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Soil morphological properties as indicators of waterlogging in soils around the Njala University College, Sierra Leone.

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CONTENTS

1. INTRODUCTION

1.1. Objective.

During a nine months stay at the Soils Department of Njala University College - The University of Sierra Leone - in the years 1966 and 1967 field work and preliminary elaboration of data started of a M.Sc.-research project for the Tropical Soils Department of the State Agricultural University of Wageningen, the Netherlands.

It was agreed that the objective of this study should be an investigation of the influence of the water regime on morphological properties of the soils in the Oil Palm Station and the North West Extension of the N.U.C.Farm, an area just being surveyed. This was believed to be useful as reversely soil morphological properties could be an indication of the water regime in the investigated and corresponding soils. The combination of three factors stimulated this research.

1. The fact that soils in the surveyed area are rather common in Sierra Leone (SIVARAJASINGHAM, 1965 and ODELL AND DIJKERMAN, 1967) and probably in the whole of West Africa (Nigeria, Liberia, Ghana, etc.
2. As the area had already been made accesible for the soil survey and a vast number of soil pits had been dug, it was not difficult to collect soil morphological data by means of soil profile descriptions.
3. The presence of climatic data collected by the Njala Weather Station and the presence of watertable data of about 70 soil pits for at least one year and at most three years. The pits could be used to obtain morphological data as well.

1.2. Drainage.

The major reason to study waterlogging in soils is because it is so closely allied to the soil drainage class. The drainage class of a soil is defined as the changes in moisture content of the rooted zone in the course of the year and thus severely affects plant growth. Soil drainage is determined by external as well as internal factors.
External factors: topography, climate (precipitation, evapotranspiration), etc.
Internal factors: permeability (structure, texture, porosity), artificial drainage, etc.
Some of these factors will be described in the next chapters.

1.3. Classification.

Another aim of waterlogging studies in soil is the use of certain found relations for the division of soils into series or for the classification of soils into classification units. The former was done in the Njala Soil Survey (DIJKERMAN and BRETELER, 1969) and the latter is becoming increasingly important in the American soil classification system (SOIL SURVEY STAFF, 1964, 1966, 1967). Both matters will be dealt with in the discussion of this paper.

2.SOILS AND CLIMATE OF THE AREA.

2.1.Soils.

An extensive report of the soils in the present area has been published recently. In order to understand the use of series names in this report a short description of the various kinds of soils and topography in the area follows.

Topography.

The surveyed area consists of four major landscape units; the upland and three river terraces. The upland lies about hundred feet above the terraces and consists of a gently undulating erosionsurface or peneplain that probably dates from the late Tertiary. At the foot of the upland colluvial material has covered part of the upper river terraces. The greater part of the area consists of river terraces. Because of the low erosion resistance of the bedrock (silt- and mudstone), an extensive floodplain developed along the Taia river where it crossed the soft sedimentary rocks. Later several changes in base level made this meandering river cut down again and again, leaving the old floodplain well above the modern floodplain. As a result at least three different terraces can be distinguished along the Taia river.

Soils.

On the upland soils are developed in a layer of gravelly colluvium over residual material. The gravelly colluvium is a secondary, highly weathered parent material, that consists mainly of sesquioxides and some kaolinite. It contains 50 to 80 volume percent of indurated plinthite (laterite) gravel. The relative amount of gravel in this material is constantly increased by termite activity and erosion. Termites bring up fine material from the subsoil to the surface to build their numerous mounds, which are subsequently eroded and the fine material is washed downslope, leaving on the upland a material very high in indurated plinthite gravel (a lag gravel).

On the colluvial footslopes and upper river terraces the gravelly colluvium is covered by a gravel free layer a few to 48 inches thick, of colluvial or alluvial origin. The middle and lower terrace consist entirely of gravel free material, which is more than four feet deep. The lower terrace usually is more silty or fine sandy than the upper and middle terrace. Its sand fraction contains a considerable amount of mica, thus indicating its low pedological age.

As the names of the various soil series will be used in the next chapters, it is important to have an impression of the soils. Table 1 gives a popular description with classification according to the '7' (supplement 1967). A schematic crossection of the landscape indicating parent materials and soil series is given in the appendix (9.2.). Details of each series are given in the survey report.

Table 1.

Popular soil series description.

Series.	Characteristics.
Momenga	Well drained, on very steep slopes, weathering bedrock within 48 ins., typic dystropept.
Njala	Well to moderately well drained, level to moderately sloping, very gravelly profile, no or very thin (<10")gravel free layer, plinthic and tropeptic plinthic haplustox.
Mokonde	Moderately well drained, level, 10-24" gravel free over gravelly subsoil, fluventic oxic plinthic dystropept.
Bonjema	Moderately well and somewhat poorly drained, level, 24-48" gravel free over gravelly lower subsoil, aquic fluventic plinthic dystropept.
Pelewahun	Poorly drained, drainageways in terrace, 24-48" gravel free layer over gravelly lower subsoil, typic plinthaquult.

Nyawama	Moderately well drained, level, $>$ 48" gravel free, thick dark surface horizon, plinthic haplustox
Kania	Somewhat poorly drained, lower areas of level terrace, $>$ 48" gravel free, thick dark surface horizon, aquic plinthic haplustox
Taiama	Poorly drained, drainageways in level terrace, $>$ 48" gravel free, thick dark surface horizon, plinthic umbraquox or plinthic tropaquept
Pujehun	Well drained, level, $>$ 48" gravel free, thin surface horizon, fine sandy clay loam to loamy fine sand, mica, fluventic oxic dystropept
Gbesebu	Well and moderately well drained, like Pujehun but texture silty clay loam, silty clay or clay, fluventic oxic dystropept
Madina	Poorly and somewhat poorly drained, like Gbesebu, but in drainageways, aquic fluventic oxic dystropept.

Soil drainage classes described above are based on field observations of soil profiles, height of the water level in swamps and creeks throughout the year, vegetation and so on.

Table 2 shows the duration of waterlogging in the different soil series in 1966.

Table 2.

Soil series	Duration waterlogging in weeks at: surface	20 ins.	40 ins.
Momenga (6)	0	0-4	0-6½
Njala (9)	0	0-4	0-9
Mokonde (2)	0-1	1	4
Bonjema (9)	0	0-8	0-18
Pelewahun (2)	1½-3	12-21	26-32
Nyawama (16)	0	0-10	0-14
Kania (4)	6-9	11	12-13
Taiama (4)	7-12	12-17	15-22
Pujehun (7)	0-½	0-3	0-9
Gbesebu (8)	0-7½	0-11	0-12
Madina (2)	8	11	13

The number in brackets indicates the number of available watertable readings (pits) per soil series. The total amount of pits is 69.

If we try to translate these data in terms of the definitions in the Soil Survey Manual (p.169) we can group the various series into the next soil drainage classes.

Soil series	Drainage class.
Momenga	well drained
Njala	well drained
Mokonde	well drained
Pujehun	well drained
Bonjema	moderately well drained
Gbesebu	moderately well drained to somewhat poorly drained
Nyawama	somewhat poorly drained to moderately well drained
Kania	somewhat poorly drained
Madina	somewhat poorly drained
Taiama	poorly drained
Pelewahun	poorly drained.

The fact that the rainfall was 18 inches over the average and the duration of the rains shorter than normal explains the difference between the drainage classes in the series descriptions and up here. Furthermore the description of drainage classes in the Manual does not take into account climatic conditions like the ones prevailing in Sierra Leone (see 2.2).

2.2.Climate.

The climate of Sierra Leone usually shows a sequence of six seasons (BARCLAYS BANK'S ECONOMIC SURVEY).

1.From late December to early February: a dry period with finally the Harmattan (hot, dry, dusty wind from the Sahara). Relative air humidity may be as low as 15 - 25 %. Daytime temperature usually is not higher than 32°C. The nights are cool, sometimes below 10°C.

2.After the Harmattan period there are 2 or 3 months of dry weather but with increasing humidity. From the end of March hot humid days are characteristic. Maximum temperature may be as high as 38°C.

3.In the course of this season (2) the rainless weather is interrupted by thunderstorms, becoming more frequent towards middle April.

4.Early June usually the first squall starts. This period has hardly a cooling effect, because immediately after the rains the weather is bright and sunny.

5.In the middle of the month June the weather suddenly changes. Continuous seawinds penetrate the country, always bringing rain, at least 2500 mm, sometimes much more, up to 3500 mm per year in the surveyed area. Early August the weather brightens slightly up but remains cool and damp. Average midday temperature does not exceed 27°C in August.

6.The second rain period starts with thunderstorms in the middle of September, with bright days in between. After this period the influence of the rains decreases and the dry period (1) recommences.

As rainfall in this study on soil drainage and waterlogging is the most important feature of the climate, precipitation data are given in table 3 for the average of the years 1926-62 and for the years 1966. and 1967. In these years watertable measurements were carried out as will be explained later. Other climatological data are found in the appendix (9.1)

Table 3.

Month	Mean monthly rainfall (ins.) 1926-62	1966	1967	Greatest daily fall 1966
January	0.23	0	0	0
February	0.69	0.42	0.32	0.25
March	3.27	3.77	0.58	2.08
April	4.92	2.45	7.28	0.64
May	9.75	5.77	5.73	1.40
June	14.36	16.35	9.71	1.83
July	15.99	21.82	21.74	4.53
August	19.93	34.68	18.60	6.77
September	17.17	19.80	14.16	3.98
October	13.36	12.62	11.10	1.46
November	7.07	7.03	5.25	1.19
December	1.53	1.61	0	0.99
Year	108.27	126.32	94.47	

Rainfall data vary widely from year to year and so do to a less extent other climatological circumstances like temperatures and the sequence of the main seasons.

3.METHODS

3.1.Climate.

Climatological data for use in this report (see chapter 2 and appendix) have been provided by the Njala Weather Station. Precipitation and other figures were obtained daily and reports on the weather were published monthly as the 'Njala Weather' bulletins and annual (MCKEE,1967 and 1968). Rainfall has been measured accurately with a standard rain gauge and data are very reliable.

For a short description of the ruling climate in the survey area we may refer to chapter 2.2. Remarks on behalf of the climate in this section are especially referring to climatic conditions as far as they affect soil drainage. As pointed out in 2.2. we have to emphasize that climatic conditions in Njala are very variable, although there exists a certain base pattern of alternating dry and wet seasons.

Data on watertables in soils (3.2.) have been collected in the year 1966 and for some sites in 1967 and 1968 as well. These are the only available waterlogging data in the area and it is clear that these data must be used very carefully. In order to understand the data it is important to know the features of the climate in the year 1966.

This year (1966) could be described as an unusual year in terms of rainfall, but so could most years. From the five types of rainy seasons, the 1966 one fits into type 4: wet start to the main rains, (July) middle, (August) or end, (October) and a high annual total precipitation (McKee, 1967). 1966 had a very false start (dry April and early May) to the rainy season, a heavy middle and a much greater than average annual total (18 ins. more than normal, table 2). The number of raindays (>0.40 ins.) and wet days (>1.00 ins.) was not significantly greater than average but heavy falls of a few inches or more in 24 hours were certainly more numerous than is average. The differnce in precipitation pattern between the years 1966 and the average of the 1926-62 period is shown in figure 1.

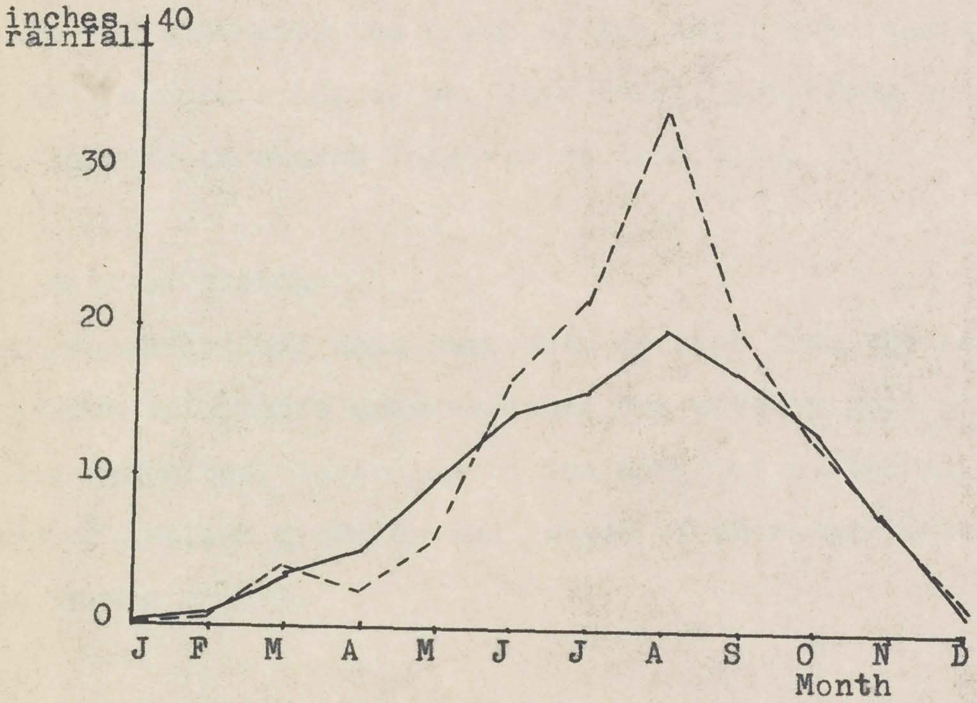

Figure 1. Mean monthly rainfall 1926-1962 (——) and rainfall in the year 1966 (- - -).

Other data on the 1966 climatic conditions have been compiled in the appendix. The next year (1967) was extraordinary because of its relative droughtiness.

3.2.Waterlogging.

The depth from the land surface to the watertable in about 70 soil pits of most recognized soil series was measured regularly. Soil pits were 3 feet wide, 4 feet long and 5 feet deep. Readings were done at least once each week (dry season) and up to three times each week (rainy season) in the year 1966. At the time that this report was prepared the data of 1966 and 1967(for some soil pits) were available.

Measurements of watertables in a soil pit are not always an exact indication of the watertable in the soil. As an estimate however, they can be used, if disadvantages are kept in mind. For instance the pits were not covered, so evaporation and run-in could take place. After a shower in some pits the depth of the watertable was measured immediately and in others one or two days later, depending on the course that the laborer in charge followed at that time.

3.3. Soil morphology.

Soil morphological data have been derived from the same pits that were used for watertable measurements. The seventy soil pits were all carefully described, according to the Soil Survey Manual. For the description of typical profiles and ranges of characteristics we may refer to the survey report.

3.4. Use of data, analysis.

Soil morphological properties as matrix color, porosity, depth of gley mottles, etc. were checked against waterlogging data for each soil pit to detect correlations.

4. RESULTS

4.1. Soil structure.

It is very hard to classify soil structure into numerical categories, because it has so many aspects. Soil structure description according to the JONGERIUS (1957)- method or the Soil Survey Manual applied to the present soils did not satisfy, due to a high degree of subjectivity and the nature (often more than 50 % gravel) of the soils. By that only a few remarks on soil structure were possible.

A typical structure was found in the subsurface horizon of some imperfectly drained soils. This A_3-horizon had a somewhat prismatic, in any case sharp angular blocky structure with a pale grayish color, lighter than the underlying horizons.

Other characteristics of this horizon in somewhat poorly drained soils are: lowest base saturation and highest aluminium content of all horizons, a firm consistence, a low cation exchange capacity and a low pH. This layer may cause special problems for root penetration. Soils with this typical horizon usually belong to the Kania series.

The present kind of soil structure is probably based on both a lack of biological activity (homogenization) and an advanced stage of weathering.

4.2. Biological activity.

a. The (somewhat) poorly drained soils usually have an umbric epipedon, the better drained soils (excepted Nyawama series) not or only under an old secondary bush cover. This phenomenon is probably caused by a high concentration of soil animals, plant roots, etc. in the upper foot of the soil resulting in a high percentage of organic matter and umbric epipedons. Imperfect drainage may be the reason for this concentration of biological activity to the topsoil, especially in the dry season when these soils never really dry out.

b.The termite mounds on well drained soils are higher and more numerous than those on poorly drained soils. Potential soil volume to build mounds of is obviously greater in the better drained soils.

c.Somewhat poorly drained soils, like the Kania series show small organogene outcrops, probably excretions of earthworms. Usually the excretions are 1/2 to 1/4 inch in diameter, 1/4 to 1/2 inch high and cover about 3/4 of the land surface. Their shape is rounded, marble-like.

The presence of these three (a,b,c) phenomena in somewhat poorly drained and not in well or poorly drained soils may be explained as follows. On well drained soils there is a tendency for the biological activity to spread all over the profile, although there is an accumulation in the topsoil. Poorly drained soils do not allow soil life at all, at least not the type of soil life that is responsible for the dark color of surface horizons. Soils in between these two extreme situations (e.g. somewhat poorly drained soils) have a biological activity that is restricted in depth by the high watertable in the soil during a great part of the year.

4.3.Soil color.

Color properties such as hue, chrama and Munsell color code (all moist values) were plotted against the duration of waterlogging at the surface of the soil and at depths of respectively 20 and 40 inches from the surface. The 'value' of the color seems to be related with the organic matter content (EMILIANI and FORNS,1968).

If we make graphs of all available soils we do not find consistent correlations. But if we rule out the younger soils we find some good correlations between soil color properties and duration of waterlogging at a certain depth, which is a part of the moisture regime in a soil. In the next graphs (figure 2 through 7) soils belonging to the older lateritic upland or the upper river terrace (Njala, Mokonde, Bonjema, Pelewahun and Taiama) are used to show correlations between color properties and waterlogging. Lack of correlation between soil color and waterlogging in the younger soils is shown in profile N 14 (Madina series, survey report p.82). This site was flooded three months in 1966 and has 10 YR 5/4,5/6,6/4 subsoil matrix colors and no gray mottles. The following results apply to the Njala soil survey area only and are derived from one year ground-water data.

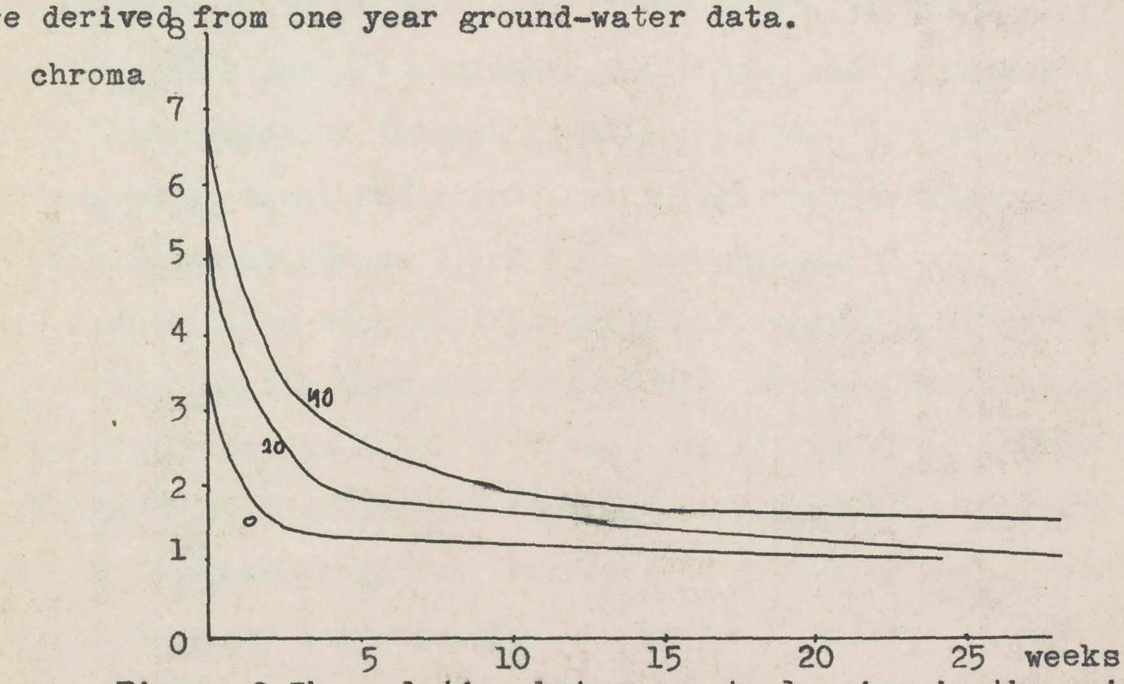

Figure 2. The relation between waterlogging in the soil at 0, 20 and 40 ins.(weeks) and the chroma of the matrix color at 40 inches for several soil series occuring in the Njala soil survey area.

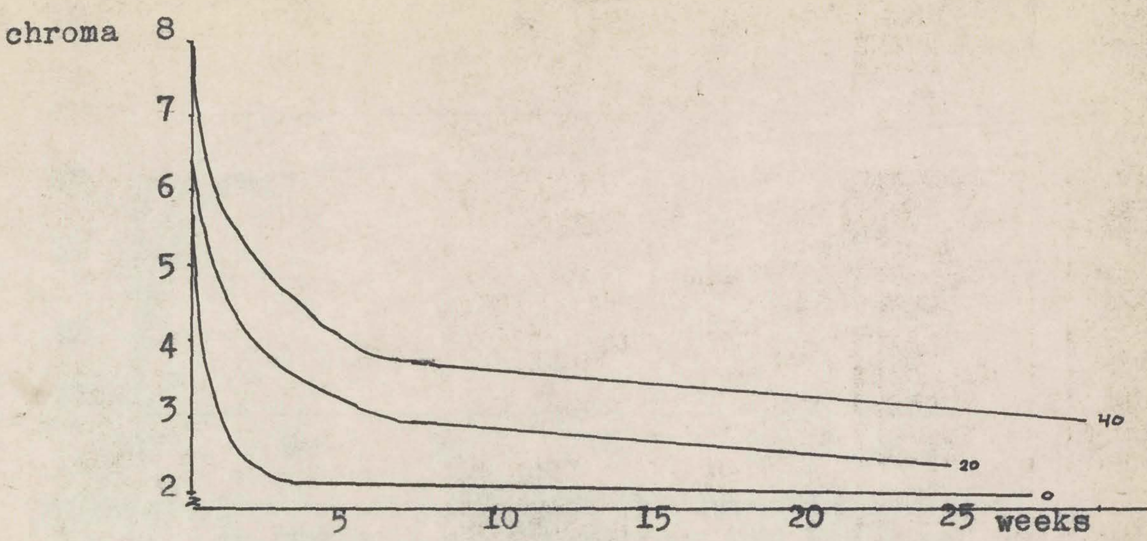

Figure 3.The relation between waterlogging in the soil at 0, 20 and 40 ins. (weeks) and the chroma of the matrix color at 20 inches for several soil series occuring in the Njala soil survey area.

There is a relation between the duration of waterlogging at the surface and at 20 and 40 inches below the surface of the soil and the chroma of the matrix color at 20 and 40 inches depth. In the figures 2 and 3 data for A-horizons are excluded. The graphs show a negative correlation between the chroma of the matrix color and the time that a soil is waterlogged at three different levels. The curves drop quickly from chroma 8 to about chroma 3 and then the chromas slowly decrease to about 2 or 1.5. As soon as this chroma is reached a longer duration of the waterlogging does not yield lower chromas. For instance the chroma of the matrix color of these soil series at 40 inches depth drops from 8 to 3 as the duration of waterlogging at 40 inches increases from 0 to 3 weeks. A further increase of the waterlogging at 40 inches to about 10 weeks decreases the chroma to 2. Further elongation of the period of waterlogging hardly affects the chroma, it varies between 2 and 1.5. The best correlations are obtained between the matrix chromas and the duration of waterlogging at 20 and 40 inches. The relation between the chromas and the duration of flooding is such that the chroma quickly drops from 8 or lower to 2 or 1.5 and then remains

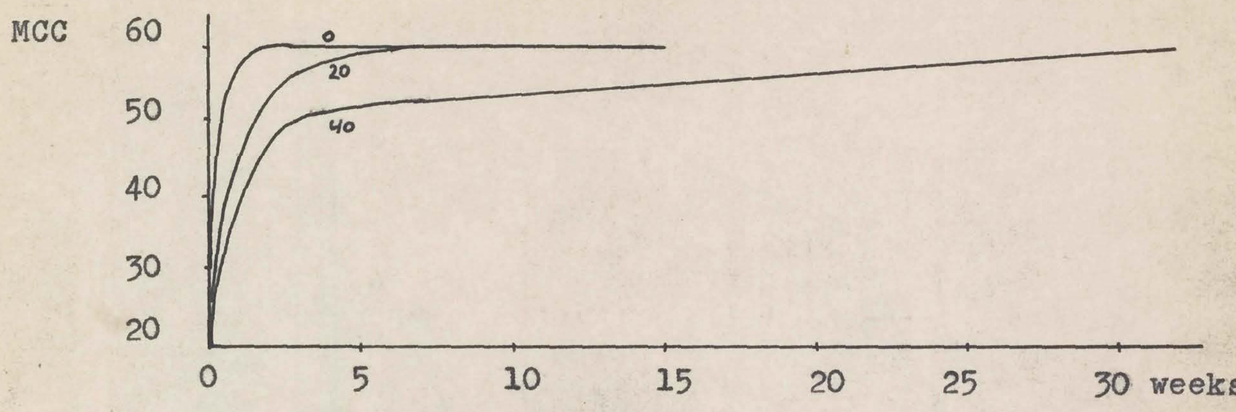

Figure 4.The relation between the duration of waterlogging in the soil at the surface and at 20 and 40 inches depth (weeks) and the Munsell Color Code of the matrix color at 20 inches depth.

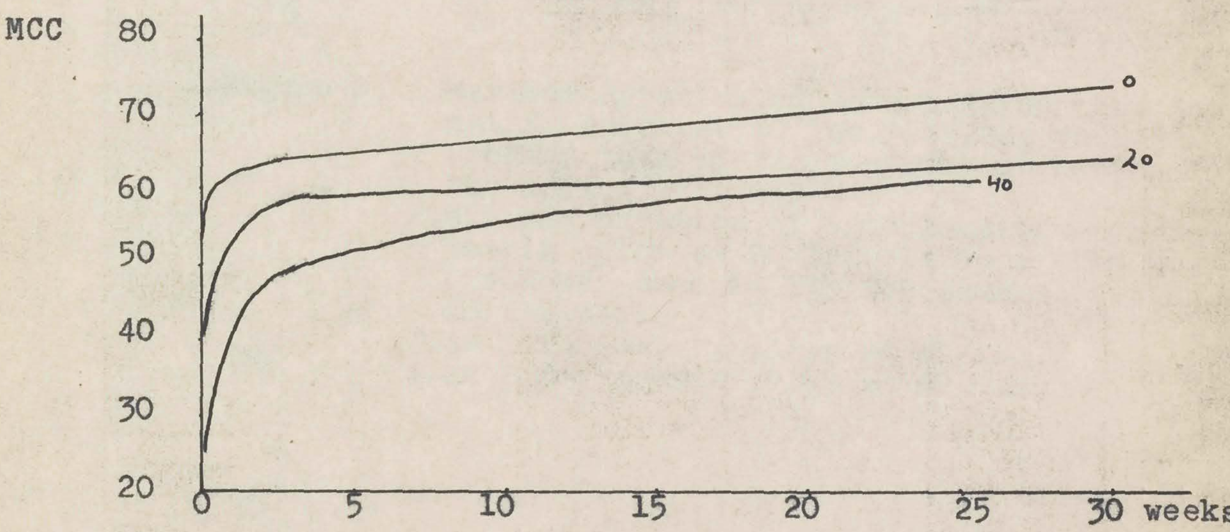

Figure 5.The relation between the duration of waterlogging in the soil at the surface and at 20 and 40 inches depth (weeks) and the Munsell Color Code of the matrix color at 40 inches depth.

M.C.C.: Hue notation: 10R=10, 2.5YR=12.5, etc. 10 YR=20, 2.5Y=25.

constant while the period of flooding extends. If it is possible to estimate the drainage situation of a soil by means of color measurements, graphs that show the influence of waterlogging duration at 40 inches on the soil color chroma could be very helpful.

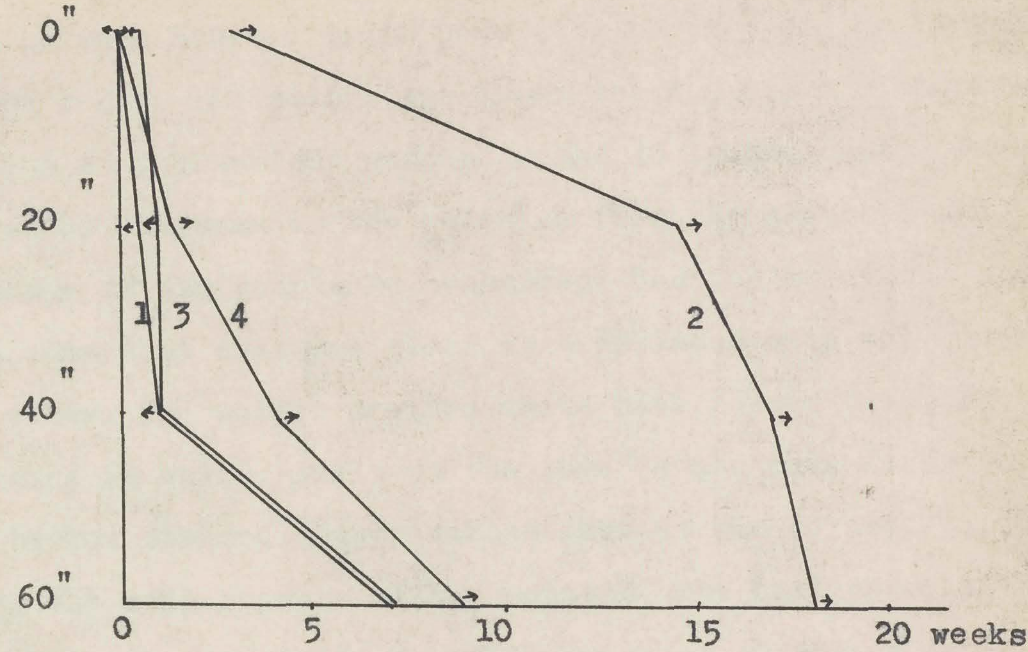

Figure 6. 1.Maximum duration of waterlogging when hue matrix color at 20 ins. is less than 20 (redder than 10 YR) for several depths in the soil.
2.Minimum duration of waterlogging when hue matrix color at 20 ins. is more than 20 (yellower than 10 YR) for several depths in the soil.
3.as 1 for matrix color at 40 ins.
4.as 2 for matrix color at 40 ins.

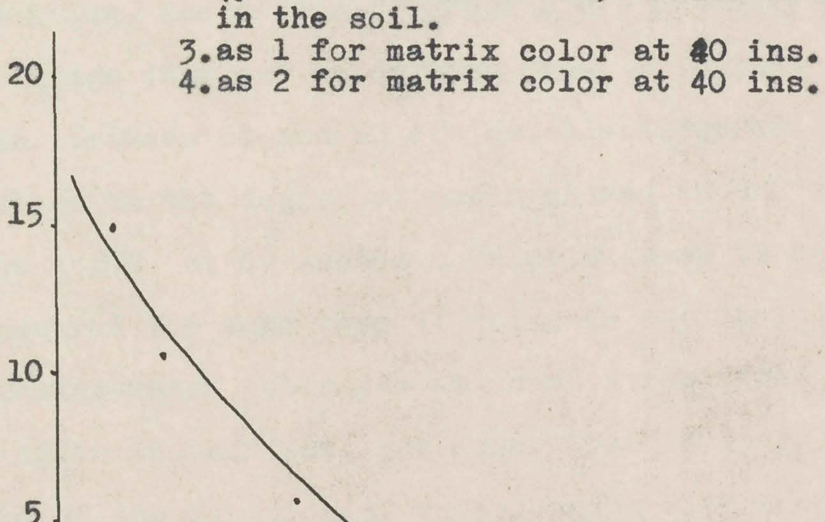

Figure 7.The relation between the depth of the gley horizon (inches) and the duration of flooding (weeks) for two poorly drained soil series: Pelewahun and Taiama.

The relation between Munsell Color Code (the product of the YR hue and the value, the redder the color, the lower the M.C.C.) and the duration of waterlogging at the surface and at 20 and 40 inches depth (figures 4 and 5) is about the same as the relation from the graphs 2 and 3, as far as the shape of the graphs is concerned. The course of the lines confirms the idea that drainage class is correlated with the hue of the soil matrix color. The better drained soils have redder hues, if there is no difference in value. Soils of the same YR-hue have lower values if they are better drained. Lower values mean darker colors, mainly influenced by the soil organic matter content. The best correlations are found between the duration of waterlogging at 40 inches depth and the Munsell Color Code at 40 inches.

Deviations of the graphs are not given, but for general conclusions the graphs certainly can be used if one takes in mind that they represent the average situation. The curves of graph 4 are not very significant. One of the few things that can be derived from it is that soils with a M.C.C. at 20 ins. between 50 and 60 are usually imperfectly drained. No further conclusions on the degree of water excess in the soils are allowed. For the M.C.C. at 40 inches a value between 60 and 70 means that flooding occured for some time of the year and for a M.C.C. between 50 and 60 the ground-water table was at least a few weeks at twenty inches or less under the surface. The lower line in graph 3 shows a gradual increase of the duration of waterlogging with increasing M.C.C. A color code below 40 means no or hardly any waterlogging at 40 inches depth. M.C.C. between 40 and 50 means up to three weeks waterlogging at 40 inches and M.C.C. between 50 and 55 means waterlogging up to ten weeks at 40 inches. M.C.C. between 55 and 60 means that the watertable is at least 10 weeks at 40 ins. or less below the surface.

Figure 6 shows some relations between hue and waterlogging. At the ordinate the depth in the soil is plotted: 0, 20, 40 and 60 inches. Sixty inches means the bottom of the examined soil pit, not always but normally 5 feet deep. The lines 1 and 2 refer to the hue of the matrix color at 20 inches. The lines 3 and 4 to the hue at 40 ins.
The lines 1 and 2 clearly demonstrate that there is a relation between the hue of the matrix color of a soil and its drainage class. Hues redder than 10 YR (line 1) mean in the present case that the soil is not or hardly waterlogged at the surface, at 20 and at 40 inches, while the maximum duration of waterlogging at 60 inches is 7 weeks. Line 2 shows that soils with a matrix color hue at 20 inches yellower than 10 YR are imperfectly drained. Flooding occurs for at least 4 weeks and at 20, 40 and 60 ins. the duration of waterlogging is 15, 17 and 18 weeks or more. The soils with a hue in between these lines (Hue 10 YR) can still greatly differ in drainage class. As far as water regime is concerned, they can better be tested on base of their matrix color chromas (figures 2 and 3). If we consider the hue of the matrices at 40 inches depth we see that line 3 corresponds with line 1, excepted a few days difference at 0 and 20 inches. Line 4 however is rather different from line 2. If the matrix color hue at 20 inches is yellower than 10 YR it means that the soil is far more poorly drained than if this is so at 40 inches depth. For hues redder than 10 YR there does not exist such a difference (lines 1 and 3). As the lines 3 and 4 are not so much apart as the lines 1 and 2, it seems that the matrix color hues at 40 inches are more suitable as draimage class indicators than the hues at 20 inches below the surface.

A good correlation was found between the duration of flooding and the depth of the gley horizon in two poorly drained soil series of the area; Pelewahun and Taiama (fig.7). For this purpose a gley horizon was defined as a horizon that has mottles or a matrix color with chromas 2 or less and values more than 4, or chromas 1 or less and values more than 3. The hue should be 10 YR, yellower than 10 YR or neutral (N).

The depth to the gley horizon decreases as the duration of flooding increases.

No correlation was detected between the depth of the laterization horizon and the duration of waterlogging at several depths in the soil. For this purpose the laterization horizon was described on base of its color properties: mottles, color of matrices, difference in color between matrix and mottles, etc. Defined in this sense there was no consistent relation.

5. DISCUSSION

Soil properties are influenced by the soil forming factor climate and as we define climate as the ruling meteorological conditions over a period of 30 years, it will be clear that it depends on the precariousness of the climate if soil properties can be correlated with one year meteorological data. On the other hand the consecution of dry and wet seasons remains the same and imperfectly drained soils will be imperfectly drained every year, although their degree of wetness may vary over a long period of time.

The analysis of waterlogging data and soil morphological properties should be done rather on a qualitative than on a quantitative base. This is backed by the fact that there can hardly be found a year in which climatic conditions approximate the long term average (McKee,1967).

Soil color.

It is believed that the influence of the soil drainage situation on soil morphology is most pronounced in the color of the soil, at least for older soils. Many times soils have been classified on base of their color. For example in the 1967 supplement of the 7th Approximation the color is used to make divisions on various levels in the system, e.g.

Order: Oxisol

Suborder: Aquox, qualifications: If free of mottles, dominant chromas are 2 or less immediately below any epipedon that has a moist color value of less than 3.5. Or if mottled with distinct or prominent mottles within 20 inches of the surface, dominant chromas are 3 or less.

Subgroup: Qualifications: It is believed that the typic subgroup should have chromas 2 in some part of the matrix of the non-plinthite materials within the horizon that contains plinthite, and in all overlying horizons.

Of course there are more criterioms than cited here. The chroma 2 or less criterion seems to be a good one for the present soils (fig.2 and 3). Matrix color chromas of 2 or less at 40 ins. depth indicate that flooding, waterlogging at 20 and waterlogging at 40 inches from the surface occurs respectively at least 1, 4 and 9 weeks in the average situation of the year 1966.
Chromas in between 2 and 5 (at 40 ins. depth) and in between 3 and 6 (at 20 ins. depth) are no sharp indicators of waterlogging. Chromas more than 5 or 6 in the present soil series indicate well drained soils. The relation of figure 7 was found by defining a gley horizon as a horizon that has mottles with chromas of 2 or less !
A rougher division of soils on base of their drainage class can be made by looking at the matrix hues, especially that at 20 ins. (fig.6).

SIVARAJASINGHAM (1966) detected some correlations, on a qualitative base, between drainage and matrix color hues for soils in the Eastern Province of Sierra Leone. "The soils of the dissected lateritic uplands are invariably of a 5 YR hue, occasionally tending towards either 7.5 YR or 2.5 YR, while the soils of the undulating uplands of intermediate relief are invariably of a 5 YR or redder hue." and "Another feature of interest is the distinction between the moderately well drained and the poorly drained soils of the low lying nearly level slopes above swamps and streams. The moderately well drained soils have at least in the upper part of the subsoil a distinct 7.5 YR hue which is not normally expected in such a low topographic position; the lower part of the subsoil may be like the subsoil of poorly drained soils. The poorly drained soils have a subsoil of 10 YR or 2.5 Y hue and containing many prominent brown and grey mottles."

MACKENZIE (1957) found that the hydrous forms of iron oxide (e.g.goethite) tend to be yellowish colored in a fine divided state and that the anhydrous forms (e.g. hematite) are strongly red in a fine grained form. SOILEAU and MCCRACKEN (1967) did a test by giving several soils an oven treatment of twelve hours at 200 and 400°C. Munsell color notations were measured initial (room temperature) and after the two treatments. No significant changes could be seen between 25 and 200°C. At 400°C all samples became redder indicating a transformation of iron minerals. This kind of reaction occurs in soil very slowly. As we assume that the kind of iron mineral that is present in a soil will be influenced by ,among others, soil drainage and that the color of the iron minerals present in a soil greatly determines the soil color, we are able to understand most found relations of the preceding chapter.

As pointed out before we can only compare colors of soils that are equal in age and that have about the same amount of free iron. Soileau and McCracken found that the chromas of the matrix colors were correlated with the amount of free iron in the particle size fractions <2 mm, 2-0.2 μ and < 0.2 μ.

Two German soil scientists (SCHWERTMANN and LENTZE, 1966) investigated the relation between soil color, using the Munsell notation, and the form of the iron oxide. As one of their results they found for synthetic iron oxides that 70 % of the goethite samples had a 7.5 YR hue and 75 % of the hematite samples had a 10 R hue. For natural iron oxides the distribution of the samples over the various hues was not so pronounced. Now 60 % of the hematite samples had a 2.5 YR color and 45 % of the goethite had a 5 YR color. Soil iron oxide samples evidently were less different in hue than synthetical samples, Natural goethite samples had hues between 10 R and 2.5 Y, while natural hematite samples were between 5 R and 7.5 YR.

Therefrom we may conclude that in iron oxide samples with hues yellower than 7.5 YR no hematite and in samples redder than 10 R no goethite will be present. It must be stated that Schwertmann and Lentze investigated a great number of different soils. This confirms the results of investigations by ALEXANDER and CADY (1962) who found the hematite in 16 samples of West African laterites uniformly distributed over the 2.5 YR, 10 R and 7.5 R hues. The two Germans showed that hematization kept pace with a shifting towards redder hues.

The results of the present investigation can be explained by using the theories mentioned before. Poorly drained soils have more reduced iron minerals thus tending towards yellowish colors (10 YR or yellower hue and low chromas) and well drained soils have more oxidized iron minerals, yielding reddish colors (7.5 YR or redder hues and high chromas). In between these drainage classes there evidently are more factors responsible for soil color as in this traject no good correlations between color properties and waterlogging were found.
The relation between the depth of the gley horizon and the duration of flooding in poorly drained soils (fig.7) is in connection with the description of MOHR and VAN BAREN (1954) who communicate about ground water laterites on page 367 of their book:"The top of the mottled layer represents the top of the ground-water for a considerable part of the year and the thickness of the layer is approximately the extent of the annual fluctuation of the ground-water surface." Apparently there is a good relation between the duration of flooding and the highest level of the water table in the soil for a considerable part of the year.
SIUTA (1967) defines gleying as a characteristic property of excessively wet and bog soils."Morphological it usually occurs in the form of

greenish, green blue and gray blue spots, bands and layers. Direct cause of gleying is a negative oxygen balance of the environment. Excess water limits the excess of air from the atmosphere, and the entire reserves of free oxygen are rapidly consumed. Especially where much and active organic matter has accumulated".This also explains why 'easy to measure' properties as matrix color chromas are such good indicators of waterlogging in a lot of soils.

6. CONCLUSIONS

With the now available knowledge some rough conclusions can be drawn about the influence of waterlogging (1 year data) on morphological properties of soils in the area.

1. The somewhat poorly drained soils - e.g. Kania series - are different from well and poorly drained soils by:

a. Prismatic A_3-horizon, grey colored, low CEC, low base saturation, low pH and a high amount of adsorbed Aluminium ions.

b. Lower and less termite mounds than on well drained soils.

c. Wormoutcrops on the land surface.

2. Correlations between duration of waterlogging at 0, 20 and 40 or 60 inches below the land surface and color properties of the soil did not yield good results unless the younger soils are ruled out, as is done in the part of the research concerned. The 'younger' soils include the Gbesebu, Madina, Pujehun, Nyawama and Kania series.

3. The hue of the matrix color at 20 ins. depth is a good indicator of the drainage class, provided it is not equal to 20 (10 YR) but yellower (towards poorly drained) or redder (towards well drained).

4. Matrix color chromas of 2 or less always indicate an imperfect drainage situation. Chromas >5 or >6 indicate that waterlogging danger is very small. Chromas in between these values do not allow distinct conclusions.

Results of correlations between waterlogging and soil properties should be interpreted very carefully, as 1966 was quite different from an 'average' year.

7. SUMMARY

Waterlogging data of soils are important in agriculture because waterlogging influences the growth of plants, tillage operations, soil stability and drainage needs. This is especially true for Sierra Leone with its pronounced wet and dry season and high annual rainfall (80-120 ins. in Njala). The objective of the present research is to find soil morphological properties which are indicators of waterlogging in soils of the Njala soil survey area. If succesful, the results may also apply to other areas with similar soils.

The duration of the watertable readings is not long enough for sound conclusions. Moreover climatic conditions during this period were far from the average. In Njala, the amount of precipitation was much higher and the duration of the wet season much shorter than usual.

Soil morphological properties as matrix color, porosity, depth of gley mottles, depth of laterization mottles, etc. were checked against waterlogging data to detect correlations.

Notwithstanding the restrictions mentioned above some correlations were found between waterlogging (drainage) and soil color, structure and biological activity. Emphasis was laid on soil color.

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9.APPENDICES

9.1.Climate.

Climatic data from the Njala Weather Station.

1.Mean monthly air temperature ($^{\circ}C$) 2.Mean monthly soil temperature

	Average	1966	1967	0900(1966)	1500	0900(1967)	1500
January	25.8	25.5	25.7	27.2	31.1	27.2	30.6
February	27.2	27.6	26.9	29.4	35.0	28.3	31.7
March	28.0	28.3	28.5			29.4	33.9
April	27.8	27.8	29.3	27.8	31.1	30.0	34.4
May	27.2	27.9	27.3	28.9	32.2	29.4	32.8
June	26.2	26.2	26.3	27.2	30.0	25.6	29.4
July	25.0	26.1	25.3	27.2	29.4	26.1	30.6
August	24.8	25.3	24.9	26.1	28.3	27.2	31.1
September	25.6	25.6	25.7	26.1	28.9	26.7	29.4
October	26.2	26.7	26.4	27.2	30.0	26.1	28.3
November	26.1	26.3	26.8	27.2	29.4	25.6	27.2
December	25.4	26.2	25.5	26.1	29.4	26.7	28.3

The 1966 data for the soil temperature are measurements at 1 foot depth, the 1967 data are measured at 6 inches.

3.Mean relative air humidity in per cents

	Average (1949-1958)	
	0900	1500
January	95	54
February	92	50
March	90	52
April	88	62
May	88	64
June	93	76
July	94	83
August	95	86
September	95	80
October	94	74
November	94	68
December	95	65

9.2.Soils

A crossection of the landscape around Njala University College with the different kinds of soils, parent materials, etc. is given in figure 8 (p.29).

9.3.Watertables.

For the height of the watertable in soil pits of various soil series we may refer to the figures 8 through 18 in the survey report.

MAJOR LANDFORM	LOWER RIVER TERRACE	UPLAND			UPPER RIVER TERRACE(S) AND COLLUVIAL FOOTSLOPES	MIDDLE RIVER TERRACE	LOWER RIVER TERRACE
SUBUNITS		STEEP ESCARPMENT SLOPE	LEVEL SUMMITS	MODERATELY SLOPING UPLAND			
SOIL SERIES	Gbesebu Pujehun Madina	Momenga	Njala, level, summit	Njala sloping	Njala, level terrace Mokonde Bonjema Pelewahun	Nyawama Kania Taiama	Gbesebu Pujehun Madina

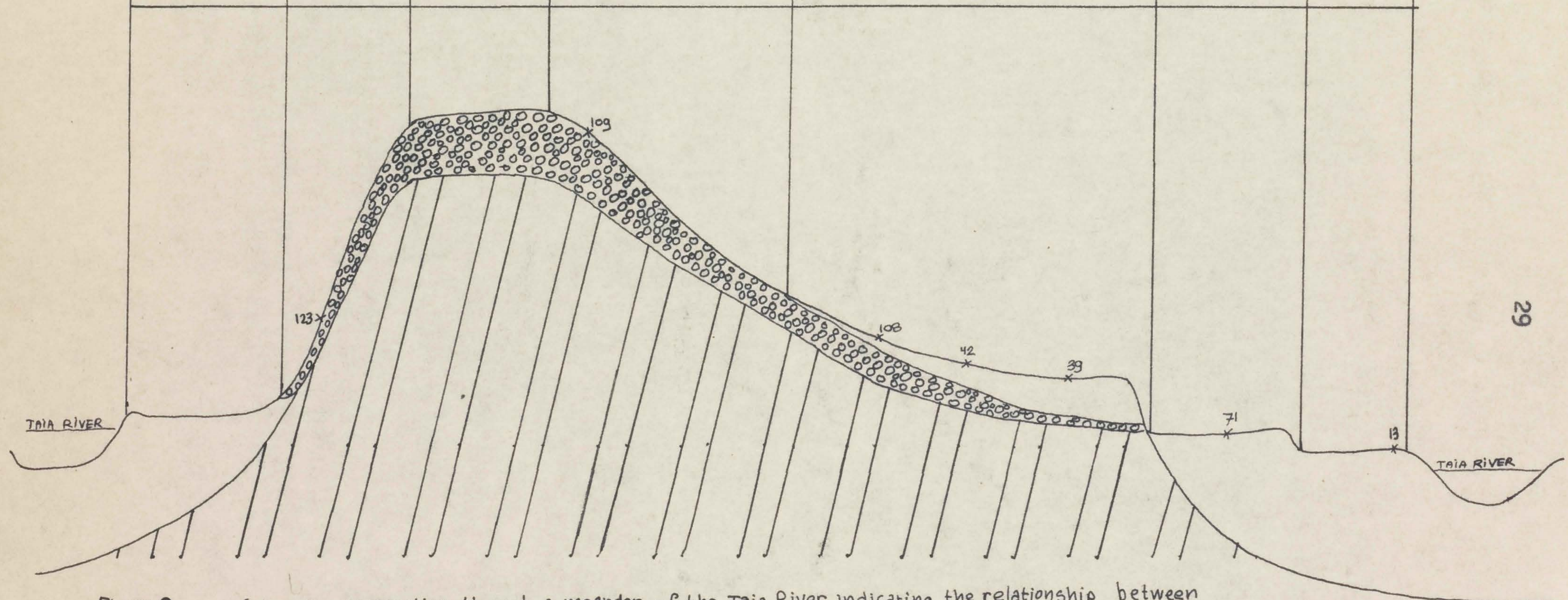

Figure 8. Schematic crossection through a meander of the Taia River indicating the relationship between landform, topography, parent material and soil series.
Numbers refer to sampled profiles for which schematic diagrams are given in figure 6 of the survey report.

Parent Materials: