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The Development of Loessial Soils in Central United States as It Reflects Differences in Climate

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ABSTRACT

A study was made of the influence of climate on soil development as reflected by changes in soil conditions. The loessial soils along the river bluffs of Central United States were studied with all factors of soil development, except climate, as nearly constant as possible under natural conditions. Quantitative measurements of the size distribution of particles in the profiles, the nature of the clay, the exchangeable bases, the organic content of the surface layers, and the mineralogical make-up of the silt fraction were used as means of ascertaining developmental differences in the soil profiles.

The clay content increased with the rainfall and temperature, and the nature of the clay also changed. The exchangeable bases in the soil decreased as the climatic conditions became more humid and warmer. The organic matter and nitrogen contents of the surface layers decreased as the temperature increased. Study of the silt fraction indicated that the parent material was constant for all locations and that the solum had undergone changes corresponding with the intensity of the climatic conditions.

The study assembles many interesting aspects of soil properties under different climatic conditions in their relation to soil development.

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INTRODUCTION

Soil development is the process whereby the loose soil mantle or parent material is changed and acquires definite characteristics that are expressed in the soil profile. Since the agencies inducing changes are largely meteorological and operative in the upper part of the soil mass, their effects are at a maximum in the surface layers and less pronounced with increasing soil depth. Accordingly, a profile results, which is differentiated into horizons of successively less difference from the original parent material as one goes downward in it. Among the factors that have a definite influence on soil development are: (a) age, (b) parent material, (c) vegetation, (d) topography and (e) climate or the combination of effective rainfall and temperature. Because of such a large number of factors involved, our understanding of soil development is limited and has been acquired very slowly. With these many factors in combination, the individual ones are not commonly operating independently of all the others. The evaluation, therefore, of their separate effects is difficult. It is almost impossible to find an extensive land area in which several of the factors of soil development are constant so that some particular one can be investigated and its influence on soil development evaluated.

Soil development and its role in making soils less or more productive, or in differentiating them by visible characteristics in their profiles, will not be fully understood until the effects of the various factors involved are segregated and determined. It was in the hope of measuring more accurately some of the soil changes, which are indices of development, as induced by climatic differences in the loessial soils extending through significant climatic variations in Central United States that this investigation was undertaken.

HISTORICAL

Soil Development

The terms "soil development" and "soil formation" are used throughout soil literature and textbooks without clear distinction. As a consequence, much uncertainty as to the exact meaning of the terms has resulted in the minds of the readers. In the early textbooks and literature, soil formation was used to denote the processes both of disintegration and decomposition of rocks into soil material. Soil investigators and pedologists of the present time apparently still regard soil formation and soil development as synonymous terms. The terms are often used interchangeably with the same meaning. The factors of soil development are closely related in part to the processes of weathering, which produced the soil materials upon which environmental forces have impressed definite soil developing processes, and which, in turn, have given different types of soil conditions. In Professor Joffe's recent book, Pedology (21), soil formation is used exclusively, and with the same meaning as Marbut (30) used it in discussing soil development.

In order to avoid confusion and misunderstanding, the term soil development will be used throughout this report to mean the processes of change whereby soil materials undergo differentiation into layers or horizons to form a soil profile. This is partially illustrated schematically in Figure 1. The soil profile will be considered as the succession of genetically related horizons in a vertical section down to the parent material. The processes of rock and soil weathering for production of soil forming materials are inseparable from those of soil development. However, in the case of loess it was all subjected to the same mechanical weathering before being deposited by the wind, hence the term soil development will deal with the changes after the materials were laid down.

The time period during which a soil has been subjected to the processes of development determines to some extent the nature of the soil and the changes that take place within the profile. Joffe (21) suggests that in the course of time, young soils age and mature, whereas mature soils reach what may be called "old age" and become degraded. Soil age refers to the stages of maturity of the profile rather than to the geologic time that has lapsed during development or since deposition of the parent material. Since the loess deposits of Central United States are associated with the glacial period of Pleistocene time, according to Antevs (6), all loess used in this study represents the same geological age.

Parent material is considered by Joffe (21) as a passive factor in soil development, because its influence tends to be obliterated by the other soil forming factors. Marbut (31) pointed out that the parent materials in the Piedmont region of Maryland and Georgia were closely related in all respects, yet the resultant soils were widely different. It is generally agreed that the parent material governs the texture of the soil. The fine textural material also controls the quantities of nutrients that can be retained. The loessial deposits are composite mixtures of glacial outwash material picked up and redeposited by the wind. The bluff deposits of major streams in Central United States are made up largely of silt. There is close similarity in composition, both chemically and physically, of all deep loess analyses reported (5, 10, 15, 40, 43). Therefore, the parent material, even of most significance in determining the characteristics of the soil is a constant factor in this study.

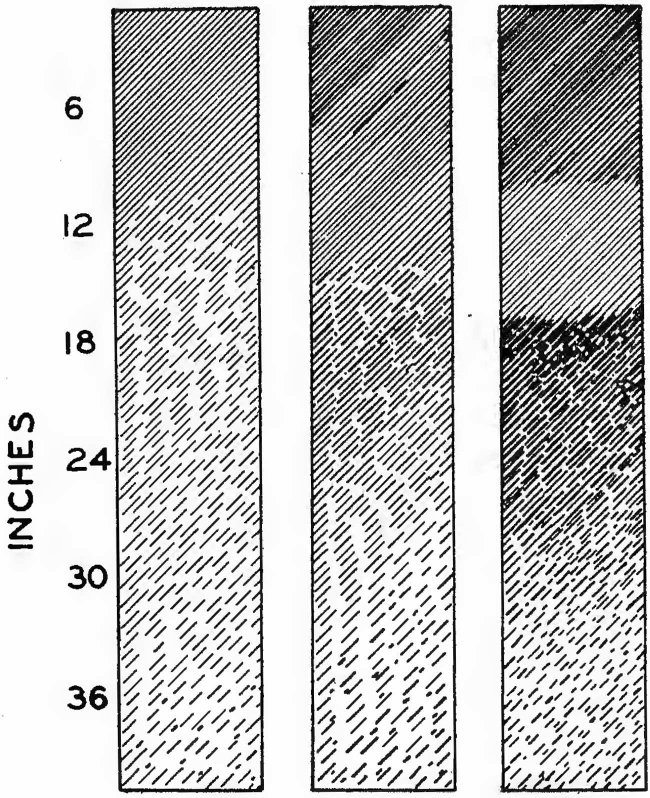

Fig. 1.—Schematic drawing showing from left to right the development of horizons in the soil profile with age. All soils tend to acquire distinct horizons as they become older. (Taken from Mo. Agr. Exp. Sta. Bul. 264, 1929.)

The natural vegetation also exerts an influence on the development of the soil. Robinson (41) concluded that natural vegetation expresses the summation of the climatic factors under which it grows. The influence of vegetation is exerted mainly through the organic matter which it contributes to the soil. Albrecht (1) has shown that decomposition of organic matter demands mineral nutrients, which must come from the soil. Thus aside from effects that are independent of vegetative composition the effect produced by the vegetation is determined by the nutrient level of the medium in which it grows, and the vegetation is a reflection of the soil conditions determining it more than the soil is determined by the vegetation. Each type of vegetation also demands a certain type of climate. Hilgard states (13) "it is obvious that there must exist a more or less intimate relation between the soils of a region and the climatic conditions that prevail or have prevailed therein." He (14) also pointed out that climatic differences may materially influence the character of the soils developed from one and the same kind of rock. So vegetation may be regarded as an expression of climate by way of the soil as well as of the direct meteorological effect. The vegetation was a constant factor throughout the scope of this study.

Topography exerts indirect effects on the character of a soil in that it modifies the climatic effect. Steep slopes hasten the run-off of the rainfall and cause less percolation. Slope also modifies the temperature. As a consequence, vegetation generally will be modified. Thus the effect of topography is an indirect one in that it modifies the effects of other natural factors active in soil development. The location of all the soil samples used in this study had similar topographic conditions.

Climate is a combination of temperature and rainfall. It has a pronounced influence on those changes occurring in the soil materials and considered as soil development. The Russian pedologists have regarded climate as the paramount factor in soil development. Their ideas were anteceded by Hilgard, and were extended by Marbut in the United States. Temperature regulates the rate of decomposition of organic matter and the chemical reactions that take place within the soil in a manner expressed by Van't Hoff's Law (46). Since many of the processes contributing to soil development are governed by the temperature, its role in soil development is very important. Jenny (20) in a study of the residual soils of the eastern part of the United States found that the clay content increased with increases in temperature. He (17) concluded also that the organic and nitrogen contents were functions of temperature. Thus, both the mineral and organic fractions vary according to the intensity of the temperature.

When considered in combination with the temperature, moisture is the primary factor in soil development. Robinson (41) suggests that the development of a soil profile is the consequence mainly of movements of water in the soil. Under the influence of water movements within the soil, the by-products of weathering and the organic residues undergo accumulation into definite layers or horizons. Alway and Rost (5) have shown from studies on the mechanical compositions and inorganic constituents of loessial soils of Nebraska, that the clay content increased with rainfall. Jenny and Leonard (18) concluded similarly in a study of a group of soils extending from Colorado to Missouri and when temperature was a constant factor. Moisture alone is very effective in the process of soil development. When combined with temperature to give climate, it becomes the main factor in soil development.

That climate exerts a decided influence on soil development is a well established fact, but quantitative data giving specific measurements of this effect are very limited. Data to indicate the influence of climate on development where the parent material has been constant are particularly inadequate. A study of such a condition, where parent material, vegetation and topography are constant factors of the environment, but where climate is a variable, should permit the evaluation of the latter as a factor in soil development and provide some useful indices for soil classification.

Loessial Soils

Loess, with its many interesting and desirable soil features, has attracted the attention of pedologists for many years. In 1860 Hilgard (15) described it in Mississippi, and compared it to the well known deposits on the Rhine Valley. Since that time, loess of the river bluff type, has been described by numerous observers in several countries (10, 40, 43). The similarity, both physical and chemical, regardless of geographical location, is evident in all descriptions of it.

The origin of loess has been debated for a long time. The nature of the climate, and the length of the period of deposition have also been debated among geologists and pedologists. Kay of Iowa reports that the loess was deposited during interglacial periods. Since there were several glaciations over parts of the midwestern states, there are several corresponding loessial deposits reported. For these Kay (22) gives the following classification, starting with the first or oldest glaciation and proceeding to the latest:

Glacial Period	*Integlacial Periods*
1. Nebraskan	Aftonian
2. Kansan	Yarmouth
3. Illinoian	Sangamon
4. Iowan	Peorian
5. Wisconsin	None reported

In some recent work in Illinois, Smith (45) suggested that the deposition of the Peorian loess was very slow. No one theory has been universally accepted as to the origin, or the manner of deposition, but the fact that the deep loess occurring on bluffs of major streams was derived from glacial outwash material that was deposited on the flood plains, and later picked up by the wind and redeposited, is well established.

A classification of loess in the lower Mississippi Valley in relation to glacial periods, so far as the author knows, has never been made nor has it been correlated definitely with that of the upper Mississippi Valley. Mabry (28) mentioned that the loess deposits in Mississippi and Tennessee may have been made during the close of the first glacial epoch. Leighton (27) reports a classification of the glacial and interglacial stages of the Mississippi Valley, but does not indicate where the interglacial materials occur. He maintains that there was no lapse of time between the Sangamon and Peorian loesses. Any information indicating differences or similarities in the loess of the lower and upper Mississippi valleys should, therefore, be of interest to geologists, pedologists and scientists in general.

PLAN AND METHODS

Plan of Experiment

This investigation was outlined as a study of soil development over a range of climatic conditions when all of the other environmental factors affecting soils were as nearly constant as possible. Of course, the natural geographic areas where several natural agencies are constant must of necessity be very limited. Fortunately there is such a condition in the loessial deposits of the river bluff type along the flood plains of the Mississippi and Missouri Rivers.

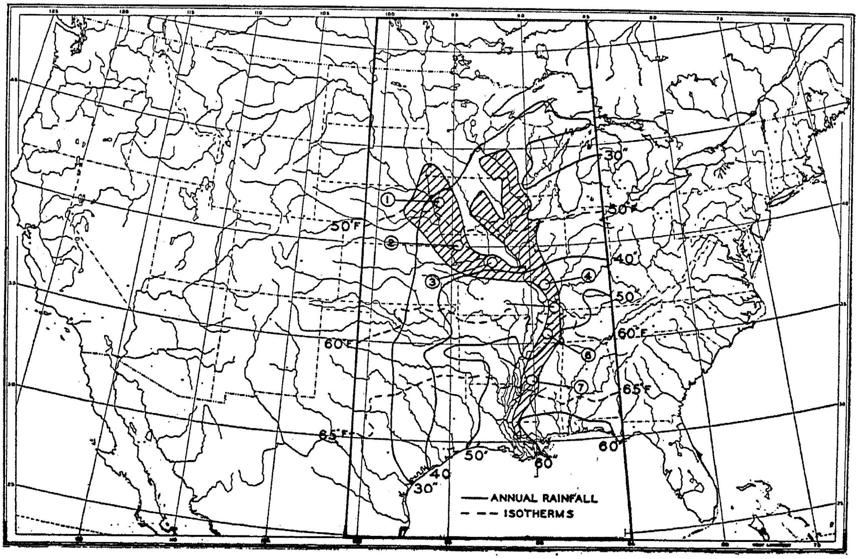

Fig. 2.—Approximate location of deep loess in Central United States, and the locations where samples were collected for the study.

The locations on loessial soils selected to represent different climatic conditions, were on the river bluffs and at points extending from Sioux City, Iowa to Vicksburg, Mississippi. The locations where samples were collected are shown on the map, Figure 2. Over this distance extending through 11 degrees of latitude, the parent material, the vegetation, the age, and the topography were all as nearly constant as attainable by such selections. The vegetation was hardwood. It consisted of oak, gum, hickory and other deciduous trees. The age of the loess is of Pleistocene time, and since the particular interglacial period during which it was deposited, is still unknown, we can assume that the time factor is constant. The glaciation occurred during the Pleistocene Epoch according to Historical Geology (34). Thus the loess used in this study was all deposited during the same geological period. The topography is steeply rolling throughout the bluff section of the loessial belt selected for investigation and can be considered constant.

Temperature and rainfall are the soil forming variables involved in the investigation. The mean annual rainfall varies from approximately 27 inches at Sioux City, Iowa, to 55 inches in Central Mississippi. The mean annual temperature varies from 8.72° C to 17.66° C at the same locations mentioned above. It was impossible to separate the effects of rainfall from those of temperature in this study. Therefore, the combined influences of the two agencies are considered as climate, and their combined effects as agencies in soil development as ascertained by physical and chemical analyses of the soils. Thus we have a laboratory, prepared by nature, where soil properties may be investigated with climate the only variable factor in the complex process of soil development.

Selection of Location and Soils.—Locations for samples in the deep loess were selected along the Missouri and Mississippi Rivers, starting near Sioux City, Iowa and extending to Central Mississippi; sample locations of the five different states were: (1) Sioux City, Iowa, (2) Oregon, Missouri, (3) McBaine, Missouri, (4) Cape Girardeau, Missouri, (5) Wickliffe, Kentucky, (6) Mempsis, Tennessee, and (7) near Vicksburg, Mississippi. The loessial soils used were Knox silt loam in the northern part of the loessial section, and the Memphis silt loam in the central and southern portions. The general boundary between the two series is near St. Louis, Missouri according to the United States system of classification. Samples of a virgin or non-cultivated area were collected at every location in order to avoid any variation caused by the action of man. Sample locations were approximately at intervals of 5 inches to 10 inches of annual rainfall.

Description of Soils.—These two soil types are described in Missouri (33) as being somewhat similar and are locally known as "bluff land" or "Brown loess soil." The Knox differs from the Memphis in being darker in the surface, has less clay in the subsoil, and is less acid throughout the profile. Both types represent relatively immature soil profiles and are usually found on the river bluffs. Both are rated as good agricultural soils but have topographic limitations for crop production.

Collection and Treatment of Samples.—The profiles were sampled according to the following horizons:

Suggested Horizon	*Depth*	*Descriptive name*
A	0-7″	Surface
B	12-20″	Subsoil (zone of accumulation)
C	36-48″	Transition zone
D	15-20′	Parent material

All samples were collected in fields, from deep cuts and excavations. Samples were placed in paper or cloth bags, brought to the laboratory and allowed to become air dry. They were then passed through a 40-mesh sieve and stored in cardboard containers until the various laboratory determinations could be made.

Analytical Methods

All samples were subjected to determinations of the following: mechanical analysis, base exchange capacity, exchangeable calcium, magnesium, potassium, and pH. Determinations of the organic matter and total nitrogen were made on surface samples. Determinations of the quartz, other than quartz, and the calcium were made on the silt fractions of the solum and of the parent materials. The SiO_2/R_2O_3 ratios and the exchange capacities of the clay fraction of the subsoil of four of the profiles were determined. The mechanical analyses were made according to the standard pipette method of the United States Bureau of Soils (37), separating the fractions according to the United States system of classification of particle size (48). The base exchange capacity was determined by leaching with ammonium acetate or the method as described by Parker (39). The exchangeable calcium and exchangeable magnesium were obtained from the ammonium acetate leachate by the methods given by Kolthoff and Sandell (26). The potassium was determined by spectrographic analysis of the ammonium acetate leachate by the method described by Ells and Marshall (11). The approximate visual inspection method as described by the above authors was used. The pH was ascertained by the glass electrode in the Beckman potentiometer. The organic matter was determined by dry combustion according to Winters and Smith (47) and the A.O.A.C. method of analysis (36). The free carbonates were removed by the procedure described by Allaway and Pierre (4). The total nitrogen determinations were made by the Kjeldahl-Gunning-Arnold method as modified by Murneek and Heinze (35). The quartz and silicate contents of the silt fraction were found by the procedure described in Public Health Record (24). The calcium was then determined in the filtrate volumetrically as described for the ammonium acetate leachate. The SiO_2/R_2O_3 ratio of the clay fraction was determined according to the A.O.A.C. methods of analysis (36). The base exchange capacity of the clay was determined conductometrically by the procedure outlined by Bradfield and Allison (7) for electrodyalized clay. The fractionation or size distribution of the clay fraction was made by the double layer centrifuge method according to Marshall (32). Some of the optical properties of the clay were observed in order to verify the suggestions brought out from the study of the clay fraction, but are not reported here. All data reported are averages of determinations in duplicate.

EXPERIMENTAL RESULTS

Mechanical Analyses as an Index of Soil Development

Since profile development is brought about mainly by the movement of water through the soil, differences in the mechanical composition should be detectable in the different horizons of profiles of different degrees of maturity. It can be observed from Table 1, that the D horizon, or parent material, in every soil was very high in silt. Each soil would classify as a silt loam. Profile No. 1 at Sioux City, Iowa varied little in clay content with depth. The sand content was somewhat higher in the surface. This may have been a result of geological erosion, which removed the finer material and left the coarser behind. Since there was only a slight difference in mechanical analysis with depth of the profile, this suggests that there has been little soil development in this profile. The annual rainfall of this location is approximately 27 inches. The same relation was found in general, of the sand content to position in profile No. 2, which was collected from a location where the rainfall is 30 inches annually. However, there was some accumulation of clay in the B horizon, which is indicative of slight soil development, even though not of higher degree. Profile No. 3, which developed under an annual rainfall of 40 inches, had a definite zone of clay accumulation and a distinct profile had developed. There was approximately 16% more clay in the B than in the A horizon. This

TABLE 1.—MECHANICAL ANALYSES AND EXCHANGE CAPACITIES

Location	Horizon	Sand %	Silt %	Clay %	Exchange Capacity M.E./100 gms.
1. Sioux City, Iowa	A	19.32	61.70	18.96	17.35
	B	11.53	69.91	18.53	13.12
	C	12.22	70.53	17.21	12.60
	D	12.20	72.00	15.79	13.00
2. Oregon, Missouri	A	13.76	64.75	21.41	21.08
	B	9.68	63.51	26.79	18.60
	C	8.87	68.42	22.92	15.55
	D	6.74	75.93	17.29	14.50
3. McBaine, Missouri	A	9.14	69.90	20.95	10.33
	B	2.86	60.83	36.32	17.91
	C	5.42	59.33	35.25	17.39
	D	28.69	48.09	23.22	11.20
4. Cape Girardeau, Missouri	A	4.37	77.47	18.90	9.54
	B	2.90	67.85	29.27	15.15
	C	4.49	75.25	20.25	14.43
	D	3.37	78.11	18.40	13.50
5. Wycliffe, Kentucky	A	2.90	84.50	12.53	7.90
	B	2.28	65.60	31.59	16.00
	C	1.94	78.37	19.70	11.82
	D	.56	88.80	10.63	6.95
6. Memphis, Tennessee	A	3.77	87.66	11.66	6.94
	B	3.08	74.23	22.92	12.98
	C	3.99	74.61	20.10	12.56
	D	1.00	94.00	5.00	6.00
7. Vicksburg, Mississippi	A	2.57	84.97	9.15	5.28
	B	1.44	79.40	21.69	11.88
	C	2.88	77.66	19.52	9.57
	D	1.00	94.00	5.00	5.94

difference between the A and B horizons was more pronounced in the other soils, as the rainfall increased. Profile No. 4, which developed under an annual rainfall of 45 inches, was similar to No. 3. In profile No. 5, which developed under slightly more rainfall, there was a more definite demarcation between A and B horizons, and there were two and one half times as much clay in the B as in the A horizon. Here the horizons were easily recognized in the field. This was also true of profiles Nos. 6 and 7. The clay content was lower also in the parent material of the profiles from Kentucky, Tennessee and Mississippi. The sand content in both the parent material and the solum decreased in going to the south. This may be due partly to a breakdown of the sand into silt by the forces of weathering. Alway and Rost (5) reported such a breakdown of the sand into silt in Nebraska.

As an indication of the possible chemical activity of these soils as related to their mechanical analyses, particularly to the clay fraction, the exchange capacities are also reported in Table 1, so they may be correlated with the texture of the different horizons. The soils, as arranged in Table 1 in numerical order, starting with the samples from low annual rainfall and temperature and proceeding regularly to locations of higher rainfall and temperature, will hereafter be arranged in this same order and numbered from 1 to 7 as in this table.

Significance of Mechanical Analysis

Changes of texture in the successive horizons in the profile have long been recognized as one of the means of estimating the stage of development of the soil. Difference in color between horizons has also served as a criterion for developmental differences. A soil with distinct horizons such as a definite surface and a definite subsoil, markedly different as to their textures and colors, is considered more highly developed than a soil without distinct profile divisions. Young soil profiles have few horizons. With increasing maturity the horizons become more distinct and greater in number. All of the soils used in this study were recent or young soils, according to the scheme of classifying stages of soil development suggested by Shaw (44) in 1927. Even within this youthful group, the effect of climatic forces is clearly evident from the data obtained by mechanical analysis alone.

Profiles Nos. 1 and 2 developed under low rainfall and there was very little difference in the texture of the horizons throughout the profile, while those that developed under higher rainfall, had marked differences in the mechanical make-up of the surface and subsoil. The profiles that developed under an annual rainfall of 50 inches or more had more than twice as much clay in the subsoil as in the surface. Naturally the horizons of these profiles were more distinct and could be easily recognized in the field by visual perception. The summation of the mechanical composition study leads to the conclusion that soils developed under high rainfall, other conditions being similar, are more highly developed than soils of similar geologic material developed under low rainfall.

Base Exchange Capacities in Relation to Climatic Differences

The base exchange capacity of a substance is related to the amount of surface exposed and the chemical nature of the adsorbing mass. Bray (9) in 1937 reported that the exchange capacities of soil colloids were related to the size of the particles and the kind of minerals in the colloid. On the basis of this fact, then, variations within the profile according to the different stages of development, should be detectable as differences in the exchange capacities of the horizons. In order to measure the differences in stages of soil development brought about by the different climatic forces the exchange properties of the soils were studied as a means of determining whether the natures of the adsorbing substances were different in the corresponding horizons in the profiles.

The base exchange capacities for the soils, as given in Table 1, page 12, varied from 21.08 M.E. per 100 grams for the surface of profile

No. 2 to as low as 5.94 in the deep parent material of profile No. 7. These capacities fluctuated according to the clay content, but equal amounts of clay did not always mean the same capacity. It is important to note that the capacity per unit of clay decreased in the samples in going from north to south. By observing the B horizons, in which the organic matter as a variable does not interfere to an appreciable extent, we find profiles Nos. 1 and 2 similar in exchange capacity when compared on equivalent clay contents. But in profile No. 3 which contained 36.32% clay there was a capacity of only 17.91 M.E. per 100 grams of soil. In going further south to profile No. 4, it is important to note the wide ratio between exchange capacity as M.E. per 100 grams and the clay as per cent. While in profiles Nos. 1 and 2 this ratio was approximately .7, it is but .5 or approximately 1 M.E. exchange capacity for each 2% clay in profile No. 4. The parent material of all soils was much higher in this respect for equivalent amounts of clay than that represented by the clay in the solum. In profile No. 7, the one located furtherest south, the parent material with but 5% clay had a capacity of 6 M.E. per 100 grams, or a ratio of 1.1 in contrast to the ratios above. Even in the C horizons there is evidence that in regions of higher rainfall and temperature, more clay is required to provide the same exchange capacity. This means then, that with increasing intensity of the climatic forces, namely, temperature and rainfall, the nature of the clay must be different if the decreasing exchange capacity per unit quantity of the clay is any index.

The clay is generally considered as the seat of base exchange and the source of nutrients released in the soil for the growth of plants. The variations in the exchange capacities of the soils from north to south emphasize the fact that there are different clay minerals that play a role in exchange capacity along with the quantity of clay present in the soil. When any amelioration practices are applied directly to the soil, the type of clay minerals predominating is of considerable importance in determining the results from such practices and should be considered as well as the amount of clay. The data obtained from the exchange capacity of the soil encouraged a more detailed investigation of the clay fraction of the soil as it was developed differently under widely different climatic conditions.

The Clay Fraction

Base Exchange Capacity.—The sand and silt separates of the soil have very little power to adsorb cations. The clay with its more extensive surface per unit mass must be given credit for most of the exchange activity of a soil. Because the exchange capacities of the soils pointed to differences in the exchange capacity as prompted mainly by the clay, this particular textural fraction was separated from the subsoil of four of the profiles from widely different climatic conditions, in order to study its properties more specifically. The base exchange capacity was determined, and the SiO_2/R_2O_3 ratio of the total clay fraction calculated from chemical analysis.

TABLE 2.—CLAY PROPERTIES IN RELATION TO RAINFALL

No.	Rainfall (inches)	Exchange Capacity	SiO_2/R_2O_3 Ratio
1	27″	73	5.06
3	40″	66	4.03
5	48″	50	3.24
7	55″	44	2.56

It can be seen clearly from the data in Table 2, and Figure 3, that the exchange capacity of the clay separate decreased as the rainfall increased, which is indicative of a difference in chemical composition of the clay. As additional evidence of clay difference, the SiO_2/R_2O_3 ratio, which has been regarded for a long time by some workers as an index of the climate under which clay is formed, gives decided support. The exchange capacities of the clays varied from 73 M.E. per 100 grams under a rainfall of 27 inches to 44 M.E. under an annual rainfall of 55 inches. Parallel with this change in the clays, there are the changing SiO_2/R_2O_3 ratios of the clay from the same locations. These varied in like manner with the climate, so that the SiO_2/R_2O_3 ratio of the clay that developed under 27 inches of annual rainfall was 5.06, and for clay that developed under 55 inches of rainfall, it was but 2.56. This indicates clearly that the climate governs the type of clay that is formed in the solum of the soils in different regions.

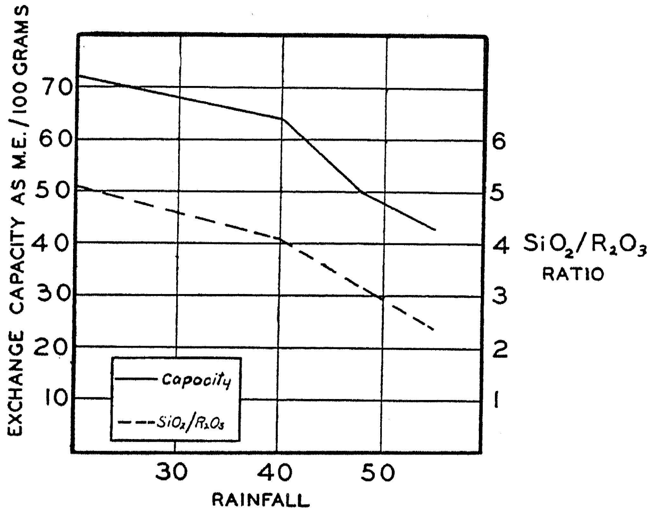

Fig. 3.—Influence of climate on properties of clay.

Significance of Base Exchange Capacity.—The decrease in the exchange capacity of the soils of comparatively constant clay contents, and the differences in the character of the separated clay establish clearly that a different kind of clay is formed under different conditions of temperature and rainfall. Since the high exchange capacity per unit of clay in the parent material in all of the profiles agreed more nearly with that for the profiles developed under lower rainfall but differed decidedly from the clay properties in the profiles of higher rainfall, there is the suggestion that the resulting clay has chemical characteristics according to the intensity of the climatic forces. This suggests further that the parent material or lower parts of the deep loess further south may have been deposited under climatic conditions approaching those now prevailing further north. The source of the loess appears to be the same for the different regions. Had any other climatic condition prevailed, a clay of different character would have resulted in the greater depths of the loess of the lower Mississippi Valley. It seems that only transportation and deposition of material containing some clay typical of a different climate at a rate rapid enough to prohibit weathering could give a clay entirely different to what the climatic locality demands.

Bray (8) in some studies of soil development reported that the base exchange capacity of the surface becomes lower, and that the differences in capacities of the various horizons become greater as the soils become more mature. Assuming that this conclusion is correct, the profiles that developed under high rainfall are more highly developed than those that developed under low rainfall.

The variations in the chemical properties of the clay gives credence to the belief that the climate is responsible for the type of clay that is produced in the solum of soils. Hough and Gile (16) in a recent study of rock weathering and soil profile development, concluded that colloids formed under high rainfall changed little, or very slowly, under subsequent weathering. Thus, the clay properties could be considered as natal properties rather than the results of changes subsequent to formation, or that clay properties arise through its formation rather than changes due to weathering after formation. In 1924, Robinson and Holmes (42) showed that the SiO_2/R_2O_3 ratio of soil colloids reflected the climate under which they were formed, and since then this ratio has been regarded by some workers as an index to soil weathering and development. Hence the variations of the SiO_2/R_2O_3 ratio may be explained by the fact that the climate is the controlling factor of the type of clay produced and the extent to which the soil has developed.

Exchangeable Bases and pH as Indices of Soil Development

Of the many chemical determinations which can be made on soils, the exchangeable bases and the pH are considered by many investigators as the most significant indicators of soil development. The presence or absence of exchangeable bases is an index to the fertility, if exchangeable nutrients represent the dominant supply for the plant. Increased weathering of the clay might well be expected to lower its supply of exchangeable bases, as the various cations are removed from the clay and hydrogen is substituted. Therefore, the degree of acidity would increase and the pH become lower. Hence, the studies of the exchangeable bases and the pH of soil developed under different climatic conditions should indicate the influence of climate on soil development (Table 3).

According to the data, the exchangeable calcium was reduced more rapidly than was the magnesium. These two became almost equal under the heavy rainfall. This active form of calcium was very plentiful in the soils that developed under annual rainfalls of 27 and 30 inches. There was more than the soil could absorb, and it was present as free carbonates. No free carbonates were present in the soils that developed under annual precipitations of 40 or more inches. When the annual rainfall was greater than 40 inches, there was only a small amount of calcium in the soil. Plants grown on these soils may be expected to contain a relatively low calcium supply. If the value for the total clay content in the solum is converted into values as M.E. of exchangeable calcium present in the same, and this figure compared with the same for the other soils, we obtain a comparison of relative calcium saturation values for the clays. For the clays in profile No. 1, this value is 2.6, while profile No. 7 has a value of only .17. These values show wide differences in exchangeable calcium or the amounts that could be offered for the growth of plants. The calcium-magnesium ratio became narrower under greater rainfall and wider under low rainfall. This narrowed ratio results more from the small calcium content than from lowered magnesium. This indicates also a possibility of calcium-magnesium ratio being used as an index to weathering. The potassium and magnesium did not behave in the same manner as did calcium with respect to rainfall. Since potassium and magnesium are commonly believed to become fixed by the clay colloids (23, 29, 28), rather than to remain wholly exchangeable, these may be the disturbing conditions.

The curve in Figure 4 representing the pH, bears a close similarity to that for the calcium content, or the reciprocal to the amount of leaching that has taken place. The decline in the curve of pH in relation to rainfall is not as steep as that for calcium. This may be expected because of the low exchange capacity of the soil, brought about by the changed nature of clays in the soil. With clays of relatively low exchange capacity, it requires only a small amount of bases to raise the pH considerably. This also shows the limitation of relying on the pH alone to estimate the amount of bases present in a soil. Therefore, the pH, the reciprocal of the exit of bases from the clay, is a poor index of the total bases present even with constant amounts of clay present. This has been shown by Albrecht (3) on some colloidal clay studies. Since it is the supply of bases in the soil that represents soil fertility and possibilities in plant nutrition, the soils developing under southern conditions may have pH values sufficiently high to cause no alarm when viewed in terms of the degree of acidity, yet they may be so deficient in total bases, particularly calcium of nutrient values, that certain crops often fail to make satisfactory growth.

Significance of Bases and pH.—As the rainfall increased, the exchangeable bases were leached from the soil and their places taken by hydrogen. This is evident from the consistent drop of pH as the rainfall increased. As soils develop toward the mature stages, some of the exchangeable bases are usually lost. According to Krusekopf (25) this is an index of soil development, and mature soils are usually deficient in bases and other plant nutrients. Therefore, soils in the early stages of maturity are at an optimum for plant growth, but as these develop further they undergo degradation with the increase in acidity of the soil, and more hydrogen on the clay. Since it has been recently shown by Graham (12) that acid clay is an agent in chemical weathering of the minerals in the silt and sand fractions, this fact may help us to understand why the soils of the southern section of the loessial area have undergone a greater degree of change in their silt as well as in the clay separates than have the soils of the northern part. The data give credence to the contention that there is very little development of a soil, in terms of the movement of clay downward for the production of definite textural horizons in the profile until most of the free bases as calcium carbonate for example, have been leached out of the soil. In support of this idea, careful consideration may be given to soils that are normally high in exchangeable bases. The commonly recognized Rendzina soils that occur over a wide range of climatic conditions have no distinct profile development save for differentiation of A horizon from parent material. It is well known that in regions of podsolization and in the vicinity of true podsol soils, there are soils which do not have the same degree of development as the podsols. Because they develop from soil materials high in carbonates and high in exchangeable bases, they develop into the so-called "Brown

Forest" soils. There are no soils, so far as the writer knows, with highly developed profiles of which the material still is high in carbonates and exchangeable bases. It seems logical to suppose that a high content of carbonates and exchangeable bases retards the actions that produce soil development and holds the processes in equilibrium until the free carbonates and exchangeable bases are lost by leaching. It is then that eluviation, both mechanical and chemical, can become active and profile development begin which results in the development of horizons that are observable in vertical cross sections of mature soils.

The exchangeable bases of the soils in this study decreased as the samples ranged from north to south. This fact is shown in Table 3.

TABLE 3.—EXCHANGEABLE BASES* AND pH

Profile No.	Horizon	Ca	Mg	K	pH
1.	A	47.00	5.66	.73	8.20
	B	46.50	5.78	.35	8.50
	C	44.30	7.35	.25	8.70
	D	45.25	8.65	.22	8.50
2.	A	23.00	7.20	1.35	7.50
	B	17.60	6.80	.50	7.80
	C	29.10	9.50	.35	8.10
	D	22.60	12.95	.43	8.00
3.	A	9.30	3.52	.25	6.80
	B	13.88	5.65	.42	5.90
	C	14.20	5.15	.23	6.25
	D	9.35	4.15	.18	6.85
4.	A	5.66	2.28	.18	5.65
	B	9.40	2.28	.19	5.10
	C	11.30	2.90	.23	5.25
	D	9.54	2.91	.23	5.90
5.	A	3.29	2.02	.11	5.05
	B	5.33	5.45	.22	4.80
	C	8.00	4.92	.18	5.65
	D	15.75	11.00	.13	8.30
6.	A	4.28	1.97	.15	5.00
	B	5.03	2.07	.24	4.85
	C	3.90	2.57	.26	5.15
	D	18.60	7.20	.17	8.45
7.	A	3.19	1.56	.13	5.25
	B	3.87	3.51	.25	5.30
	C	4.13	4.53	.22	5.00
	D	24.26	12.54	.13	8.30

*Expressed as M. E. per 100 grams.

The pH can be correlated with the exchangeable bases. It varied from 8.5 under an annual rainfall of 20 inches to 5.00 under an annual rainfall of 50 inches. Among the exchangeable bases, the amount of calcium in the solum was inversely proportional to the annual rainfall. The magnesium and potassium did not occur in such close correlation, but the trend was similar. Two of these bases, namely, calcium and magnesium, present in larger exchangeable quantities, are pictured graphically in Figure 4 in which their amounts are shown in relation to the pH and the rainfall.

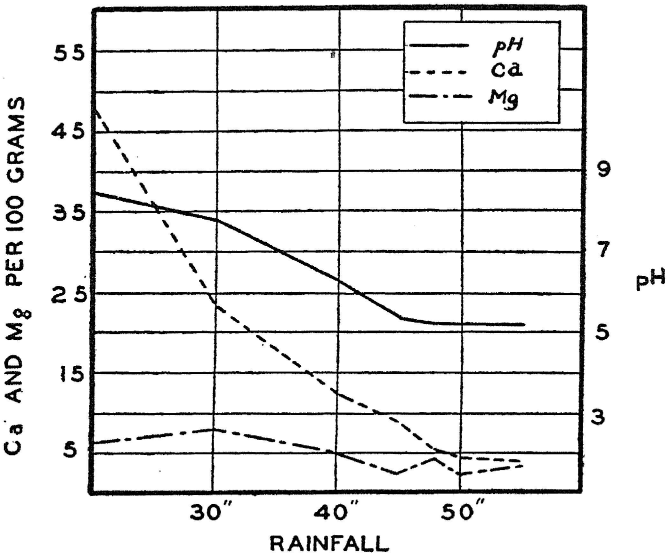

Fig. 4.—Exchangeable calcium and exchangeable magnesium in relation to rainfall and pH.

Base Saturation in Relation to Rainfall

That the relative loss of bases from the exchange complex is greater as the rainfall increases may be clearly demonstrated by the percentage of base saturation of these loessial soils according to their location. The exchangeable bases which were measured included calcium, magnesium and potassium. It should be noted that the base saturation observed by using the sum of the amounts of these three exchangeable bases present as the value of 100 per cent base saturation for any of the soils that are neutral, as for example that with 27 inches of rainfall and pH 8.2 or that with 30 inches of rainfall and pH 7.5, or even that with 40 inches of rainfall and pH 6.8, and comparing with it similar values for the soils located farther south in higher rainfalls, then it becomes readily evident that the percentage saturation of the soil by bases decreases with increasing rainfall. The data obtained by this method of calculation are given in Table 4, when only the surface (0-7") horizons were considered.

Table 4.—Base Saturation and Rainfall

No.	Annual Rainfall	Saturation	pH
1	27"	100%	8.2
2	30"	100%	7.5
3	40"	100%	6.80
4	45"	96%	5.65
5	48"	69%	5.05
6	50"	66%	5.00
7	55"	56%	5.25

The southernmost soil was but 56% saturated with bases. Since this study involves only young soils, and those developed from material high in bases, the base content was relatively high when compared with the more mature soils in that region. The lower base saturation of the southern soils is an index of the greater amount of leaching that has taken place. It was shown in Table 1 that the southern profiles had low exchange capacities. Therefore, it may be assumed that a small quantity of applied bases would produce a relatively high degree of base saturation. This low exchange capacity may explain why heavy applications of lime have often produced detrimental results on southern soils even though the soils were low in available bases. The applied calcium, seemingly small, represents complete calcium saturation and displacement of all other nutrient cations and, therefore, plant starvation may occur because of a deficiency of the latter.

Soil Development as Reflected by the Soil Contents of Organic Matter and of Total Nitrogen

Because the amount of organic matter in the subsoils used in this investigation was small, only the surface (0-7″) layers were considered in connection with the scrutiny of the organic matter and its nitrogen content as these were associated with differences in the character of the profile. When the organic content, the total nitrogen, and the C/N ratio are shown for the samples arranged according to increasing rainfall and temperature as in Table 5, some interesting facts become evident.

TABLE 5.—ORGANIC MATTER AND TOTAL NITROGEN IN RELATION TO CLIMATIC CHANGES

No.	Annual Temperature °C	Annual Rainfall inches	Organic Matter %	Nitrogen %	Carbon/ Nitrogen
1	8.72°C	27″	3.00	.19	9.2
2	11.22°C	30″	4.00	.23	10.0
3	12.50°C	40″	2.10	.12	10.0
4	14.33°C	45″	1.70	.10	9.9
5	15.39°C	48″	1.88	.09	12.0
6	16.44°C	50″	1.83	.08	9.5
7	17.66°C	55″	1.78	.09	9.2

The percentages of the organic matter in the soil increased in going from locations No. 1 to No. 2, and then decreased with continued increase in temperature and rainfall. Since it has been shown by Jenny (19) that within limits of 10 to 30 inches of annual rainfall, the percentages of nitrogen increased with the rainfall, the increase in the surface of profile No. 2 over No. 1, may be expected. In this case the increased rainfall as a means of increasing the organic matter probably more than offset the small increase in temperature which would tend to decrease the organic content. The total nitrogen, expressed as per cent, behaved in the same order as the organic matter. This is quite significant, since the vegetation was of the same type at every location. This fact verifies Van't Hoff's Law and substantiates the fact that organic matter will not accumulate under higher temperatures. It is also in agreement with the data by Jenny (17), who has shown that the organic matter and total nitrogen contents of soils varied inversely with the annual temperature. The C/N ratio of the organic matter remained almost constant with the exception of profile No. 5. If we should disregard this one case, it can well be said that in going from north to south there is a tendency for this property of the organic matter to remain constant. This may not be according to common expectation, nor in confirmation with some past data on the subject. However, all of these soils developed from similar parent materials and under similar vegetation. The extent of the area under this study is not, however, as great as Jenny reports for his variations in the nitrogen content of soils in relation to temperature. It is difficult to understand why the C/N ratios did not change even in the climatic ranges of this study, unless all soils investigated have reached a state of equilibrium under their environment and the organic matter of soils developed from similar parent material and vegetation will vary in quantity more than in its nature as a result of climatic differences.

The decreasing contents of organic matter and of total nitrogen in the soils as the rainfall increases are indices of different climatic conditions prevailing where the soils developed. The rise in organic matter and nitrogen in the first two soils indicates that the fertility of the soil increases with the developmental processes under less than 40 inches of rainfall and then declines in the advanced development of the latter stages of maturity common under higher rainfalls. Krusekopf (25) reported that mature soils have little ability to produce or retain nitrogen. This decrease in percentage of nitrogen as the rainfall and temperature increase suggests greater degrees of maturity of the soil profiles, even though the soils used in this study had not reached the mature stage of development, and gives additional support to the influence of climate in soil development.

The frequent statement that most of the soils in the south are low in nitrogen, is well substantiated by these data. They suggest further the reason why nitrogenous fertilizers usually produce good responses when applied to the southern soils, even in the fertile alluvial bottoms. The problem of maintaining soil fertility is a very grave one under such climatic conditions as prevail in the southern states, and an understanding of what has happened and what is going on at present in the soils is very desirable in connection with sound soil management practices.

The Silt Fraction. Variation in Relation to Climate

The divergence in accordance with different climatic environments of the clay fraction, the chemically active portion of the soils, in terms of exchange capacity, chemical composition, degree of base saturation and pH from these properties in the respective parent materials has already pointed to the profound influence of climatic forces on the nature of the soil. Mechanical analysis of soils showed that all contained a high percentage of silt. Richtofen (40) gave data of the deep loess deposits in China that likewise showed a high percentage of silt. Demolon (10) reported similar data and descriptions of loess from France as did Scheidig (43) from Germany. Since the silt fraction comprises the greater part of the loess soils not only in United States but in other countries as well, it seemed desirable to learn whether the silt fraction, which is relatively inactive chemically, might not reflect chemical and mineralogical differences according to the various locations where samples were collected for this particular study.

It appeared logical to believe that the silt separate had been largely the source of the clay and other by-products of weathering as well as the available plant nutrients except those contributed by the organic matter. Therefore, it should have undergone changes according to the forces of weathering.

Because the increasing content of quartz in the silt fraction, or its reciprocal, the decreasing content of "other-than-quartz" minerals, reflects the increasing loss of the latter by the greater degree of weathering, the quartz content was determined in the silt fraction. The silt fraction, after its separation from the entire solum, was acid washed in order to remove all free and exchangeable bases and was then treated with hydrofluosilicic acid for twenty-four hours at room temperature in order to separate out the insoluble quartz. The unattacked quartz was then determined gravimetrically, and the "other-than-quartz" by difference. The filtrate served as basis for the determination of calcium which was made volumetrically. This process was used for the silt fraction of the parent material also, and the results compared with the corresponding contents of the solum.

Constancy of Parent Material.—It was surprising to find a close agreement among all the analyses of the silt fractions obtained from the deep unweathered parent materials from the various locations, which represent different climatic conditions, according to the data shown in Table 6. The quartz and calcium contents of the silt of the parent materials were almost constant for all locations with the exception of two samples which represented shallow deposits of loess, and could have suffered some degree of weathering during deposition.

TABLE 6.—QUARTZ AND CALCIUM IN SILT FRACTION OF PARENT MATERIALS

No.	Annual Rainfall in inches	Quartz	Other than Quartz	Calcium
		%	%	%
1	27	58.5	41.5	1.53
2	30	60.5	39.5	1.34
3	40	68.2	31.8	1.07
4	45	68.0	32.0	1.08
5	48	61.5	38.5	1.46
6	50	58.8	41.2	1.42
7	55	58.0	42.0	1.53

The constancy of the calcium and the quartz contents of the silt separate, which constitutes the greater part of the material, indicates that the parent material was similar in the areas from Sioux City, Iowa to Vicksburg, Mississippi.

Solum Different from the Parent Material According to Climate.—While the data for the parent materials in these different localities of widely varying rainfall are impressive because of their similarity, the same evaluations for the entire solumn developed in the same locations indicate wide dissimilarities. This is evident from the data given in Table 7 representing the soils developed from the parent materials of which the corresponding data are shown in Table 6.

TABLE 7.—QUARTZ AND CALCIUM IN SILT FRACTION OF SOLUM

No.	Annual Rainfall in inches	Quartz	Other than Quartz	Calcium	
				%	M.E./100 gms.
		%	%		
1	27	62.5	37.5	1.44	72.2
2	30	65.0	35.0	1.02	51.1
3	40	70.5	29.5	.92	46.4
4	45	72.0	28.0	.80	40.3
5	48	75.7	24.3	.80	40.2
6	50	76.0	24.0	.76	38.4
7	55	76.2	23.8	.76	38.4

The analysis of the silt fraction of each solum presents its own individual picture, when related to its parent material. The quartz content was 62.5% at Sioux City, Iowa, where the soil had not weathered to any appreciable degree. This is a figure which did not differ much from the average figure for the combined parent materials. This mineral constituent of the silt fraction increased gradually on going southward, until in Mississippi where, with 55 inches rainfall, quartz comprised 76% of the silt fraction. The increase in resistant quartz indicates that the soil has undergone intense weathering. The calcium content of the silt fraction decreased with increasing quartz content. The soils which were developed under low rainfall and low temperature were low in quartz and high in calcium. This is indicative of very little breakdown of the silt particles by weathering forces. The soils that developed under high rainfall and high temperature had high quartz and low calcium contents in the silt fraction, which indicates that the silt particles have been broken down by weathering processes and that the calcium bearing minerals, such as felspars and hornblends have been decomposed. Recent studies by Graham (12) show that calcium bearing minerals weather rapidly when in particles of silt size.

The calcium content of the silt fraction of the Mississippi soil was only .76%, and the quartz content was about 80%. This suggests that the quartz-calcium ratio can be used as an index of the degree of weathering that loessial soils have undergone under any specific environmental or climatic condition.

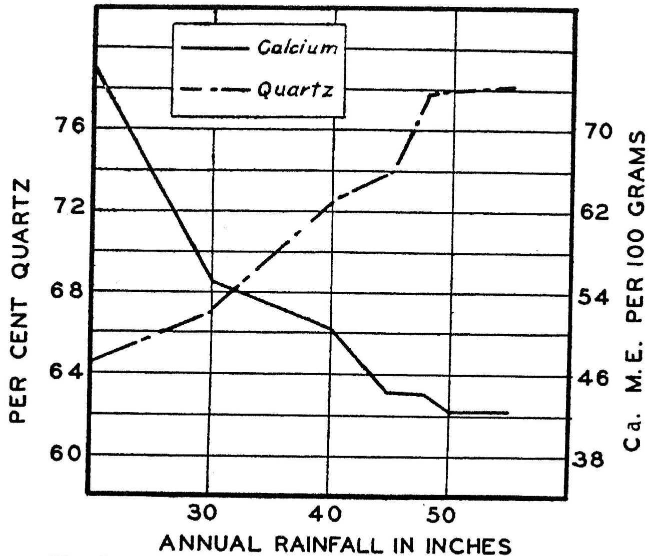

Fig. 5.—Calcium and quartz contents in the silt fraction of solum of loessial soils.

The close agreement between increasing quartz and decreasing calcium in the silt fraction in relation to rainfall, is shown in Figure 5, in which the calcium and quartz contents are plotted against the rainfall.

From the viewpoint of soil fertility, this graph would suggest that a plant grown on loessial soils developed under high rainfall and temperature would tend to be low in calcium and high in silica. This would give a plant composition which would reflect a low feeding value. In general, the data show that, as the silt particles weather, so that the calcium bearing minerals are decomposed and the calcium is leached out, there is a decrease in the exchangeable calcium in the soil for plant use and a corresponding increase in the content of quartz.

TABLE 8.—SUMMARY OF ALL ANALYSES OF THE STUDY

Location and No. of Profiles	Horizon	Mechanical Analysis			Exchange Capacity	M.E. Ca.	M.E. Mg.	M.E. K	pH	% O.M.	% Total N	C/N Ratio	Exchange Capacity of Clay	SiO_2/R_2O_3 Clay	% Quartz in Silt	% Ca in Silt
		% Sand	% Silt	% Clay												
No. 1 Sioux City, Iowa	A	19.32	61.70	18.96	17.35	47.00	5.66	.73	8.2	3.0	.19	9.2				
	B	11.53	69.91	18.53	13.12	46.50	5.78	.35	8.5				73	5.06	62.5*	1.44
	C	12.22	70.53	17.21	12.60	44.30	7.35	.25	8.7							
	D	12.20	72.00	15.79	13.00	45.25	8.65	.22	8.5						58.5	1.53
No. 2 Oregon, Missouri	A	13.76	64.75	21.41	21.08	23.00	7.20	1.35	7.5	4.0	.23	10.0				
	B	9.68	63.51	26.79	18.60	17.60	6.80	.50	7.8						65.0*	1.02
	C	8.87	68.42	22.92	15.55	29.10	9.50	.35	8.1							
	D	6.74	75.93	17.29	14.15	22.60	12.95	.43	8.0						60.5	1.34
No. 3 McBaine, Missouri	A	9.14	69.90	20.95	10.33	9.30	3.52	.25	6.80	2.1	.12	10.0				
	B	2.86	60.83	36.32	17.91	13.88	5.65	.42	5.90				66	4.03	70.5*	.92
	C	5.42	59.33	35.25	17.39	14.20	5.15	.23	6.25							
	D	28.69	48.09	23.22	11.20	9.35	4.15	.18	6.85						68.2	1.07
No. 4 Cape Girardeau, Missouri	A	4.37	77.47	18.90	9.54	5.66	2.28	.18	5.65	1.70	.10	9.9				
	B	2.90	67.85	29.27	15.15	9.40	2.28	.19	5.10						72.0*	.80
	C	4.49	75.25	20.25	14.43	11.30	2.90	.23	5.25							
	D	3.37	78.11	18.40	13.50	9.54	2.91	.23	5.90						68.0	1.08
No. 5 Wicliffe, Kentucky	A	2.90	84.50	12.53	7.90	3.29	2.02	.11	5.05	1.88	.09	12.0				
	B	2.28	65.60	31.59	16.00	5.33	5.45	.22	4.80				50	3.24	75.7*	.80
	C	1.94	78.37	19.70	11.82	8.00	4.92	.18	5.65							
	D	.56	88.80	10.63	6.95	15.75	11.00	.13	8.30						61.5	1.46
No. 6 Memphis, Tennessee	A	3.12	85.20	12.07	7.07	3.03	1.88	.26	5.00	1.83	.08	9.5				
	B	2.19	76.62	21.72	11.44	5.03	2.34	.23	4.85						76.0	.76
	C	2.10	77.19	20.08	13.03	3.11	3.02	.23	5.15							
	D	1.00	94.00	5.00	6.00	18.60	13.37	.11	8.45						58.8	1.42
No. 7 Vicksburg, Mississippi	A	4.37	83.15	12.48	6.55	1.98	1.56	.13	5.25	1.78	.09	9.2				
	B	2.87	74.45	26.70	15.79	3.87	3.51	.49	5.30				44	2.56	76.2	.76
	C	3.11	76.43	20.42	13.12	4.13	4.53	.38	5.00							
	D	1.00	93.15	5.00	5.94	24.26	12.54	.31	8.30						58.0	1.52

*Silt listed as B horizon represents entire Solum.

The silt fraction of the soils collected from locations representing 30 inches and less of annual rainfall might be expected to contain a reserve of calcium and other bases that will be released as the processes of weathering continue. This may explain why some of the loessial soils, even though subjected to sufficient rainfall to leach out all excess bases, still maintain free carbonates in the upper portion of the profiles. The release of bases by breakdown of silt particles apparently replaces all that is lost by the leaching processes and the soil maintains a high base saturation.

DISCUSSION

The results obtained in this study (analytical data summarized in Table 8, Page 26) show that climate in terms of "rainfall and temperature" within a range of approximately 11° latitude or as limited as that between Sioux City, Iowa and Vicksburg, Mississippi produces definite changes in soils. These changes can be detected from the visual properties as well as chemical properties. The clay content of the solum increased with increasing rainfall and temperature, from north south. As the clay content increased, distinct textural horizons or zones of accumulation were more apparent, indicating the development of more definite profiles.

There was a close relationship between the exchange capacity of the total soil and the rainfall. The exchange capacities varied according to the clay content, but equal amounts of clay did not always yield the same exchange capacity. The capacity of the clay per unit mass decreased from north to south. The decreasing exchange capacity with increasing climatic intensity for constant amounts of clay is evidence of change in the nature of the clay. This was further substantiated by a more detailed study of the clay fraction, separated from the subsoils, of four of the profiles. This study indicated that the climate governs the type of clay formed in the solum of a soil, and that the type of clay in the greater depths of the loess of the southern region could not have been formed under the climate that prevails there at present. The similarity of this clay in the parent material to that in the solum of some of the profiles collected further north suggests that a climate similar to that of the north may have prevailed in the south when the clay in the deep parent material of the loessial soils there was formed. At present this deep parent material of the south is still unleached. It appears that only rapid deposition of the loess containing a small amount of clay that was produced under other climatic environment could account for a clay so different from that which the climatic conditions of the locality today demand.

The exchangeable bases and pH showed a decrease as the rainfall increased. Calcium in the exchangeable form decreased more than did magnesium and potassium. The relative decrease in pH was not as great as the decrease in exchangeable bases and suggests limitations in the use of pH determinations as measures of available bases or plant nutrients present in a soil. The data support the belief that there is very little development of a soil, in terms of the movement of clay downward for the production of definite textural horizons in the profile, until most of the free bases such as calcium carbonate, for example, have been leached out of the soil. The base saturation also decreased with increasing rainfall although all the relatively immature soils used in this study were relatively high in this respect.

The organic matter and the total nitrogen contents in the surface horizons of the samples as arranged in climatic order decreased in general as the rainfall and temperature increased. The nitrogen content in Holt County, Missouri, was approximately three times that for a soil at Memphis, Tennessee. This difference is of considerable significance, since the vegetation was the same. The decrease in organic matter, substantiates the fact that organic matter will not accumulate within the soil to any great degree under high temperatures and high rainfalls.

Chemical and mineralogical study of the silt fractions of the solum and parent materials indicated that the latter were all similar throughout the distance covered in this study. The quartz and calcium contents of the silt separate of the solum varied with the rainfall. The quartz content increased with rainfall, while the calcium decreased in the same order. This suggests that under higher rainfall and temperature the silt particles in the solum have undergone more weathering and the calcium-bearing minerals have decomposed, thus concentrating the resistant quartz. This is significant since the soils were all decidedly silty in texture, and the silt fraction is probably the main source of all the available plant nutrients except that derived from the organic matter. The low calcium content and the high quartz content obtained on the most southern soils suggest that plants grown on these soils should be low in calcium and other bases and high in silica which would decrease the feeding value of the forage.

The interpretation of the developmental features of the soil as they are expressions of change induced by the factors of soil development is a signal achievement of modern Soil Science. A definite correlation between soil development and soil productivity is desirable although sometimes very difficult to establish. In this study an attempt was made to measure soil changes with all factors constant, except climate, by determination of (a) the amount of clay, (b) the nature and kind of clay, (c) the available bases, (d) the degree of base saturation, (e) the organic matter, and (f) the reserve of nutrient-bearing minerals in the silt fraction in the soil. The summarized results are shown in Table 8. Although these data were used to measure soil development, it is interesting to note that Albrecht (2) points out that soil productivity is determined by the same soil conditions mentioned above. The investigation warrants the observation that climatic conditions induce definite changes in soils. These progressive changes represent what is known as soil development which is revealed by profile features. These changed conditions can be measured by mechanical and chemical means. Thus, it seems that mechanical and chemical determinations of certain features of a soil, reinforced by mineralogical study, may be an adequate method of measuring soil development and at the same time evaluating the productivity of the land.

SUMMARY AND CONCLUSIONS

A study was made of the physical and chemical changes in the soil induced by climate. The brown loessial soils of central United States were used in this investigation since they have all factors of soil development constant except climate. Determinations or quantitative measurements were made giving attention to the size distribution of particles, exchange capacity, exchangeable bases, and humus content in the soils. The chemical and mineralogical contents of the silt and clay fractions were also studied because these represent the most highly weathered portion of the soil. On the basis of this study, the following variations in the development of loessial soils are revealed as a result of climatic differences:

1. The amount of clay increased with rainfall and temperature.
2. The nature of the clay changed with differences in climate as revealed by the changes in exchange capacity and SiO_2/R_2O_3 ratio.
3. The available bases decreased under more humid and warmer climatic conditions.
4. The base saturation appeared to be a function of the intensity of the climate, which decreased with higher temperature and rainfalls beyond 40 inches.
5. The organic matter and nitrogen contents decreased with increased temperature.
6. The quartz and calcium contents of the silt fraction of the parent materials were nearly constant for all locations.
7. The quartz in the silt fraction of the solum increased with the rainfall, while the calcium decreased.

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