Lectures on

Soil Organic Matter

by

Prof. Dr. W. Flaig*
Visiting Professor

March, April, May 1959

Department of Agronomy
Iowa State College
Ames, Iowa, U. S. A.

Business address:

* Direktor de Institut für Biochemie des Bodens Forschungsanstalt für Landwirtschaft, Braunschweig-Volkenrode

Home address:

Braunschweig, Bundessallee 50
Germany

Foreword

To my friends and the friends of the subject.

In this manuscript are some unpublished results and therefore only for friends and not to use for publication.

I would enjoy having any comments on this material.

W. Flaig

Acknowledgments

This manuscript came about as a result of the kind invitation of Prof. Dr. W. H. Pierre, Head, Department of Agronomy, to give lectures about soil biochemistry. I am very thankful for this opportunity.

I would like to express my best thanks also to my colleague, Prof. Dr. Lloyd Frederick, who stood by me helpfully at all times during the writing of these lectures in the English language and I appreciate his suggestions during our many discussions.

Without the help of his co-workers, Messrs. McIntosh Sims, Horton, Brown, and of the secretaries, Mrs. McLaughlin, Misses Sansgaard and Zart, it would not have been possible to mimeograph the lectures. Also to these, many thanks.

June, 1959 W. Flaig

SOIL ORGANIC MATTER

Table of Contents

Humic Substances and Plant Growth in General

The system "humus" is a dynamic one. On the one hand, products decompose; on the other, new are always synthesized. The process depends upon the soil formation, the different kinds of plants, the amount of micro-organisms and mineral nutrients, the influence of the climate, the chemical and physical properties of soils, and last but not least, upon the action of man. The combination and the interactions of all these factors characterize the organic part of the soil, the quantity and composition of the humic substances, the distribution in the soil, their characteristic properties and the kind of sorption on the minerals. In contrast to the true inorganic composition of pulverized minerals and rocks or their products of weathering a soil is formed of inorganic and organic components. The influence of the organic substances on the alteration of the soil begins with the formation of the soil. The organic substances have an effect on the parent materials. Some authors speak of bio-geo-chemical processes. They observed that the micro-organisms take part in the beginning of the processes. Several authors, Winogradsky (1896), Nadson (1903), Omeliansky (1927) and others, showed that micro-organisms decompose different compounds of iron, sulphur, calcium, phosphorus - some believe also silicate - during their metabolism. The importance of the soil organic matter is given by the definition of the soils.

The organic substances have an important function for the origin of soil productivity. After mineralization the inorganic compounds of the plants serve as plant nutrients. At the same time, the organic substances have a function for the formation of soil productivity. These functions have more a physical character, as in the case of the formation of soil structure. The influence of soil organic matter on physical properties of the soil, such as water capacity and regulation of temperature, is important. The exchange capacity is very much influenced by the amount of organic substances in the soils. Several aspects of the physical properties we will discuss later on.

If we discuss the effect of soil organic matter, we must divide the compounds in the soil into those that are specific, like humic substances and those that are non-specific, for instance, aliphatic acids. The most simple influence of non-specific organic substances on the minerals is that of increasing the solubility of phosphates, carbonates and other compounds. The roots secrete carbon dioxide and organic acids. These and other metabolic products are produced also by micro-organisms. The low molecular organic acids are butyric, lactic, acetic, propionic, glucuronic, oxalic, fumaric, etc. Among their metabolic products there are also inorganic compounds like carbon dioxide, HNO_3, H_2S.

Besides other authors, Omeliansky (1927) investigated the influence of different metabolic products of micro-organisms on the solubility of mineral compounds. Such reactions have great importance for the processes of life in soil. Of the papers on the transformation of phosphates into soluble form the publications of Stoklasa (1911) and the more recent ones of Pikow Skaja (1948) and Gerretsen (1948) can be mentioned. S 1 K/676. In a paper by Waksman in 1927, the solubility of different phosphates in organic acids is described. From this it can be seen that even slightly soluble phosphates become soluble through organic acids. Investigations as to the decomposition of minerals and rocks were made by several scientists. On this I should not want to comment any further.

Not only the acids from the metabolism of lower organisms and all plant roots seem to play a part, but also some physical processes. Frey in 1924 published a paper about the weathering of rocks by lichens. In his opinion the immediate effect of slimy substances of lichens on the substrate consists of rocks and minerals being broken off in little particles as the slimy substances dry. This has to be explained by the fact that the slimy substances of micro-organisms possess a strong adhesive capacity, since the breaking up of the adhering rock particles during drying of the slimy substances requires tremendous mechanical forces.

The humic substances also take part in splitting up the minerals. They have nearly the same effect as weak acids. The bases of the minerals are removed and silicic acid is accumulated. In this stage, the sesquioxides are not dissolved. If alkali is present, the alkaline solutions of humates are formed. Glinka (1935) believes that these alkaline solutions also intensively decompose the silicates. The decomposition is accompanied by an exchange among the undecomposed parts of the aluminum silicates or the mineral complexes in the solution. Therein the alkali and the earth alkali as well as the sesquioxides take part.

In other cases, the humic substances have a transportation effect. An example for these processes is the formation of podsol. In connection with the development of the colloid chemistry, this process of formation of podsol has been discussed from the colloid chemical standpoint (Gedroiz 1927, 1928). According to his ideas, the humus colloids are dispersed by the acid reaction in the upper horizons of podsolic soils. They show a protective effect towards the inorganic soil colloids such as hydrates of ferric- and aluminum-oxide and clay particles. The sols leached in the lower horizons would be neutralized by the bases present there or would be flocculated by each other. Rode (1937) drew the conclusion that the most significant action in this process belongs to the fulvic acids. Aluminum and iron form complex compounds with these and migrate as such. Tjurin (1940-1944) and Ponomarewa (1947, 1949) described that the most important effect in the process of podsolization is the mobilizing of the sodium and calcium salts of fulvic acids and their ability to form complex salts with the hydrates of sesquioxides. Their solubility, their reactions and flocculation depends upon the pH value and the concentration of the fulvic acids as well as of the sesquioxides. The mobility of the ferric ions is greater than of the aluminum. The organo-mineral complexes migrate under weak acid conditions, which are found in podsolic soils, as dispersed sols from the upper into the deeper horizons, which have a nearly neutral reaction. The complexes are flocculated as gels and form a new illuvial horizon.

Sallans, Snell, et al (1937) showed that not only fulvic acids but also definite acids such as aliphatic acids may form soluble calcium salts, and especially citric and oxalic acid form complex salts with iron under acid conditions. These salts coagulate in neutral or weak alkaline conditions (Wiszhniakow and Rabinowitsch (1935). The low molecular acids cause therefore the movement of calcium and potassium in the podsolic soils.

These are some examples of the effects of organic matter on the different kinds of processes in the soil. Now, we must try to subdivide them to get some classification.

For the formation and alteration of humic substances during the circulation of carbon in nature we must have at first an idea about the amount distributed on the earth. Waksman (1936) has given the following numbers. S. 2 K/678.

It can be noticed that carbon content of the living organisms is nearly twice that of the cultivated part of the soil. If we compare how many organic chemical compou are known in the organisms and in the soil today, it is not the ratio 2:1. There are many more compounds unknown in the organic part of the soil than in the organisms. This fact should be an encouragement to work about these compounds. S. 3 A/45.

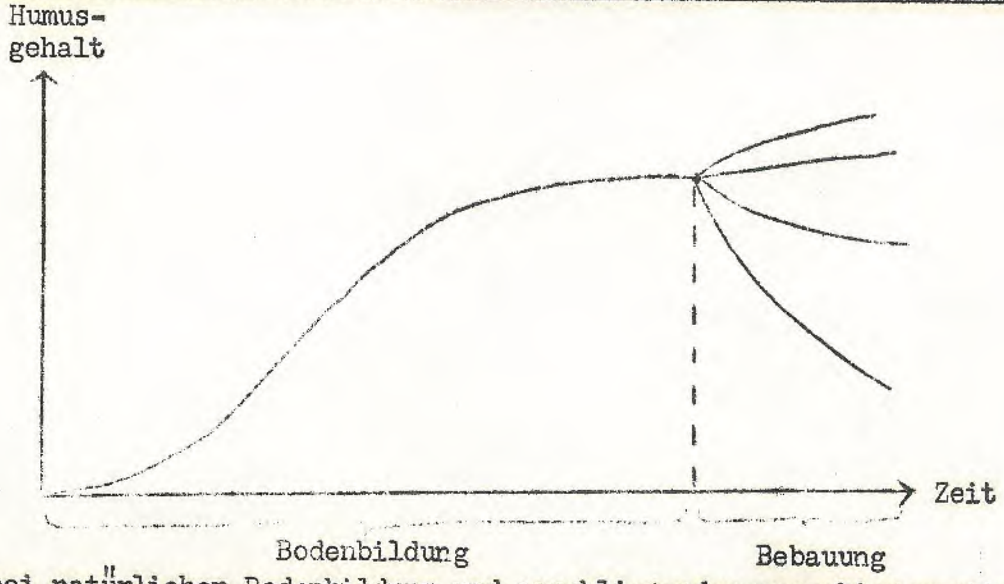
Waksman, 1936	Kohlenstoffgehalt in Mill. Tonnen
Atmosphäre	600
Hydrosphäre	16400
Anthrazit	422
Bitumenkohle	2732
Braunkohle	1499
In allen Torfarten	1123
In der Bodenschicht bis 30 cm	400
In lebenden Organismen	700

K/676

Die Löslichkeit verschiedener Phosphate in organischen Säuren (Waksman, 1927)

Phosphate	P_2O_5-Gehalt in %	Prozentuale Löslichkeit in 0,5% iger		Löslichkeit in CO_2-haltigem Wasser in %
		Essigsäure	Fumarsäure	
Dicalciumphosphat	41,0	97,13	99,54	45,79
Tricalciumphosphat	41,0	73,83	90,90	25,01
Monodiferriphosphat	47,0	19,58	29,35	27,41
Triferriphosphat	38,0	8,13	16,00	7,87
Triammoniumphosphat	44,0	22,09	93,79	-
"Florida"-Phosphat	36,0	16,31	54,04	-
Granitboden	0,103	7,76	6,79	4,85
Basaltboden	0,180	7,22	8,33	5,50

S 4 A/44



Humusgehalt bei natürlicher Bodenbildung und anschließender verschiedenartiger Bebauung (schematisch, nach Jenny, 1941)

If we look at the percentage of the carbon and other important plant nutrients such as the nitrogen in the raw materials for soil, in rocks, there are on the average only 0.1% carbon and 0.001% nitrogen. In the soils there are 0.1% nitrogen and 2% carbon. The humus calculated from these data is nearly 3 up to 4%. Winogradow (1954). S.4 A/44

In soil formation there is an increasing of humus content with time (Jenny 1941, Deuel, H., Humus and Bodenforsuchtbarkeit, Schweiz. Landw, Monatshefte 33, 2, (1955). After a certain time, there is a balance between the formation and decomposition of humus. The level of humus in a soil depends mainly upon the climatic conditions. During cultivation the humus content usually decreases by the manipulations of man. The amount and speed of decrease depends upon the kind of management.

The increase of humus content can be caused by special natural conditions, for instance, by formation of fens (mucks or peats), or by artificial conditions such as in garden soil, or the "Plaggenböden" in Netherlands or north-western part of Germany.

The methods for preservation of humus content are not completely known. Sometimes it is done by organic fertilizing. But also inorganic fertilizers are a help to preserve the humus content, especially nitrogen fertilizer. Adequate inorganic fertilization results in an increased yield of organic residues. There are some reactions of humification of those residues and nitrogen consumption.

It has been mentioned above that the humus content depends also upon climatic conditions. The formation and decomposition of humic substances are in a balance which is characterized not only by the climate but also by the inorganic components of the soils.

Tiurin (1937) made some extensive studies to determine the geographic regularities of formation of humus in his country. (See p. 1 of mimeographed graphs on studies by Tiurin). He included the most important soil types which are described briefly below.

Characteristics of soils.

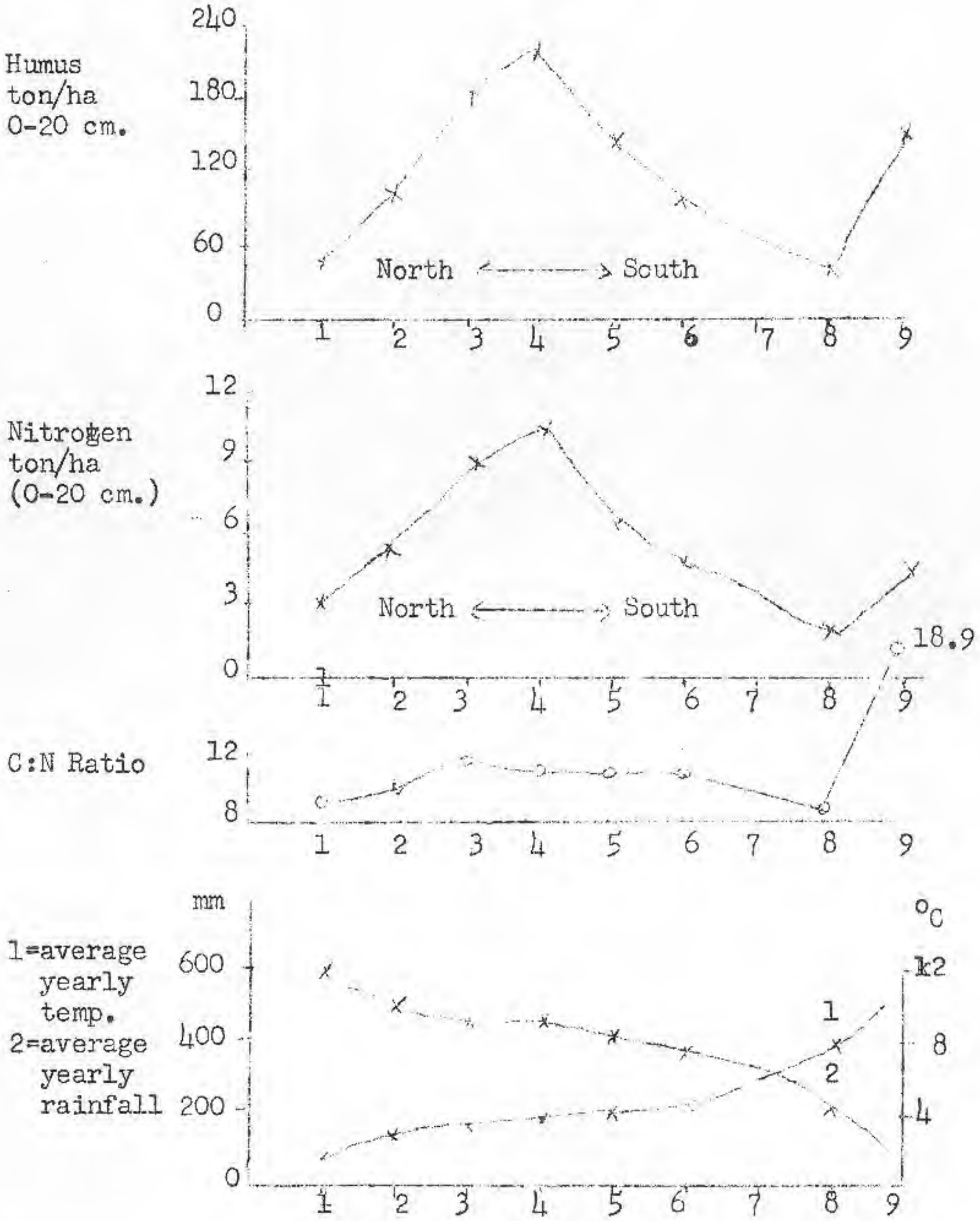
The most important properties of soils in No. 1 to 9 on the average.

No. 1. Podzolic soil

The investigated podzolic soils are mainly in the Northern part of Russia and in the North of Siberia. They cover a large area. In these humid areas the average yearly rainfall amounts to 500 to 600 mm and decreases to the East down to 300 to 400 mm. The podzolic soils are mainly to be found on moraines, alluvial sediments and sands. They are acid soils with a pH value of 4.3 up to 5.2. The number of micro-organisms is limited.

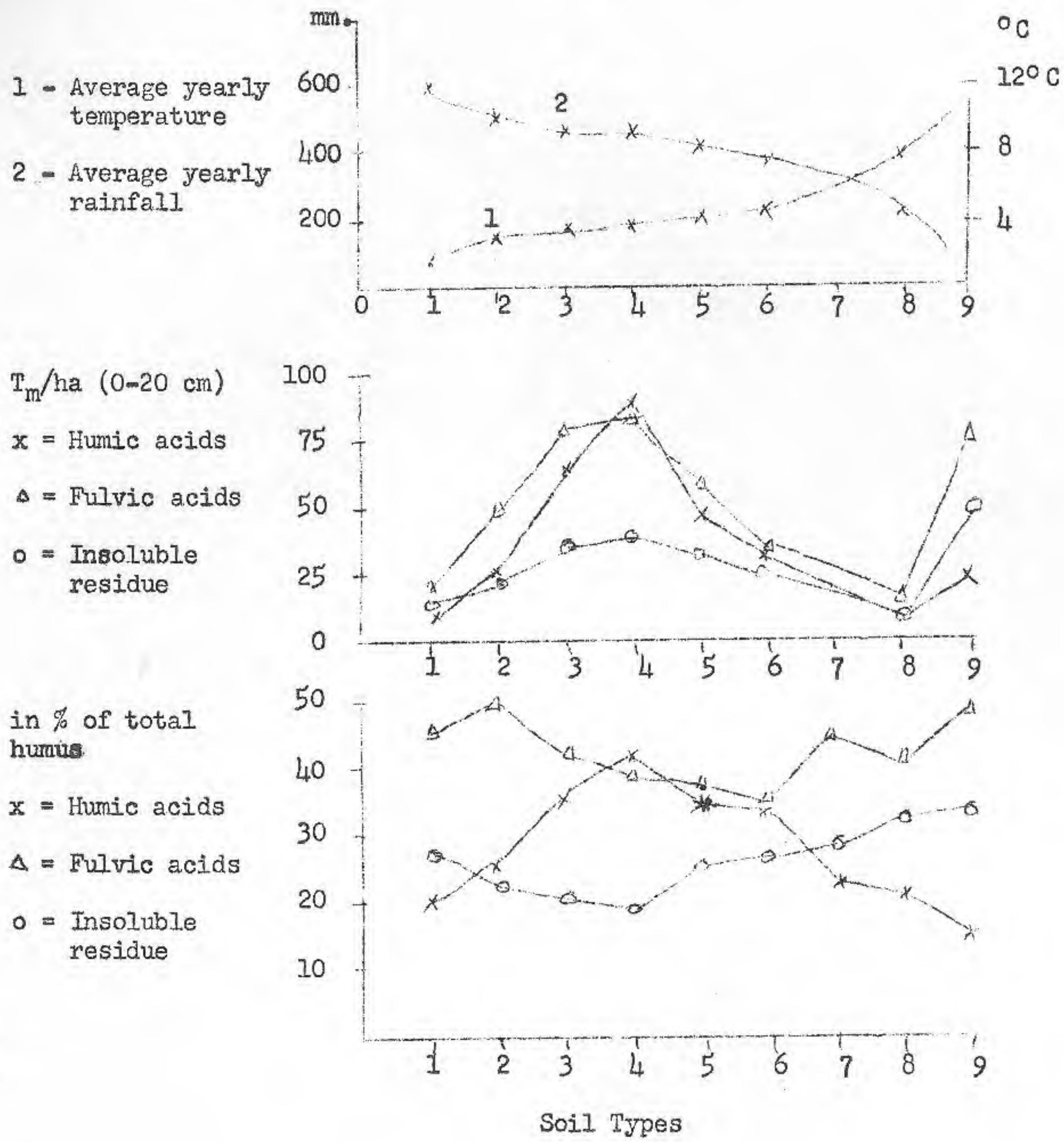
No. 2. Grey podzolic forest soil

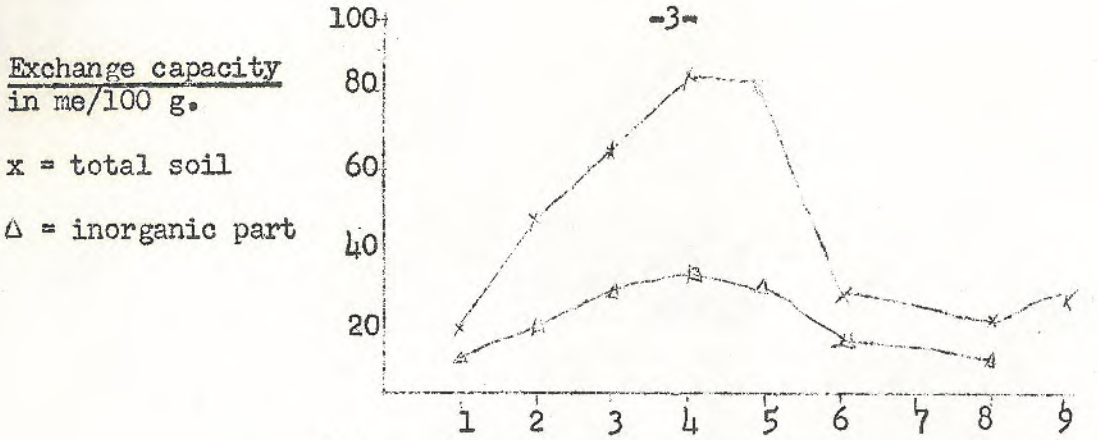
Between the podzolic soils and the chernozem there is a narrow strip. The development of the grey podzolic forest soils can be found in deciduous forests, mainly in oak forests. The opinions on their development are yet divided. Some authors believe that the grey forest soils are formed by the influence of the advanced forest vegetation, which has degraded the chernozem. They are weakly acid. The pH value is an average 6.5. (Comparable to Gray-Brown Podzolic?)

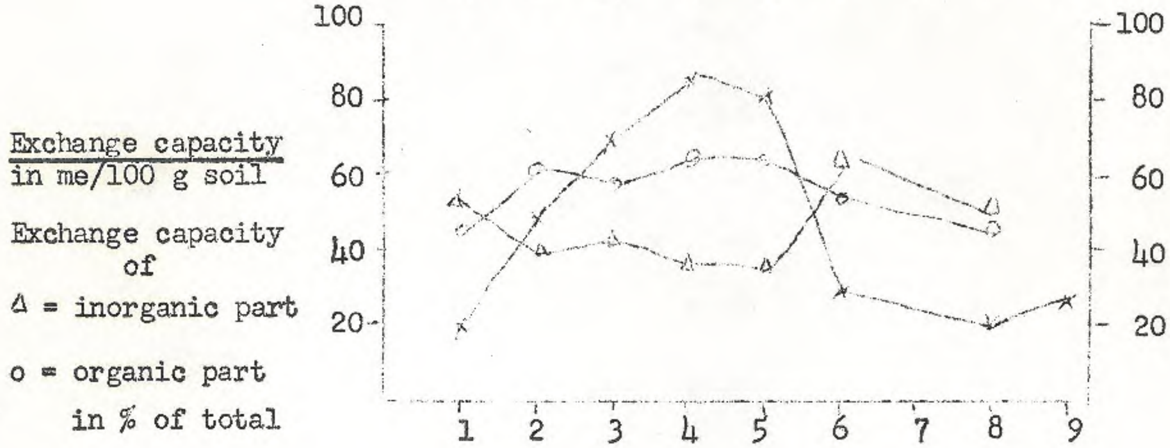


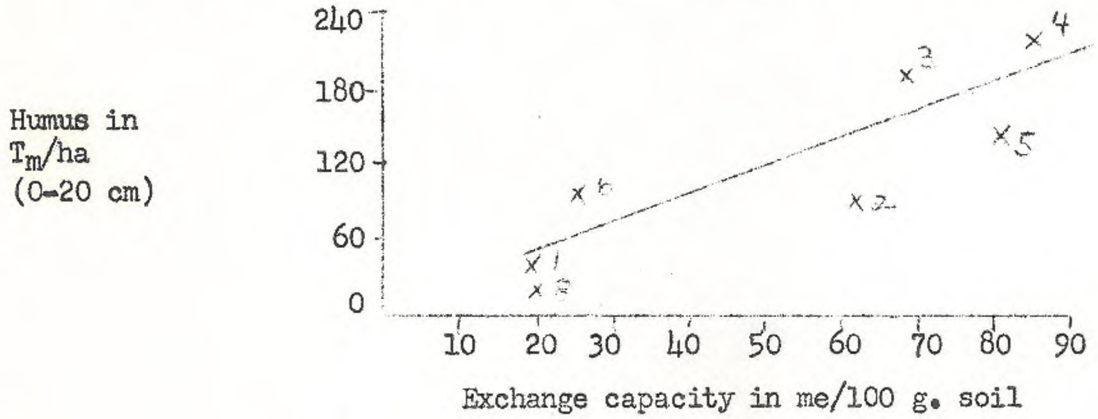
1. Podzolic Soil
2. Grey-Podzolic Forest Soil
3. Degraded Chernozem
4. Deep Chernozem
5. Normal Chernozem
6. Chestnut Soil
7. Solonez
8. Grey-Earth
9. Red-Earth

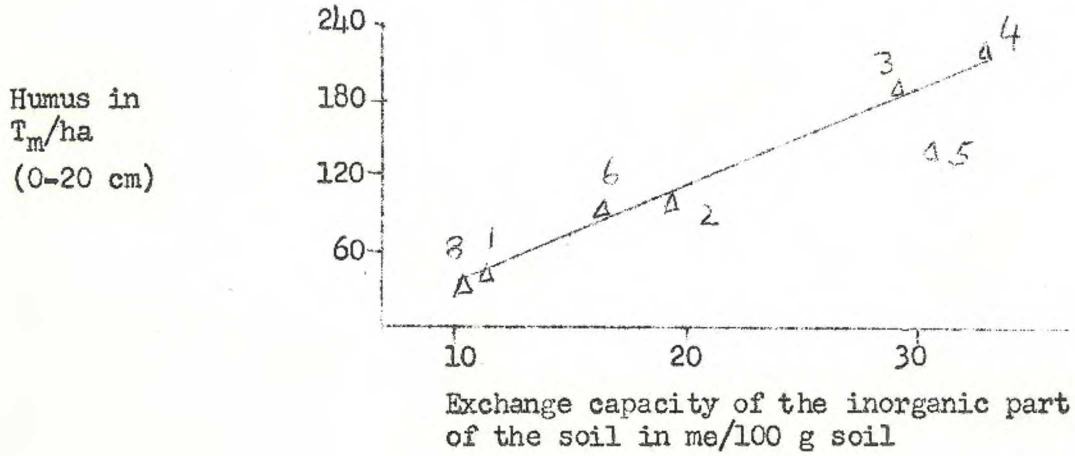
Summary of several papers of Tjurin, Kononowa a. o. (M. M. Kononowa: Die Humusstoffe Des Bodens. VEB Deutscher Verlag Der Wissenschaften, Berlin (1958) ubersetzt und bearbeitet von H. Beutelspacher.

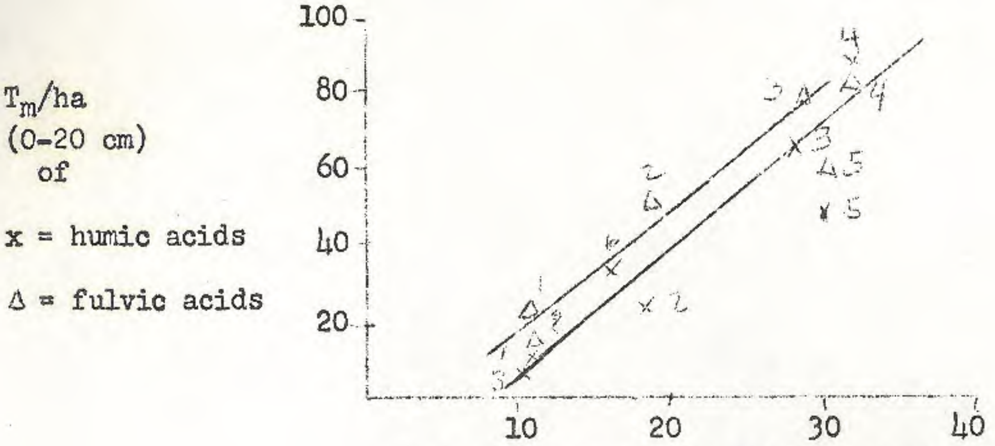

1 - Average yearly temperature
2 - Average yearly rainfall
mm.
600
400
200
°C
12° C
8
4
0 1 2 3 4 5 6 7 8 9
T_m/ha (0-20 cm)
x = Humic acids
Δ = Fulvic acids
o = Insoluble residue
100
75
50
25
0
1 2 3 4 5 6 7 8 9
in % of total humus
x = Humic acids
Δ = Fulvic acids
o = Insoluble residue
50
40
30
20
10
1 2 3 4 5 6 7 8 9
Soil Types


Exchange capacity in me/100 g.
x = total soil
Δ = inorganic part
100
80
60
40
20
1 2 3 4 5 6 7 8 9


Exchange capacity in me/100 g soil
Exchange capacity of
Δ = inorganic part
o = organic part
in % of total
100
80
60
40
20
1 2 3 4 5 6 7 8 9


Humus in Tm/ha (0-20 cm)
240
180
120
60
0
10 20 30 40 50 60 70 80 90
Exchange capacity in me/100 g. soil


Humus in Tm/ha (0-20 cm)
240
180
120
60
10 20 30
Exchange capacity of the inorganic part of the soil in me/100 g soil



Exchange capacity of the inorganic part of the soil in me/100 g soil

Soil Type	Humus T_m/ha (0-20 cm)	Nitrogen T_m/ha (0-20 cm)	C:N	Humus in % of soil	Humic acids in % of humus	T_m/ha (0-20 cm)	Fulvic acids in % of humus	Fulvic acids T_m/ha (0-20 cm)
1. Podzolic Soil	53	3.2	9.7	3.5	20	11	47	25
2. Grey-Podzolic Forest Soil	109	6	10.5	3.0	25	27	50	54
3. Degraded Chernozem	192	9.4	11.8	7.5	35	67	42	81
4. Deep Chernozem	224	11.3	11.5	10.0	40	89	39	87
5. Normal Chernozem	137	7.0	11.3	7.5	35	48	37	61
6. Chestnut Soil	99	5.6	11.2	2.7	34	34	35	35
7. Solonez	-	-	-	3.0	23	-	45	-
8. Grey-Earth	37	2.5	8.2	1.5	27	8	41	15
9. Red-Earth	153	4.7	18.9	5.0	15	23	50	76

	Insoluble Residue in % of humus	Insoluble Residue T_m/ha (0-20 cm)	Exchange capacity me/100g soil	Exchange capacity of the inorganic part in % of total	in me/100 g	Exchange capacity of the organic part in % of total
1.	28	15	19.6	56	11	44
2.	22	24	49.0	39	19	67
3.	20	38	68.5	42	29	58
4.	19	43	86.5	38	33	62
5.	25	34	82.5	37	30	63
6.	26	26	25.3	65	16	35
7.	28	-	-	-	-	-
8.	32	12	20.0	52	10	48
9.	33	50	25	-	-	-

No. 3. Degraded chernozem

The podzolised respectively degraded chernozem and the leached chernozem are distributed in the wood prairie and in the Northern part of the prairie. The relatively high moisture causes a more intensive decomposition of the plant residues in the soils and leaching of calcium carbonate and other mineral compounds. They are weakly acid. (Comparable to Brunizem?)

No. 4. Deep chernozem

The deep chernozem is mainly in the West of Russia. The depth of the humus-horizon is from 80 to 140 cm. The typical chernozem is neutral and has a crumb structure which is not compact and porous. (pH value 6.8 to 7.2)

No. 5. Normal chernozem

The normal chernozem is distributed in the Ukraine. The humus can have a depth up to 1 m. The reaction is also nearly neutral.

No. 6. Chestnut soil

In the area of the chernozem soil there are extreme fluctuations of air temperature during days and season. There also exists a high transpiration. In the surface soil there is a high amount of calcium carbonate and magnesium carbonate. The humification of the plant residues is very slow.

No. 7. Solonez

Solonez soils contain exchangeable sodium in their sorption complexes. They are distributed in spots up to the size of 1 hectare.

No. 8. Grey earth

The grey earths are formed on loess in the lower mountains of the Asiatic part of Russia. In the summertime, the temperature of the air can be up to 40° C and the temperature of the soil rises up to 80° C. The pH value is between neutral and weakly alkaline. There are gypseous horizons at the depth of 80 to 100 cms. (Comparable to Gray Desert or Brown?)

No. 9. Red Earth

This type of soil is found in the humid tropical areas. The high amounts of rainfall, yearly up to 2000 mms, and the high temperatures cause a high speed of weathering processes. In the upper horizons there are remarkable amounts of sesquioxides. The ferric hydroxide hydrates give the soils a yellow to red color. The sorption complex is saturated with calcium-, magnesium-, and hydrogen ions. The pH value is acid. (Comparable to Latosol?)

The humus reserves depends upon the temperatures and the rainfall. There is no steady increase from the North to the South, from podzolic soils to grey earth. Instead, the highest humus reserves are in area with an average rainfall of 400 mm and an average temperature of 4° C, in areas of deep chernozem. Surely this result does not only depend upon these two climatic factors; the inorganic part of the soil also plays a role. It is rather difficult in such a case to work out regularities, because the conditions vary too much.

Wolobujew (1948) continued these investigations and gave a formula concerning the humus reserve and the value of the so called hydrofactor (Hf). This factor characterizes the change of moisture at different quantities of rainfall (P) and the average of the yearly temperature (T).

$$T = 43.2 \log P - Hf$$

T and P are variable, Hf is a parameter, which has a certain importance for every hydroseries.

The soils rich in humus have a medium hydrofactor from 105 up to 112. Deep chernozems with the highest content of humus have a hydrofactor of 110. At lower values than 105 and higher ones than 112, the humus content falls off rapidly. The cause of this regularity, for which Wolobujew gives empirical equation, is unknown.

Jenny (1948) considered the factors of soil formation as independent variable factors. He determines the one or other property of the soils depending upon one factor, believing that the different others are constant. But if one factor is changed, the others are also no longer the same. Temperature or moisture, etc., cause different microbiological activity. The equations of Jenny can be used for limited conditions of soil formation. The dependence of the amount of nitrogen upon the moisture between the mountains and the Atlantic ocean follows the formula:

$$N = 320 (1 - e^{-0,0034NSQ})$$

N = Total amount of nitrogen in a depth of 0-18 cm.
NSQ = Moisture factor according to Meyer.

Jenny emphasizes that this equation is not to be used for soils which are under analgous climatic conditions and had been covered with forest in earlier times.

Jenny also gave an equation for the relation betw een the amount of humus and the temperature. This he formulated following the law of van t' Hoff, according to which chemical reactions are accelerated two-or three- fold with the increase of temperature of 10° C.

$$N = C \cdot e^{-kT}$$

N = Total amount of nitrogen
T = Temperature
C and k = constants

If the soils have uniform conditions of moisture and an identical plant vegetation, the speed of decomposition must be lowered by one-half or one-third with a decreasing of temperature for 10° C. Some of the biological factors disturb this equation.

The next figure shows several numbers of the humus content of different soils. (Goldschmidt (1954).

Organic C-Content in % 50 cm Soil Depth	C
fen-soils	6-33
chernozem	5
prairie soil	3.5
podsol	1.7
tropical virgin forest	0.5-7

The content of carbon differs from horizon to horizon. The data give therefore only a survey in general. Except the fen soils for which extreme conditions exist, the content of humus does not vary as much as the climate.

Humus Content of Soils in Switzerland

Percent of investigated soils	humus content weight %	Indication of humus content
3.5	<2	poorly humic
35.7	2-5	weakly humic
42.9	5-10	humic
11.7	10-20	richly humic
6.8	>20	very richly humic

Frey (1948) determined the content of humus in 20,000 samples of soils from Switzerland. This country is very small and has extremely different conditions; mountains with an altitude of 4,000 m and plains only 200 m. The climate in one case has an average under 0° C and in another is nearly subtropical. The soils are divided into poorly humic, weakly humic, humic, richly humic, very richly humic soils.

In the next table the content of humus, nitrogen and phosphoric acid of some Russian soils are summarized. (Kononowa, Buch S 44 vgl. Lit. Stellen.)

S 8 K/679

Vorrat in Tonnen pro Hektar an Humus, organisch gebundenem Stickstoff und Phosphorsäure in den Böden der UdSSR

Boden	Humus in der Schicht*)		Stickstoff in der Schicht*)		P_2O_5 in der gepflügten Schicht**)	
	0-20 cm	0-100 cm	0-20 cm	0-100 cm	mineralisch	organisch
Podsolige Böden	53	99	3,2	6,6	1,27-1,44	0,56-0,63
Graue Waldböden	109	215	6,0	12,0	1,72	1,32
Ausgelaugte Schwarzerde	192	549	9,4	26,5	-	-
Mächtige Schwarzerde	224	709	11,3	35,8	2,87	1,56
Gewöhnliche Schwarzerde	137	426	7,0	24,0	-	
Dunkelkastanienfarbige Böden	99	229	5,6	-	2,09	0,63
Grauerde	37	83	2,5	7,5	1,68-1,91	0,30
Roterde	153	282	4,7	10,5	-	-

*) Aus den Arbeiten von Tjurin (1949)
**) Aus den Arbeiten von Cheifez-Strausberg (1950)

It must be discussed about the nitrogen and phosphorus forms of organic compounds. Especially nitrogen is mostly connected with organic matter. (Iodidi (1910), Schmuck (1914), Lathrop (1916), Kudriawzewa (1924), Kojima(1947), Bremner (1950), Davidson, Sowden and Atkinson (1951), Dadd, Sowden and Pearsall (1953), Stevenson, Marks, Varner, and Martin (1952)). By hydrolysis with inorganic acids, amino acids could be identified.

One part of nitrogen is not hydrolysable. This is considered as combined heterocyclic form. Furthermore it has been described that the availability of nitrogen and phosphorus compounds to the microorganisms is influenced by adsorption on different inorganic soil colloids. Ensminger and Gieseking (1942), Mortland and Gieseking (1952) and other authors, observed that clay minerals decrease the enzymatical hydrolysis of organic phosphorus compounds such as phytin, lecithin and others. Goring and Bartholomew (1949, 1950, 1951, 1952) have published that the mineralization of nucleic acids is lowered more by bentonite than by kaolinite. Allison and Pinck (1951), and Douglas and McLaren (1954) had the same results.

In some cases, for instance chernozem, the reserves of humus are remarkable. But it is not sure that crops can use all this nitrogen as a plant nutrient. A large amount of this nitrogen is involved in the humic substances. With the mobilization of this nitrogen the humic substances decompose. The physical properties of the soil would also be altered, and therefore the soil productivity. The decrease of the soil productivity is inevitable, if the natural productivity only is used. The reserves of humus disappear more and more and with them the reserves of plant nutrients. It is therefore impossible to produce high yields without fertilization, especially with nitrogen.

One of the most noticeable raw materials for the formation of humus are the residues of the roots. Tiurin (1946) has given a summary of different papers.

S 9 K/689

Laumbwald = deciduous forest
Nadel = coniferous forest
Mischwald = mixed forest

Waldboden = forest soil
jumg fräu licher Boden = virgin soil

It has been mentioned above that the participation of the plant residues depends also upon how they are incorporated into the soils. The composition is not the only important factor. The figure gives an idea on the reactions between the amount of plant residues, the kind of incorporation and the reserve of humus in the soils.

The largest amount of reserves of roots is found in the forested soils of the prairie or the forest prairie zone. Their weight is 20-27 tons per ha in the layer of 0-27 cm. But the amount of humus is lower in the forest soils than in the idle land, although the content of humus is higher in the idle land with 11-12 tons per ha.

There cannot be observed any direct relationship between the amount of humus and the reserves of roots in the different soil types. In some cases such as strongly podsolic, loamy clay soil, the amount of humus in the depth of 0-20 cm is the same but the reserves of roots are very different.

Trockengewicht an Wurzeln und Humus in Tonnen pro Hektar (Tjurin, 1946)

Boden	Pflanzenbestand	Horizont in cm	Humus	Wurzein: lebende: insgesamt	Wurzein: lebende: davon dünne	Wurzein: tote	Autor
Podsoliger Boden, Lehm (Versuchsstation Sobakino, Moskauer Gebiet)	13jähr. Brachland	0-20	53,2	12,88	10,0	-	Katschinski, 1925
	Roggen	0-20	53,2	4,41	2,33	-	
	Hafer	0-20	53,2	3,68	3,25	-	
	Mischwald	0-12	32,1	18,58	7,00	-	
		0-27	45,7	27,12	7,32	-	
Stark podsolierter, lehmiger Tonboden (Lisino, Leningrader Gebiet)	Mehrj. Brachland	0-24	85,0	11,0	nicht bestimmt		Tjurin, 1935
	Nadelwald	5-10	16,10	8,8	nicht bestimmt		
		5-25	43,5	12,4	nicht bestimmt		
Schwach podsolierter, dunkelgrauer Waldboden	Laubwald	0-15	130,7	15,95	8,14	6,3	
Degradierte Schwarzerde, tonig	Roggen	0-25	217,4	17,34	9,3	6,76	Maljanow, 1937
	Jungfräul. Boden	0-10	101,2	8,54	6,59	2,12	
	"	0-20	202,2	12,73	9,85	3,04	
Mächtige Schwarzerde, lehmig	14jähr. Brachland	0-10	133,2	5,19	5,19	4,03	Maljanow, 1937
		0-25	291,0	8,68	8,68	4,19	
Schwerer, dunkelkastanienfarbiger Boden (Versuchsstation Krasnokutskaja, Gebiet Saratow)	Jungfräul. Boden (Stipa-Festuca-Steppe)	0-15	75,2	3,25	3,25	2,68	Sawwinow u. Pankowa, 1942
		0-25	113,0	4,55	4,55	3,23	
Solonezboden (Station Ma'ousenski, Gebiet Saratow)	Jungfräul. Boden (Festuca-Artemisia martima Steppe)	0-22	71,6	8,79	-	-	Kononowa, 1943
Helle Grauerde (Sowchos Pachta-Aral, Kasachische SSR)	Jungfräul. Boden	0-10	15,8	20,5	-	-	Kononowa, 1943
		0-26	23,0	21,3	-	-	
	3jähr. Luzerne	0-26	40,4	12,1	-	-	

These big differences may depend upon the methods used to determine the humus content. The residues are sieved out before the humus content is determined. Another factor may be that the biological activity is not considered. The latter is influenced by the kind of materials which decompose and the climatic conditions.

During the conference of the International Soil Science Society, Commission II and IV, at Hamburg in the last year Tiurin spoke about systematic investigations of humus content in the Russian soils. Some of these data, which are from former work, are reported. They summarize the papers of different authors.

S 10 K/695

Humus- und Stickstoffvorrat in Tonnen pro Hektar in den Böden der Sowjetunion
(Tjurin, 1949)

Bodergruppen	Humus		Stickstoff		C:N
	in der Schicht von 0-100 cm	in der Schicht von 0-20 cm	in der Schicht von 0-100 cm	in der Schicht von 0-20 cm	in der Schicht von 0-20 cm
Stark podsolierte	101	63	6,6	3,4	10,8
Mäßig podsolierte	94	50	6,1	3,2	9,0
Schwach podsolierte	104	54	7,2	3,1	10,1
Podsolige, im Mittel	99	53 / 54*	6,6	3,2	9,7
Graue, schwach podsolierte	175	-	9,4	5,6	10,7
Dunkelgraue, schwach podsolierte	296	-	14,0	6,6	10,3
Podsolierte, graueWaldböden i.Mittel...	215	109 / 51	12,0	6,0	10,5
Degradierte Schwarzerden..............	452	132	25,2	7,0	11,0
Ausgelaugte Schwarzerden..............	549	192	26,5	9,4	11,8
Degradierte und ausgelaugte Schwarzerden, im Mittel	512	164 / 32	-	-	-
Mächtige Schwarzerden	709	224 / 32	35,8	11,3	11,5
Gewöhnliche Schwarzerden	426	137* / 32	24,0	7,0	11,3
Südliche Schwarzerden	391	93 / 24	17,0	6,3	8,6
Dunkelkastanienfarbige Böden	229	99 / 43	13,2 (0-50 cm)	5,6	11,2
Kastanienfarbige Böden	156	-	-	-	-
Dunkle Grauerden	128	-	11,8	3,8	8,2
Typische Grauerden	83	-	7,5	2,5	8,4
Helle Grauerden	67	-	6,4	2,3	7,8
Grauerden im Mittel	83	37 / 45	-	-	-
Roterden	282	153 / 54	10,5	4,7	18,9

*) Der Nenner gibt den prozentualen Humasanteil der Schicht von 0-20 cm, verglichen mit der Schicht von 0-100 cm an.

In the different kinds of black earth are the largest amounts of humus and nitrogen. The humus content decreases more in the soils which are in the south than in those of the north.

There are remarkable differences between the humus content in the surface soil and in the layer of 100 cm in the profiles of the different soils. In the northern and in the southern soils with more or less extreme climatic conditions, nearly half of the humus content is in the surface soils. In the area of chernozem most of the humus content is in the upper 20 cm.

The C:N ratio is wider in chernozem than in podsolic soils. A narrower ratio has been observed in the grey earth. The humus contains more nitrogen in this type of soils.

The wet, subtropical soils, the red-earths have more than 50% of total humus in the upper layer of 20 cm. These soils have a C:N ratio of 18 and a low humus content is characteristic for them.

As a characteristic for the humus content, the amount of humic substances have been studied. Tjurin believes that the natural conditions which stimulate the formation of humus also increase the formation of humic acids.

The humus content of the different soil types in a depth of 20 cm. increases from north to south to a maximum in the deep chernozem and then it decreases.

S 11 K/697

Composition of the Humus in the 0-20 cm layer for the various soil groups in the USSR in % of humus content (Tiurin, 1937)

	Average of humus content in %	Humic acids	Fulvic acids	Insoluble residue	Ratio: Humic acid to fulvic acid	Ratio: Humic acid to residue	Waxes and residue
1. Podzolic Soil	3.0-4.0	15-25	47	28	0.4	0.7	5
2. Grey-Podzolic Forest Soil	4.0-6.0	25	50	22	0.5	1.1	3
3. Degraded Chernozem	7.0-8.0	35	42	20	0.8	1.7	3
4. Deep Chernozem	10.0	40	39	19	1.0	2.0	2
5. Normal Chernozem	7.0-8.0	35	37	25	1.0	1.4	3
6. Chestnut Soil	3.0-4.0	34	35	26	1.0	1.3	5
7. Solonez	3.0	23	45	28	0.5	0.8	4
8. Grey-Earth	1.0-2.0	21	41	32	0.5	0.7	6
9. Red-Earth	4.0-6.0	15	50	33	0.3	0.5	2

The content of humic and fulvic acids in percent of total humus is also characteristic according to this procedure of analysis. In the determination of humic substances the fulvic acids are all the organic substances which can be determined in the acid solutions after precipitating the humic acids out of the alkaline solution. In the podsolic soils, in chest-nut soils and especially in the red earth soils, the content is relatively high.

The insoluble residue of organic components is also relatively high. The ratio between humic and fulvic acids is one (1) in the different chernozems and decreases in both directions. The content of waxes and resins is low in chernozem soils.

If one considers these numbers, it seems to me that the biological activity may be one of the factors to explain the differences. In soils with an intense biological activity, even less available compounds are destroyed and therefore there are low values for insoluble residues and waxes in chernozems. Perhaps also a greater part of the fulvic acids are decomposed by the microorganisms.

Another factor may be the nitrogen content. Chernozem has the highest content of nitrogen. We will see later that this is an important factor for condensation reactions. In this type of soil the condensation of lower molecular substances could have taken place. Therefore the content of fulvic acids is not so high as in other soil. These are only some ideas to explain the results. Several experiments can be referred to support them.

Tjurin and his co-workers (1949) made some experiments to classify the humic substances. He used the solubility in different solvents. With these he has been able to separate different fractions of humic substances. The humic substances are present in different combinations in the soils, several perhaps as free acids, others as salts of calcium, others in complexes with hydrates of sesquioxides or others adsorbed on inorganic soil colloids.

Tjurin divides the humic substances in different parts according to their kind of combination. a) Humus substances which are soluble in dilute alkali solution (0.1 N NaOH) without separation of the exchangeable calcium ions (columns headed "NaOH soluble"). These can be free humic acids, i.e., they are not saturated with bases. They can also be connected with the part of hydrates of sesquioxides which are movable. In some cases they are connected with sodium, for instance in the Solonez soils. Tjurin believes also that a part of humic acids is connected with the fulvic acids in a complex form. b) Humic substances which can only be extracted with alkaline solutions if the exchangeable calcium is separated from the soil by acidifying and washing. (Columns headed "Combined with Ca" and "Sol. with humic acids"). Tjurin speaks also in this case of mixed complexes of humic acids and fulvic acids. c) In this group are the kind of substances which are difficultly extractable. They must be dissolved with alternating treatment with dilute acids (5% H_2SO_4) and alkali solutions (0.1 N NaOH) (Column headed "Combined with R_2O_3") In the case of humic acids these are those which are connected relatively strongly with sesquioxides. A part of the fulvic acids are dissolved along with humic acids after the alternating treatment. d) According to Tjurin, there is besides the mentioned fractions, also another of fulvic acids, which can be dissolved by the treatment of the soils with dilute mineral acids (column headed "Acid-soluble"). This fraction consists partly of free fulvic acids but in the most cases of salts and complex compounds of movable sesquioxides, hydrates of sesquioxides, especially with aluminum.

S 13 K/698

Approximate Division of Humic Acids According to the Different Kinds of Combination in Percent of the Total Amount of Humus in the Layer from 0 to 20 cm (Tjurin, 1949)

Soils	Humic Acids			Fulvic Acids		
	NaOH Soluble	Combined with Calcium	Combined with R_2O_3	Acid Sol.	NaOH Sol.	Soluble with Humic Acids*
Podzolic soils of the Northern forest zone	16-5	0-6	4-10	6-4	20-10	14-23
Weakly podzolized Grey forest soils of the forest-prairie zone	6	12	7	3	19	18
Deep chernozem	0-2	23	13	2	14	17
Usual chernozem	0-2	22	10	3	9	16
Solonez of the Chestnut-colored soils	8	10	5	6	16	16
Grey-earth	0	9	12	8	5	19
Red-earth	12	1	2	14	24	4

* Combined with Ca++; especially with R_2O_3.

Tjurin describes some regularities of the composition of humic substances in different soil types. In the chernozem, and less in the chestnut soils and grey forest soils, the humic acids are mostly combined with calcium ions. This is also the same observation which he made for the fulvic acids. The free humic and the free fulvic acids in these types of soils are very low. In the red earth especially, but also in the typical podzolic soils, the content of humic acids is low. Most of them are in free form.

Acid soils have a high content of fulvic acids, which can be dissolved with dilute mineral acids. These soils are not saturated with calcium, especially in the red earths. The content of free humic acids is large in podzolic soils and red earth. This type of fractions cannot be found in chernozem and other soils which contain calcium.

Tjurin describes that not only the ratio of the different important groups of humus substances is changed in the different soil types but also the properties.

All these humic substances have been isolated. The content of carbon in the humic acids of chernozem is larger and the content of oxygen and hydrogen smaller than with the podzolic soils. Hand in hand with this change of elementary analysis, several properties are also changed. Later we will discuss these facts.

Tjurin believes that these differences are caused by the natural conditions of soil formation.

One of the important factors of the humic substances in the soil is the exchange capacity. For instance, it is higher in chernozem than in podzolic soils. The cation exchange of the soil is dependent on both of the organic and inorganic components. S. 14 A/56. In this table given by Schachtschabel (Scheffer, F. and Schachtschabel. P.: Lehrbuch der Agrikulturchemie. I: Bodenkunde, Stuttgart-Encke, 1952. S. 76.) the percent of humus of different soil types is mentioned, and the different T value (the exchange capacity) in milliequivalent/ 100 g. soil is given. It says that the organic part of the soils, the humus, is one of the most important factors for exchange capacity. The part of humus is relatively low and participates in 35 to 70% on the total sorption.

The amount of absorption capacity can vary with the kind of humus. In weakly acid and neutral soils, the part of absorbing organic matter is related to the content of clay minerals, but have never been found to be higher than the inorganic (P. Schachtschabel, Landw. Forschung II, 57(1950)). The different kind of clay minerals have a different exchange capacity. Therefore, composts are made together with high active clay minerals such as montmorillonite, to form a high sorption capacity. In fen and raw humus soils, there are no relations between the part of sorption due to the inorganic and organic components. (49, 60). S. 15 694.

In an extensive study, Gorbunow (1948) has given the relation between exchange capacity and humus content in the soils of his country. In the last two columns the ratio of the percent of exchange capacity in the humus part and in the mineral part is given. This has been two examples for different countries. The res ults are nearly the same.

In tropical soils, the humus shall be the main factor for sorption. (Camargo, Th. and Vageler, P.: Z. Bodenk, Pflanzenern. 4. 137 (1937) Vageler, P. Grundriss, der tropischen und, subtropischen Bodenkunde. Berlin, Verlagsgesellschaft für Ackerbau, 2. Aufl. 1938). The clay minerals which are strongly able for sorption shall be destroyed. Evidence against this investigation is given by Siegel, O. (Z. Bodenk, Pflanzenern. 29. 100 (1943) who determined the sorption capacity of humus of African soils and found only sorption capacity of 30 to 45%.

According to L. D. Swindale and J. P. Richardson (S/44 (70)) the inorganic component contributes also a part to the exchange capacity of tropical soils. They found that the high sorption capacity of the soils on the Cook Islands depends probably from the high sorption capacity of aluminum hydroxides. The sorption capacity of aluminum is 350 milliequivalents/100 g. s. It may be that not all tropical soils are such reactive aluminum hydroxides. Therefore, there must be other reactive inorganic parts of the soil fraction which have an influence on the exchange capacity.

The sorption capacity has been determined the following way. With ammonium acetate the absorption capacity of the total soil is measured. After oxidation with H_2O_2 of the organic components, the sorption capacity of the inorganic part is determined. The difference between sorption capacity of total soil and sorption of the inorganic part is the sorption capacity of the organic matter in soils.

The sorption capacity of clay minerals is normally not influenced by treatment with H_2O_2 (30, 46, 61). It has been found that not all organic matter can be oxidized by H_2O_2 (50, 65, 64).

The figure for the sorption capacity of inorganic and organic parts shows that the sorption capacity of clay minerals has an effect on the formation of organic matter in soils. The organic substances in the soil are formed in a different way in podzolic soils than in grey earth. Therefore, they show also another behavior.

Absorption Capacity of Organic Matter from Podzol = 30 up to 100 me/100 g.

Absorption Capacity of Organic Matter from Chernozem = 250 up to 300 me/100 g.

It may be that the clay minerals formed under the conditions of the genesis of the soil have a different effect on the formation as well as on the enrichment of certain substances in humus.

After talking about the humus content and its components such as humic acids, fulvic acids, insoluble residues in soils and about the relation of these to the sorption capacity of different soils, we will mention the biological activity. For this purpose, I will give some examples of the soils which we have spoken of.

To study the biological activity of some soil types Kononowa and her co-worker Beltschikowa used the following methods:

(1) The content of humus and nitrogen was determined. When the volume-weight of the soils was known, the distribution of the amount of humus in the profile was given.

(2) The amount of plant residues and their distribution in the soil profiles were determined.

(3) Different groups of humic substances are determined following the methods of Tjurin.

   (a) Substances which are soluble in a mixture of alcohol-benzene.

   (b) Free humic acids.

   (c) Humic acids combined with Ca^{++} and sesquioxides.

   (d) Fulvic acids, i.e., those substances which remain in the acid solution after precipitating the humic acids.

   (e) The residues of organic components which remain in the soils after treatment with the mentioned extraction solutions.

(4) Kononowa believes that in some cases the extinction coefficient of visible light of certain wavelength of the humate solutions is a measure for the chromophoric groups of the humic acids and gives indirect references for the chemical constitution. These data I will give in the summary because some physical investigations show that one can have some doubts about this hypothesis.

(5) The values of coagulation with calcium chloride. These can be a measure for some colloidal properties.

For the determination of the activity of the microorganisms Kononowa determined the moisture coefficient M, which had been proposed by Iwanow (1948). This coefficient is the ratio between the amount of rainfall and the amount of evaporated water. Later we will see that there are many other possibilities to determine the activity of microorganisms, but at that time some of the methods could not have been used. In this case it had been also a question of the development of apparatus.

The moisture coefficient according to Iwanow results the following values for the different zones:

M 1.5 - zones with moisture in excess (humid forests)

from 1 to 1.9 - zones with sufficient moisture (forest with sufficient moisture)

from 0.60 to 1.00 - zones with moderate moisture (forest prairie)

from 0.30 to 0.60 - zones with insufficient moisture (prairie)

from 0.13 to 0.30 - zones with deficient moisture (half desert)

from 0.00 to 0.12 - zones with unimportant moisture (desert)

Temperature and moisture influence the formation of the humic substances. These factors are combined with the activity of microorganisms.

It can be suggested that the moisture has also an effect on the kind and composition of humic acids. The different transformation and condensation reactions vary. In the zones with a high amount of water such as podzolic soils and also red earths more low molecular substances such as fulvic acids are present than in soils with a lower moisture regime such as chernozems. These processes are very complicated. It has been suggested that the formation of humic acids in chernozems is so high in contrast to that of fulvic acids, because the alternating drying and wetting climatic conditions are favorable. But also of importance is the fact that chemical reactions can be different in different dilutions, especially for the formation of high-molecular substances. Also the rate of growth of microorganisms depends on a lower or a higher content of water. If the metabolism of microorganisms is changed there are also different substances in the medium "soil" which can react. Two extreme types are sporulation during dryness (no substances are available for chemical reactions) and a high rate of growth in presence of sufficient moisture (different kinds of reactive products are formed).

One factor influences the others. For some physical properties of the soil the molecular weight of the humic substances is not only important, but also their chemical constitution. The physical conditions also influence plant growth, which in turn influences the life of microorganisms and these again influence humification. The system "soil" is a dynamic one as well as a cycle.

Now for some relationships between climatic factors as temperature and rainfall, the formation and composition of humus depending upon the organic residues of plants and some physical properties of humic and fulvic acids in different soil types.

Podzolic soils

A strongly podzolic soil was investigated. The sample was collected in a spruce forest. The soil was covered with moss. The layer of moss was 8 cm.;

A_2 - podzolized horizon 8 - 72 cm.

B_1 - alluvial horizon 12 - 32 cm.

B_2 - loam

			pH in water
A_0	0-8 cm.	layer of moss	5.2
A_2	9-12 cm.	podzolized horizon	4.3
B_1	12-32 cm.	illuvial horizon	5.2
B_2	32-60 cm.	loam	5.2

The layer of raw humus had an exchange capacity of 46.9 me. In the mineral horizons the sum of bases (Ca + Mg) was 1.2 - 2.5 me/100 g soil and has not been important.

The course of the analysis is the following:

(1) Determination of humus with $K_2Cr_1O_7$ (0.4 n) in sulfuric acid solution with Ag_2SO_4 as catalyst. Titration with a solution according to Mohr $(NH_4)_2SO_4$ $FeSO_4 \cdot 6H_2O$) (0.1N) and diphenylamine as indicator.

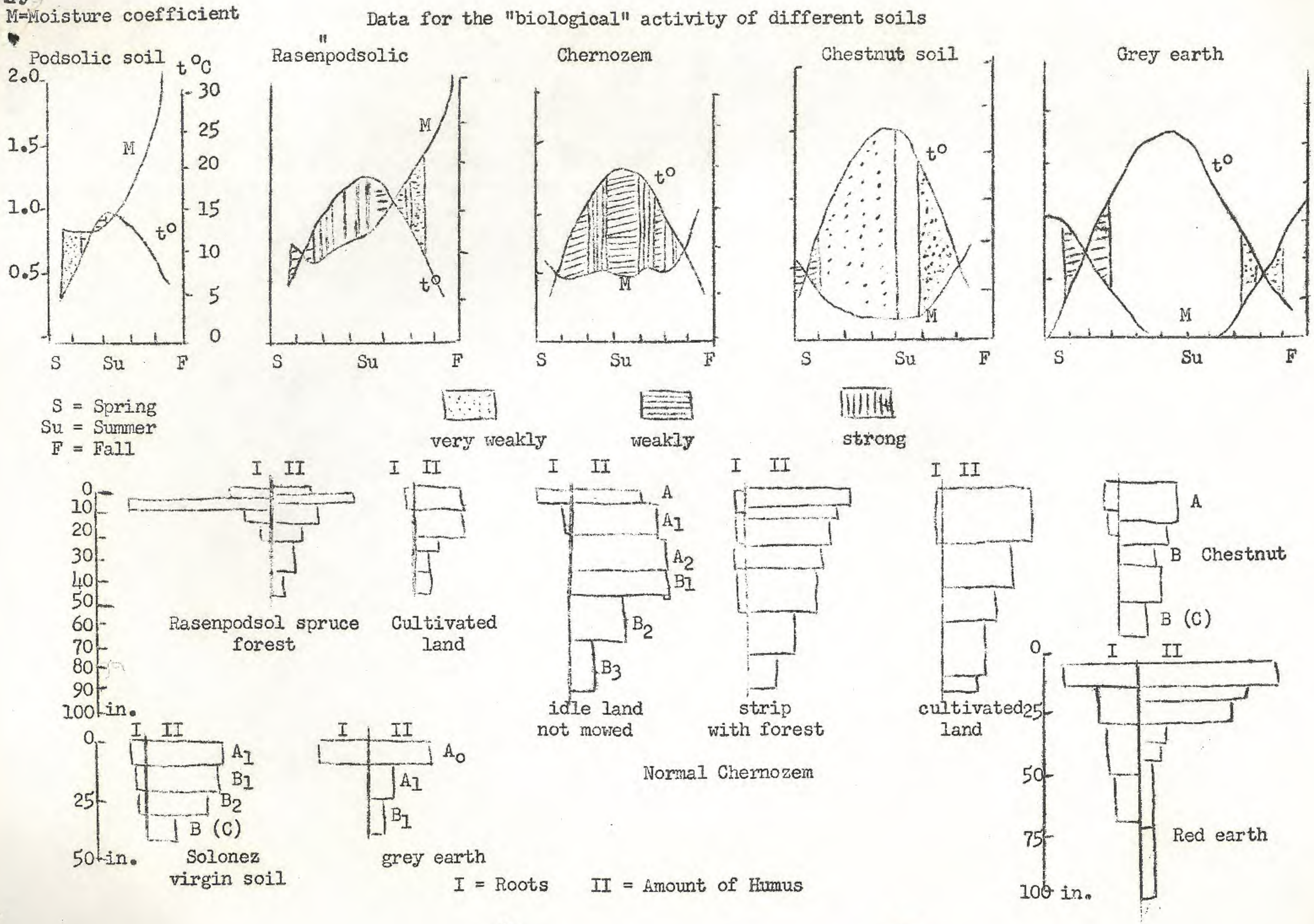
$$\% \text{ humus} = \frac{(a-b) \cdot 0.0005172 \cdot 100}{\text{amount weighed}}$$

(2) Extraction with alcohol-benzene 1:1. Evaporation of the solvent mixture.

(3) Extracted residue was treated with dilute HCl, Ca++ precipitated with H_2SO_4 and residue washed with water. C and N were determined. The difference before and after treatment with dilute acids is the acid soluble part of these elements.

(4) The acidified residue was extracted with 0.1N NaOH, acidified with 0.1N H_2SO_4 and the precipitated humic acids filtered.

Data for the "biological" activity of different soils



Soil Type	Horizon	Depth	Humus in % in soil	Percent of total amount of humus: Alcohol benzene soluble	El. Ca++ soluble in acid	H.S.	F.S.	Insoluble residue	Sum of humus substances	Moveable form of H.S.: $\frac{H.S.}{F.S.}$	% of total humus	% of humus acids	Content of C and N in soil in %: C	N	C:N
Strongly Podzolized Soil	A_2	8-12	2.3	17.9	11.2	13.5	23.9	31.3	98	0.56	12.7	94			
	B_1	15-20	3.5	9.9	20.8	16.8	33.2	18.3	99	0.51	15.3	92			
	B_2	25-30	1.1	17.7	16.2	14.5	21.0	25.8	95	0.69	—				
Rasen podzolic soil (Transition soil)															
Forest	A_1	4-7	6.9	12.2	2.0	22.3	28.3	34.7	99	0.79	21.1	100	4.03	0.26	15.5
	A_1	7-15	1.7	12.2	11.2	15.3	26.5	34.8	100	0.58	–	–	0.98	0.08	12.3
	A_1	15-23	1.0	17.2	1.7	13.8	24.1	41.4	98	0.57	15.5	100	0.58	0.06	9.7
	A_2	23-38	0.5	23.4	3.3	13.3	26.7	33.3	100	0.50	–	–	0.30	0.03	110.0
Cultivated soil	A_1	0-10	2.0	6.3	0.9	22.3	29.2	38.8	97	0.77	20.0	89	1.16	0.14	8.3
	A_1	10-23	2.1	12.0	4.9	16.9	28.9	37.2	100	0.58	16.9	100	1.21	0.13	9.3
	A_1A_2	23-29	0.9	14.5	6.7	15.4	28.8	34.6	100	0.54			0.52		
Grey forest soil	A_0	3-10	10.5	3.6	10.5	28.2	25.4	32.0	100	1.11	9.3	33.1			
	A_1	12-19	5.6	4.0	6.2	36.2	23.2	29.4	99	1.57	6.5	17.8			
	A_2	23-30	4.0	5.2	2.2	47.1	19.7	24.0	98	2.40	3.1	6.5			
	B_1	34-42	3.2	6.2	4.2	47.2	18.1	24.5	98	2.47	2.1	4.8			
Chernozem															
Prairie - not mowed	A_0	0-7		3.7	4.1	36.3	22.4	31.2	98	1.6			7.35	0.54	13.6
	A_1	10-20		4.1	2.2	38.8	22.5	31.2	99	1.7			5.16	0.44	11.2
	A_2	25-35		4.2	1.2	43.5	20.4	30.2	99	2.1			4.32	0.36	12.0
Cultivated land	A_1	0-20		4.0	2.2	40.5	19.6	33.5	100	2.1			4.79	0.37	12.9
	A_2	20-25		4.0	1.5	42.7	20.1	30.9	99	2.1			4.82	0.44	11.0
	A_3	30-35		5.3	1.1	37.3	18.5	36.1	98	2.0			3.57	0.35	10.[illegible]
Chestnut	A	0-15	3.1	7.4	0.6	33.5	19.8			1.7			1.82	0.17	10.7
	A	15-25	2.9	10.1	0.6	32.5	24.7			1.3			1.66	0.15	11.0
	B	30-45	1.8	6.6	0.9	25.5	20.9			1.2			1.06	0.10	10.6
Solonez	A	0-12	2.2	–	1.6	28.3	30.1			0.9			1.23	0.12	10.2
	B_1	12-22	1.8	7.2	1.9	26.0	25.7			1.0			1.05	0.12	8.7
	B_2	22-32	1.4	4.2	5.9	17.9	24.9			0.7			0.84	0.08	10.5
Grey earth (pale) Virgin soil			2.2			10.4							1.28	0.14	9.1
Cultivated cotton			1.2			16.5	22.5	34.4		0.7			0.72	0.09	8.0
Grey earth (typical) Cultivated with cotton			1.3	7.7	9.0	20.5	23.0	30.8		0.9			0.78	0.08	9.8
Red earth															
Forest		10-15	12.1	3.4	11.4	23.5	28.5	28.5	95	0.83			7.01		
		35-40	2.0	4.4	20.0	5.2	22.6	46.1	98	0.23			1.15		
Under fern		5-10	7.03	5.4	7.3	20.1	31.1	32.5	96	0.65			4.09		
		10-15	5.23	5.8	7.2	16.0	33.2	32.6	95	0.48			3.07		

(5) Determination of C-content, oxidative titration with K_2CrO_7 and calculation of fulvic acids.

(6) The residue is extracted with acid and alkaline solution, is dried, and the carbon content determined and calculated for insoluble residue.

(7) The movable forms of humic acids are determined by extraction of the soil sample with 0.1N NaOH without acidifying before.

The podzolic soils in the north have a weak biological activity. The number of microorganisms is low. The climatic conditions are unfavorable. The temperature is low and the amount of water in the soil is high.

In the next diagram is a scheme for the possible biological activity. For the temperature and the moisture the average value of different zones was determined. The scheme can give only an idea of the manner in which the different soil types vary.

It may be that in the podzolic soils the microorganisms are active only in the short period of summertime. Intensity is generally weak.

The speed of humification is very slow. The formation of intermediates cause the relatively high amount of fulvic and low amount of humic acids. The moveable forms of humic acids show that they are free or combined with moveable forms of sesquioxides.

Not only the high water content but also the acid reaction of the soil influences the formation and the composition of humic acids. Later on we will see the extent to which the formation of humic acids out of lignin fragments and their oxidation products are derived from these facts.

The values of flocculation of the humic acids of different soils with $CaCl_2$ are different.

For this purpose the humic acids are dialyzed and dissolved in 0.02 N solution of $NaHCO_3$. The pH values are set at 7.2 with 0.1 N $NaHCO_3$. The concentration of all solutions of humate are standardized at 0.136 g carbon/liter. In the centrifugated humate solutions (5 ml.) different amounts of the $CaCl_2$ solutions are brought. All solutions are filled up to 6 ml. with distilled water. Time and amount of electrolyte at which turbidity begins and sedimentation is complete, are determined.

The values of flocculation for Na-humate solution of strongly podzolic soils are characteristic; even a high amount of electrolyte does not flocculate them completely.

	Beginning of coagulation at m.e. $CaCl_2$/1 solution	Complete coagulation	
		Time in hours	m.e. $CaCl_2$ per 1 solution
Na-humate (strongly podzolic soil)	20	3	38
Normal fulvic acid	25	6	40

The numbers show that there is a relationship among the humic acids and the normal fulvic acids isolated from different soils. They are relatively soluble. In this type of soil, the humic acids are relatively soluble as well as moveable. This fact is important in order to explain the process of podsolization in general.

The humification, the amount and composition of the rotted products and properties of the humic acids are influenced in strongly podzolized soils by the following facts:

(1) Raw materials are either of needles and moss.

(2) The number of microorganisms is low, the acid medium favors the decomposition by fungi.

(3) The unfavorable climatic conditions - low average yearly temperature and high rainfall - lower the speed of decomposition. Upon these facts depend also the composition and the physical behavior of this kind of humic acid. The process of forming podzolic soils is an effect of their properties.

"Rasen" podsolic soils (transition soils)

The next sample is a transition soil on a heavy loam and comes from a decidious forest. The layer of moss was only weakly developed. Not only the needles of spruce and moss but also the leaves of the trees and the grass served as raw materials for humic substances. The pH (water) was 5.1 - 5.4.

4-7 cm. Exchange capacity 11.6 m.e./100 gm. soil.

7-15 cm. Exchange capacity 6-7 m.e./100 gm. soil; 50% of exchange capacity belongs to calcium and magnesium ions.

The cultivated soil has been fertilized with manure. It has also been cultivated periodically with clover. The influence of the culture could be seen on the morphological construction of the soil. The A_2 horizon was less pronounced. The humus content and the exchange capacity was higher than in the soil before. There were few exchangeable hydrogen ions.

pH (water) 6.0 - 6.3.

4-7 cm. Exchange capacity 7.6 m.e./100 gm. soil.

7-15 cm. Exchange capacity 9-10 m.e./100 gm. soil.

Scheme of possible intensity of biological activity in transition soils.

In the transition soils, the conditions for the microorganisms are much better than in the previous soils. The temperature is higher and the water content is lower. Therefore the biological activity is more extensive during the year. The next table gives a summary of the different properties of the humic substances in this kind of soil.

The amount of organic substances in transition soils (spruce forest and cultivated land). The total amount of plant residues in the forest soil is relatively higher. It is mainly concentrated in the litter. The most part of the root residues is coarse and large and comes from the trees. Only 10% of the residues of vegetation comes from thin roots.

In the cultivated soil, the amount of roots is not so large as in the forest soil. The residues of roots in the cultivated soils have more value for the formation of humic substances. They consist of thinner roots.

Composition of humic substances in % of the "Rasen" podsolic soils (transition soils)

The different climatic conditions for the formation of humus in comparison with those of the strongly podsolized soils, influenced also the composition of humus. In the A_1 horizons of the "Rasen" podsolic soils, the absolute and relative content of humic acids is increased. Therefore, the ratio of humic acids to fulvic acids is increased to 0.79. In the A_2 horizon, the ratio remained the same as in the strongly podsolized soils. Most of the humic acids are free or combined with the moveable sesquioxides.

It must also be mentioned that the substances which are soluble in dilute acids after elimination of calcium ions were lower. This means that the humic acids were more combined with calcium ions. But the A_2 horizons of the forest soils also contain humus of large mobility.

The composition of the humic acids is also changed. One can suggest that they are a little bit higher in molecular weight. This can be seen from the flocculation values of the humic acids.

Na-humate (forest soil)	Beginning of the coagulation at m.e. $CaCl_2$/1 solution	Complete Coagulation	
		Time in hours	at m.e. $CaCl_2$/1 solution
4-7 cm.	12	2	20
7-15 cm.	9	2	14

Sodium humates isolated from different depths coagulate with much smaller amounts of electrolytes than the humus of strongly podzolized soils. The particles of the humic acids seem to be larger than those of the soil mentioned before. Therefore, they play a larger role in the formation of soil structure.

With the methods used for determination of coagulation, it has not been possible to differentiate between the two soils. The action of cultivating had no influence which could be measured.

Grey-forest soils

This soil has been covered with oak, maple and a small amount of grass vegetation. The layer of litter has been 2-3 cm thick and consisted mainly of leaves which were humified in different degrees.

pH value (water) 6.3 in litter.

pH value (water) 6.8 in A_1 and A_2 horizons.

In the mineral horizon, the exchange capacity was relatively high with values from 50-57 m.e./100 g soil. 58-90% were calcium ions and the rest were magnesium ions.

The grey forest soils are relatively rich in microorganisms. Their activity is favored by the conditions of temperature and moisture.

Generally, the conditions for the resynthesis and stabilization of humic substances is relatively favorable in the grey-forest soils.

Composition of humic substances in % of dark grey forest soils.

Some characteristic properties of the humic substances of dark grey forest soils are:

1. Relatively high content of humus in the upper layer (3-10 cm.)

2. The absolute and relative amount of humic acids increase in comparison with the fulvic acids. The ratio of humic acids to fulvic acids is greater than one and even in the lower layers, greater than two.

The amount of organic compounds which can be extracted after elimination of calcium ions is high only in the A_0 horizon.

The largest part of humic acids are combined with calcium and magnesium ions. Only in the uppermost horizons are there moveable humic acids which can be extracted without elimination of calcium ions, 33 and 18, respectively. This is a big difference from the two soils mentioned before. In the former cases, nearly all humic acids could be extracted with 0.1 N NaOH without prior treatment with acids.

The conditions for the formation of humic substances in these kinds of soils are better than those in the podzolic soils. Humic acids of higher molecular weight can be formed.

Na-humate	Beginning of the coagulation at m.e. $CaCl_2$/1 solution	Complete coagulation	
		Time in hours	at m.e. $CaCl_2$/1 solution
3-10 cm.	7	2	16
23-30 cm.	4	2	6

This can be seen by the values for the beginning of coagulation. The numbers show also, that the humic acids in the upper horizons differ from those of the lower by a higher dispersity.

Normal Chernozem

For the characterization of the processes of this soil type, there are given three examples. They come from an area of natural conservation, one from not mowed prairie meadow, one from a cultivated land and one from a strip planted to forest which is 50 years of age. They were all close to the same area.

pH (water) 6.8-7.2.

Exchange capacity 56-58 m.e./100 g. soil; 56 m.e. of calcium ions and 2 m.e. of Mg ions.

Scheme of the possible intensity of the biological activity in the zone of chernozem with alternating soil moisture

In chernozem soils, the activity of the microorganisms is relatively high. The scheme of the possible intensity of the biological activity shows that the biological activity alternates with alternating soil moisture during the year. The enlarged activity of the microorganisms during the time of rainfall is stopped by the depression of periods of dryness. These conditions increase the formation of humus. The organic matter is not so quickly transformed in the biological cycle. The conservation of humic components in form of organomineral components contributes remarkably to the high exchange capacity of the normal chernozem. All the factors for soil formation results in an increase of essential amounts of humus.

Humus content in % of the normal chernozem used for different purposes

Horizon	Not mowed prairie	Mowed prairie	Forest strip	Cultivated land
A_0	12.64	12.97	11.32	8.26
A_1	8.88	9.89	9.96	8.26
A_2	7.43	7.60	7.67	6.07
B_1	7.07	4.88	5.92	4.58
B_2	3.37	3.33	3.17	3.47
B_3	1.27	1.27	1.81	2.25

Percentage content of humus in different soils varies, depending upon the use. In the soil of the cultivated land, the content of humus is lower than in the uncultivated.

Amount of organic substances in normal chernozem.

A. Prairie, not mowed

B. Strip of forest

C. Cultivated land

The content of wood residues is higher in the unmowed land than in the strip of forest and in the cultivated land. The content of organic substances does not vary remarkably.

The distribution of humus is characteristic for the strongly humic chernozems. There is an accumulation in the total soil profile to a depth of 1 meter.

Composition of humic substances in % of normal chernozem by different uses.

In both cases, the high content of humic acids compared to that of fulvic acids, is typical. The ratio between humic acids and fulvic acids is between 1.5 and 2.0 and sometimes a little bit higher. It has not been possible to determine essential differences of the most important groups of humic substances when the land was used in a different manner.

The humic acids in chernozems are mainly combined with calcium. It is only possible to extract the humic acids after treatment of the soil with dilute acids.

The amount of humic acids which can be extracted by once treating with 0.1 N NaOH, without elimination of calcium ions.

	Unmowed Prairie		Cultivated land			Strip of forest		
	Depth in cm.							
	0-7	10-20	0-20	20-25	30-35	3-8	10-16	32-37
Amount of total humus in %	9.5	5.0	1.7	2.7	0.6	9.0	14.1	5.7
Amount of moveable humic acids in % of total humic acids	25.9	12.9	4.1	5.8	1.5	23.0	27.9	10.7

The composition of the humic acids which can be extracted without elimination of calcium ions in comparison with the total parts of humic acids extracted after elimination of calcium ions shows that on the uncultivated areas an intensive resynthesis of humic acids occurs. This cannot be ascertained in the cultivated land.

The humic acids from chernozem seems to be those with the highest molecular weight. From other investigations of the different authors, it can be concluded that this type of humic acids can be called prototype.

Land used and depth of horizon in cm.	Beginning of coagulation at m.e. of $CaCl_2/1$ solution	Complete coagulation Time in hrs. at m.e. $CaCl_2/1$ solution	
Unmowed prairie			
0.7	7	2	11
10-20	4	2	5.5
25-35	4	2	4.5
Cultivated land			
0-20	4	2	4
Strip of forest			
3-8	5	2	9
17-22	4.5	2	7
32-37	4	2	5

Kononowa believes that slightly higher values of coagulation of the humates in the upper horizons of the unmowed prairie and the strip of forest confirmed that the newly formed humic acids are more highly dispersed than the aged. The tendency of the humic acids of chernozems to coagulate quicker is one reason for their accumulation in the soil and their ability for the formation of crumbs. The good structure of chernozems is caused by their properties.

If one compares the mentioned soil organic matter of strongly podzolized soils, transition soils, gray forest soils and normal chernozems, (in this order), the following regularities can be determined:

(1) The amount of humus increases in the same sequence.

(2) The content of humic acids increases in the total amount of humus.

(3) The stability of humus increases.

(4) It can be said that the size of the particles of humic acids increases, as measured by their flocculation value.

Chestnut Soils

This soil type is under climatic conditions with limited amounts of rainfall and intensive fluctuations in temperature during day and season. There is also a high evaporation coefficient. This kind of climatic condition is unfavorable for the activity of microorganisms. These soils have according to the results of different other authors, (A. A. Richter and W. A. Richter (1925), Sacharowa (1933), Krassilnikow, Kriss and Litwinow (1936), Riuger (1940), a relatively rich microflora.

Scheme of the possible intensity of biological activity in chestnut soil of the zones of deficient soil moisture.

The possible intensity of biological activity is limited to a short time in spring and in the beginning of summer. During the rest of the summer the activity is low. Under these conditions the humification of plant residues is very slow. This is one of the causes which lowers the humus content in comparison to chernozem.

Amount of organic substances in Chestnut soils.

The soil has been investigated by Antipow-Karatajew and Filippowa (1937). This soil is a heavy loam with neutral reaction. The exchange capacity is relatively high, nearly 35 m.e./100 g. soil. The ratio of calcium ions to Mg ions to Na ions to K ions is 74:23:1:5. The investigation has been made on old idle land and the vegetation was typical for the dry prairie. The amount of roots was not very high.

The composition of humic substances in % in chestnut soils.

The composition of the humic substances are similar to those of chernozem. It is suggested that this type of s oils belong to the chernozem type, but there are some differences. The chestnut soils are lower in humus content than chernozem and contain less humic acids. The ratio between humic acids and fulvic acids is narrower than in the chernozem. The relative content of fulvic acid is higher.

Solonez soils

This soil has also been investigated for its composition by Antipow-Karatajew and co-workers, (1937). It is a heavy loam on an alluvial clay. Among the exchangeable bases there is up to 16% Na in the solonez horizon. The exchangeable Na increases the peptization of humic substances. Therefore, they are more available for the microorganisms and can also be moved.

Composition of humic substances in % in solonez.

The conditions for the formation of humic substances is poorer. The content of humus is lower in the solonez soils than in the chestnut soils. The content of humic acids decreases remarkably. The ratio between humic acids and fulvic acids is nearly one or smaller.

Gray-Earth (Serozem)

The specific conditions for the formation of humus in gray earth are determined by the intensive biological activity. The neutral up to weak alkaline reaction and the long season with high temperatures are favorable conditions for most microorganisms. The activity is therefore high if sufficient moisture is present. By irrigations these soils can be used as cultivated land.

The virgin gray earth has only in the period of spring a high biological activity and a smaller one in fall.

Scheme of the possible biological activity in a non-irrigated gray earth.

The relationship between temperature and moisture coefficients can be seen from the diagram. Short-lived vegetation is characteristic for virgin gray earth.

Amount of organic substances in gray earth (virgin soil).

The vegetation is characteristic in its composition, in its ecology and its rhythm of its development. The root system is well developed and in the upper part of the soil. The amount in kg/ha in the depths of 5-7 cm. is nearly the same as in the virgin soils of chernozem, but they do not grow deeper. The exchange capacity is relatively low for the inorganic part (under 10 m.e./100 g soil). All these conditions have an effect on the composition of the humus of the gray earth.

Composition of humic substances in % in gray earth.

The humic and fulvic acids are approximately 20% in each soil.

Red Earth

Red earths are mostly subtropical soils. Moisture is in excess and the temperature is high. The rich vegetation of forest produces a high amount of plant residues such as leaves and roots.

An intensive process of weathering is characteristic. This is the effect of organic substances in the presence of an acid soil reaction. The exchange capacity of the red earth is relatively high. It is 20-30 m.e./100 g soil. The sorption of hydrogen and of aluminum ions is predominant. The high temperature and the high moisture increasesthe intensity of mineralization of the organic residues.

The high rainfall causes a periodic supersaturation with water and therefore anaerobic conditions which decrease the normal course of microbiological activity. Denitrificants are the most active microorganisms.

The amount of organic substances in % in red earth.

The amount of roots in the soil profile or a depth of one meter was 10.15 kg/sq. meter. It is the highest amount of all soils discussed before. But the largest part are roots of trees which are unfavorable for the formation of humus in red earth.

The intensive humification of the high amount of residues results in larger amounts of newly formed humus which are leached and migrate to the deeper layers of the soil. The conditions of humification in the red earths, the formation of humus substances in the litter, the excess rainfall and the acid soil reaction, cause many properties comparable with those of podzolic soils.

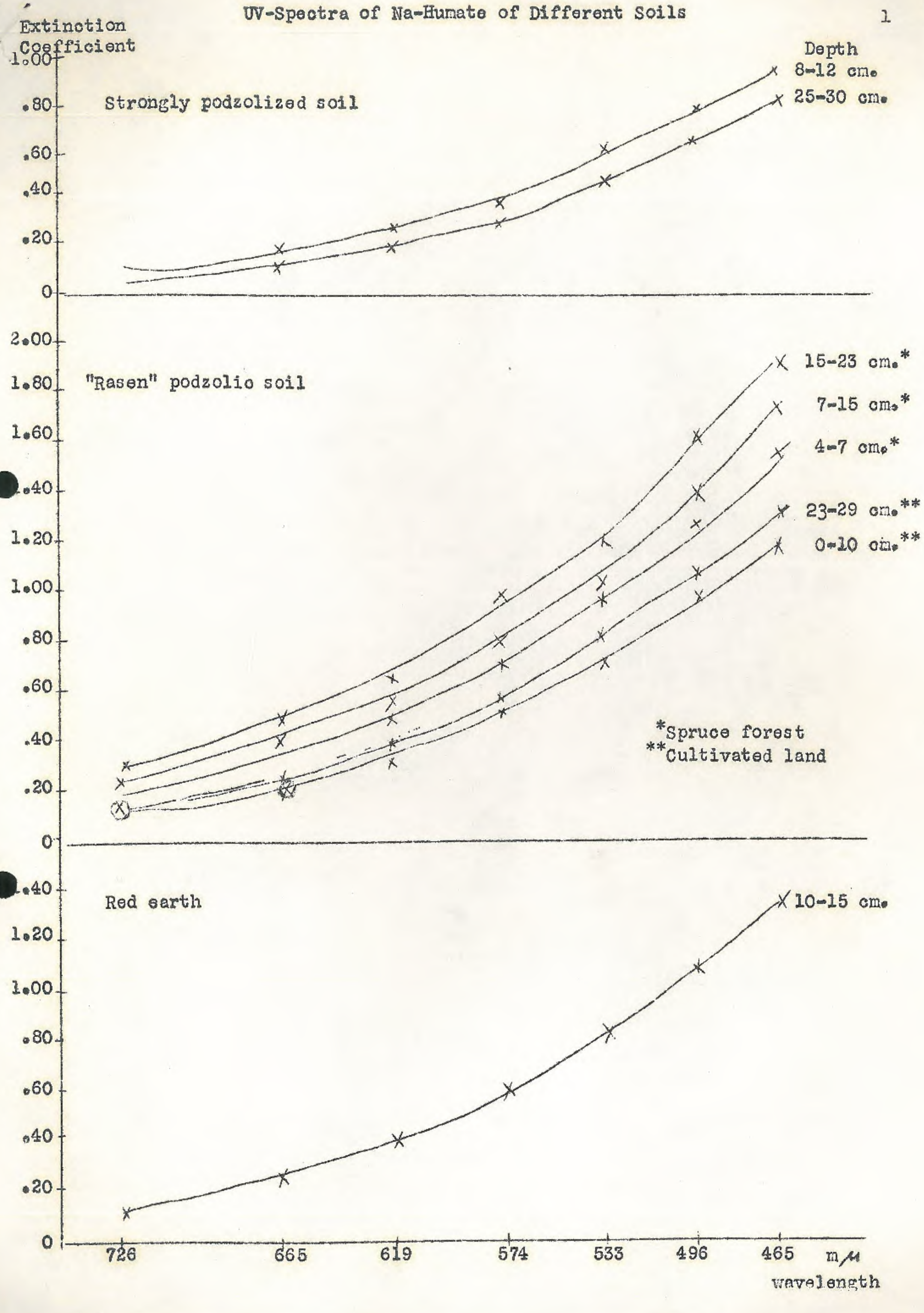
Composition of humic substances in % in red earth.

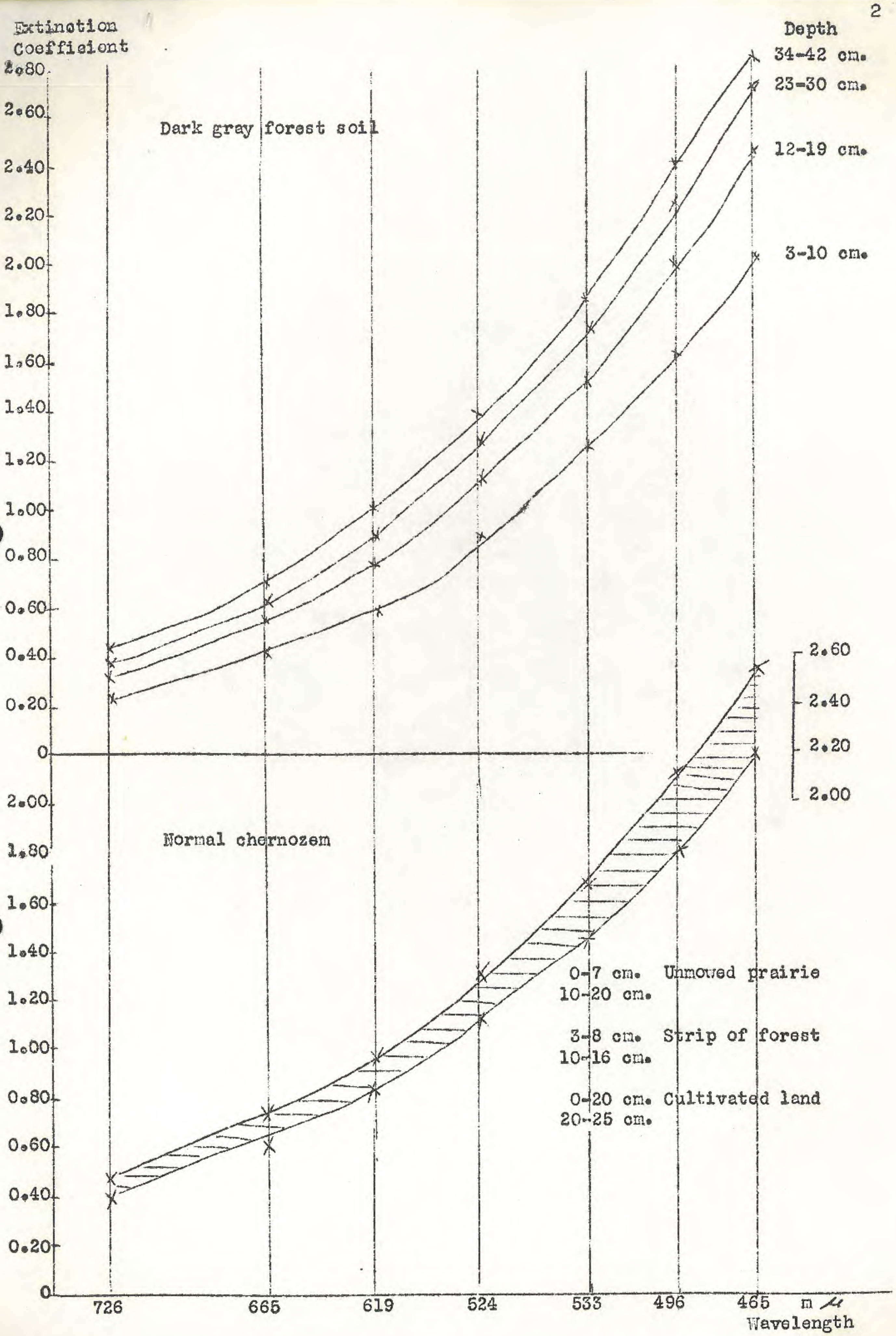
In the humus of red earth there is a smaller amount of humic acids than of fulvic acids. The humic substances are combined in red earth with sesquioxides or are in a free form. The humic acids of red earth can be suggested to have a lower molecular weight because they are only coagulated by higher amounts of electrolytes.

In the next diagram, there are shown the different extinction coefficients at the different wave lengths. The concentration of the solution had always been the same, namely, 0.136 gc./L. In all cases the extinction coefficient decreases with the increasing wavelength. All curves show no specific absorption. Only their slope is different. Some of the different properties of the soils which we have spoken of, have the same regularities, i.e., the content of humus/ha, the content of humic acids in % of total humus, the exchange capacity of the organic part increases and then decreases in the same manner as the extinction coefficient decreases and increases. Similar regularities can be observed for the coagulation with $CaCl_2$.

Mainly the absorption of the organic compounds is dependent upon the number of chromophoric groups. In this case, the substances have a typical absorption in a certain range of the spectrum. The humic acids have no special absorption and therefore I believe that the observed relationship between absorption and conditions of formation of humic acids depend not alone upon the number of chromophoric groups in the acids. Later on we will see that the humic acids are spheric colloids and higher molecular substances. It must be investigated which properties of the colloidal humic acids have an influence on the absorption.

UV-Spectra of Na-Humate of Different Soils




Extinction Coefficient
Depth
34-42 cm.
23-30 cm.
12-19 cm.
3-10 cm.
Dark gray forest soil
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0
Normal chernozem
2.60
2.40
2.20
2.00
0-7 cm. Unmowed prairie
10-20 cm.
3-8 cm. Strip of forest
10-16 cm.
0-20 cm. Cultivated land
20-25 cm.
726
665
619
524
533
496
465
m μ
Wavelength

30. Gedroiz, K. K.: Udobrenie i Urozhai 3, 814 (1931)

46. McGeorge, W. T.: J. Amer. Soc. Agric. Ames 26, 275 (1934)

49. Norman, A. G.: Proc. Soil Sci. Soc. Amer. 7, 7 (1942)

50. Olson, L. C. und Bray, R. H.: Soil Sci. 45, 483 (1933)

60. Schachtschabel, P.: Landw. Forsch. 2, 57 (1950)

61. Scheffer, F. und Schachtschabel, P.: Z. Bodenk. Pflanzenern. 21/22, 643 (1940)

64. Siegel, O.: Z. Bodenk. Pflanzenern. 29, 100 (1943)

65. Schoen, U.: Z. PflErnähr. Düng. 63, 97 (1953)

70. Swindale, L. D. und Richardson, J. T.: Soil Sci. 74, 197 (1952)

Kononowa, M. M.: Die Humusstoffe das Bodens, ubersetzt und bearbeitet von H. Beutelspacher. Erweiterte und varänderte ausgabe. VEB Deutcher Verlag der Wessenschaften, Berlin, 1958.

Frey - Goldschmidt: Ref. in Deuel, H., Humus und Bodenfruchtbarkeit., Schweiz. Landw. Monatshefte 33, page 3-12, 1955.

Russian articles translated into German

Antipow-Karatajew, I. N., u. W. N. Filippowa: Charakteristik der dunkelkastanienfarbigen Böden der hinteren Wolga. Arbeiten der Kommission über Irrigation, Heft 10. Isd. A. N. SSSR. Moskau 1937

Antipow-Karatajew, I. N., N. I. Sawwinow, W. N. Filippowa u. a.: Arbeiten des Malousensker Stationars. Arbeiten der Kommission über Irrigation, Heft 9, Isd. A. N. SSSR. Moskau 1937.

Winogradow, A. P., u. J. A. Boitschenko: Die Zersetzung der Kaolins durch Diatomeen. Berichte d. Akad. d. Wiss. d. UdSSR 37, Nr. 4, 1942.

Winogradski, S. N.: Über die Rolle der Mikroorganismen im allgemeinen Kreislauf des Lebens. Vortrag, gehalten auf der Versammlung der Mitglieder des Instituts für experimentelle Medizin am 8. Dezember 1896.

Wischnjakow, A. P., u. S. A. Rabinowitsch: Der Einflu der organischen Säuren auf die Beweglichkeit des Eisens im Boden. Sammelhefte über physikalisch-chemische Untersuchungen an Böden. Arbeiten der Leningrader Abt. des Unions-Instituts f. Düngung u. Agrobodenkunde, Heft 36, 1935.

Wolobujew, W. R.: Die Veränderung des Humusgehaltes in den Böden der UdSSR in Abhängigkeit vom Klima. Berichte d. Akad. d. Wiss. d. UdSSR 60, Nr. 1, 1948.

Gedroiz, K. K.: Der Adsorptionskomplex des Bodens. Arbeiten der landw. Versuchsstation Nossowskaja, 1927.

Gedroiz, K. K.: Der Solonezböden, ihre Herkunft, Eigenschaften und Melioration. Arbeiten der landw. Versuchsstation Nossowskaja, 1928.

Glinka, K. D.: Bodenkunde. Selchosgis, Moskau 1935.

Gorbunow, N. I.: Die Sorptionsfähigkeit der Böden und ihre Natur. Selchosgis 1948.

Sacharowa, T. S.: Charakteristik der mikrobiologischen Prozesse der hellkastanienfarbigen Böden im Kreis der Waluisker Versuchs-Meliorations-Station. Sammelband über Mikrobiologie des Bodens und Düngung. Arbeiten d. wiss. Institute f. Düngung, Heft 108, 1933.

Iwanow, N. N.: Klimatische Landschaftszonen des Erdballs. Schriften d. geograph. Gesellsch. 1 (neue Serie). Isd. A. N. SSSR. Moskau 1948.

Jenni, H.: Faktoren der Bodenbildung. Gosinoisdat. Moskau 1948.

Krassilnikow, N., A. Kriss u. M. Litwinow: Mikrobiologische Charakteristik der Rhizosphäre der Kulturpflanzen. Mikrobiologie 5, 1936.

Kudrjawzewa, A.: Umwandlung der Stickstofformen im Boden im Zusammenhang mit der Nitrifikation. Wissenschaftl.-agronomisch. J., Nr. 4, 1924.

Nadson, G. A.: Mikroorganismen als geologische Helfer. Arbeiten der Kommission über die Erforschung der Slawjansker Mineralseen. St. Petersburg 1903.

Omeljanski, W. L.: Die Rolle der Mikroorganismen bei der Verwitterung von Gesteinen. Jubiläumsband zu Ehren von I. P. Borodin, 1927.

Pikowskaja, R. I.: Die Mobilisierung der Bodenphosphate im Zusammenhang mit der Lebenstätigkeit einiger Mikrobenarten. Mikrobiologie 17, Heft 5, 1948.

Ponomarewa, W. W.: Über die Methode zur Gewinnung und die chemische Natur der Fulvosäuren. Bodenkunde, Nr. 12, 1947.

Ponomarewa, W. W.: Über die Wechselwirkung von Fulvosäuren mit Sesquioxyden. Bodenkunde, Nr. 11, 1949.

Richter, A. A., u. W. A., Richter: Zur Frage über die mikroskopischen Bodenuntersuchungen. Wissenschaftl. Schriften d. Staatsuniversität in Saratow 4, Heft 2, 1925.

Rode, A. A.: Der Podsolierungsprozess. Isd. A. N. SSSR. Moskau 1937.

Tjurin, I. W.: Die organischen Stoffe der Böden. Selchosgis. Moskau 1937.

Tjurin, I. W.: Zur Frage über die Natur der Fulvosäuren des Bodenhumus. Arbeiten des Dokutschajew-Instituts f. Bodenkunde 23, 1940.

Tjurin, I. W.: Zur Erforschung des Prozesses der Podsolbildung. Bodenkunde, Nr. 10, 1944.

Tjurin, I. W.: Über die mengenmässigen Anteile von lebenden Stoffen im organischen Teil der Böden. Bodenkunde, Nr. 1, 1946.

Tjurin, I. W.: Geographische Gesetzmässigkeiten bei der Humusbildung. Arbeiten der Jubiläumstagung anlässlich des 100. Geburtstages von W. W. Dokutschajew. Isd. A. N. SSSR. Moskau 1949.

Schmuk, A. A.: Einige Ergebnisse zur Frage über die Stickstofformen im Boden. J.f. experimentelle Agronomie 15, 139, 1914.

German and other articles

Bartholomew, W., u. C. Goring: Microbial products and soil organic matter. Proc. Soil Scie. Soc. Amer. 13, 238 (1949).

Dadd, C., L. Fowden u. W. Pearsall: An investigation of the free amino-acids in organic soil types using paper partition chromatography. J. Soil Sci. 4, 69 (1953).

Davidson, D., F. Sowden, F., u. H. Atkinson: Application of paper chromatography to identification and quantitative estimation of amino-acids in soil organic matter fractions. Soil Sci. 71, 347 (1951)

Fry, J.: A suggested explanation of the mechanical action of Lichens on rocks. Ann. of Bot. 38 (1924).

Gerretsen, F.: The influence of microorganisms on the phosphate uptake by the plant. Plant and Soil 1, Nr. 1 (1948)

Goring, C., u. W. Bartholomew: Microbial products and soil organic matter. 2. The effect of clay on the decomposition and separation of the phosphorus compounds in microorganisms. Proc. Soil Sci. Soc. Amer. 14, 152 (1950) 3. Adsorption of carbohydrate phosphates by clays. Ibid. 15, 189 (1951).

Adsorption of mononucleotides, nucleic acids and nucleoproteins by clays. Soil Sci. 74, Nr. 2, 149 (1952).

Jodidi, S.: The chemical nature of the organic nitrogen in the soil. J. Amer. Chem. Soc. 32, 396 (1910); 33, 1226 (1911); 34, 94 (1912), J. Franklin Inst. 175, 483 (1913).

Kojima, R.: Soil organic nitrogen. I. Nature of the organic nitrogen in a Muck Soil from Geneva, New York. Soil Sci. 64, 157 (1947). II. Some Studies on the amino-acids of protein materials in a Muck Soil. ibid. 64, 245 (1947).

Lathrop, E.: Protein decomposition in soils. Soil Sci. 1, 509 (1916).

Mortland, M., u. J. Gieseking: The influence of clay minerals on the enzymatic hydrolysis of organic phosphorus compounds. Proc. Soil Sci. Soc. Amer. 16, 10 (1952).

Sallans, H., J. Snell u. a.: Water substances in the raw humus of podsol soils. Canad. J. Res. 15, 315 (1937).

Stevenson, E., K. Marks, J. Varner u. W. Martin: Electrophoretic and chromatographic investigations of clay adsorbed organic colloids. I. Preliminary investigations Proc. Soil Sci. Soc. Amer. 16, 69 (1952).

Stoklasa, J.: Biochemischer Kreislauf des Phosphat-Ions im Boden. Zbl. Bakt. Abt. II 29, 385 (1911).

Waksman, S.: Principles of soil-microbiology. London (1927).

Waksman, S. u. F. Tenney: Composition of natural organic material and their decomposition in the soil. Soil Sci. 24,275,317 (1927);28,55(1929);30,143(1930)

Waksman, S. u. I. Hutchings: Decomposition of lignin by microorganisms. Soil Sci. 42, 119 (1936).

Bremner, J.: The amino-acid composition of the protein material in soil. Biochem. J. 47, 538 (1950)

Ensminger, E., u. I. Gieseking: Resistance of clay absorbed proteins to proteolytic Hydrolysis. Soil Sci. 53, Nr. 3 (1942)