recent alluvial Meuse, Geul and Roer soils are more hampered by floods than in others. They are mainly need for grasslands. The heavy textured terra fusca and rendzina soils are richest in plant nutrients but have poor permeability ($k = 10^{-8}$ cm/sec). But with careful treatment high yields of wheat, sugar beet and grass may be obtained.

The Low-terrace and Aeolian sand soils are deficient in N, P and K. They need large amounts of fertilizer, *e.g.* up to 150 kg N, 150 kg P_2O_5 and 300 kg K_2O/ha annually, depending on the kind of crop and other conditions of plant growth (drainage, weather).

The loess, Recent alluvial, rendzina and terra fusca soils are better supplied and their fertilizer needs are smaller accordingly. The alluvial soils of Meuse, Roer and Geul have a marked tendency to fix potassium and need up to 600 kg K_2O/ha if their potassium level is low. Magnesium fertilizer in amounts of 50—75 kg MgO/ha annually is applied to river-terrace soils and Aeolian sand soils, all of which contain $<$ 0,100 % MgO, this being the minimum required (BROEK and MAREL, 1959). Potassium and magnesium dressings should be applied with care owing to K-Mg antagonism, especially in the case of potatoes, apples (and oats) (FIG. 7 and 8). Thus where the proportion of Mg of the total K + Ca + Mg (mol) is less than 12 % in potato foliage and less than about 15 % in the leaves of apples, Mg deficiency appears. Conversely when K makes up less than 50 % of the total K + Ca + Mg in the potato foliage, or less than 20 % in apple leaves, potash fertilizer is needed.

The pH (water) of the river-terrace soils, sandy loess and Aeolian sand soils (3,8—4,8) is too low. Mg-deficiency is increased by a low pH, especially with apple, oat and rye. In practice these soils are limed.

As fertility is an important aspect of land classification the specific differences in the chemical constitution of the various soil types will give basic information on their production capacity. Closely connected with these differences are the characteristics of structure, root permeability, waterlogging, water permeability and ground water which can be estimated by morphological examination.

Apart from the chemical and the clay mineral characteristics these detailed investigations are important for land classification purposes.

The weather in Limburg (and in western Europa in general) varies from year to year, especially in the critical periods of blossoming and ripening.

As a result yields are not constant from year to year and great variations may also occur on the same soil type in the same year, and even between individual fields on the same farm. Nor is the same amount of fertilizer required each year (BROUWER, 1926; HOLDEFLEISS, 1929; GOESELE, 1929; FRANKEMA, 1932; BAUMANN, 1938, 1951 and 1959; ESSER, 1942; PAAUW, 1949, 1959; TAMM, 1950; DOBBEN, 1951 and 1960; BERKNER, 1951; GISIGER, 1953; DE WIT, 1958; TIURIN and SOKOLOV, 1958; DAWTJAN and BABAJAN, 1958).

FIG. 9 shows the yields from several Government demonstration farms where the crops were grown under optimum conditions of management and fertilizing. They demonstrate that variations may exceed 100 % in this region. Also the results of experimental fields and concerning soil analyses are too widely spread around an average to be significant. Hence the optimum amount of a given fertilizer to be applied to a given crop on a given soil type can only be roughly established.

As the cost of applying fertilizer is small compared to the value of harvests, excess of fertilizer should generally be applied. With other variables (weather, manuring, invested labour, etc.) so greatly influencing crop results, a sequence of yields obtained on a given soil in a given year no more than supplies qualitative or comparative information on its potential production capacity. The highest yield obtained on a field, although achieved only once in several years, may afford a better idea of its potential production capacity as this yield is obtained when many conditions favouring crop growth are simultaneously present. Increased yields may also be obtained by varying the crop rotation system, *e.g.* including leguminoseae. This was found to be very successful for loess soils in Limburg.

It is much easier to make a quantitative estimate of the potential production capacity of soils occupied by long-standing crops than by seasonal crops.

In the former case the variable influences of the preceding years have a cumulative and hence levelling effect. In the latter case the variable influence is measured each year.

6. Conclusions

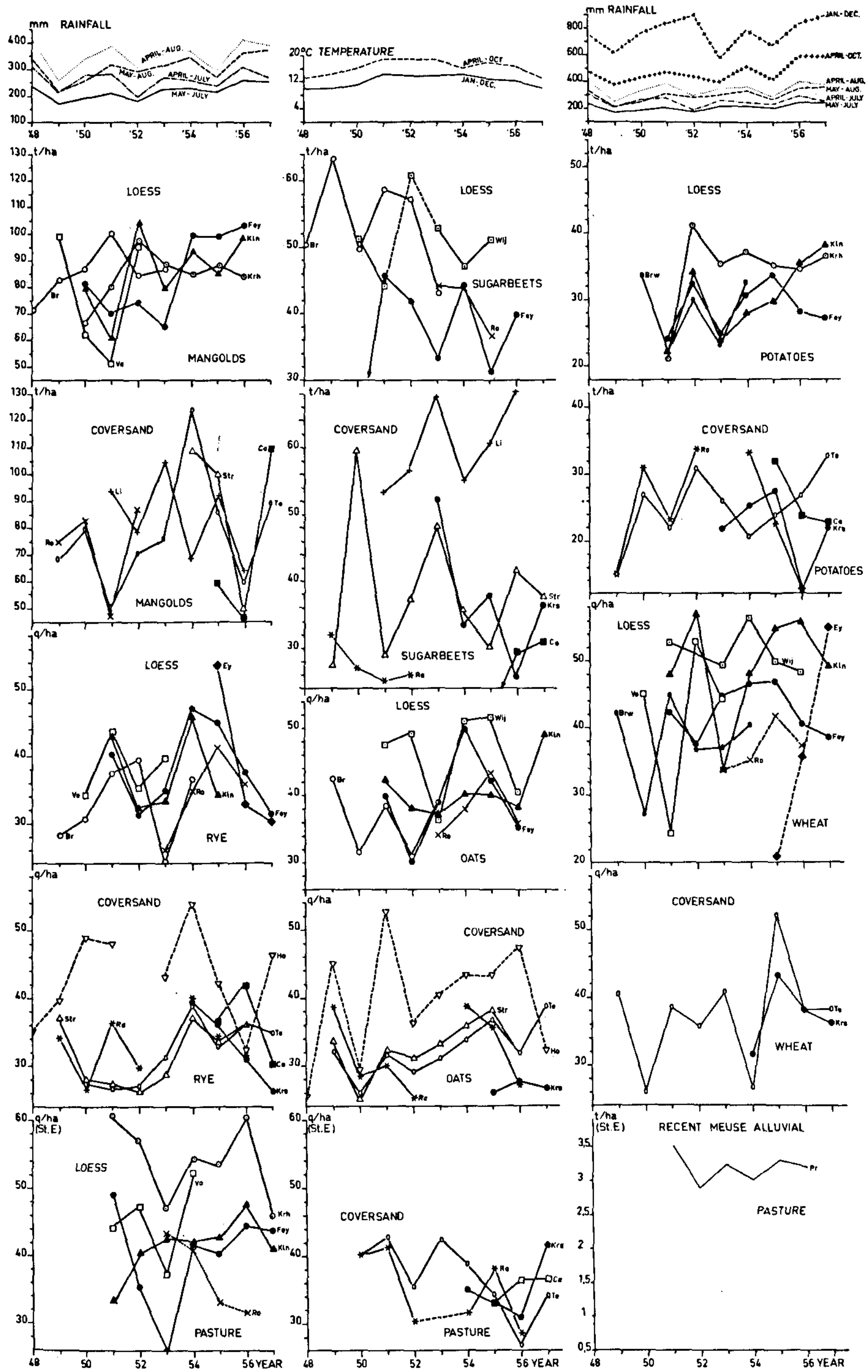
The chemical and clay-mineral characteristics discussed above have been shown to be related to the morphological features and to the fertility of the soil groupes defined.

Knowledge of the chemical proporties of a soil and the mineral composition of its clay separate also gives an insight in the cause of the specific properties found in the type of soil examinated, *e.g.* K-fixation, swelling, reserve of plant nutrients, etc.

It has further been indicated that in this region as in western Europe in general, it is fairly difficult to classify the distinct soil types into classes according to their potential productivity. External factors such as farm management, agricultural practice, type of crops and rotation, as well as the variable weather conditions, lead to great differences in production from year to year and from place to place. They may amount to 100 % and over. The data obtained from many years of research for the purpose of estimating the production capacity of a given field is usually without much significance, mainly because it is very greatly influenced by the continually changing and improving agricultural production methods (new variaties, improved cultivation methods, etc.).

The various types of soil can be more readily classified into production classes in regions of more equable climatic conditions, especially where there are monocultures of long-term crops, *e.g.* the grasslands of New Zealand, the oil-palm, rubber and

FIG. 9. Yields, temperature and rainfall on some Government demonstration farms indicated Fey, Wij, Krs, etc. in Limburg (Netherlands)



tea plantations in tropical regions of equally distributed rainfall; the wheat and corn belts of Central U.S.A., Russia, the cotton regions of the Sudan and India, etc.
In these areas failures are an exception. Yields can be accurately predicted to within 5—10 % in case of long-term crops under known conditions of soil type, farm management and fertilizing.
But when fertility research is combined with morphological, chemical and clay mineral research of soils, it can also provide the basis for the improvement of production on soils in regions of more variable conditions of plant growth.

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