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TERNATIONALE DE LA SCIENCE DU SOL

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SOCIETY OF SOIL SCIENCE

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NALEN BODENKUNDLICHEN
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D E L S U E L O

PEDOLOGY IN USSR

PAPERS

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P R E F A C E

During the period of time that has passed since the 2nd International Congress of Soil Science, the Soviet Section of the International Society¹ was able to publish several compendiums of reports on the occasion of the International Conferences of the various Commissions of the² Society. Only the 5-th Commission formed an exception to this rule, and this was due to the circumstance that 1st International Conference, appointed for 1934 in Spain, has been postponed.

Notwithstanding, the Soviet Section considers it necessary to unite the reports of the Soviet members of the I.S.S. which were to be presented to this Conference in a separate book which will be published on the occasion of the 3-d International Congress.

Therefore the present publication contains only the reports on questions belonging to the scope of the remaining five commissions of the I.S.S., i. e. except the V-th one.

Besides the usual, re-appearing every year, subjects of study, it is necessary to draw attention to some problems and questions, which as yet had been but little and infrequently touched upon by the Soviet soil literature, and even such as have been never before considered in it. To the latter belong e. g. on one hand the theoretically so important new field of knowledge, which is being intensely studied in the USSR of late,— biogeochemistry (report by A. P. Vinogradov), on the other—the practically extremely important problem of spray-irrigation; standing in direct connection to vast measures being undertaken for the purpose of raising the yielding capacity and eliminating its wide fluctuations in the vast droughty areas of this country.

Soil structure is discussed here not only from the angle of agrotechnical interests but also from that of road construction soil-science (ground-science). New methodics, recommended by the late K. K. Gedroiz, are being introduced into the study of the soil's humine acids.

The work of N. A. Kachinsky is a summary his long, continued through many years studies of an extremely vast scope concerning the root-system of free-growing and cultural plants.

I. N. Antipov-Karataev presents a summary of the recent researches of Soviet soilscientists and agrochemists concerning the physico-chemical properties of soil.

The field of soil biology is represented by the reports of the most eminent experts of the Soviet Union.

The immense construction work in the USSR, the range and tempo of which increase day by day lays ever increasing claims to Soviet soilscientists dictating to them new subjects of study.

President of the Soviet Section of I.S.S

Prof. Dr. A. A. Yarilov

DAS WURZELSYSTEM WILDWACHSENDER UND KULTURPFLANZEN IN VERSCHIEDENEN BODENARTEN IN VERBINDUNG MIT DEN WASSER- UND NÄHRSTOFF-VERHÄLTNISSEN DER BÖDEN

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Zusammenfassung

I. Ziel der Arbeit

Eine ganze Reihe von Fragen der Bodenkunde, der Agrikulturchemie und der Agronomie sehen zu ihrer Lösung die Kenntnis des inneren Wesens und der Art der Entwicklung des Wurzelsystems verschiedener Pflanzen voraus. Solche Fragen sind die der Wasser- und Nährstoffverhältnisse des Bodens, der Humusbildung und der Strukturformation, Fragen der Bodenbearbeitung und der Düngung u.a.m. Zwecks Aufklärung dieser Fragen haben wir gleichzeitig mit einem allseitigen Studium der Bodeneigenschaften, eine Untersuchung des Wurzelsystems verschiedener wildwachsender und Kulturpflanzen vorgenommen.

II. Programm der Untersuchung

Zwecks Feststellung der Gesetzmässigkeit der Entwicklung des Wurzelsystems der Pflanzen in verschiedenen Bodenarten haben wir zu unserer Untersuchung die drei hauptsächlichsten Bodentypen der UdSSR gewählt: 1. für die Waldzone — podsolige Böden verschiedener mechanischer Zusammensetzung, von verschiedenem Grade der Podsolierung und verschiedenem Kulturzustand — nahmen wir Boden vom Territorium der Moskauer landwirtschaftlichen Versuchsstation (nicht weit von Moskau); 2. für die Zone der Waldsteppe — graue Waldböden — entnahmen wir die Bodenprobe dem Versuchsfeld von Staroschilowo (vorm. Rjasan Gouv.); 3. die dritte Bodenprobe stammt aus dem Versuchselektionsfeld «Kruglik № 1» bei Krasnodar, und stellt einen west-ziskaukasischen ausgelaugten Tschernosem dar.

1. In podsoligen Böden wurde das Wurzelsystem folgender Pflanzen untersucht: von gemischtwachsenden Gräsern wie *Secale cereale*, *Avena sativa*, *Solanum tuberosum*, *Brassica oleracea*, *Beta vulgaris*, *Linum usitatissimum vulgare*, *Trifolium pratense* L., *Medicago sativa*, *Lupinus perennis* und *Barbarea vulgaris*; des Laubwaldes — nach Abtrieb folgender Baumarten aufgewachsen:

Betula alba, *Populus tremula*, *Acer platanoides*, *Rhamus frangula* und selten, *Picea excelsa*. Waldbestand ungefähr zwanzigjähriger — Mittelbauholzwald.

Das Wurzelsystem des Hafers wurde in Böden verschiedenen Kulturzustands untersucht.

2. In grauen Waldböden untersuchten wir das Wurzelsystem folgender Mischgräser: *Medicago sativa*, *Trifolium pratense*, und den Laubwald — Mittelbauholzwald, nach Abtrieb folgender Baumarten entstanden — *Quercus pedunculata*, *Betula alba*, *Populus tremula*, *Corylus Avellana* u.a., mit gut entwickelter Grasdecke.

3. In dem west-ziskaukasischen, ausgelaugten Tschernosem wurden untersucht: Mischgräser: *Triticum durum*, *Medicago sativa*, *Zea Mays*, *Helianthus annuus*, und Laubwald: *Quercus pedunculata*, *Acer tataricum*, *Fraxinus*, *Pirus communis*, *Pirus malus* u.a. mit Nachwuchs und dichtem Unterwald aus *Ilmus campestris*, *Crataegus monogyna*, *Cornus sanguinea*, *Prunus divaricata* u.a. Alter des Bestandes — mehr als 200 Jahre.

Das Wurzelsystem der Sonnenblume wurde bei verschiedenen Bodenbearbeitungsmethoden studiert.

4. Die oberirdischen Teile der Pflanzen. Bei der Untersuchung der Gräser wurden ausser dem Wurzelsystem auch ihre oberirdischen Teile in Rücksicht gezogen. Die Bestimmungen wurden im Stadium der besten Entfaltung der grünen Masse der oberirdischen Teile der Pflanzen vorgenommen. Das gestellte Ziel: Bestimmung der Gesetzmässigkeit der Wechselbeziehungen zwischen der Masse der oberirdischen und unterirdischen Teile bei verschiedenen Pflanzen, der Veränderungen dieser Wechselbeziehungen und ihre Abhängigkeit von Typus und Varietät der Böden, von Kulturzustand und Bearbeitungsweise.

5. Untersuchung der chemischen Zusammensetzung, der physikalischen Eigenschaften und der Wasserverhältnisse der Böden. Die Wurzelsysteme wurden auf Parzellen untersucht, auf welchen man gleichzeitig auch die chemische Zusammensetzung des Bodens, seine physikalischen Eigenschaften und die in ihm herrschenden Wasserverhältnisse studiert hat. Bodeneigenschaften und Wurzelsysteme der Pflanzen wurden am Bodenprofil bis zur Tiefe von 2 bis 5 m verfolgt, und die Wasserverhältnisse in allen Fällen bis zur Tiefe von 2 m. Die Beobachtungen wurden auf podsoligen Böden 6 Jahre lang und in der Waldsteppe und auf dem Tschernosem 3 Jahre lang fortgesetzt; zwar auf den podsoligen Böden das ganze Jahr hindurch alle 10 Tage, und in der Waldsteppe und im Nord-Kaukasus — in der Zeit vom April bis Ende Oktober.

III. Untersuchungsmethode

Die Wurzelsysteme der Pflanzen wurden gleichzeitig nach verschiedenen Verfahren untersucht.

1. Zwecks Bestimmung der Wurzelmasse in einem bestimmten Bodenvolumen und zur Aufnahme der Intensität der Entfaltung der Wur-

zeln in der Ackerkrume und den einzelnen genetischen Horizonten des Bodens hat man die Bauschmethode von N. A. Katschinsky (1) angewandt. Nach dieser Methode werden an einer typischen Stelle des untersuchten Schlages horizontale Monolithe von quadratischem Querschnitt, der eine tiefer als der andere, jedoch nicht tiefer als die Wurzeln der Pflanzen reichen, ausgehoben und in Kisten gelegt (Fig. 1).

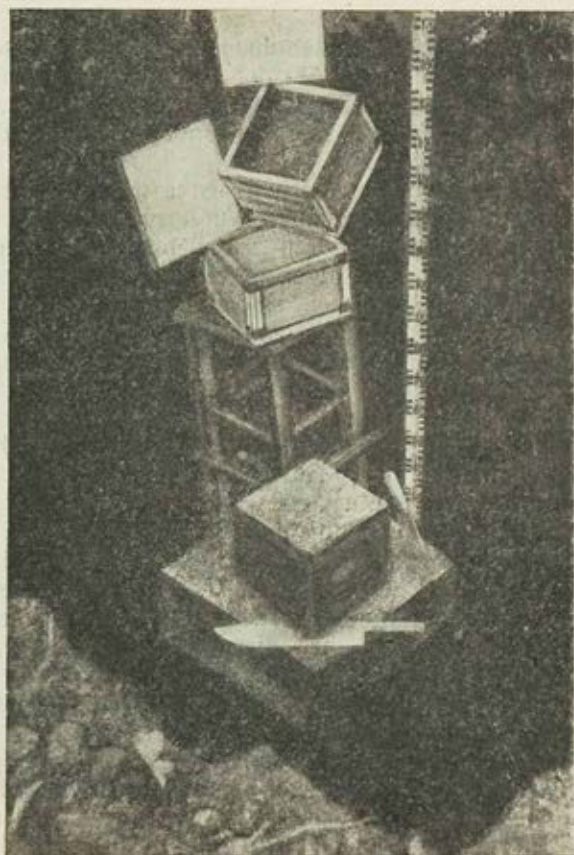


Fig. 1. Bodenprobeentnahme zur Auswaschung und Auslese der Wurzeln nach der Methode von Katschinsky.

Der Querschnitt der Kiste variierte je nach der untersuchten Pflanze zwischen 625 und 2500 cm². Höhe der Kisten — 10, 20, 30 und 40 cm — je nach der Mächtigkeit der Ackerschicht, der verschiedenen genetischen Bodenhorizonte und der Detaillierung der Arbeit innerhalb der einzelnen Horizonte. Die Kisten, eigentlich Rahmen, mit dem herausgeschnittenen Boden wurden unten und oben mit Deckeln versehen und zugeschraubt und im Laboratorium einer speziellen Untersuchung unterzogen. Die grössten, gut sichtbaren Wurzeln wurden mittels Pinzetten herausgelesen, und dann der Boden mehrmals mit Wasser durch

ein Sieb mit 0,25 mm- Lochdiameter, durchgeseibt; alle Wurzeln und alle auf dem Siebe zurückgebliebenen organischen Reste hat man alsdann gesammelt und folgenderweise klassifiziert — lebende Wurzeln, abgestorbene Wurzeln und organische Reste. Ausserdem wurden die lebenden Wurzeln je nach Grösse, Epidermis und Behaarung, in Saug- und Durchleitwurzeln eingeteilt. Die herausgeschiedenen Fraktionen hat man im Thermostat bei 90° C getrocknet und mit einer Präzision bis 0,01 g gewogen.

Bei der Entnahme der Bodenmonolithe, der Auslese und Ausspülung der Wurzeln wurden die Art der Wurzelentwicklung und die morphologischen Eigentümlichkeiten betrachtet, die Wurzeln gezeichnet oder photographiert, und die Beobachtungen in ein Feld- oder Laboratoriumsdiarium eingetragen.

Aus der Beschreibung der Methode ist ersichtlich, dass es nicht ihr Ziel ist, aus dem Boden das ganze Wurzelsystem eines Pflanzenindividuums herauszunehmen, sondern vielmehr eine Mittelprobe zwecks Bestimmung der mittleren Mächtigkeit der Wurzelsysteme mehrerer Pflanzen in einem bestimmten Bodenvolumen.

Bei der Untersuchung von Gemüsepflanzen, wie Kartoffel, Kohl, Rübe, Sonnenblume und Mais wurde dafür gesorgt, dass die so entnommene untersuchte Pflanze in die Mitte des Monoliths (50×50 cm im Querschnitt) zu liegen kam.

Im Walde entnahm man die Monolithe in den Zwischenräumen zwischen den Stämmen, zwecks Auffangen des aktivsten Teils der Wurzeln der untersuchten Baumarten.

Zugleich mit der Herausnahme der Wurzeln wurde von der Bodenoberfläche, über den Monolithen, dicht am Boden, die oberirdischen Teile der untersuchten Pflanzen abgeschnitten (zur Blütezeit oder vor dem Ausreifen). Die oberirdische Masse wurde ebenfalls getrocknet und gewogen.

2. Ausser den Angaben über die Wurzelmasse der Pflanzen muss man auch die Art und die Tiefe der Ausbreitung dieser Wurzeln längs des Bodenprofils kennen. Wir bedienten uns hier der Methode der Tranchen von Weaver (2). Spezielle Tranchen wurden nicht angelegt, wir benützen zur Präparierung und Aufzeichnung der Wurzeln immer die vier Wände des Grabens, der bei der Entnahme der horizontalen Bodenmonolithe gemacht wurde. Die Wurzeln wurden mittels Stemmeisen und Pfriem präpariert. Um einem Abreißen der präparierten Wurzeln vorzubeugen, wurden diese mit Metallklammern an ihrem Standorte an den Boden festgesteckt; die Wurzeln wurden weiss gefärbt und photographiert. Fig. 2 zeigt eine Aufnahme der präparierten Wurzeln von *Medicago sativa* im grauen Waldboden und im ausgelaugten Tschernosem, des westlichen Ziskaukasien.

3. Und endlich, zur Festsetzung der Art der Ausnützung der Nahrung durch die Pflanze aus dem ihr zugänglichen Bodenvolumen und zur Lösung der Frage über die symmetrische oder asymmetrische Wurzelentfaltung der einzelnen Pflanzenexemplare haben wir die Methode der horizontalen Ausgrabungen von Katschinsky (3) gewählt. Dieser Methode entsprechend, wurden beginnend beim Stengel der Pflanze, den Wurzeln entlang, nach allen Richtungen in einer 30cm mächtigen Schicht, Ausgrabungen vorgenommen. Die Wurzeln wurden gezeichnet und

photographiert. Man erhält somit das Bild des Wurzelsystems der Pflanzen, in Form eines Plans, für eine 30cm mächtige Bodenschicht.

Fig. 3 zeigt eine Aufnahme der in der Oberflächenschicht präparierten Durchleitwurzeln von *Corylus Avellana* — grauer Waldboden.

Die Kombinierung der drei beschriebenen Methoden gibt ein volles Bild der Morphologie des Wurzelsystems der Pflanzen in dem Augen-



Fig. 2. Wurzeln von *Medicago sativa* — grauer Waldboden; präpariert nach der Methode von Weaver.

blick der Entnahme der Probe (maximale Entwicklung); nebenbei gewinnt man auch Angaben über ihre Physiologie. Es seien hier kurz die hauptsächlichsten Schlussfolgerungen, die auf Grund der Resultate der durchgeführten Arbeit gezogen werden können, angeführt.

4. Die chemischen und physiologischen Eigenschaften des Bodens und die in diesem herrschenden Wasserverhältnisse wurden unter strenger Berücksichtigung der Eigentümlichkeiten der Ackerschicht und der genetischen Horizonte des Bodens untersucht. Die physikalischen Eigenschaften wurden an Proben mit unverletzter Struktur studiert, wenn möglich in der natürlichen Lagerung dieses Bodens. Infolge Platzmangels führen wir hier nur einen kleinen Teil der Daten über die Wasserverhältnisse des Bodens an.

IV. Kurze vergleichende Charakteristik der wichtigsten untersuchten Böden

Tabelle 1, 2 und 3 zeigen eine kurze Zusammenfassung der Analysendaten über die hauptsächlichsten untersuchten Bodentypen. Die Analysen decken das Wesen des Unterschieds, der zwischen diesen besteht, auf.

1. Podsoliger Boden — mit dünner Humusschicht, die schroff abbricht beim Uebergang zum Podsolhorizont; arm an Humus, reich an Stickstoff, Kali und Phosphat. Die oberen Horizonte, besonders der Horizont A, sind ausgelaugt, der absorbierende Komplex ist arm, halb-



Fig. 3. Wurzeln von *Corylus Avellana* — grauer Waldboden; präpariert nach der Methode von Katschinsky.

zerstört. In den Horizonten B_1 , B_2 und B_3 verläuft ein stark ausgeprägter illuvialer Prozess. Dem Chemismus des Bodens entsprechend, sind auch die physikalischen Eigenschaften dieses Bodens vertreten. Mehr oder weniger günstig sind sie in der Ackerschicht (A_0). Im podsoligen Horizonte sind diese Eigenschaften ungünstiger, infolge der blättrigen Struktur des Horizontes. Letzterer ist von Wurmgingen durchzogen, durch welche leicht Wasser und Luft eindringen. An den Stellen, wo keine Wurmginge vorhanden sind, bilden die zahlreichen Strukturamellen des Horizontes für Wasser, Luft und Wurzeln ein unüberwindliches Hindernis. Die Lockerung des Bodens, ohne ergänzende Meliorierungsmassnahmen, verschlechtert die Eigenschaften des Horizontes, da sie die Ausfüllung der Wurmginge fördert.

Noch schlimmer steht es mit den physikalischen Eigenschaften im illuvialen Horizonte (B_1 , B_2 und B_3). Dieser Horizont ist sehr verdichtet

Tabelle 1
Mittel podsolierter, schwer lehmiger Boden. Mischgräser Braust mit HCl nicht auf.

Horizont	Tiefe in cm	Partikel		Humus in %	Absorb. Ba- sen in %		Daten der Bauschanalyse in %						Physikalische Eigenschaften					Wasser- durchlässig- keit in cm je 1 Std. zu Beginn der Begleitung
		0,01 mm	0,001 mm		CaO	MgO	SiO ₂	R ₂ O ₃ +P ₂ O ₅	Fe ₂ O ₃	CaO	MgO	Porosität in %	Wasserkapazität in % des Troc- des Bodens	Maximale Hygrosko- pizität in %				
A ₀	0-10	44,51	3,81	2,23	0,17	0,05	80,04	14,75	2,94	0,95	1,25	51,8	39,6	3,20	123			
A ₀	10-17	46,18	4,12	1,66	0,14	0,04	80,65	14,19	2,60	0,25	1,00	50,2	35,0	3,00	—			
A ₂	19-27	45,09	3,50	0,65	0,12	0,04	84,03	12,76	2,37	0,61	0,63	46,3	30,3	2,94	447			
B ₁	36-44	52,11	15,08	0,25	0,18	0,06	75,11	20,65	4,00	0,56	1,10	40,0	23,1	5,49	—			
B ₃	95-103	54,93	16,90	0,19	0,26	0,13	75,35	21,0	4,54	0,63	0,92	29,2	16,0	7,00	1,6			
B ₃	123-131	57,18	22,01	—	0,25	0,13	—	—	—	—	—	29,6	15,6	8,41	0,12			
B ₃	145-153	52,04	9,73	—	0,25	0,12	75,97	20,21	4,45	0,79	0,94	30,8	16,1	4,66	0,10			

Tabelle 2
Grauer toniger Waldboden. Luzerne. Braust mit HCl auf von der Tiefe von 230 cm ab.

Horizont	Tiefe in cm	Partikel		Humus in %	Absorb. Ba- sen in %		Daten der Bauschanalyse in %					Physikalische Eigenschaften				
		0,01 mm	0,001 mm		CaO	MgO	SiO ₂	R ₂ O ₃ +P ₂ O ₅	Fe ₂ O ₃	CaO	MgO	Porosität in %	Wasserkapa- zität in %	des Troc- des Bodens	Maximale Hygrosko- pizität in %	Wasser- durchlässig- keit in 1 Std. zu Beginn der Beglössung
A ₀	0-10	48,96	8,12	2,93	0,42	0,09	71,70	14,52	4,68	2,54	1,43	51,0	39,0	4,41	181	
A ₀	10-20	51,32	9,97	3,15	0,42	0,11	71,11	13,91	5,37	3,09	1,60	46,9	34,1	4,81	—	
A ₂	20-30	53,90	11,87	2,99	0,59	0,14	71,16	15,26	6,08	3,09	2,00	45,1	29,1	7,10	55	
A ₂	30-40	56,45	11,86	1,90	0,60	0,19	69,69	16,23	6,09	2,74	1,98	44,6	28,4	7,97	—	
B ₁	40-50	55,39	11,29	1,80	0,70	0,19	69,63	16,38	6,20	3,29	1,79	44,3	27,5	8,15	210	
B ₂	90-100	60,09	15,76	0,66	0,56	0,18	69,99	16,83	7,22	3,20	1,87	43,9	28,4	8,49	—	
B ₂	120-130	55,76	13,09	0,68	0,56	0,16	71,42	17,58	6,27	2,62	1,73	43,0	27,4	7,40	572	
C	150-160	36,33	8,62	0,22	0,40	0,14	73,08	15,69	6,56	3,04	1,38	42,5	28,3	5,51	16	

Tabelle 3

Toniger, ausgetaugter Tschernosem des westlichen Ziskaukasiens. Luzerne. Braust mit HCl auf,
von der Tiefe von 150 cm ab.

Horizont	Tiefe in cm	Partikel		Humus in %	Absorb. Ba- sen in %		Daten der Bausanalyse in %					Physikalische Eigenschaften				
		0,01 mm	0,001 mm		CaO	MgO	SiO ₂	R ₂ O ₃ +P ₂ O ₅	Fe ₂ O ₃	CaO	MgO	Porosität in %	Wasserkapa- zität in % des Trocken- gewichts des Bodens	Maximale Hygroskopizi- tät in %	Wasserdurch- lässigkeit in cm je 1 Std zu Beginn der Begießung	
A ₀	0—10	57,09	18,43	3,67	0,95	0,19	59,09	22,88	4,96	3,03	2,00	51,5	42,5	8,30	372	
A ₀	10—20	54,87	16,69	3,99	0,93	0,19	59,59	24,95	4,87	2,70	2,15	49,2	35,7	8,45	—	
A ₂	20—30	57,47	19,27	3,78	0,99	0,20	59,14	24,05	5,06	2,22	2,33	51,5	34,9	8,73	597	
A ₂	30—40	51,40	17,70	3,37	0,98	0,19	—	—	—	—	—	49,6	32,6	8,98	—	
A ₂	40—50	50,62	15,20	2,95	0,99	0,20	59,46	23,15	5,09	2,45	2,75	50,1	31,9	8,97	382	
A ₃	90—100	54,06	16,09	2,18	0,99	0,19	59,74	23,91	5,10	2,40	2,70	46,6	31,8	8,75	211	
B	125—135	52,88	15,30	1,57	0,89	0,18	—	—	—	—	—	46,3	31,8	8,48	—	
B/C	150—160	48,95	16,46	1,26	—	—	58,50	24,95	4,98	3,76	2,50	46,1	32,3	8,32	256	

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infolge Einspülungen. Die Porosität, die Wasserkapazität und die Wasserdurchdringlichkeit erreichen hier limitativ kleine Werte. Es sind hier deutliche Zeichen der Versumpfung zu bemerken.

2. Der ausgelaugte Tschernosem aus dem westlichen Ziskaukasien zeichnet sich durch entgegengesetzte Eigenschaften aus. Er weist einen geringen Gehalt an Humus auf, doch ist die Mächtigkeit seiner Humushorizonte ausserordentlich gross (bis 150 cm und mehr). Er ist relativ reich an Nährstoffen und besitzt einen mächtigen absorbierenden Komplex, der in der Hauptsache mit Kalzium gesättigt ist; dieser Boden zeichnet sich durch vortrefflich ausgeprägte, ausgeglichene physikalische Eigenschaften aus, er ist strukturell, weist ein hohes Wasserhaltungsvermögen auf, ist leicht wasser- und luftdurchdringlich. Er wird bis zur Tiefe von 5m und mehr von lössartigem Lehm unterlagert, dessen ganze Schicht von zahlreichen Wurmängen (540 Wurmgänge je 1m²) mit Querschnitt von 8 bis 10mm durchzogen ist.

3. Der graue Waldboden nimmt bezüglich chemischer Zusammensetzung und physikalischer Eigenschaften eine Mittelstellung ein. Die Analysendaten weisen auf einen deutlich ausgeprägten Degradationsprozess hin.

V. Das Wurzelsystem der Pflanzen

1. Das Wurzelsystem sowohl der Gras-, als auch der Holzvegetation entwickelt sich den Eigenschaften ihres Standortes entsprechend. Der Boden, auf dem die Pflanze lebt, diktiert sozusagen ihrem Wurzelsystem seine Entwicklungsform. Dieser Zusammenhang ist so eng, dass man auf Grund des Studiums der Pflanzenwurzeln die Eigenschaften des Bodens beurteilen kann, auf dem die Pflanze sich entfaltet hat, und umgekehrt, kann man, wenn man den Boden kennt, im Voraus sagen, wie die Entfaltung des Wurzelsystems in diesem vor sich gehen wird. Die Pflanze passt ihr Wurzelsystem den Eigenschaften des Bodens an, wirkt aber gleichzeitig durch ihre Wurzeln (und Stengel) auch auf den Bodenbildungsprozess ein: sie verschärft die sich im Boden andeutenden typischen Merkmale und stimuliert die Dynamik des Bodenprozesses in der Richtung der Humusbildung, der Strukturformierung, der biologischen Aktivität u.a.

In den untersuchten Böden (Podsolboden, ausgelaugter Tschernosem, grauer Waldboden) sehen wir drei Typen der Wurzelsysteme.

2. In einem reichlich befeuchteten, podsoligen Boden ist die überwältigende Masse der Wurzeln (von 80 bis 95 und mehr Prozent) in der an die Oberfläche grenzenden Schicht konzentriert, in der Schicht, welche am besten durchwärmt und durchlüftet wird und sich durch die günstigsten chemischen und physikalischen Eigenschaften auszeichnet, und zwar in dem humusakkumulativen Horizonte. Die Wurzeln der Holz- und der Grasvegetation bilden in dieser Schicht ein dichtes Netz, das manchmal sich in eine Wurzelfilzschicht verwandelt.

Der Uebergang zu dem darunterliegenden wenig fruchtbaren und seinen physikalischen Eigenschaften nach ungünstigen Podsolhorizont macht sich durch eine starke Verringerung der Zahl der Wurzeln kund; wobei diese letzteren sich zu den zahlreichen hier vorhandenen Wurm-

gängen hinziehen. Weiter nach der Tiefe hin, in den verdichteten Illuvialhorizonten, die Zeichen einer Versumpfung aufweisen, findet man noch weniger Wurzeln. Sie nisten sich in die Wurmgänge und die Risse ein, bedecken die Wände der Hohlräume und umflechten die Kanten der Struktureinheiten. Tiefer als ein Meter dringen in einem gut entwickelten Podsolboden nur sehr wenig Wurzeln ein; dies sind vereinzelte Wurzeln, die kein zusammenhängendes Netz in der Bodenschicht bilden.

Mit der Schwächung der Podsolierung und dem Leichterwerden der mechanischen Zusammensetzung, wächst das Prozent der Wurzeln, die über die Grenzen des humosen Horizontes in die tieferliegenden Bodenschichten reichen, progressiv an; doch wird die hier vorhandene Menge der Wurzeln 30% der Gesamtmasse der Wurzeln der Pflanze nie übersteigen.

3. Ein anderes Bild zeigt das Wurzelsystem der Pflanzen in dem ausgelaugten Tschernosem aus dem westlichen Ziskaukasus. Sein mächtiger Humushorizont ist relativ gut mit Pflanzennährstoffen versorgt und weist günstige physikalische Eigenschaften auf, ebenso wie der sich durch gute physikalische Eigenschaften auszeichnende lössartige Lehm, der ihn unterlagert; dies erlaubt den Wurzeln, tiefer in den Boden einzudringen. Hier finden wir in der Ackerschicht (0 bis 20 cm) von 10 bis 76% der Gesamtmasse der Wurzeln der Pflanze — die übrigen 24 bis 90% der Wurzeln werden also von der Pflanze in die tieferliegenden Schichten des Bodens gesandt. So findet man in der Schicht 0 bis 20 cm unter Wald nur 9,88% Wurzeln, unter Mischgrasbestand — 76,31%, unter Luzerne — 56,52% usw. Entsprechend wächst auch die Menge der Wurzeln an, welche tiefer als 1m dringen. Diese Menge schwankt hier innerhalb des Bereichs von 7 bis 20%. Die Anzahl der Wurzeln nimmt hier nach der Tiefe hin viel langsamer ab als in den podsoligen Böden; das Gesamtbild nähert sich dem umgekehrten Kegel der Wurzelmasse, von dem Prof. W. Williams (4) spricht. Bei den Waldarten wird hier sogar eine Versetzung des Wurzelmaximums von der Oberfläche nach der Tiefe hin beobachtet, wobei bei feinen Wurzeln (dünner als 1mm) dieses Maximum in der Schicht von 20 bis 60cm liegt.

In der Tiefe von mehr als 100 bis 150 cm ist die Mehrzahl der Wurzeln in vertikaler Richtung orientiert. Die Pflanze spart ihre Masse und die Zeit und treibt ihre Wurzeln zu den tief lagernden wasserführenden Schichten ohne Abweichungen, den Geraden entlang. Bezeichnend ist, dass auch im Tschernosem und den relativ lockeren Waldböden die Pflanze vorzugsweise die Hohlräume (Maulwurfsgänge, Risse, Wurmgänge) ausnützt, diese mit «Wurzelschnürchen» ausfüllend und die einzelnen Teile der Wände dieser Hohlräume mit «Wurzeltätzchen» umflechtend. In solchen Hohlräumen ist die Behaarung der Wurzeln mit Saughärchen sehr gut ausgeprägt.

Weizen, Mais und Gräser entfalten hier ihr Wurzelsystem in der Schicht — 250 cm. Die Wurzeln der Sonnenblume und der Luzerne, — und unter den Holzgewächsen, von Eiche und weisser Akazie — laufen bis zur Tiefe von 6m, wo sie das Grundwasser erreichen.

Die Tatsache, dass die Wurzeln der Pflanzen bis zu dem Grundwasser reichen, kann sie nur zum Teil von den Folgen der Dürre bewahren.

Allem Anscheine nach reicht der kleine Teil der Wurzeln, die vom Grundwasser umspült werden, nicht aus, um die ganze Pflanze in normaler Weise mit Wasser zu versorgen. Ausserdem ist die Hauptmasse der Wurzeln, die sich in der ausgetrockneten, fruchtbaren Oberflächenschicht konzentriert, nicht imstande, die Nährelemente in normaler Weise aufzunehmen, entgegen den Angaben von F. Breazeale (5). Im Sommer 1928 haben wir auf einer fruchtbaren Kulturparzelle eine unterdrückte Entwicklung der Sonnenblume (bei langdauerndem Trockenwetter) beobachtet, obwohl ein Teil ihres Wurzelsystems bis zu den Grundwassern vorgedrungen war. Auf den Parzellen, auf welchen die Pflanzen später ausgesät wurden und deren Wurzeln den Grundwasserstand noch nicht erreicht hatten, als die Dürre sich einstellte, verdorrten die Pflanzen in diesem Jahr gänzlich.

4. Die Wurzelsysteme verschiedener Pflanzen haben in den grauen Waldböden eine Zwischenstellung eingenommen zwischen den Wurzeltypen in podsoligen Böden und in den Tschernosems. Je mehr der Boden degradiert und je deutlicher in ihm der Podsolierungsprozess ausgeprägt ist, um so weiter entfernt sich die Wurzeltype in diesen Böden von jener, die im Tschernosem beobachtet wird, und um so mehr nähert sie sich ihrem Wesen nach dem Wurzelsystem der Pflanzen auf podsoligen Böden. In den grauen Waldböden und den dunkelgrauen Böden, die sich den degradierten Tschernosems nähern, ist dagegen das Wurzelsystem jenem ähnlicher, das wir im Tschernosem sehen.

5. Die übliche Einteilung der Pflanzen in tief- und seichtwurzelnde ist sehr bedingt. Ein und dieselbe Pflanze kann, je nach den vorhandenen Bodenbedingungen, bald seicht, bald tief wurzeln. Beispiele: die Kiefer hat auf leichten, schwach podsolierten Böden Wurzeln, welche tief in den Boden eindringen, — auf Podsolböden, insbesondere den schweren, kriechen ihre Wurzeln an der Oberfläche. Die Luzerne zeigt in Trockengebieten mit lössartigem Unterboden bis 10 m lange Wurzeln, die sich bis zu den Grundwassern hinziehen; auf podsoligen Böden aber dringen die Wurzeln der Luzerne selten tiefer als 1 m, so dass sie in dieser Hinsicht sogar den Wurzeln des Flachses nachstehen; einzelne Wurzelfasern dieses letzteren erreichen die Länge von 180 cm. Wir könnten noch viele ähnliche Beispiele anführen.

6. Bei der Betrachtung der Unterschiede, welche das Wurzelsystem der Pflanzen in verschiedenen Böden zeigen, muss darauf hingewiesen werden, dass in allen Bodentypen die Grundmasse der Wurzeln (7 bis 100%) sich in der ersten 1 m mächtigen Schicht befindet.

7. Die Wurzelsysteme der Pflanzen, welche als dichtgeschlossener Gras- oder Baumbestand wachsen, breiten sich symmetrisch nach allen Richtungen hin aus und entwickeln das dichteste Netz zwischen den Pflanzenreihen. Pflanzen — Bäume und Kräuter — die als einzeln stehende Individuen wachsen (z. B. der Kohl), bilden ein asymmetrisch entwickeltes Wurzelsystem, das südwärts orientiert ist.

8. Es stellte sich heraus, dass die Ausbreitung des Wurzelsystems im Tschernosem und in grauen Waldböden ungefähr dieselbe ist. Ihr Maximum beträgt bei verschiedenen Pflanzen: Weizen und Roggen — 35 bis 50 cm, Klee und Luzerne — dreijährige — 50 bis 90 cm, Mais —

250 bis 300 cm, Sonnenblume — 150 bis 160 cm, Eiche, Ahorn, Linde — im Mittelbauholzstadium — bis 10 m, Espe — bis 15 m. Espenwäldchen, die aus einigen Dutzenden dieser Bäume bestehen, stellen oft eine einzige Familie dar mit einem eng verschlungenen, zusammenhängenden Wurzelsystem (Nebenschösslinge).

9. Wir können die hohe Empfindlichkeit der Pflanzen gegenüber den Bodeneigenschaften beim Aufbau des Wurzelsystems ausnützen, indem wir die Struktur des Wurzelsystems der Pflanzen durch agrotechnische Massnahmen nach der gewünschten Seite verschieben und folglich die Ernährungsbedingungen der Pflanze ändern. Aus Tabelle 4 ist ersichtlich, dass die verschiedenen Methoden der Bearbeitung des Podsolbodens nicht ohne Einfluss bleiben auf die Entwicklung des Wurzelsystems und der oberirdischen Teile des Hafers. Durch tiefere Bearbeitung fördern wir ein tieferes Eindringen der Pflanzenwurzeln und steigern somit den Pflanzenenertrag.

10. Wenn in Podsolböden die Kartoffeln in hochaufgeworfene Reihen gelockerten Bodens gepflanzt werden, befindet sich das gesamte Wurzelsystem in der Ackerschicht, besonders in den «Kämmen» der Haufen. Bei einer solchen Bearbeitungsweise wird der Boden gut durchwärmt und durchlüftet; bei überschüssigen Niederschlägen werden optimale Bedingungen für die Entwicklung der Pflanze geschaffen, welche von dieser auch maximal ausgenützt werden: beim Abwaschen des Bodens haben wir festgestellt, dass die «Kämme» gleichzeitig auch die Maxima des Wurzelsystems der Kartoffeln enthalten, während die tieferliegenden Bodenhorizonte von Kartoffeln viel weniger ausgenützt werden als von Gräsern und den Leguminosen. Nur vereinzelte Wurzeln gehen bis zur Tiefe von 1 m.

Ähnlich verhalten sich die Wurzelsysteme des Kohls und der ägyptischen Zuckerrübe. Die Wurzeln konzentrieren sich in der Ackerschicht, nur sehr wenige dringen tiefer ein. Maximales Eindringen der Wurzeln des Kohls — 130 cm, der Zuckerrübe — 75 cm. Ausbreitung des Wurzelsystems der Kartoffeln, des Kohls und der Zuckerrübe — 100 bis 130 cm.

11. Das Verhältnis der unterirdischen Masse zur oberirdischen Masse der Pflanze variiert je nach der Art des Bodens und des Pflanzentypus innerhalb sehr weiter Grenzen — von 0,14 bis 1,71 (Tab. 4). Das grösste Wurzelsystem hinsichtlich seiner Masse und im Verhältnis zu den Stengeln besitzen die Gräser und die Leguminosen: hieraus wird klar, dass ihre Rolle bei der Struktur- und Humusbildung eine positive sein muss.

Die Gesetzmässigkeit in dem Verhältnis zwischen unterirdischen und oberirdischen Pflanzenteilen, die sich bei unseren Versuchen angedeutet hat, ist wie folgt: je höher der Kulturzustand des Bodens, um so schwächer (im Verhältnis zu den unterirdischen Teilen) ist das Wurzelsystem der Pflanze entwickelt.

12. Ueber die Quellen des Humus im Boden. Die Arbeiten von Lewakowsky (6), Hoppe-Seyler (7), Sljoskin (8) und insbesondere die klassisch gewordene Arbeit von Krawkow (9) haben längst bewiesen, dass die Quelle des Humus im Boden in den wasserlöslichen organischen Stoffen zu suchen ist, welche aus den oberirdischen und unterirdischen Pflan-

Tabelle 4

Verhältnis zwischen dem absoluten Trockengewicht der oberirdischen und der unterirdischen Teile der Pflanzen.

	Oberirdische Teile (A) von der Fläche von 625 cm ² in Zollen	Unterirdische Teile (B) entsprech- end der Oberfläche von 625 cm ² in Zollen	$\frac{B \cdot 100}{A} = \frac{0,0}{A}$	Boden
Barbarea vulgaris	24,3	10,31	42,4	} Mittel podsoliger Boden
Linum usitatissimum . .	25,2	9,38	37,2	
Avena sativa	42,72	12,10	28,3	
Avena sativa	71,84	21,31	29,7	} Lehmiger Podsol; A ₀ —9 cm; A ₂ (unverletzt) — 18 cm
Avena sativa	126,46	17,21	13,8	
Triticum vulgare	44,77	31,20	69,7	
Hackfrüchte				} Lehmiger Podsol A ₂ ist durch A ₀ bis zur Tiefe von 24 cm ersetzt
Solanum tuberosum . . .	21,18	9,38	44,3	
Beta vulgaris "	12,44	9,78	78,6	
" "	12,44	66,75	536,6	} Ausgelaugter Tscherno- zem aus dem westlichen Ziskaukasien
Helianthus annuus . . .	152,39	38,40	25,2	
Zea Mays	280,71	44,88	16,0	
Wiesengräser	44,0	70,07	160,7	} Lehmiger Podsol Stark podsoliger Sand- lehm auf Lehm
" "	32,2	32,45	97,7	
" "	52,9	41,75	78,9	
" "	42,62	59,23	139,0	} Schwach podsolierter Sandlehm auf Sand Grauer toniger Waldboden
" "	28,93	21,31	73,7	
Leguminosen				
Trifolium	35,9	24,83	69,2	} Ausgelaugter Tscherno- zem aus dem westlichen Ziskaukasien
Lupinus	45,1	33,71	74,7	
Medicago sativa	34,3	58,55	170,7	
" "	35,05	57,91	165,2	} Grauer toniger Waldboden Ausgelaugter Tscherno- sem aus dem westlichen Ziskaukasien
" "	28,93	53,21	166,0	

zenteilen mit dem Wasser der Niederschläge herausgewaschen werden. Die erwähnten Gelehrten schreiben den oberirdischen Teilen bei diesem Prozesse die leitende Rolle zu. Dagegen hat Kostytschew (10) die Meinung ausgesprochen, dass die Hauptquelle der Humusbildung im Boden durch die Wurzelmasse der Pflanzen gebildet wird.

Wir haben eine weitgreifende Vergleichung des Humusgehalts und der Entwicklung des Wurzelsystems verschiedener Pflanzen im Bodenprofil verschiedener Böden verschiedener Zonen vorgenommen. Der Korrelationszusammenhang zwischen diesen beiden Erscheinungen ist gross (etwa $+0,8$, $+0,9$). Wir stimmen der Meinung der erstgenannten Autoren bei und schreiben den Wurzeln die Hauptrolle in dieser Erscheinung zu.

Von Interesse ist, dass die Masse lebender Wurzeln verschiedener Pflanzen auch in der an Humus reichsten Ackerschicht nur 0,1 bis 0,7% des Bodengewichts ausmacht und selten bis auf 1% steigt, d. h., dass die Masse der Wurzeln im Boden bedeutend geringer ist als der Humusgehalt dieses Bodens. Die Anzahl der abgestorbenen Wurzeln stellt einen noch geringeren Wert vor, etwa $\frac{1}{10}$ oder $\frac{1}{15}$ der Masse lebender Wurzeln. Folglich ist der Humus ein Produkt, das von einer langen Reihe von Pflanzengenerationen angehäuft wurde. Die ersten Etappen der Wurzelzerlegung gehen schnell vor sich und die sich bei diesem Prozess bildenden Humusstoffe erhalten eine gegen Mineralisierung widerstandsfähige Form.

13. Das Vorhandensein verschiedener Einwurzelungsarten der Pflanzen in verschiedenen Böden bewegt uns, die Frage von der Art, in welcher der Boden durch die Pflanzenwurzeln ausgetrocknet wird, in ganz anderer Weise aufzustellen. In podsoliger Zone wird z. B. in erster Reihe und in der Hauptsache der Oberflächenhorizont durch die Waldvegetation, und die Grasvegetation desgleichen, ausgetrocknet. Die tieferliegenden Horizonte werden unter solchen Bedingungen auf Kosten des kapillarischen Anstiegs des Wassers in die zu der Oberfläche näher lagernden, austrocknenden Schichten ihren Wassergehalt verlieren; in geringerem Ausmass werden die tieferliegenden Horizonte durch unmittelbare Aufnahme des Wassers durch Wurzeln der Pflanzen ausgetrocknet.

In der Tschernosemzone werden je nach Art der angebauten Pflanze und ihres Einwurzelungssystems bald tiefer, bald näher an der Oberfläche lagernde Bodenschichten unmittelbar des Wassers beraubt. Das Verhältnis von Feuchtigkeitsgrad des Bodens im Wald und unter Feldpflanzen, wie es im allgemeinen gegeben ist (im Walde sind die tieferliegenden Schichten trockener als die oberen, auf dem Felde sind die oberen Schichten trockener als die unteren), wird oft in Abhängigkeit von Wald- oder Feldkulturen gestört. Es wurden für die Podsolzone zahlreiche Fälle verzeichnet, wo der Wald, der sich unter denselben Bedingungen befindet wie das Feld, den Boden stärker von der Oberfläche ab entwässert als die Feldkulturen; andererseits kommen in der Tschernosemzone Fälle vor, wo solche Kulturen wie Sonnenblume, Mais und Luzerne bei guter Entwicklung den Boden längs der ganzen 2 m mächtigen Schicht stärker seines Wassers berauben als der nebenstehende Wald. Wenn man solche Vergleichen vornimmt, muss

der Feuchtigkeitsgrad des Bodens, selbstverständlich nicht in absoluten Grössen, sondern in Prozenten der relativen Feuchtigkeit, ausgedrückt werden. Unter letzterer verstehen wir den absoluten Feuchtigkeitsgehalt in Prozenten der kapillarischen Wasserkapazität des Bodens berechnet.

LITERATUR

- (1) N. A. Katschinsky — Das Wurzelsystem der Pflanzen in Böden des podsoligen Typus. Moskau 1925.
- (2) J. Weaver — The ecological relations of roots. Carneg. Inst. Wash. Publ. No. 286, pp. 1—128, 1919.
- (3) N. A. Katschinsky — Studien der physikalischen Eigenschaften des Bodens und der Wurzelsysteme der Pflanzen bei territorialen bodenkundlichen Untersuchungen. 2. Aufl., Moskau 1931.
- (4) W. R. Williams — Allgemeiner Ackerbau mit Grundlagen der Bodenkunde. Moskau 1931.
- (5) F. Breazeale — Maintenance of moisture equilibrium and nutrition of plants at and below the wilting percentage. Univ. of Arizona. Agr. Exp. St. Techn. Bull. 29, 1930.
- (6) I. F. Lewakowsky — Einige nachträgliche Bemerkungen zur Untersuchung des Tschernosems. Abh. der Gesellschaft der Naturforscher an der Universität Charkow, Bd. 22, S. 103, 1888.
- (7) Hoppe-Seyler — Zeitschr. f. physikal. Chemie, XIII, 1880.
- (8) Sijoskin — Skizzen über den Humus. Kiew 1900.
- (9) S. P. Krawkow — Untersuchungen auf dem Gebiete der Untersuchung der Rolle der toten Vegetationsdecke beim Bodenbildungsprozess, S. 97 u. ff.
- (10) Kostytschew — 1) Ueber die Bedingungen der Tschernosembildung. Abh. d. Freien Ökonom. Ges., Bd. III, Lfg. II, S. 141, 1884.
2) Böden des Tschernosemgebiets Russlands. S. 169—171, 1886.
- (11) I. W. Krassowskaja — Das Wurzelsystem der Pflanzen und seine Entfaltung in Abhängigkeit von äusseren Faktoren. Abh. f. angew. Botanik, Genetik und Selektion, Bd. XV, No. 5, Leningrad 1925, Mit Index der Arbeiten über das Wurzelsystem.
- (12) I. W. Krassowskaja — Uebersicht der Arbeiten über Morphologie und Physiologie der Wurzeln. Abh. f. angew. Botanik, Genetik und Selektion, Bd. XVIII, Leningrad 1928, Mit Index der Arbeiten über das Wurzelsystem.
- (13) I. Beideman — Kurze Uebersicht der Wurzelsysteme der Halbwüstenpflanzen. 1934. Mit Index der Arbeiten über das Wurzelsystem.

DEFORMATIONS IN THE MICROSTRUCTURE OF SOILS CAUSED BY COMPRESSION

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Extracts from a Report read by the author in January, 1934, before the All-Union Conference of the Soviet Section of the USSR on Soil Physics and Soil Science as applied to Road Construction

In modern mechanics soils are studied as systems or combinations of granulometric elements, the various forms of which may be combined into two general types of complexes, i. e., clay and sand. The first may be characterized, according to the principles of the theory of friable bodies, as an aggregation of laminate particles¹. The second consists of «compact» elements of more or less equal dimensions. Sand, as Prof. K. Terzaghi conceives it, is a heap of rubble, while clay is a pile of cut-up paper in the form of minute leaflets.

All the cohesive soils (e. g., clay or loam) contain within themselves «certain cementatory resources». In this respect they differ sharply from the friable (sandy) groups which lack this cementatory quality.

Passing now from these theoretical schemes, which are concerned chiefly with the mechanics of soils, to actual conditions, it is evident, a priori, that these theories do not exhaust all the possible differences existing between soils and do not help us very much to understand the essential nature of the phenomena taking place in them. As we know from the basic principles of soil science and geology, it is impossible to study soils and grounds in any way except genetically and dynamically. It follows from this that not one of the so-called physico-mechanical constants accepted as the technical characteristics of soils can be correctly explained or applied without a comprehensive genetic analysis. The correctness of this is confirmed by numerous instances mentioned in the special literature on this subject recently published; but in this brief paper it is impracticable to quote them.

At present the theoretical explanation of clay and sand complexes meets our requirements only in one direction; that is, it demonstrates clearly the marked difference in actual work between soils, the granulometrical composition of which is sandy and those which are clayey,

¹ It is assumed that the size of these lamellae is about 2μ in diameter and 0.1μ in thickness.

and allows us to represent this difference with some clarity in the form of a mathematical deduction.

It is, therefore, quite correct for Prof. N. N. Ivanov, to write in his book «The constructional Peculiarities of Earths» (p. 5), that «it seems for the present unnecessary to prove that it is impossible to apply the statics of friable bodies to the cohesive grounds». Further on the same author notes that „the complexity of the problems in the study of grounds which involves so many physical, chemical, mineralogical and even biological factors, forces us to turn to the methods of natural history rather than attempt to depend entirely on mathematics and on artificially devised schemes and models of grounds created to make our calculations easier.

And in fact even the most convinced representatives of soil mechanics are more and more frequently forced to abandon purely theoretical schemes when dealing with problems which have a profound importance in production and pure science. Here it is sufficient to quote the view of Prof. K. Terzaghi's school regarding the structure of cohesive grounds. According to Prof. Terzaghi's theory this structure «may be represented by a model in the form of a bed of exactly similar balls regularly distributed». However «flaky» and «clotted» structures, according to the same author, occur in soils «as the result of coagulation of suspensions by electrolytes as they were being formed».

Such a treatment of the problem, though not exhaustive and somewhat dogmatic, nevertheless already exceeds the limits of models of ground structure.

The views and theories of the mechanics of soils referred to above urgently demand serious discussion and the experimental verification of many of their basic statements in order to determine with finality the actual limits of their applicability and to provide the necessary corrections to the coefficients and formulas which form the basis of many engineering-technical calculations.

In this paper we shall attempt to clarify the real significance of the form and character of its structure during the process of the deformation of soil. It is a basic question in contemporary soil mechanics which regards the deformation of soils as a phenomenon exclusively connected with the shape of granulometric elements which react to the deforming stresses.

I

If we put a suspension of clay particles (<0.001 mm. in diam.) into a cylindrical glass vessel and let it stand in an isothermic chamber, in the dark, at room temperature, then it is possible to prove almost immediately, by various methods, the presence in the suspension of the phenomenon of the coagulation of the finest particles of clay. This coagulation will take place as the result of shocks among the particles as explained by "Brown's movement". According to Wiegner the process which takes place is what is known as perikinetic coagulation.

A careful examination under a microscope of the "coagulum" precipitated at the bottom of the vessel shows that the clay particles in this clot form a cell-like, flocculent structure. If taken out into the air, the

clay "coagulum" shows the presence of internal stresses which develop in the filmy walls of structural cells, while air may be pinched in the micropores and fissures.

Let us assume that clean, ignited quartz sand (particles 0.01 mm. to 0.25 mm.) is introduced into a vessel containing the clay suspension in which the perikinetic coagulation is taking place. Under these conditions the movement of the different granulometric fractions of the particles in relation to one another will result in the superimposition of the orthokinetic coagulation upon the perikinetic one and as a result a complicated clay-sand complex will be obtained having a special microstructure.

Our studies of this complex under a microscope give a picture of a flocculent mass consisting of films of the clay particles between which the sandy particles have collected into groups in the cells of the clay «coagulum». (See Fig. 1).



Fig. 1. Sand-clay coagulum. Microphoto. Photograph magnified about 300 times. It shows the filmy network (a) in which the pulverulent and sandy grains are held (b), and the cells of the net (c) containing the entangled air.

The numerous experiments we have made with the precipitation of sand-clay suspensions under conditions excluding the presence of electrolytes and of thermic influences, actually show, in the process, phenomena connected with the surface energy of the particles. The curves which we have obtained when studying the movements of the «mutual-adsorption» of the particles at different concentrations of the suspensions confirm this.

II

We obtained the curves showing the process of this adsorption of hard particles by direct experimentation in the precipitation of clay suspensions of various degrees of concentration by identical amounts of fine, pure sand.

In Fig. 2 the curves represent the process of precipitation by 1,000 gr. of sand of four different clays out of suspensions of following concentrations: in 1 L = 0.005, 0.01, 0.02 and 0.03 gr.

The curves show that the clay is adsorbed by the sand more and more intensively in proportion to the increase in the concentration of the

suspensions, but only up to a certain limit beyond which the adsorption ceases and all further increase of concentration is without effect.

From this we can make the deduction that the purely mechanical adsorption of particles from suspensions, for instance during their filtration

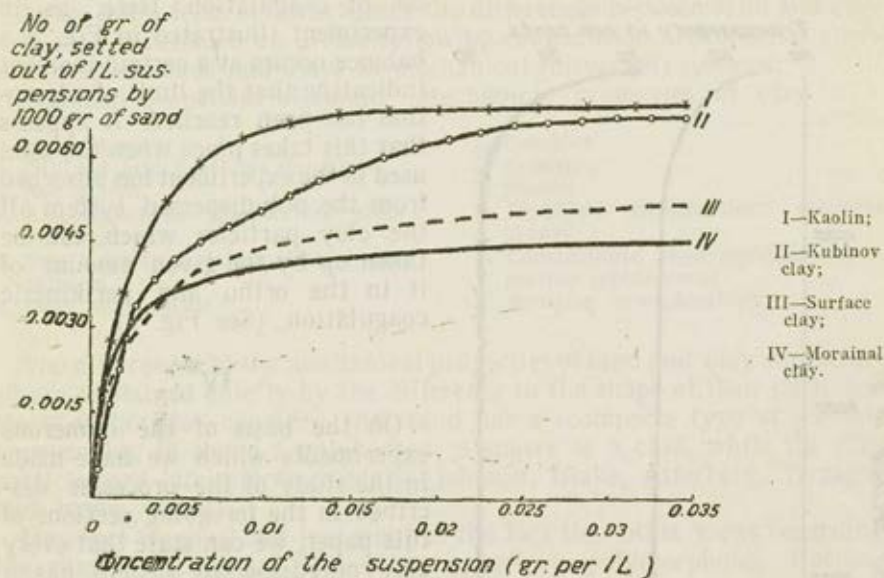


Fig. 2. These curves show that more of the finer particles of sand settle out of the denser suspensions. However, this rule holds only within certain limits beyond which the amounts of clay which settle become constant; that is, are not affected by the concentration of the suspension. The same amount of sand—1000 gr.—was used throughout the experiment.

through the soil, cannot occur, because in this case it is certain that there will occur a coagulation of particles of an ortho- and perikinetic character.

From what we have said in § I it also follows that every clay-sand material which has originated from the precipitation of a poly-dispersed suspension has a flocculent, filmy structure with cells in which air is pinched. The latter is taken up by the suspension chiefly during its preparation (shaking, decanting, entering both from the water and from the rock itself).

III

The coagulation of hard particles suspended in water may be conveniently observed by means of an apparatus called a diaphanometer (Diaphanometer konstruiert nach den Angaben von Geheimrat Prof. Dr. I. König in Münster i. W.). This instrument makes it possible to measure how much light passes through the suspension, for white, green

and red rays, in percentages, and, with practice, is sufficiently accurate¹.

In Fig. 3 are shown the curves representing the increase of transparency for the white rays for three polydispersed suspensions (clay plus increasing amounts of sand) in proportion to the development in them of the process of coagulation. Here, as in

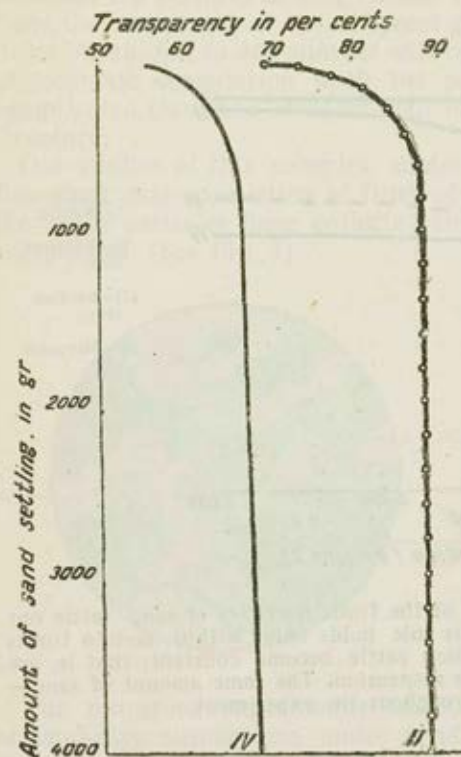


Fig. 3. Curves show increase of transparency of the suspensions as precipitated (carried) down by the diaphanometer.

IV—Morainal clay;
II—Kudinov clay.

lation of particles, and therefore it does not show any marked elastic (resilient) properties. The sandy rock does not contain in itself any

¹ Prof. E. König's diaphanometer is constructed on the principle of two tubes which may be immersed in the solution to be tested, the transparency of which is measured by means of a Lummer Brodhun prism.

In the field of vision a circle is seen in which a second concentric circle appears. Each circle receives light from one of the tubes. When the illumination is equal, the boundary line between the circles vanishes and the entire field of vision is equally illuminated.

It is possible to obtain an equal illumination by changing the level of immersion of one of the tubes. The other tube serves to equalize the optical relations by a system consisting of a glass plate, liquid and glass plate.

IV

On the basis of the numerous experiments which we have made in the study of the processes described in the foregoing sections of this paper, we can state that every clay polydispersed system has a microstructure, the characteristic peculiarities of which are: 1. Cellularity, 2. The presence of pores with pinched air, 3. The presence of filmy partitions separating the cells. These filmy partitions are elastic and show interior stresses—like every coagulum capable of periodical swelling giving rise to subsequent shrinkage.

It is clear that sandy rock (sand) cannot have any structure genetically connected with the coagulation.

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V

As we know from soil mechanics the differences between sand and clay rock may be summed up in the following enumeration of properties characteristic of sands and clays as mechanical (dispersed) systems:

Mechanical properties of sand Mechanical properties of clay

- | | |
|--|--|
| 1. Not cohesive | 1. Cohesive |
| 2. Divided into particles (friable) | 2. Cohesive |
| 3. Not plastic | 3. Plastic |
| 4. Small resilient deformation; recovers instantly | 4. Resilient deformation; recovers slowly |
| 5. Small residual deformation; (subsidence) | 5. Considerable slow residual deformation (subsidence) |
| 6. Does not subside | 6. Subsides (considerably) |

The differences in the mechanical properties of sand and clay enumerated are explained chiefly by the difference in the shape of their particles. Most authorities consider that sand has a «compact» type of particle approaching in shape a polyhedron, a sphere or a clod, while the clay particles are laminiform or scaly (Johnson, Blake, Atterberg, Terzaghi and many others).

However we must not lose sight of the fact that other views regarding the shape of clay particles (e. g. spherical, polymorphous, fibrous, spongy, structural, etc.) are also well supported.

Modern soil mechanics, of which Prof. Terzaghi is the most distinguished exponent, takes the position that the scaly shape of the clay particles explains the above-enumerated differences in the properties of sand and clay in the following manner¹:

A — S a n d

(a) The small resilient deformations in sand are the sum of the elementary deformations of the individual sand grains representing ag-

By means of special glasses, the degree of transparency of which has been determined and which may be placed over the lefthand tube, it is possible to measure the transparency of a layer of liquid of a thickness of 10 or of 5 cm. The transparency is expressed in percentages and may be determined to 99 per cent. Zeitschrift f. Untersuchung der Nahrungs-und Genussmittel, 1904, Heft 3, s. 129.

¹ According to Terzaghi's investigations the actual dividing line between particles of sand and particles of physical clay is approximately 0.002 mm. He considers the smallest size of clay particles as being 0.0001 mm. In order to study the shape of these particles a specially constructed interferometer was used consisting of two glass plates with a film of water between them of a thickness of 0.0001 mm. By the change in color of the Newton's rings when pressing on the plates at a sharp contact point, Terzaghi was able to calculate the minutest distances between them. When water containing particles of clay about 0.002 mm. in size floating in it was put into this apparatus, it was found that the interferential indicator of contact was not affected, and the thickness of the film of water remained 0.0001 mm. From this it is possible to make the deduction that the clay particles have the shape of a lamella (or scale) of a thickness not more than 0.0001 mm., as otherwise they could not have been accommodated in so thin a layer of water.

gregates of rock of a considerable size. These deformations cannot be large because they are limited by the all-sided character of the compression of the compact particles and by the comparatively small number of the latter per unit of volume.

(b) The non-resilient deformations which, in sand, are the result of changes in the mutual distribution of the particles, cannot be very great because in sand only the individual grains are in an unstable position. The sum total of the not very numerous small shifts of position resulting from their slipping on one another can produce only a small residual deformation.

(c) The slight amount of compression in sand, even in fine sand, is connected with a negligible capillary pressure (not exceeding 0.005 kg. per sq. cm.). Such a pressure is too slight to produce any effect on the soil.

(d) The lack of plasticity in all sands, varying from coarse to colloidal, is the result of the angular-compact (block) shape of the sand grains. With such shaped grains the parent rock cannot change its form without a corresponding change of volume. (See Reynold's classical experiment with moist sand and moist clay enclosed in sacks. In this experiment the moist sand takes on a hard consistency while the clay preserves its plasticity).

(e) The rapidity of subsidence of moist sand under load is due to the fact that sand is easily permeated by water, and the water may be rapidly expressed from the pores.

B — Clay

(a) Resilient deformations in clay are due to the fact that the scale-like particles of which clay is composed combine the elementary compressions and elementary sagging of the individual particles. This sagging may be described as like that of a beam with its ends resting on two separate supports.

Of course as a result of the small dimensions of the particles the total effect of the minute deformations is also small.

(b) Non-resilient deformations which may occur to a considerable extent in clay under the action of load are the result of the very "fantastic" arrangement of the scaly particles in the soil mass capable of being shifted catastrophically or even of breaking.

These interior shifts and the disintegration of the particles may amount, in clays, to large residual deformations (subsidence of clays).

(c) The importance of subsidence of clays is associated with the high capillary pressure (over 200 kg. per sq. cm.) which develops in the finest capillaries and inter-particle pores, resulting in shrinkage of clay from drying.

(d) The slowness of settling of the moist clay is due to its low permeability by water.

VI

So far we have subjected only two questions to experimental verification: (a) the actual shape of the particles in sand and in clay, and

(b) the m

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(b) the relation of clay and sand to the deforming stresses resulting from the micro-structure.

VII

According to our observations, made with a microscope, with an oil immersion and with an ultra-microscope, the shape of the visible clay particles in the majority of cases, shows a tendency to laminarity (scaliness).

Thus our measurements and calculations show that there are a good many particles of an indisputably lamino-scaly shape in a number of clays. For instance, Kudinov white clay (of the kaolin type) contains from 72 to 80 per cent by number¹; the mantle clay around Moscow contains 68 per cent of laminiform particles, the Caspian schist-like clay contains about 87 per cent; the black Jura clay, 62 per cent; Poltava loess, 94 per cent, and finally silty river clay about 89 per cent.

However, it is not only the clay particles visible under the microscope (0.005 to 0.001 mm. in diam.) that are laminiform, but also nearly all the pulverescent elements. Only the sandy particles are block-shaped and therefore differ markedly from the other granulometric elements in the soil.

On the basis of material which is found in the literature of the subject combined with our own observations, we come to the conclusion that a sandy soil as a type consists of particles of a block-shape with more or less sharp ribs in the sand of the mother rock, but with abraded surfaces in sands of alluvial genesis.

Clays consist chiefly of laminiform or scaly particles.

Mica sands form an exception to this general rule. Their granulometric elements for the most part have a leafy shape. The carbonate clays contain grains of a spherical shape in juxtaposition with the scaly grains.

When making the detailed study of clays under the microscope it became evident that the concept of the structural nature of the clay particles might also be assumed to a certain degree for the other clays which we have mentioned — Kudinov, mantle clay near Moscow, black Jura and brown Caspian clays.

Thus when we treated the clay suspension with a 1/10,000-n water solution of organic dyes (methyl-violet, eosin) for three hours, shaking it from time to time, we observed coloring of the clay particles by the dye. In the majority of cases the color had a sharp limit in the interior of the particles and merged very gradually (like shading) to zero into the liquid medium. In this instance the dye was not only positively adsorbed on the periphery of the particle, but also penetrated the colloid coating of the granulometric element, which confirms the presence of such a coating. The visibility of the particles in the microscope which have an undoubted capacity to manifest molecular phenomena of the surface, indicates, incidentally, the fact that the particles having di-

¹ The percentage content of laminiform particles is given by number, not by weight or volume, and refers to particles larger than 0.001 mm.

mensions considerably exceeding the usual limit assigned for clay granulometric elements may be characterized by the colloid features and properties of the so-called emulsoid clay. We observed the unmistakable adsorption of the dye and its penetration to the interior for particles from 0.005 to 0.001 mm. (5μ — 1μ). Thus our data conflict with the conclusions of Zsigmondy who indicates 200μ as the upper limit to which particles still preserve their colloid properties, and more nearly approach the values of Freundlich who estimates the sizes of the colloid particles at 1μ and less.

It is also established that there are among the particles of clay granulometric elements which become «completely» dyed. These particles lie at the extreme limit of visibility (and below) in the microscope with oil immersion, but it would appear that they must be regarded as belonging completely to emulsoid clay.

Concerning the shape and structure of such clay particles we can say nothing.

VIII

The sandy and clay soils discussed above with relation to the shape of the particles, were subjected to the action of load by means of Amstler's press. The purpose of this was to trace the character of the deformations occurring in the soil from the point of view of microstructure and to clarify the significance of the shape of the particles during deformation.

IX. Experiments with sandy soils

Samples were taken from the following soils as material for our experiments in this section of the investigation:

1. Fraction of medium sand (i.e., particles from 1 to 0.5 mm.).
2. Glacial loamy fine, sand.
3. Siliceous sand (from weathered granite).

No. 1 was a sifted-out fraction of quartz sand consisting of particles from 1 to 0.05 mm. in diameter (100%).

The quartz grains had a ribbed, partly abraded form.

No. 2 contained 83 per cent of sandy grains (particles from 0.25 to 1.5 mm.), the remainder being pulverescent and clay particles. Among the sandy and pulverescent particles were many grains of weathered feldspar, a very few leaflets of mica and other minerals.

No. 3 was a coarse, sandy mass containing 93 per cent of sandy elements (particles from 0.25 to 2 mm.), the rest being dust and clay. The entire mass of this sand consisted of typical products of the mechanical weathering of Finnish granite in which there were also many grains of partly weathered red orthoclase.

Table 1 below embodies the results of the granulometric analysis of the sandy material which was the subject of our experiments.

These samples were enclosed in cylindrical containers of massive steel and compressed, in an air-dried condition, by a load of 530 kg.

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Table 1

Sabanin-Robinson Method.
Analysts—N. A. Maximovich, M. M. Filatov.

N ^o of sample	1-2	1-0.5	0.5-0.25	0.25-0.05	0.05-0.015	0.015-0.005	0.005-0.001	< 0.001
1	—	100.0	—	—	—	—	—	—
2	1.2	8.0	74.0	11.20	4.27	—	1.33	—
3	29.0	44.2	12.6	11.7	2.1	—	0.40	—

per sq. cm. in an Amsler press. Then, after removing the load, the contents of the cylinder were carefully studied with reference to (a) deformations taking place in the sand grain and in the structure, and (b) granulometric composition.

The results of this experiment were as follows:

1. The majority of the sandy grains (pearls) were fissured and many of them were entirely pulverized. Some of the larger grains were found to have been chipped on the facets.

The greatest amount of deformation in the grains and the structure was shown by sand № 1, i. e. the soil with the coarsest pores and which was most homogeneous in its granulometric and mineralogical composition.

2. All the sands showed a clear residual deformation occurring as the result of the fractionalization of the sandy grains and of the consolidation of the mass caused by the shifting of the grains within it, the sand thus acquiring a finely porous structure.

Table 2

After compression by 530 kg. per sq. cm.
Granulometric composition in percentages by Sabanin/Robinson method.
Analysts—N. A. Maximovich, M. M. Filatov.

N ^o of sample	1-2	1-0.5	0.5-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	0.001
1	—	55.50	17.85	18.51	3.97	0.66	2.12	1.39
2	1.0	7.22	64.13	20.87	5.31	—	1.47	—
3	26.01	38.82	13.99	17.41	3.30	—	0.47	—

3. Sands № 2 and 3 changed their granulometric composition less than № 1 and may therefore be considered more stable physically and mechanically. It would appear in general that grounds containing granulometric fractions in certain definite relations to one another have a density and a fine porosity which makes them more stable as an earth

mass. In road construction such grounds are called "optimal mixtures" as regards "carrying capacity".

No mechanical change was observed in the mineralogical composition of the sand under a load of 530 kg. per sq. cm.

The results of the granulometric analysis of the sand after compression in the press appear in Table 2 and confirm the observations made above.

Comparing Tables 1 and 2 it appears that in all cases the granulometric composition of the sand after compression in the press, changed in the direction of a finer division into particles. In sand No. 1 new fractions appear including clay particles, while in No. 2 and 3 there was a considerable increase of large dust (0.25 to 0.01). All these changes occurred chiefly at the expense of the sandy particles.

Thus our experiments show that under certain loads, ground's consisting of sandy fractions may suffer a considerable residual deformation, the principal cause of which is found to be, not so much the slipping (shifting) of the particles, as their crushing and the greater density of the crumbled mass thus obtained. These experiments have also indirectly indicated that the finely pulverescent and clay particles, if they are present in ground in the process of deformation, remain quantitatively stable. The small increase in the number of particles of—0.01 (in No 2 and 3) occurs here as the result of their accumulation when the sand grains are ground down under the load. Moreover, from subsequent experiments with clays, this conclusion receives convincing confirmation.

It is certain also that the carrying capacity of sand which contains in its composition other mechanical fractions in some definite relationship, must be higher than in homogeneous sand. This latter statement is confirmed by the data of our experiment, viz, in sand No. 1, 45.5 per cent of the sandy material was ground or crushed, while in sand No. 2, particles from 2 to 0.25 mm. only 13 per cent was found to be crushed, while in No. 2 it was only about 9 per cent by weight.

X. Experiments with clayey grounds

We took for these experiments:

1. Glukhov kaolin.
2. Kudinov white clay.
3. Heavy mantle loam.

The experiments were performed in the same manner as with the sand. The air-dried samples of clay soil were placed in massive cylindrical steel containers and compressed with an Amsler press under a load of 2,000 kg. per sq. cm.

The following Table 3 shows the results of the granulometric analysis of these samples before and after compression.

Table 3 shows that none of the three samples of ground used by us in this experiment changed their granulometric composition in any essential manner when compressed in the press, and the variations obtained in the measurements made before and after the experiments lie within the limits of analytical error.

Table 3

Granulometric composition in percentages by Sabanin-Robinson method.

No of sample	1-0.25	< 0.25	0.25-0.05	< 0.05	0.05-0.01	< 0.01	0.01-0.005	< 0.005	0.005-0.001	< 0.001
I	13.54 11.95	86.47 88.05	1.35 2.05	85.12 86.00	17.11 18.91	68.01 67.09	29.01 28.00	39.00 39.09	19.90 19.55	19.10 19.54
II	— —	— —	— —	— —	7.64 7.90	92.36 92.10	31.98 32.35	60.38 59.75	17.16 16.02	43.22 43.73
III	— —	— —	7.30 7.29	92.70 92.71	30.80 30.86	61.90 61.85	38.90 38.97	23.00 22.88	— —	— —

Note. Sec. II of the granulometric composition refers to soils which have been subjected to load. The analyses of the compression of soil under pressure were made by Aspirant N. A. Maximovich and soil scientist G. G. Rogov.

Starting from these results we have absolutely no reason to suppose that the residual deformations caused by compression in clay is chiefly due to the breaking up or cleavage of the scale-like grains of clay in accordance with the usual theory of soil mechanics. It is obvious that the non-reversability of deformations in clay must depend upon other causes which permit the shifting of the clay particles without destroying their integrity.

As the result of observations to be described farther on, there would seem to be two such causes: viz., (1) the flocculent, filmy structure with cells in which air is pinched, and (2) the structural nature of the clay particles. The fact that both these conditions are present in clay grounds has already been noted (See Sections, I, II and VII above).

XI

In order to make quite clear what goes on in the soil in respect of its macro- and microstructure when compressed under load, two lines of investigation were followed: firstly, of the nature of the surface of the breakages in the clay sample both before and after compression and, secondly, slides of the sample were prepared for study under a microscope magnifying from 150 to 300 times.

The deformation of the clay soils by compression under a load of 2,000 kg. per sq. cm., is accompanied by the appearance in the sample of a pronounced schistosity which appears on the surface of breakage of the sample in the form of parallel ribs. The air-dried sample of clay used for experiment acquires a temporary resistance (toughness) estimated at about 150 kg. per sq. cm.

As appears in Fig. 4, the slide showed in the most convincing manner, the transformation (metamorphosis) of the flocculent, filmy structure shown in Fig. 1, into a structure in which the pores have

become flattened and in some places have even collapsed (that is, have become narrower and lost the air which was contained in them). Fig. 4 shows how the principal mass of pores has become denser in the line of the acting force P which has elongated the pores perpendicularly to the line of that force.

Those observations, of which we have sufficient number for a good many clays and loams, show that the deformations which remain in such grounds are primarily consequent on the forcing out of the pinched air from the mass of the ground. Until that the deformation is re-

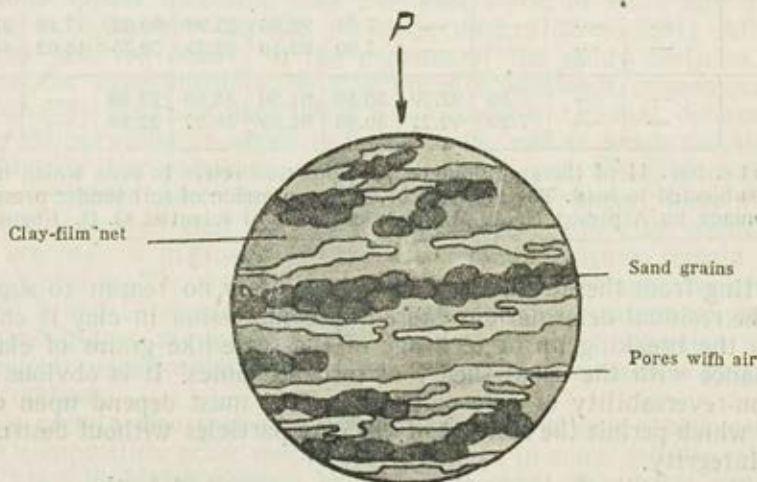


Fig. 4. Drawing by hand of a microscope slide showing clay deformed by load P equal to 2,000 kg. per sq. sm, magnified about 300 times.

versible and is due chiefly to the resiliency of the air in the enclosed pores (pores whose walls consist of films of clayey substances). The formation of schistosity is accompanied by a parallel distribution of the films of clayey material resulting from the effect of the load in the same way as schistosity produced by the parallel distribution of laminae minerals in fine-layered rocks.

XII

Nevertheless, resilient deformations may also be compared with another phenomenon described below which takes place in soils. This phenomenon, with the physico-mechanical deformations of the character described above belonging to the macrostructure of the soil, combine into the visible, mechanical effect of compression (or subsidence) of the soil under load.

In Section VII the presence of a colloidal coating entering into the composition of the clay particles was proved. According to our experiment (see below) this coating has a tendency to spread out over the particle under pressure applied in any given direction. When, this pressure ceases, the coating returns to its original position, so

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that in this case we have a typical resilient deformation, the total of which in the mass of the soil may result in its having a considerable resilient deformation. It is, of course, evident that this resilient deformation occurs not from the compression of the colloidal coating, but as a result of the shifting of the particles. The experiment described below confirms this statement.

XIII

A drop of clay suspension, colored and diluted with water, is placed on the lower glass of the microscope. The cover-glass is so placed over

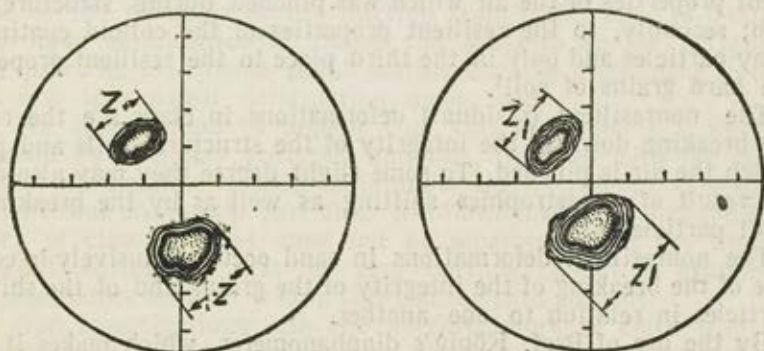


Fig. 5. Drawing by hand of two particles of clay as seen under microscope with oil immersion. The cover glass is lying freely upon the object glass.

Fig. 6. Drawing by hand of the same two particles as in Fig. 5. Here the cover glass is pressed by capillary attraction against the object glass so that it is fixed.

the drop that no air bubbles get into the liquid. When the suspension is examined under a microscope with oil immersion, it is possible to see the picture represented in Fig. 6; that is, particles can be distinctly seen in the field of vision, each surrounded by a colored zone which shades off to nothing. The round outline of this zone is distinctly seen against the background of the faintly colored medium in which the particles are suspended.

If, then, the liquid which exudes around the edges of the cover-glass is removed by means of filter paper, the result will be that the upper glass will be pressed strongly against the under glass by the capillary attraction which develops underneath the cover-glass, and it will then be possible to see in the microscope quite a different picture from that in Fig. 5 — that is, the conditions shown in Fig. 6.

But if we once more insert an excess of water under the cover glass and thus eliminate the force of the capillary attraction in the suspension under examination, then it will soon be observed that the coating of the particles returns to its original position. That is, the condition shown in Fig. 5 is completely restored.

XIV

Starting from the experiments and considerations set forth above, it is possible to arrive at the following fundamental deductions:

1. Our investigations confirm the presence of laminiform particles of clay, visible in a microscope with oil immersion, and also show the presence on the periphery of these particles of a coating capable of reacting to organic dyes and of resilient deformation under load.

2. In general the microstructural formation of clay soils depends upon many factors and in its initial stages takes place chiefly under the influence of peri- and orthokinetic coagulation. It is accompanied by the development of special tensions in the soil and by pinching of air in its most minute pores and fissures.

3. The resilient deformations in clay soils are due, firstly, to the resilient properties of the air which was pinched during structure formation; secondly, to the resilient properties of the colloid coating of the clay particles and only in the third place to the resilient properties of the hard grains of soil¹.

4. The nonresilient (residual) deformations in clays are the result of the breaking down of the integrity of the structural cells and pores in which the air is pinched. To some slight degree they may also occur as the result of «catastrophic» shifting as well as by the breaking of the soil particles.

5. The nonresilient deformations in sand occur exclusively in consequence of the breaking of the integrity of the grains and of the shifting of particles in relation to one another.

6. By the use of Prof. König's diaphanometer, which makes it possible to calculate the most minute changes in the concentrates of suspensions by their transparency for red, green and white rays, the phenomena of peri- and orthokinetic coagulation in clay suspensions may be observed with great precision.

Summary

1. The abundant material found in the scientific literature of the world dealing with the experimental investigations of the shape of clay particles and their microstructure, may be classified in four type theories, viz:

a) The theory of finely divided structure (Whitney, Beyer, Daubrée and others).

b) The theory of spherical-shaped particles (Aarón, Williams and others).

c) The theory of laminiform structure (Johnson, Blake, Biedermann, Atterberg, Terzaghi, and others).

d) The theory of a colloidal coating on the clay particles (Rohland, Davis, Bole, Gushman, Mellor and others).

2. In soil mechanics the theory of the laminiform structure of clay,

¹ Deformations resulting from the resilience of the earth grains (particles) and of water cannot be of any practical importance since the contractility of the latter is entirely negligible, and for water (distilled water) the coefficient is 0.00005. For the earth grains the coefficient is about 0.000005. The minuteness of these values as compared with the coefficient of porosity ($e = B:A$ where B is the volume of the pore and A the volume of the rigid soil skeleton) allows us to disregard the possibility of an independent contraction of the soil skeleton or of the water. Earth, saturated with water, is practically incompressible if enclosed in a hermetically sealed container (a basic law of soil mechanics).

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as worked out by Prof. Terzaghi has been most generally accepted. He has established the laminar shape of the clay particles and the flocculent microstructure of clays by experimental investigation and by means of measurements and examinations under the microscope.

3. According to the theory of K. Terzaghi and his followers, deformations in clays are due to the laminar shape of the particles and are to be explained chiefly by the twistings and catastrophic shiftings of the clay particles under load.

4. Our examinations under a microscope with oil immersion (magnifying 1,200 times) have confirmed for a number of clays the laminar shape of the particles of the fraction from 0.005 mm. to 0.001 mm. They have simultaneously shown the presence on the periphery of these particles of a dense zonal coating capable of reacting to organic dyes and to resilient deformation under load.

5. We have reason to believe that this envelope is a water film adsorbed by the clay particles and this, together with the colloidal crust of the particle is observable under the microscope as a diffused, resilient zone around the particles. It follows therefore, that the laminar theory of clay particles must not be separated from the theory of a colloidal coating and that the clay particle cannot be examined in soil mechanics without taking this coating into account.

6. Our investigations into the microstructure of clays lead to the conclusion that the so-called «zero friction» (Terzaghi) which arises at the moment of the formation of clay sediments, may be due to the phenomenon of the mutual adsorption of the suspensions of an ortho- and perikinetic type which, according to the most recent investigations, takes place in accordance with laws which are similar to those governing the adsorption of colloids.

7. The process of structure formation in clay soils which depends on many factors and, in its initial stages takes place, as we suppose, as the result of conditions which have been referred to in the first six paragraphs of this summary, leads to the development in these soils of special tensions which are accompanied by the pinching of air in their minutest pores and fissures.

8. From all these considerations we are led to infer that:

a) The resilient deformations in clay soils depend primarily on the resilient properties of the air pinched (enclosed) during the structural process, and in the second place on the resilient properties of the adsorptive and colloid coatings of the clay particles.

b) The non-resilient (residual) deformations are chiefly the result of the breaking-down of the structural cells and pores in the soil with the resulting «expulsion» (forcing out under pressure) of the enclosed air, and also, apparently, though to a negligible degree, of catastrophic shifts of the soil grains themselves in the manner described in section III.

9. In order to observe and calculate the phenomena of ortho- and perikinetic coagulation Prof. König's diaphanometer gives most satisfactory results since this instrument makes it possible to determine even the most minute changes in the concentration of the suspensions by changes in their transparency.

SUR LA PROPRIÉTÉ DES SOLS DE FIXER L'EAU

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1) Le sol est un système polydisperse à plusieurs phases, composé de particules dispersées, dont les dimensions varient dans des limites très larges.

La phase liquide des sols, de même que dans la majorité des colloïdes est plus ou moins fixée à la surface des particules des sols, étant alors adsorbée à la surface de la phase dispersée—à l'interface intérieure—et dans cet état d'adsorption, possède des propriétés particulières qui la distinguent de l'eau libre ordinaire. Le phénomène d'adsorption se produit avec une forte contraction, ce qui est accompagné d'un dégagement de chaleur considérable. En partant de la chaleur d'adsorption ou de la valeur de contraction, on peut calculer la pression qui s'obtient dans la couche d'eau adsorbée. Ainsi, par exemple, Harkins et Ewing (1) trouvent une pression de 37.000 atm. pour l'eau adsorbée sur le charbon. Nutting (2) y donne 17.410 atm. pour le gel de l'acide silicique.

Pour des surfaces adsorbantes comme le mica, Hochberg (3) et autres, donnent 20—30 molécules pour l'épaisseur de la couche adsorbée. Cette couche d'eau a les propriétés non plus d'un liquide, mais d'un corps solide, ce qu'indique, par exemple, N. Marinesco (4) et ce temps dernier, B. Deriaguine (5). La couche d'adsorption possède une élasticité de forme, grâce à quoi les systèmes de dispersion, dont les particules solides sont réunies par les couches «quasi-solides» de l'eau sont douées de plasticité, c'est-à-dire de la propriété de conserver leur forme, ce qui se voit parfaitement sur les argiles et, naturellement, dans les sols (7). L'épaisseur de cette couche élastique atteint 0,15 μ et davantage (Deriaguine).

Nous avons indiqué que cette pression sous laquelle se trouve l'eau fixée possède un ordre de grandeur de 10^4 atmosphères. Les recherches de Marinesco (4) montrent que cette pression est encore plus grande et correspond à plus de 10^5 atmosphères. La compression de l'eau dans les sols a été indiquée par Tchapek (8). Cette compression n'est pas la même pour différentes espèces des sols, c'est-à-dire qu'elle est liée à leur degré de dispersion comme à la hydrophilie des parties composantes. A. Rakowsky et T. Poliansky (9) ont déterminé la densité de l'eau d'amidon adsorbée, comme étant de 1,3 à 2,4. M. Tchapek (10) a montré que la densité de l'eau adsorbée par le sol atteint 1,7.

L'eau des couches adsorbées douées d'une forte densité et de la propriété d'un corps solide (11) se compose de molécules orientées, rappelant par sa structure, un corps cristallin. Ce qu'on vient de dire permet de supposer qu'il existe encore d'autres propriétés qui distinguent cette eau de l'eau ordinaire. Et en effet, l'eau adsorbée, ou comme nous la désignerons, l'eau liée est un relativement faible dissolvant. Il s'entend que l'eau liée ne gèle pas, parce qu'elle possède déjà les propriétés d'un corps solide. Elle s'évapore moins bien, parce que sa tension de vapeur est beaucoup moindre. Et enfin, la valeur de sa constante diélectrique est beaucoup moindre, (2,2 d'après Marinesco, au lieu de 82) et, certainement, elle a en général d'autres constantes physiques, par exemple l'indice de réfraction.

Dans notre cas, dans leur application au sol, ce sont les propriétés suivantes de l'eau liée, qui sont surtout d'une grande importance:

a) son état analogue à celui d'un corps solide; état, auquel se rattachent les propriétés élastiques du sol humide;

b) la perte par l'eau, à l'état fixé, des propriétés d'un dissolvant, à la suite de laquelle la circulation des substances dissoutes ne se produit que dans l'eau libre.

c) sa tension de vapeur moindre.

On peut déterminer l'eau liée des sols, à l'aide de plusieurs méthodes, fondées sur les particularités de cette eau. Les méthodes les plus connues peuvent être classées d'une manière suivante:

a) Méthodes fondées sur le fait que l'eau liée ne gèle pas, ayant déjà les propriétés d'une phase solide, alors que l'eau libre, en se refroidissant au-dessous de zéro, se transforme en glace. À ce groupe appartiennent les méthodes dilatométriques et calorimétriques (12,13).

b) Dans le second groupe nous placerons les méthodes fondées sur le fait, que l'eau liée ne dissout pas plusieurs substances comme par exemple les sels et les sucres. Grâce à cela, le sucre qu'on a ajouté, par exemple se dissolvant dans l'eau d'un système dispersé, donne une solution plus concentrée qu'elle ne le serait si toute l'eau était libre. Étant donnée la concentration qui aurait dû être obtenue, déterminant la concentration vraie, on détermine la quantité de l'eau qui ne fonctionne pas comme dissolvant, c'est-à-dire de l'eau liée. On peut trouver la concentration du sucre, en la déterminant directement, par exemple à l'aide d'un réfractomètre (14) ou cryoscopiquement (15).

c) Au troisième groupe appartiennent les méthodes fondées sur les changements des constantes physiques, lors du passage de l'eau de l'état libre à l'état fixée. À ce groupe appartient la méthode de Marinesco (4)—détermination de la constante diélectrique.

Pour les sols, on appliquait la méthode du dilatomètre et la méthode cryoscopique (16). La méthode cryoscopique (Gortner) est fondée sur la détermination cryoscopique de la variation de concentration de la solution de sucre ajoutée. Cette méthode est assez compliquée, exige relativement beaucoup de temps et, à cause des phénomènes de surfusion, donne souvent des valeurs inexactes. La méthode du dilatomètre, décrite par Bouyoucos (17) dans la série de ses travaux intéressants, est fondée sur ce que l'eau se dilate en se congelant et que, d'ap-

rès la dilatation constatée on peut déterminer la quantité de l'eau libre qui se congèle. Connaissant le contenu total d'eau, on détermine la quantité d'eau fixée par la différence. Cette méthode présente un inconvénient, c'est que dans les capillaires du sol, l'eau se congèle à de très basses températures et, à cause de cela on ne peut pas toujours être sûr de ce que toute l'eau libre a été congelée. À cause de cela on obtient une trop grande valeur pour la quantité d'eau liée. On comprend que, dans aucun cas, on ne peut considérer comme de l'eau liée les catégories d'eau connues en pédologie: eau maximale hygroscopique (d'après Mitscherlich), eau maximale moléculaire (d'après Lébédév, etc.), parce que presque toujours, c'est la valeur totale qui est déterminée, c'est-à-dire l'eau liée plus l'eau capillaire.

2) À l'Institut de Chimie des Colloïdes à Voronège nous avons élaboré une méthode (14) qui convient le mieux au but en question. Dans son application aux sols, la méthode s'effectue d'une façon suivante: on prend une pesée exacte d'environ 20 g d'un échantillon du sol qu'on place dans un ballon conique de 100—150 cm³, ensuite, à l'aide d'une pipette de 10—15 cm³, on y verse une solution de sucre de concentration déterminée b_1 (20—25%), après quoi on pèse soigneusement le ballon contenant l'échantillon du sol et la solution, et on détermine la pesée de la solution de sucre B exactement. Ensuite le ballon est fortement agité et laissé au repos, de 20 minutes à 1 heure. Après que le liquide s'est déposé, on prend quelques gouttes du liquide supérieur transparent, et on détermine l'indice de réfraction à 20° à l'aide du réfractomètre d'Abbé. Connaissant l'indice de réfraction, on trouve par les tables la concentration (en poids) du sucre. Le calcul se fait d'après la formule:

$$x = \frac{ap}{100} + B \frac{b_2 - b_1}{b_2} \quad (1)$$

où x est la quantité d'eau, fixée par le poids entier de l'échantillon du sol;

p — poids du sol;

a — humidité du sol en pourcents;

B — poids de la solution de sucre;

b_1 — concentration en pourcents de la solution du sucre;

b_2 — concentration en pourcents de la solution du sucre obtenue lors du mélange avec le sol.

L'humidité — a — a été déterminée par séchage dans un dessiccateur, à 110° jusqu'à un poids constant. La concentration de la solution du sucre prise, était aussi déterminée au moyen du réfractomètre.

L'équation (1) n'est applicable qu'au sol, ne possédant pas une quantité appréciable de substances solubles, ce qu'il faut déterminer préalablement. À cet effet, on agite le sol avec une petite quantité d'eau, et une goutte de cette solution est examinée au réfractomètre, et ensuite, l'indice de réfraction obtenu est comparé à l'indice de réfraction de l'eau prise. Si les indices de réfraction de l'eau prise, et de l'eau après une extraction du sol, sont égaux ou bien présentent une très faible différence, on peut se servir de l'équation (1). S'il n'en est pas ainsi, alors, d'après l'indice de réfraction obtenu dans l'ex-

trait aqueux à l'aide des tables déjà indiquées auparavant, on détermine la concentration des substances dissoutes, en les exprimant en pourcents de sucre. Dans ce cas le calcul se fait d'après une autre équation:

$$x = \frac{ap}{100} + \frac{B(b_1 - b_2)(100 - b_2) + Ab_0(100 - b_2)}{100(b_0 - b_2)} \quad (2)$$

où, en plus des valeurs déjà connues, il entre:

A — poids de l'eau ajoutée pour l'extraction du sol,

b_0 — composition de l'extrait du sol en poids, exprimé en pourcents de sucre.

Dans les sols que nous avons étudiés dans le présent travail la quantité des substances dissoutes était si minime, qu'on pouvait les négliger; nous nous sommes servis seulement de la première équation. En fin de compte, la quantité de l'eau liée était calculée pour un gramme de sol sec:

$$x_0 = \frac{x}{p - \frac{ap}{100}}$$

Attendu que la quantité de l'eau liée a été déterminée lors du mélange du sol avec une quantité complémentaire, toujours la même, d'eau, il serait plus exact de nommer les valeurs déterminées «capacité du sol de fixer l'eau à son dilution donnée dans l'eau».

3) Les recherches faites avec les sols ont montré que la quantité de l'eau liée varie avec le degré de dispersion et l'humidité du sol (depuis 3 jusqu'à 8%) (18).

Voilà quelques unes des données de ces recherches:

D'après les données de A. Doumanskaïa.

Table 1

N° des sols	TYPES du sol	x_0
1	Tchernosiome ordinaire	7,84
2	Tchernosiome lessivé	6,92
3	Tchernosiome fortement lessivé.	3,82
4	Sol gris-sombre	3,64
5	Sol gris	2,96

Dans les argiles, la quantité de l'eau liée s'est montrée considérablement plus élevée, que dans les sols, ce qui s'explique naturellement par leur haut degré de dispersion.

Plus loin nous donnons les déterminations de notre collaborateur B. Zaprométov pour les argiles de Voronège.

D'après les données de B. Zaprométov.

Table 2

N ^o des argiles	Origine des argiles	x_0
1	Médovo	20,8
2	Lissyé Gorky	11,6
3	Karatchun	8,3
4	Latnoje	7,97
5	Kaoline de Sérlikovo	6,03
6	Cendre volcanique	5,26

L'influence de la partie limoneuse et du humus des sols sur les eaux qu'ils lient se voit nettement sur la table suivante:

D'après les données de A. P. Doumanskaïa.

Table 3

N ^o	Types du sol	x_0	% de limon	% de humus
1	Tchernosiome du midi	7,60	50,2	7,3
2	Tchernosiome lessivé	6,92	38,0	7,4
3	Gris-sombre	3,64	17,9	3,1
4	Gris-clair	2,90	12,00	3,1

4) Afin d'éclairer le rôle du humus du sol, nous avons fait une étude comparée de la propriété des sols de fixer l'eau à un état non oxydé ou bien oxydé par H_2O_2 . L'oxydation se faisait par 30% de H_2O_2 , à une température de 60—70°. Voici les résultats obtenus.

D'après les données de A. Fedortchenkova.

Table 4

N ^o des sols	Types du sol	% humus H	% limon	Capacité de lier l'eau en g par 100 g de sol sec		
				Non oxydé x_1	Oxydé x_2	$\frac{x_1 - x_2}{H}$
1	Gris-clair	0,94	5,19	1,92	0,43	1,59
2	Gris	1,97	9,77	2,13	1,07	0,54
3	Gris-sombre	3,34	20,87	4,57	1,50	0,92
4	Tchernosiome lessivé	5,06	26,09	7,51	4,35	0,62
5	Tchernosiome puissant	9,87	33,53	7,17	2,33	0,50

Comme nous le voyons, le rapport entre la perte du pouvoir des sols de fixer l'eau et le pourcent du contenu de humus, varie d'envi-

ron 0,5—0,9. Evidemment, ceci s'explique par le degré apparent de dispersion et par la hydrophilie différente du humus de divers sols.

L'influence des ions adsorbés, sur la fixation de l'eau par le sol a été étudiée ces dernières années dans une série de recherches spéciales, par P. Vageler (19), H. Janert (20), P. Szigeti ((21), A. Doumansky (22) et M. Tchapek (23) et autres. Les auteurs du dernier travail sont arrivés à la conclusion suivante:

1. Le même cation adsorbé, selon la nature de l'adsorbant, n'exerce pas la même influence sur la liaison de l'eau 2. L'action des cations adsorbés sur la liaison de l'eau par l'adsorbant est d'autant plus grande que ce dernier est plus hydrophobe.

Ces conclusions ne concordent pas avec celles des travaux de P. Szigeti, de P. Vageler et des autres auteurs qui ont établi une dépendance directe entre la liaison de l'eau par l'adsorbant et l'hydratation de l'ion libre.

Après que des expériences préalables ont démontré l'influence d'une dessiccation du sol sur sa capacité de lier l'eau, des recherches détaillées furent entreprises afin d'élucider les causes de l'influence d'un séchage sur la liaison de l'eau par les sols.

Afin d'exclure l'action de la température, le séchage avait lieu simultanément dans le dessiccateur à 80°C et en présence de P_2O_5 . Après qu'on eut enlevé au sol (tchernosiome lessivé) une part d'eau considérable, on déterminait, dans une partie de l'échantillon, la quantité d'eau qui était restée, et dans une autre part de l'échantillon du sol, sa capacité de fixer l'eau selon la méthode de A. Doumansky. Une autre série de sols desséchés de cette façon, était amenée à l'état sec à l'air et soumise ensuite aux mêmes recherches (détermination de l'humidité et détermination de l'eau liée). Les données obtenues (voyez la table suivante) ont montré d'abord, que le séchage provoque des phénomènes irréversibles, d'où il résulte une diminution de la capacité de fixer l'eau des sols.

La température aussi exerce une action analogue, d'où il résulte que la capacité des sols desséchés à 80°C. de lier l'eau, s'abaisse encore davantage et que, malgré une humidification ultérieure, ces sols ne peuvent pas regagner leur capacité première de fixer l'eau.

Ces expériences présentent naturellement un grand intérêt, car fréquemment dans la nature, l'horizon supérieur des sols, sous l'influence des rayons du soleil, est fortement desséché, c'est pourquoi il était important de rechercher comment ce phénomène réagit sur la propriété des sols de fixer l'eau.

La possibilité de l'existence dans la dynamique du sol, des processus irréversibles a été indiquée par H. Kuron (24). Cependant, il ressort de ses données, que cette valeur, pas si grande, est de l'ordre de quelques pourcents seulement. Au point de vue du développement évolutif des sols, un rôle passif doit être accordé dans la dynamique des sols aux processus irréversibles, autrement nous nous mettrions sur la voie d'une augmentation de l'entropie. Nous devons admettre qu'à côté des processus irréversibles qui diminuent les propriétés adsorbantes du sol, il doit y exister aussi des processus parallèles, rétablissant leurs

D'après les données de E. Churyguina.

Table 5

Séchage à 80°C	0/0/0 d'eau	X ₀	Séchage en présence de P ₂ O ₅	0/0/0 humidité	X ₀
Echantillon initial . . .	3,47	3,93	Echantillon initial . . .	3,47	3,93
Après séchage de 12 jours (de 24 heures) .	0,72	2,68	Après séchage de 12 jours (de 24 heures) .	0,34	3,68
Après séchage de 12 jours, et rammené en- suite à un état sec à l'air pendant 1 mois .	2,73	2,68	Après séchage de 12 jours et rammené jus- qu'à un état sec à l'air pendant 1 jour (de 24 heures)	4,29	3,67
Après séchage de 12 jours et ensuite une mouillage pendant 4 jours (de 24 heures)	22,64	3,25			

propriétés d'adsorption. Ces processus peuvent être dus surtout à l'activité des microorganismes du sol.

Afin de tracer la dynamique de l'eau fixée des sols, dans ses sources naturelles, des observations de dix jours en dix jours ont été faites pendant l'année végétative de 1934, sur l'humidité et la teneur de l'eau fixée (d'après la méthode décrite plus haut), sur les blés d'hiver et le tchernosiome en friche (tchernosiome lessivé, territoire de l'Institut Agricole, et le tchernosiome puissant, territoire de la Station Agricole Expérimentale).

Ces déterminations ont montré que la dynamique de l'eau fixée du sol, se trouve avant tout en dépendance correlative directe avec la dynamique de l'humidité (au moment de la prise de l'échantillon).

La cause de cette union de l'humidité du sol avec l'eau fixée est évidemment à chercher dans la concentration des électrolytes. On sait, que lorsque l'humidité du sol augmente, il se produit une dilution des électrolytes se trouvant dans la solution du sol, ce qui, à son tour, exerce une action sur la fixation de l'eau par la parcelle du sol.

Ensuite, il est possible, que le phénomène de l'hystérésis de mouillabilité et du gonflement peut exercer une certaine influence sur la liaison de l'eau par les sols. Évidemment ce phénomène sera d'autant plus fort que les changements de l'humidité entre les prises de l'échantillon (c'est-à-dire entre les déterminations) seront plus grands.

L'humidité du sol a exercé une influence si puissante sur la dynamique de l'eau liée qu'elle nivelle l'action de tous les autres facteurs (agrotechnique, engrais).

Sur les tables suivantes sont donnés en partie les matériaux numériques obtenus.

Se rattachant aux données citées plus haut, l'influence des électrolytes a été étudiée plus en détail dans les conditions du laboratoire.

La dynamique de l'eau liée pendant l'année de végétation de 1934
(d'après les données de N. Davydova).

Dates de l'observation	Profondeur 0—3 cm		Profondeur 10—13 cm	
	X_0	$\frac{\%}{\%}$ d'humidité	X_0	$\frac{\%}{\%}$ d'humidité
21/IV	3,81	10,22	3,99	17,53
11/V	3,38	5,61	3,84	17,38
22/V	3,31	3,59	3,03	14,53
10/VI	3,95	11,98	3,92	15,29
21/VI	4,91	17,47	4,71	17,06
2/VII	3,46	3,78	3,79	16,06
14/VII	3,69	16,42	—	14,65
23/VII	3,09	12,08	3,72	17,81
2/VIII	4,98	17,37	5,11	18,70
11/VIII	4,50	8,99	4,83	17,11
4/IX	4,11	6,26	3,71	14,32

Table 7

La dynamique de l'eau liée pendant l'année de végétation de 1934
(d'après les données de N. Davydova).

Dates de l'observation	Profondeur 0—3 cm		Profondeur de 10—13 cm	
	X_0	$\frac{\%}{\%}$ d'humidité	X_0	$\frac{\%}{\%}$ d'humidité
19/IV	4,35	10,58	—	17,16
28/IV	3,37	9,86	3,78	16,18
8/V	3,23	4,34	4,02	10,79
20/V	3,27	2,96	3,69	6,18
5/VI	3,89	17,68	3,69	16,62
49/VI	4,04	5,91	3,88	9,67
28/VI	4,06	6,15	4,20	8,66
9/VII	4,08	14,03	3,74	7,20
20/VII	—	12,71	3,37	13,41
31/VII	3,79	8,23	3,27	10,57
1/IX	3,09	4,79	3,43	10,39
19/IX	3,36	4,89	3,34	8,62
3/X	3,10	4,42	4,84	6,77

Dans un sol d'une sécheresse absolue (contenant diverses concentrations d'électrolytes) on déterminait une quantité d'eau liée, d'après A. Doumanský. Les calculs s'effectuaient d'après la formule:

$$x = \frac{B(b_2 - b_1)}{b_2}$$

où b_2 et b_1 , représentent d'une façon correspondante la concentration de la solution de sucre en présence de diverses concentrations du sel, avant et après son action réciproque avec le sol.

Voici les données obtenues:

Table 8

D'après les données de A. Fedortchenkova.

N ^o	Addition de KCl en g pour 100 g de sol	X ₀
1	0,0	7,52
2	0,01	5,89
3	0,1	5,52
4	1,0	5,36
5	10,0	4,40

Comme on le voit, avec l'augmentation de la concentration de KCl, la faculté du sol de lier l'eau s'abaisse d'une façon aiguë. Ceci est dû, en une certaine mesure, à l'action des électrolytes (en vertu de leur hydratation).

L'importance de l'eau fixée du sol dans la vie du sol lui-même, et aussi dans celle de la plante est extrêmement grande. La répartition de l'eau fixée à la surface des parcelles du sol se présente à nous de la manière suivante: la surface des parcelles du sol est recouverte (il se peut localement, et non pas d'une manière intégrale), par une membrane d'eau. La couche intérieure des ions se trouve entre la surface des parcelles du sol, et l'eau fixée par elles, alors que la couche extérieure diffuse des ions, semble être, pour ainsi dire, plongée dans la membrane de l'eau liée. Les réaction et l'adsorption d'échange sont localisées justement dans la membrane de l'eau fixée, et ce ne sont que les produits d'échange solubles dans l'eau, qui auront la possibilité de passer par diffusion dans la solution du sol.

Par conséquent, l'action naturelle de la plante et du sol se réalise à travers la membrane de l'eau fixée.

Pour le moment, nous ne disposons pas de données bien établies sur la répartition des sels et des gaz dans l'eau libre et dans l'eau fixée, car les données existantes sont incomplètes et contradictoires (25,26).

Les singularités de l'eau liée déterminent ses rapports à l'égard des plantes, c'est-à-dire son inaccessibilité pour celles-ci¹.

À côté de son inaccessibilité pour les plantes il faut encore signaler que l'eau fixée constitue un milieu défavorable pour l'activité des microbes; ces derniers ne peuvent développer leur activité qu'avec une humidité dépassant celle de l'eau physiquement fixée.

Nous avons examiné une série des propriétés de l'eau liée en étudiant les rapports mutuels entre les plantes et le sol. Il ne reste seulement qu'à dire quelques mots sur les perspectives d'une étude de l'eau dans le sol.

Avant tout, il est nécessaire d'approfondir les recherches sur les propriétés physiques de l'eau fixée: capacité calorifique, propriétés électriques, l'épaisseur de la couche de l'eau fixée, la nature de sa

¹ Voyez pour plus de détails le travail de A. Doumansky et M. Tchapek.

répartition à la surface etc., c'est-à-dire des questions, touchant la nature de cette eau, car ce n'est qu'une connaissance approfondie de ses propriétés, qui permettra d'appliquer ces recherches pour résoudre des problèmes industriels et pédologiques.

Le dernier but de toutes recherches sur les propriétés aqueuses du sol — c'est de trouver le moyens de régulariser le régime aqueux du sol; ce ne sera possible qu'après avoir étudié en général les propriétés et la nature de l'eau liée du sol.

LITTÉRATURE

- (1) W. Harkins and D. Ewing — J. Am. Ch. Soc. 43, 1787, 1921.
- (2) P. Nutting — J. ph. Ch. 31, 531, 1927.
- (3) Hochberg — J. de la phys. exper. et théor. 1, 5, 1931.
- (4) N. Marinesco — J. chim. phys., 28, 51, 1931.
- (5) B. Deriaguine — J. chim. phys., 3, 29, 1932.
- (6) P. Lazarev — J. chim. appl., 6, 107, 1929.
- (7) Travaux de l'Inst. des Matér. constr., 1, 1931.
- (8) M. Tchapek. Pedology, 1, 18, 1933.
- (9) A. Rakovsky et T. Poliansky. — J. chim. phys. 2, 151, 1931.
- (10) M. Tchapek — Z. f. Pfl., D. B. 34, 1934.
- (11) G. Pokrovsky et V. Boulytchev. K. Z. 60, 210, 1932; 61, 389, 1932; 61, 383, 1932.
- (12) H. Foot a. B. Baxton — J. Am. Ch. Soc. 38, 588, 1916.
John a. Gortner — J. ph. Ch., 38, 1, 1932; M. M. Cool a. C. Miller, Bot. Gaz. 70, 317, 1920.
- (13) F. Tohnes — Bioch. Z. 157, 174, 1925; W. Robinson, Coll. Symp. Monogr. 5, 109, 1928.
- (14) A. Doumansky. Koll. Z. 65, 178, 1933.
- (15) R. Gortner u. Newton. Bot. Baz. 74, 44, 1922.
- (16) M. H. MacCool a. A. W. Biedemann — Soil sci. 20, 3, 1925.
- (17) G. Bouyoucos — J. Agr. Res. VIII, 6, 1917. Mich. Agr. Exp. Techn. Bul 36, 1917.
- (18) A. Doumansky et A. P. Doumanskaïa — Trav. de l'Inst. de la Chim. coll. 2, 43, 1934.
- (19) P. Vageler — Der Kationen- und Wasserhaushalt d. Bodens. Berlin 1932.
- (20) H. Janert — Z. f. Pfl., D. u. B. 34, 100, 1934.
- (21) P. Szigeti — Koll. Beih. 38, 3—9, 1934.
- (22) A. Doumansky u. Tschapek — Koll. Ztschr.
- (23) M. Tchapek. Trav. de l'Inst. de la chim. coll. 2, 67, 1934.
- (24) H. Kuron. Z. f. Pfl., D. u. B. 25, 3/4, 1932.
- (25) A. Trofimov — J. arg. sci. 2, 613, 1925.
- (26) M. Thomes — S. Sci. 250, 409, 1928.

THE PROBLEM OF THE FORMATION OF A SOLID SOIL STRUCTURE

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The dispersion of soil, i. e. the distribution of the particles of soil, plays an important part in the development of its fertility.

This dispersion is connected with the general specific surface of the soil and consequently with the quantitative character of its physical and chemical properties. (K. K. Gedroiz — 1).

In the history of the origin and development of soils, the dispersion of their components is the primary cause which has allowed lifeless rocks to be transformed into vital organic structures, which can retain water, air and chemical solution.

However, the physical properties of soil become worse with continued increase of its dispersion.

If we take, for instance, the rate of water flow into soil as 0.08 gr/sec. when the radius of the pores is 2×10^{-1} cm., the hydrostatic pressure is unity, and the length of the capillary is unity, then to maintain this rate when the radius is 0.25×10^{-1} cm. the required difference of pressure is 5.3 atmospheres; a radius of 10^{-2} cm. will require 210 atm.; a radius of 10^{-4} cm. — 2×100^{10} atm. etc.

It is obvious, that if in soil there were no other aggregation processes, then a definite limit of solid particle dispersion (or their optimum combination) would occur, and this would limit soil fertility.

Disintegration above this limit would decrease the value of these soils, thanks to the sharp change for the worse of their physical properties¹.

The soil structure formation or aggregation process is, to a certain degree, the opposite of the dispersion process.

The essential element is the sticking of the disintegrated particles of the solid phases of the soil.

This sticking, or adhesion may be of two kinds:

1) The finest particles adhere by their surfaces (or by some points of their surfaces). This type of sticking follows essentially the law of coagulation of lyophobic colloids or related types.

¹ For attempts to establish an optimum physical composition of soils, see — "Soils in the Pskov District" by Glinka.

This problem has been made sufficiently clear in the works of J. M. van Bemmelen (2), K. K. Gedroiz (3), Hissink (4), G. Wiegner (5), S. Matson (6), Bradfield (7) and others.

2) The particles stick together by the aid of sols precipitated among them, which may gelatinize and be transformed into solid interlayers, which hold the soil particles together.

This type of adhesion follows laws approximating those for the gelatination of the lyophil colloids or of similar systems.

The laws of this latter type of sticking depend not only on the loading of particles, and to a lesser degree, upon their loading and the presence of electrolytes in the solution, but also upon the hydrational and de-hydrational capacity of particles under the given conditions.

This type of sticking, which surely exists in fertile structural soils (as indicated by work of Rabinerson and Fuchs—8) has been undeservedly little studied by soil scientists. Some investigators are now paying attention to this (A. F. Tiulin—9).

When the particles stick together the total surface of the soil decreases. It is easy to show, however, by simple computations and experiments that this decrease is not very great. The order of magnitude of the interfacial surface is maintained during structure formation.

Consideration of these points gives us the right to conclude that the structure formation process is very important in agriculture, and that it is possible to change the physical characteristics of soil for its improvement, without disturbing, at the same time, its well developed total interfacial surface.

The works of Schumacher, Wollny and especially of Williams (10), Doyarenko (11), Kvasnikov (12) and others, show that this good influence on the physical character of soil is only observed when the soil contains two systems of colloids, differing radically in the diameters of their particles.

Usually this is attained by the presence of large pores between the clods or lumps of soil, the latter must not be of very small sizes (from 2 mm. and up), and also must have small pores within the aggregates themselves. With a decrease of the pore diameters below 0.25 mm. the pores approach a uniform capillary system and the structural composition becomes of poor utility. Owing to a number of physical causes the clods must not be too large (over 10 mm.).

As was stated previously, the structure formation process in soils is conceived in soil science as a colloidal coagulation process (due to the effects of electrolytes and their mutual coagulation).

K. K. Gedroiz (13), M.A.S., as early as 1926 said: "Two factors apparently play a decisive rôle in structure phenomena, i. e. pressure and coagulation".

E. Russell, speaking of the building up of a soil structure by tillage, says: "The science of soil cultivation is still very young, but its foundation has been laid in Rothamsted and other places by discovery of the under-lying principles of the empirical methods".

Generally speaking these principles are:

The mixing of soil components into a homogeneous mass, the transformation of decoagulated into coagulated colloids, and the maintenance of the state of coagulation (14).

The methods of soil structure formation derive from:

1) Liming, 2) the addition of organic matters, and 3) mechanical cultivation.

The Institute of Agronomical Physics (Leningrad, USSR), considering the importance of the structural composition of soils and knowing that this structure may influence almost all of their physical properties, has proposed the problem of the creation of a stable soil structure by a new and heretofore unknown method. The main point of this new method lies in the creation of a stable structure by the introduction of sticky substances into the soil.

The studies of coagulation kinetics in lyophil colloidal systems, made by von Smoluchowski, Müller, Tuorilla and Wiegner (15) show that this type of cohesion does not allow one to assume the formation of large aggregates in soils.

Observations on colloidal coagulation under nearly ideal conditions have not shown any formation of aggregates larger than 0.05 mm. These micro-aggregates have not much significance in the establishment of a structure valuable for agricultural purposes.

The cohesion in colloid systems of this type is found to be of small mechanical stability because of the poor contact between the particles (Kruyt—16).

Furthermore the stability of the aggregates formed as a result of coagulation depends considerably on the cation responsible for this coagulation and depends also on the phenomena of ion adsorption in the soil.

Structure formation by introduction of sticky materials includes two problems:

1) the filling up of the pores between the particles of soil by systems which are capable of hardening and of forming interlayers of fair mechanical stability. They must be affected but very little by metabolic reactions in the soil and must be able to hold moisture without being destroyed by it. In the main, this part of the problem is but a question of the stability and resistance of the material which is used as the glue;

2) The increase of the adhesive power of the hardening interlayer surface towards the surfaces of the soil solids.

This part of the problem consists in the change of the surface energy in the interface of the glue-solid soil phase.

The first part of the problem is solved by the choice of an adequate gluing material, and by an increase of its stability. The latter allows, to a certain degree, the diminishing of the amount of material introduced into the soil.

The most satisfactory substances, considering these requirements, are some groups of the lyophil colloid class.

The stability of a sticky material depends mainly on its physical properties; more particularly, upon its viscosity.

The introduction of adequate plastificators allows one to influence these properties.

The second part of the problem, i.e. the increase of the adhesive power of the sticky materials towards the soil particles is solved by the intro-

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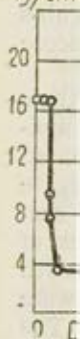


Fig.

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duction of materials having active surfaces (so called — "molecular solders"). The curves plotted in our laboratory by V. P. Konstantinova (17) (fig. 1) show the dependence of the stability on the thickness of the interlayer, the "solder", as well as the relation between the stability and the molecular weight of the "solder" during the sticking of two quartz surfaces (fig. 2).

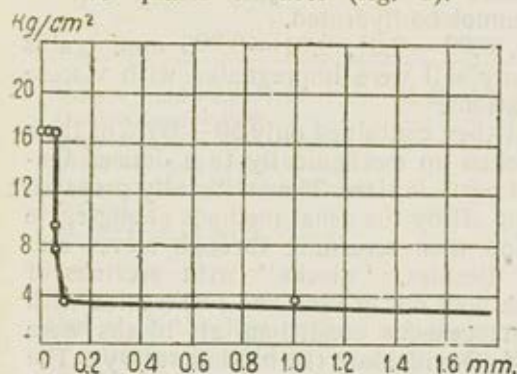


Fig. 1. The effect of the thickness of the layer of glue upon the stability.

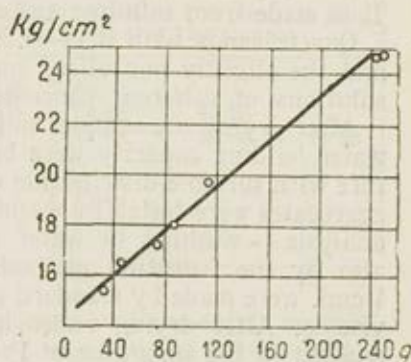


Fig. 2. The effect of the molecular weight of the "solder" on the sticking strength of two quartz surfaces.

The adhesive strength for a given "solder" depends also upon the character of the surfaces stuck together, as may be seen from the table given below. Paraffin was used as gluing material. Besides the alcohols, acids were tested. These data show the marked increase of the strength of adhesion with increase of the molecular weight of the "solder", thus confirming the rule of Traube.

Table 1

Name of solder	Molecular weight	Tensile strength in kg/cm²	
		Quartz plates	Calcite plates
Without solder (paraffin)	—	14.85	13.0
Methyl alcohol	32.03	15.4	—
Ethyl alc.	46.05	16.3	18.0
Butyl alc.	74.05	17.2	19.51
Amyl. alc.	88.1	—	25.1
Heptyl alc.	116.93	19.6	28.21
Cetyl alc.	242.27	24.5	36.0

With a view to determining the possibility of creating a suitable soil structure by the above method, laboratory researches were made in 1933—1934 based on the work of D. Talmud (18) and under his guidance.

The main point of the method is to introduce into the soil the sticky materials in a liquid state (or dry but with the possibility of peptization

in the soil moisture) and then after some drying of the soil, to subject it to mechanical treatment. Thus it is possible to create such a structure as is required, without the risk of turning it into dust.

The sticky materials tested were:

a) The technical product *viscose*, the gelatinization of which depends very little upon the presence of the electrolytes in the solution. It is made from cellulose and cannot be hydrated.

Quartz sands with 0.5—0.25, 0.09—0.01, 0.01—0.005 mm. grains and the slightly podzolized loamy soil were impregnated with viscose solutions of different concentrations.

After drying the samples until they contained only 50—60% of their water holding capacity were broken up mechanically to a desired texture with suitable distribution of particle sizes. The artificially prepared aggregates were tested by washing off by the usual methods of aggregate analysis—washing in water and then screening through sieves and also by the filtration method. Besides, "blocks" with sections of 1 cm². were made by standard methods out of sand and soil treated with viscose. After drying under homogeneous conditions all blocks were crushed in the apparatus of Prof. Davidenkov (in his laboratory). The loading in kg/cm²., when crushing of samples began, was considered as a criterion of mechanical stability.

The sum of the weights of the two fractions (in percentages) of aggregate analysis (0.5—0.25 and below 0.25 mm.) before and after dipping in water, as well as the character of the filtration curve, were adopted as resistance factors against washing off.

In fig. 3 are given the logarithmic curves of the mechanical stability of pure quartz sands, impregnated with viscose of different concentrations.

As is seen in the figure, the resistance to crushing has a linear dependence upon the concentration; the size of particle influences the stability and it is further to be remarked, that there are definite optimum sizes of capillaries for a given concentration of viscose and that these limit the increase of stability for the smaller particles.

The physical constants of the sticky material, especially its viscosity, play the decisive part in this.

The data of aggregate analyses show the same results (Table 2).

Analogous data result from seepage analysis. Those are not given here because of lack of space.

A constant water filtration during 12 days did not destroy the aggregates prepared with the aid of viscose, but the aggregates made of the soil not treated were all destroyed and the soil ceased to filtrate.

The second substance used in the laboratory experiments is the colloid "A" (as we call it) which was prepared in our laboratory according to the procedure of D. L. Talmud.

It is obtained by the action of glutine extracted from the ossein of bones, upon the materials of the so called "sulphite alkali", the latter coming from the waste sulphitetar acid of wood-pulp.

The yield from the boiling of the cellulose remains almost constant (yield 45—48%), the pitches and greases being converted into emulsion; penthozans and hexovans undergoing some modifications and to-

Table 2

Soils	Concentration of viscose		Relation of the technical viscose to the water		
	1:1	1:2	1:4	1:8	1:12
	The sum of aggregates below 0.5 mm. in percents of the weight of the sample				
Quartz sand = 0.5—0.25 . .	20.92	36.0	38.56	—	—
Quartz sand = 0.09—0.01 .	—	16.6	24.38	42.28	—
Quartz sand = 0.01—0.005 .	—	—	12.6	16.96	14.28
Slightly podzolized loam (not impregnated with viscose)	—	—	64.7*	—	—
Same, treated with viscose	—	—	19.92	—	—

gether with the lignine forming the compounds of ligno-sulphane acid. The cellulose is used in industry, and the compounds of ligno-sulphane acid, "sulphite alkali", as wastes of production, are thrown away. 10% of glutine (so called "broth") is poured into the "sulphite-alkali" by a small jet.

This results in a yellowish porous precipitate (glutine-lignine) which is colloid "A".

This colloidal precipitate has a number of properties, i.e. it is peptized in the alkali medium and is coagulated in the acid, becoming insoluble in water.

This colloid was of particular interest because, with its aid, the main question of the possible obtaining of a sticky material that can be introduced into soil in a dry state has been solved.

The results of the experiments show that there are no basic difficulties in this question.

The precipitated mass of gluten-lignine is peptized by the alkali NH_3 , KOH etc. evaporated, dried and then broken into pieces as small as possible and in that form is ready to be introduced into the soil in the rôle of a sticky material.

In the soil moisture this powder is peptized again and comes into metabolic reaction with the absorbing soil mass. The cation of the alkali forces out H (in the northern podzolized soils) from the surface of the soil particles and consequently the soil solution becomes acidic and causes the precipitation of the glutine-lignine colloidal combination.

In the process of conversion of the sol into gel (gelatinization) this becomes insoluble in water and binds the soil particles together.

Colloid "A" was also subjected to tests for mechanical stability and to that of washing off by water by the above-mentioned methods.

As is seen in table 3, the mechanical stability of colloid "A" has not been observed directly, as is the case with viscose, because of the additional factors involved in the use of the peptisator and coagulator.

* Only for comparison with soil treated with viscose.

Table 3

Soils	Percentages of colloid contents in solution «A» introduced into soil	Peptisator	Coagulator	Loading for crushing kg/cm ²	Observations
Slightly podzolized loamy soil. From lowland of the Neva river.	20%	KOH 0.1%	without coag.	22.0	1.5% of the soil weight
	20%	"	HNO ₃ 0.01%	32.0	
	10%	NH ₃ 0.05%	HNO ₃ 0.05%	17.3	
	5%	"	"	4.05	
	3%	"	"	4.00	
	1%	"	"	2.4	
	0.5%	"	"	2.1	
	10%	NH ₃ 0.025%	"	9.5	
	5%	"	"	8.7	
	3%	"	"	7.05	
	1%	"	"	4.0	
	Without colloid «A»	"	"	3.8	
Slightly podzolized heavy loamy soil	3%	KOH 0.005 n	without coag.	15.5	1.5% of the soil weight
	3%	"	HCl 0.1%	10.3	
On bandy loamy-fine sands (Peterhof)	3%	" 0.1	Without coag.	17.05	
	3%	" "	agul.	20.6	
	Without colloid «A»	"	HCl 0.1%	8.2	

The resultant dependence of the mechanical stability upon the concentration of the sticky material is manifested here.

The concentration of the peptizing material and its physico-chemical properties are now being investigated. The effects of the coagulation are good but quite insignificant, and its introduction into podzolized soils is unnecessary. The stability with respect to washing off is shown in the table below. Colloid «A» introduced in the dry state, showed analogous indexes.

Table 4

Soils	Colloid «A» content in %	Peptisator	Coagulator	Amount of particles below 0.5 mm. after "bathing" in %
Slightly podzolized loamy soil from the lowland near the Neva river	3%	NH ₃ 0.025 n	HNO ₃ 0.05%	17.24
		without introduction of colloid «A»		64.7
Slightly podzolized heavy loamy soil of the bandy loamy sands (Peterhof)	3%	KOH 0.05 n	Without coag.	48.58
	3%	KOH 0.05 n	HCl 0.1 n	55.44
	3%	NH ₃ 0.1 n	HCl 0.1 n	37.48
		Soil without introduction of colloid «A»		98.86

The good results obtained with these materials compelled us to look for cheaper and more available products to be used in practice. Such materials are primarily peat and straw. The experiments made in our

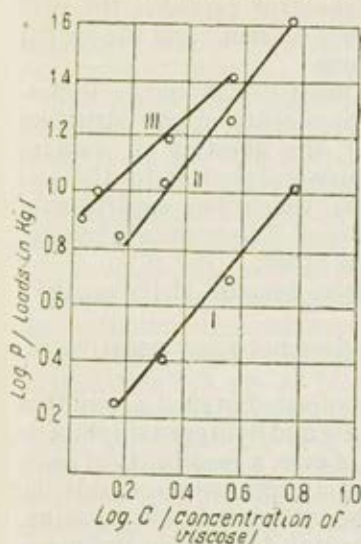


Fig. 3. The mechanical stability of sand, impregnated by viscose. I—quartz sand with particles diameter 0.5—0.25 mm. II—0.09—0.01; III—0.01—0.005.

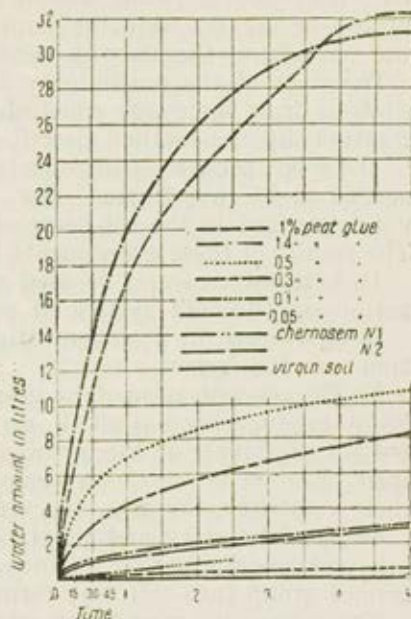


Fig. 4. Resistance of soil aggregates against washing off by water.

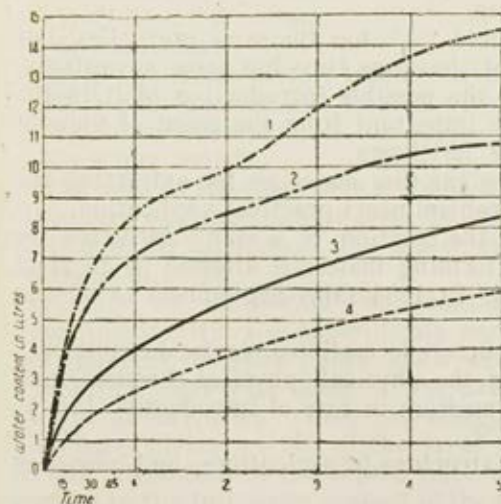


Fig. 5. The comparison of the sticking capacity of different glues:

- 1—0.1% viscose;
- 2—0.5% peat glue;
- 3—0.5% straw glue;
- 4—0.5% silicate of sodium.

laboratory by N.J. Solechnik showed the possibility of getting the sticky products out of these two raw materials.

We give the curves of resistance of the podzolized soil aggregates against washing off by water. The water filtration was tested on the apparatus of W. R. Williams under general standard conditions for all cases, i.e., water was filtered under constant pressure, the sizes of the aggregates were the same in all cases (2—3 mm.) and the weight and packing of the samples were also the same.

The data of the preliminary laboratory investigations made it possible to draw some new conclusions on the possibility of soil structure creation by the method described. However, the question of damage to the crops because of introduction of the new substances in the soil needed to be investigated. For this purpose vegetation experiments were arranged in the hot-house of the Institute of Agronomical Physics. The results of these experiments have showed, that:

1) Ammoniac cannot be used as a peptisator, because of its negative action on the root system of plants;

2) KOH even in a concentration of 0.1% does not show negative action on the germs;

3) The concentration of the viscose may be adjusted in such a way that its by-products such as alkali, carbon disulphite and hydrogen sulphite do not act negatively on the germination; there is even a possibility of using their negative properties by employing them as mordants, considering their volatility. For this, the viscose must be introduced before sowing.

4) The laboratory and vegetation experimental data allow the possibility of concluding that the introduction of sticky matters of the lyophil colloid group into soil may form aggregates in it.

This procedure may be associated with the mechanical treatment of the soil. The structure created with the aid of the introduction of sol and viscose into sands and soil has very important and valuable properties, as: a fair mechanical stability, resistance as regards water penetration, and moderate swelling.

The structure created with colloid "A" has the same properties, but in somewhat lesser degree, and at the same time has some advantages; the more important of which is the possible introduction of it in the form of a powder, which is very important from the point of view of preparing the structure forming fertilizers.

Peat and straw may be used as the raw materials for extracting the gluing substances and thus the problem nears practical application.

These laboratory researches on the creation of a stable structure by means of intrusion of the texture forming materials allowed us to start and to develop field experiments in 1934 (May-September) to answer the following questions:

1) Is it possible, to control the structure formation under field conditions?

2) What changes take place in the physical, physical-chemical, and biological conditions in the soil medium in case of introduction into it of these "physical fertilizers"?

3) What is the rôle of the soil structure in agriculture, and how does it affect the crop?

The field experiments were made in the soviet farm (sovkhoz) No 1, near Leningrad. The soil of this experimental field may be described as heavy podzolized and sandy loamy. Its mother strata are the ancient

fine sands of the lakes (ancyl) and sandy loams. The reaction of the medium is acid. In the surface layers pH—4.0; 1.5 m. below the surface pH—4.4.

For tests under field conditions, the glue made from peat, that from alkali sulphide (colloid "A") and also viscose were used, the last being an excellent material for preparing the models of soil structures.

The experiments included also the test of the new method of soil mulching. This method was elaborated in our Institute and consisted of covering the soil with a thin layer of bituminous emulsion. In this case we proceed from the assumption of the possible control of the thermal conditions of the soil by means of a modification of the optical properties of its surface as well as of the water content. As the control plot, one covered with ordinary paper mulch, was used.

These methods of regulating the soil conditions were carried out under optimum circumstances of mineral nourishment, i.e. the usual method of tillage before seeding with liming and with a complete mineral fertilization (45 kg. of N, 45 kg. P_2O_5 , and 60 kg. K_2O).

To demonstrate clearly the structure created by introduction of different glues into the soil, some special plots with supplementary additions, the so called "compensated control plots" were prepared; these receiving, besides the usual fertilizers, additional N and K in amounts corresponding to the assimilative capacities of the plants.

Thus the scheme of the experiments included the following plots:

- 1) Control plot (without fertilizers).
- 2) Lime (Ca).
- 3) Complete mineral fertilization (N, P, K).
- 4) Ca+N,P,K.
- 5) Ca+N,P,K + "compensation" (N and K).
- 6) Colloid "A" dry.
- 7) Colloid "A" liquid.
- 8) Peat glue.
- 9) 3 cm. layer of soil treated with viscose.
- 10) 7 cm. layer of soil treated with viscose.
- 11) Bituminous film.
- 12) Paper mulch.

The sizes of the plots were of $5 \times 8 = 40$ sq. m. All tests were made twice. Oats were used for the test crop. To observe the change due to the physical character of the soil, the experiment was repeated on fallow land (without plants).

Finally, to understand the action of these methods, which depend upon the acidity, the experiments were repeated with liming but without mineral fertilizers and again without fertilizers or liming.

All these tests were made to give data answering the above questions. "Physical fertilizers" were introduced in terms of 0.5% of the dry glue mass of the weight of the layer under cultivation; the gluing materials introduced in the liquid state were provided with water in proportion to the full water content of the soil. Per 1 sq. m. of the tested area we introduced 0.3 kg. of peat glue, 0.3 kg. and 0.7 kg. of viscose, 0.6 kg. of Colloid "A", finally bituminous emulsion containing 0.2 kg. of dry bitumen.

The method of introducing dry structural fertilizers is similar to that of the usual mineral fertilizers, but the liquid materials were sprayed on the soil surface, then time was allowed for drying (12—20 hours), after which the soil was harrowed to divide it into the desired sizes of aggregates. In the case of the bituminous emulsion, the mechanical treatment was not performed.

The experiments were started on June 2 and the oats were seeded June 5.

To estimate the effects of the structure creating substances and of the soil mulching method upon the physical and biological conditions and on the growth of plants, observations on the thermal, water and nourishment conditions, as well as of the changes and activities of the soil microflora were conducted during the whole season. These observations were made on fallow land and on the plots under oats.

We now give a description of the method of measurement, and of the data obtained.

Soil temperature

The temperature was taken with thermocouples inserted in the centre of each plot to the depth of 0.5, 10, 20 and 40 cm., during the period from 23/VI to 1/X, systematically 3 times per day at 8 a.m., 2 p.m. and 10 p. m. Besides on June 27 and 28, and August 6, 7, 8 the temperature was taken every two hours, 10—15 minutes before measuring, the cold junction of the thermocouple was placed in melting ice and was kept there during the whole time of measurement.

The soil temperature data were used as follows: systematic measurement during the whole season allows an estimate of the soundness of the procedure of placing the thermocouples in soil and of the isolation of their terminals and lead wires.

The temperature, taken every 2 hours, was used as the basis of comparison of the soil temperature at the different plots, depending on the applied treatments of the soil. As examples of the temperature distribution of each plot during 24 hours the results obtained on August 6, 7 and 8 are given in figs. 6 and 7. The diagram shows the reading of thermocouples placed at three depths: on the surface (0 cm.), at 10 cm. and at 20 cm., for the different plots.

The highest mean daily temperatures were observed on plots 12, 11, 10 and 9 (colloid "A" without vegetation, colloid "A" with planting, peat and viscose). The amplitude of the fluctuation between the maximum and minimum temperatures of these plots was the smallest. It depends apparently on the fact that the crust appearing on the soil surface during structure formation prevents an excess evaporation of moisture, which is also shown by the comparative data on the increased moisture content of these plots. The plots covered by mulch and bitumen show the highest temperatures during the day time, but sharply lowered ones during the night: this is apparently due to the absorptive and radiative properties of these substances.

The results obtained are sufficient to prove that the use of thermocouples for taking soil temperature is quite practicable; and with careful use may give quite reliable data on soil temperatures at all depths under different meteorological conditions.



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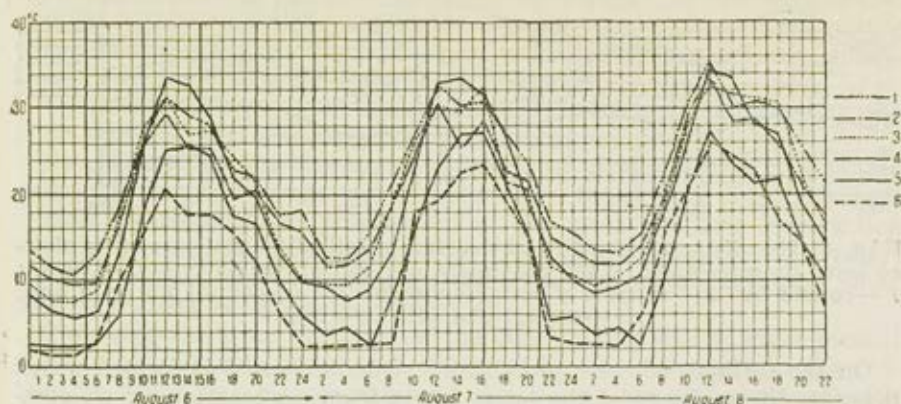


Fig. 6. The effects of the artificial structure of soil upon its temperature (fallow land at a depth of 0 cm.): 1—colloid "A" without vegetation; 2—peat; 3—viscose; 4—bitumen; 5—mulch; 6—control plot with mineral fertilizers.

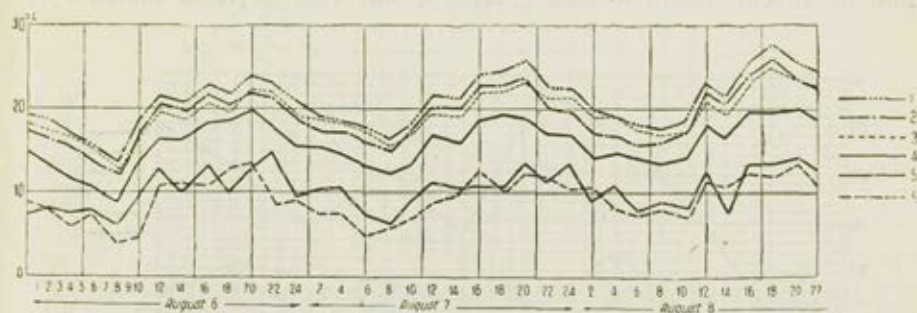


Fig. 7. The effect of the artificial structure of soil upon its temperature. Legend—see fig. 6.

On the other hand, it is necessary to state that the structure forming materials introduced sharply modify the temperature conditions of the cultivated soil layer; they decrease the amplitude of fluctuation between day and night and increase the mean daily temperature by 5—10° C. As we shall see further, all this affected the growth and development of the experimental crop.

Soil moisture

The measurements of moisture content were made on the cultivated and on the underlying layers of soil once every 10 days by means of the usual method of weighing¹. Diagram 8 shows the great advantages in this respect of the plots with created structures.

¹ B. Alexandrov's apparatus for measuring moisture content by electrostatic capacity (*Problèmes de la Physique du sol*, A. 2, 1934) could not be used under field conditions. Work on its simplification is now being done.

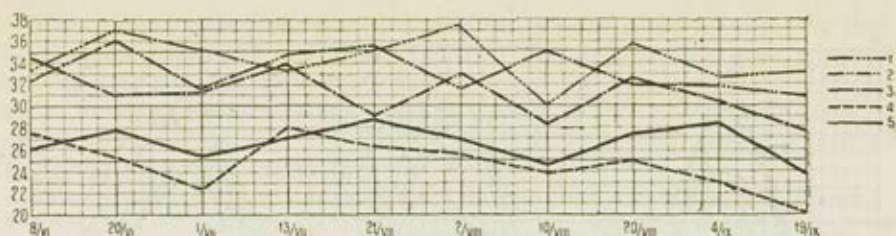


Fig. 8. The effects of the artificial structure of soil on the moisture of its plowed layer (in percentages of the absolutely dry soil of the layer of 0—15 cm.): 1—colloid "A" 2—extracts of peat; 3—viscose "7"; 4—control plot with lime; 5—control plot with Ca + Mg.

On the surfaces of these plots a dry structural crust is formed which prevents the moisture of the lower layers from evaporation. If we compare the surface layer 0—3 cm. of the plots: control, peat, glue and colloid "A", then mean summer moisture contents were 14.5%; 11.3%; 11.5% respectively and simultaneously the lower layer at 10 cm. depth had 27%; 31.5%; 34.7%; at 20 cm. depth — 26.2%; 30.5%; 36.6%; and at 40 cm. depth — 16.3%; 21.3% and 19.5%. Some increase of

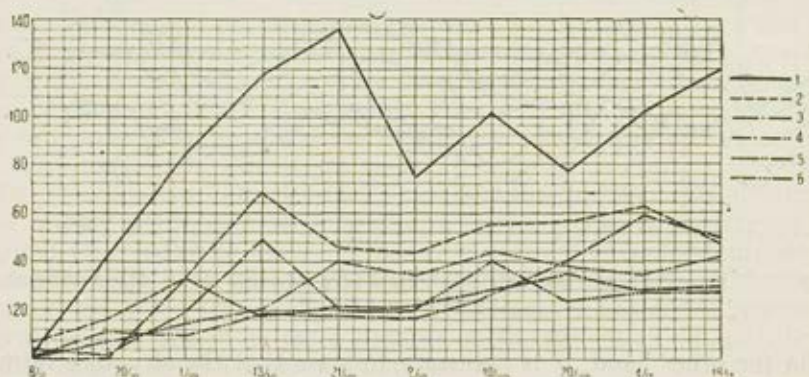


Fig. 9. The effects of the artificial structure of soil upon its nitrification. (1 mg. NO_2 per 1 kg. of absolutely dry soil): 1—colloid "A"; 2—extracts of peat; 3—viscose "7"; 4—control plot with lime; 5—viscose "3"; 6—mineral fertilizers.

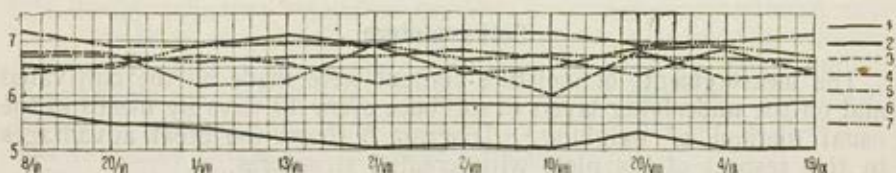


Fig. 10. The reaction of the soil medium depending upon the kind of structural fertilizers: 1—control plot; 2—colloid "A"; 3—extracts of peat; 4—viscose "7"; 5—control plot with lime; 6—bitumen; 7—mulch.

humidity was observed also on the plots covered by the bituminous emulsion and by mulch. These regularities in the humidities of the experimental plots are in full accord with the soil temperature conditions in their dependence upon our treatment.

The lessened evaporation makes for better thermal conditions on the plots supplied with the structural fertilizers.

To characterize the physical and chemical processes occurring in the cultivated layer, average soil samples were taken once every 10 days during the summer for preparation of the water extracts from which were determined the contents of NO_3 , NO_2 , pH, the hydrolytic acidity, Ca and water soluble organic materials by the usual methods. Some data are given in diagrams 9 and 10.

Observing the time variation of the NO_3 content of the experimental plots (diagr. 9) it is found that the greatest amounts occur in the colloid "A" plot and in that with peat glue, i.e. in the plot provided with physical fertilizers.

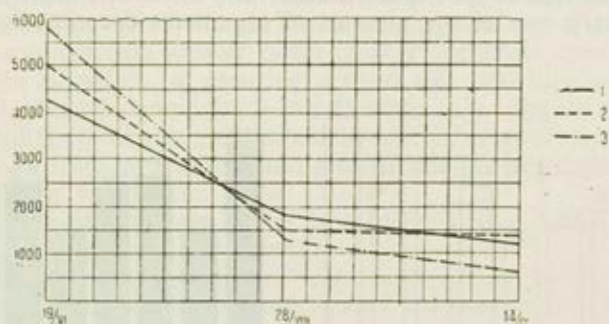


Fig. 11. Total number of microorganisms in millions per gram of soil. Fallow land. 1 — control plot; 2 — viscose; 3 — colloid "A".

The best aeration, increased temperature, and smallest fluctuation of the humidity offered the best conditions for development of nitrogen products.

Viscose, which contains carbon disulphide retards somewhat the nitrification process and, as will be seen further on, injures the germination of the seeds.

As regards the acidity of the colloid "A" plot, this appears to be sharply increased, which is to be explained as an exchange absorption process of potassium with hydrogen and as the increase of nitrification as well.

But in the case of the peat glue and viscose there is a change of pH towards an alkaline condition (diagr. 10).

It was quite important also to follow the effects of the constructive fertilizers upon the soil microflora. The total amount of microorganisms was checked and observations on the vitality of bacteria decomposing the albumens and cellulose were made.

Diagram 11 gives the total amount of microorganisms.

The effects of the constructive fertilizers on the total amount of microorganisms in soil are qualitatively similar in the plots of fallow land and those under oats but are more pronounced in the fallow land plots.

Apparently the presence of plants equalizes the difference of living conditions of the microorganisms due to the introduction of structural fertilizers in the soil.

Colloid "A" during the initial period after its introduction stimulates the development of microorganisms as compared with the control plot and that containing viscose. At the end of the vegetation period however the amount of microorganisms in the plot of colloid "A" had sharply decreased.

The viscose definitely increases the content of organisms at the beginning and at the end of the vegetation period as compared with the control plot.

Colloid "A" stimulates the development of the microorganisms decomposing cellulose under aerated conditions, which is quite clear because the maximum acidity of this group is near to pH—5.8.

Viscose, as was to be expected according to its chemical composition, causes a sharp rise of the amount of organisms decomposing the cellulose.

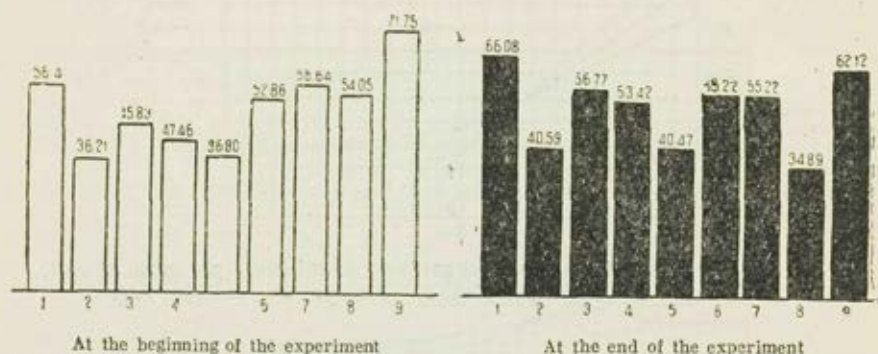


Fig. 12. The amount of the particles less than 0.5 mm. in soil subject to aggregate analysis: 1—control plot; 2—colloid "A" liquid; 3—colloid "A" dry; 4—peat; 5—viscose "7"; 6—viscose "3"; 7—manure; 8—manure + viscose; 9—compensated control (control + NK).

During the investigations it was considered very important to draw some conclusions concerning the stability of the created structure in relation to water, i.e. the degree of washing off of the applied glues, degree of destruction of the same by bacteria etc.

With the practical goal in mind to work out and try in the field such constructive fertilizers as would offer something real and of long duration, we made aggregate analyses of soil samples of the experimental plots at the starting and the end of the investigations. This was done in addition to testing the mechanical strength of aggregates and the visual estimation of plow land behaviour during the season.

The samples were first passed through sieves to determine their aggregate composition, then the average sample from the sieves was washed

10 times in water and the changes occurring in its aggregate composition were computed.

The absolute fraction of the particles with diameters less than 0.5 mm. are given in diagram 12, which allows us to judge of the soil structure stability of the control and other plots at the beginning and at the end of the experiments in the Autumn.

From the analysis of this data we conclude, that the introduction of structural fertilizers greatly increases soil structure stability with respect to action of water and that this stability remains during the whole of the season.

Concerning the rate of influence upon soil structure the materials tested may be placed in the following order: viscose, colloid "A", peats, glue.

All these structural fertilizers are more effective than manure which affects soil structure only towards the end of the season.

It is worth noting that Ca and N, P, K increase the action of the structure forming materials and especially of viscose.

The bituminous film and the mulch paper showed favorable influences on the conservation of soil structure prepared by tillage.

All these experiments answer quite clearly the basic question of the possibility, in principle, of creating a solid soil structure under actual field conditions and demonstrate the considerable improvement of the physical conditions of the soil, which in turn favorably influence the biological conditions of the soil and also the crop of agricultural plants, as will be seen further on.

Let us now see the effects of the structure creating fertilizers on the growth and development of plants.

As was stated, the experiments were made using oats. These were sown on June 6, because of the late spring, to the amount of 2 centers per hectare; June 14 sprouts appeared simultaneously on all plots, except on that covered by bituminous emulsion, on which germination was observed on June 11.

This is quite understandable if we remember the temperature conditions of the surfaces of this plot, especially during the daytime.

About the time of branching of the plant the plots began to exhibit their individual differences. The process of growing in bushes (and also that of forming the panicles) on the structured plots and on the bituminous began 4 days earlier than on the control plots.

The plants looked more vigorous, were very green, and surpassed those of the control plots in the height of the stalk and also in the width of the leaves.

The viscose plot gave widely separated stalks, which is to be remembered when checking the crop data.

Due to the presence of carbon disulphide, sowing must not occur too soon after the introduction of the viscose.

Below is a tabulation of the condition of the plants by the time of the milk stage of maturity.

There were also similar relations for the width of the leaves. The most vigorous development of the vegetative organs are on the plots supplied by "physical fertilizers".

With respect to the time of beginning of the different phases of the development of the oats, ripening included, or the plots of bituminous film and of peat glue these phases were advanced 4—5 days compared to the other plots.

To conclude, below are given the crop data of the experimental plots (diagram 13).

Comparing the crops from the plots with applied structural fertilizers and that of the control plots (with additions — the compensated

Table 5
The condition of plants on August 7.

Name of plots	Average height in cm. of 57 plants	
	<i>M</i>	$\pm m$
Colloid "A"	122.5	1.47
Peat glue	115.7	1.38
Viscose (3 cm)	115.3	1.95
Viscose (4 cm)	114.5	1.7
Bituminous film	112.3	1.26
Ca + N, P, K	117.7	1.7
Ca	100.9	1.08
Control plot without fertilizer	100.0	1.24

plots) thus somehow separating physical from chemical factors, we can see the agricultural importance of soil structure and estimate the effects of these structure creating materials on crop productivity.

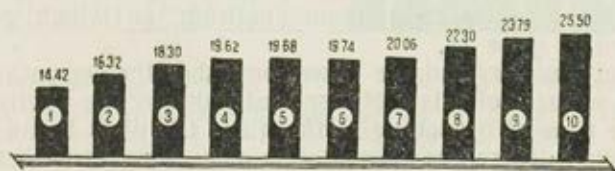


Fig. 13. The influence of the artificial soil structure upon the oats crop. Experiment of 1934. 1—control plot; 2—Ca; 3—NPK; 4—viscose 7 cm. (on the layer of Ca + NPK); 5—Ca + NPK; 6—viscose 3 cm. (on the layer Ca + NPK); 7—Ca + NPK + compensation; 8—bituminous film (on the layer of Ca + NPK); 9—peat glue (on the layer Ca + NPK); 10—colloid "A" liquid (on the layer of Ca + NPK).

Colloid "A" plot gave an additional crop of 5.44 centners that is, a 27% surplus over the compensated control plot. Peat glue gave +20%, bituminous film +15%. Coming with an already good crop these supplements are especially striking.

The viscose plot must be considered in particular. The above mentioned sparseness of sowing lowered the crop output of this plot with respect to the control; but estimation of the crop per plant with allow-

ance for the nourishment area shows an excellent behaviour of the plot in question. As regards its crop, this plot occupies one of the first places.

These figures of the crop output answer positively the last question, that of the importance of the soil structure in general, and at the same time give a certain appreciation of the value of the applied glues.

It is to be remembered that these experiments were made on light soils, on which it is more difficult to show the differences and to find the effects of physical factors as well as to produce the process of structure formation.

The results obtained make it certain that the effects of these physical fertilizers will be more pronounced in heavy soils.

In 1935 we are starting experiments with heavy clay loams of the podzolized zone (Leningrad district) and with the cultivated, irrigated, clayey serozems of Middle Asia (Tashkent). Thus we have found as well the possible raw products for preparing the structural fertilizers, using waste products from local industry and agriculture.

REFERENCES

- (1) Gedroiz, K. K. — The study of soil absorbing capacity, 1927.
- (2) Van Bemmelen, J. M. — Die Adsorption. Dresden, 1910. J. prakt. Chemie 23, 324, 1881.
- (3) Gedroiz, K. K. — Bulletin of the Institute of Experimental Agronomy, 1926 v. IV, № 3. Chemical Soil Analysis, 3-d edition, 1929.
- (4) Hissink — Inter. Mitteil. f. Bodenkunde, 10, 20, 1920.
- (5) Wiegner, G. — Koll. ZS. 8, № 27 (19n) 31, 1922, 38 — 1926, 47 — 1927, 51 — 1930.
ZS. f. Physik, Chem. 140, 1929.
ZS. f. Pflanzen-, Düng-u. Bodenk. 11 — 1928 and others.
- (6) Mattson, S. — Koll. Zeit. 1922, Journ. Agr. Res. 1926, Journ. Phys. Chem. 1932.
- (7) Bradfield, R. — Koll. Zeit. 47. 1929. Jour. Amer. Soc. Agr. 18, 1926.
- (8) Rabinerson, A. I. and Fuchs — The Structure of soil colloids. Proceedings of the Leningrad Filial of the Institute for Fertil. a. Agron. Soil Sci., 22 — 1933.
- (9) Tulin, A. F. — Genesis of soil structure and methods of its Determination. Proceedings of the Institute for Fertil. a. Agron. Soil Sci.
- (10) Williams, W. R. — The general Agriculture with the Basis of Soil Sci. 1932.
- (11) Doyarenko, A. G. — Agronomical Scientific Journal 7 — 8, 1924, 3, 1925, 3, 12, 1926.
- (12) Kvasnikov, V. V. — Proceedings of Samara Agricultural Institute, IV, 1927.
- (13) Gedroiz, K. K. — Bulletin of the Institute of Experimental Agronomy, IV, 3, 1926.
- (14) Russell, E. — Soil conditions and plants growth.
- (15) Wiegner, G. — Koll. Z. 58, 1932.
- (16) Kruyt, H. R. — Colloids.
- (17) Konstantinova, V. P. — Physic.-Chemical Journal, V, 8, 1934. Acta physicochimica U.R.S.S., 2, 1934.
- (18) Talimud, D. A. — Surface Phenomena (monography). The Successes of physical science. 1934. Acta physicochimica, 1, 2, 1934.

MIGRATION BIOGÈNE DES ÉLÉMENTS CHIMIQUES RARES

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Résumé

1. À l'exception de l'hydrogène, de l'oxygène, du carbone, de l'azote, du sodium, du magnésium, de l'aluminium, du silicium, du chlore, du potassium, du calcium et du fer (en partie du phosphore, du titane, du manganèse et du soufre), tous les autres éléments chimiques se trouvent ordinairement dans les sols, les plantes, les animaux en quantité beaucoup moindre que 0,1% du poids. La somme de ces éléments qu'on trouve dans les sols, les plantes comme dans les animaux ne dépasse 0,5%.

Cependant le rôle physiologique de ces éléments chimiques existant dans les sols, les plantes et les animaux en petites quantités (resp. micro-éléments) comme par exemple — le bore, le zinc, le vanadium, le cuivre, le manganèse, l'iode, le radium et beaucoup d'autres, devient d'année en année plus connu et son importance s'affirme.

Le problème acquiert non seulement un intérêt théorique considérable, mais une grande valeur pratique.

2. Nos connaissances dans ce domaine sont déterminées 1) par les observations nombreuses sur l'action physiologique qu'exercent de faibles concentrations d'une série d'éléments chimiques sur différentes plantes et divers animaux (observations non encore généralisées théoriquement); 2) par des données (peu nombreuses et non systématisées encore) sur la teneur des microéléments dans quelques plantes et dans certains animaux; 3) par une ignorance presque complète de la distribution de ces éléments dans divers sols, sous-sols et solutions des sols.

D'après le mode d'expérimentation en usage jusqu'ici, l'étude de la fréquence des microéléments dans les sols, les plantes et les animaux s'est faite indépendamment dans chaque cas isolé. Le processus naturel, celui du déplacement des substances, — la migration des atomes du système complexe et indivisible du sol — solutions du sol — plantes — animaux — en entier a échappé à la vision des investigateurs scientifiques.

3. Cependant la composition chimique élémentaire du sol, des plantes et des animaux — la distribution et la combinaison en eux d'éléments — les atomes-chimiques déterminés — malgré toute son originalité et son caractère particulier est soumis aux lois géochimiques — à l'histoire générale des atomes.

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Les lois géochimiques qui régissent la distribution des éléments chimiques-atomes dans l'écorce terrestre — le sol — régissent aussi toute matière vivante.

La migration des atomes dans le système sol — solutions de sol — plantes — animaux étudiée à ce point de vue, — nous permet maintenant 1) introduire une large base théorique dans un phénomène compliqué et important; 2) permet aux géochimistes, aux pédologues et aux biologistes, s'intéressant à ce problème chacun à son point de vue spécial pour la première fois de trouver une langue commune.

4. Le tableau de la distribution quantitative des microéléments dans les sols commence à être connu.

Aujourd'hui souvent nous ne pouvons que faire des suppositions sur la teneur d'un tel ou tel microélément dans le sol, en nous basant sur la géochimie de la décomposition des roches et des couches sédimentaires en général. C'est pourquoi nous connaissons surtout théoriquement plus que pratiquement l'augmentation possible de la teneur de Ti, Fe, Mn, Co, Ni et d'autres éléments, qui résultent de la décomposition des roches basiques. Nous avons un phénomène inverse dans le cas de la genèse des sols provenant des roches granitiques acides etc.

Les composants des sols argileux augmentent la teneur du vanadium, de l'arsenic et de beaucoup d'autres éléments; dans les sols provenant des sédiments marins littoraux — des limons marins, c'est la teneur du bore, brome, iode, arsenic etc. qui s'accroît.

Au contraire, les sols contenant beaucoup de sable et de calcaire en contiennent peu. Les sols latéritiques riches en Mn, Fe (Ti, V et autres) et d'autres sols, constituent des cas à part. Ceci crée une inégalité de répartition horizontale des microéléments dans les sols.

Dans les sols ayant atteint leur maturité contenant beaucoup de matière organique, résultant de l'action de la matière vivante — dans le processus de la migration biogène il se produit une stratification verticale des microéléments (As, B, Ge, Ni etc.).

La matière organique (le humus) des pâturages, des sols des forêts et d'autres sols, s'enrichit plus de ces éléments que les horizons des sols se trouvant au-dessous.

5. La composition moyenne chimique des sols en pourcents d'atomes (d'après des déterminations directes) est caractérisée par une courbe inclinée comme le montre la figure. La courbe présente une alternation plus ou moins régulière de la position des éléments séparés en minimum et d'autres en maximum. La comparaison entre la composition des sols et la composition moyenne de l'écorce terrestre indique une tendance d'augmentation dans les sols des éléments chimiques surtout ayant un nombre impair et la diminution de ceux avec un nombre pair, surtout ceux qui dans les conditions naturelles ne forment pas des composés solubles (le thorium, le zircon, en partie le titan etc.).

6. On a découvert systématiquement dans les plantes et dans les animaux plus de 60 éléments chimiques. Il est connu depuis longtemps que les organismes qui concentrent le silicium, le calcium, le fer, le soufre etc. prennent part à la formation de la roche biogène. Aujourd'hui on connaît les organismes (et leurs différentes espèces) accumulant dans leurs tissus le vanadium, le bore, le zink, le cuivre, le brome, l'iode,

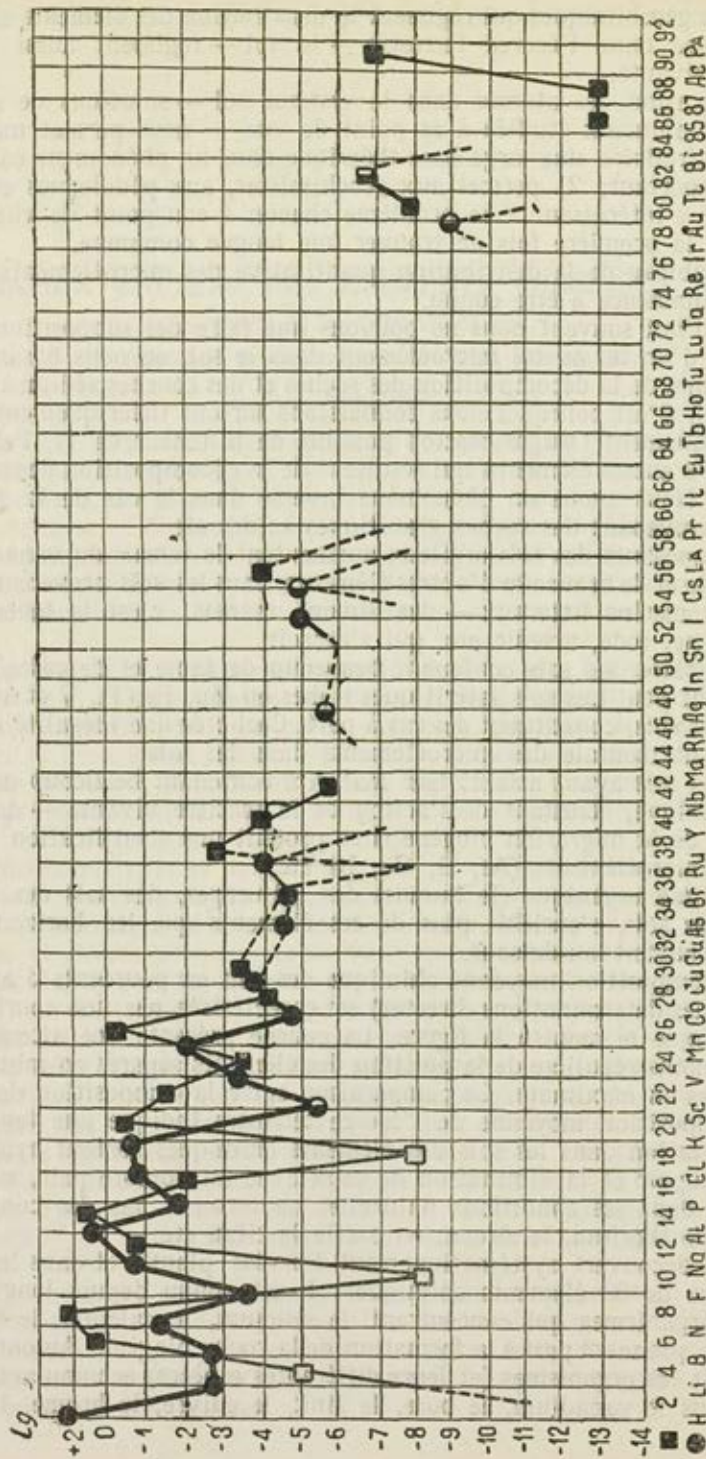


Fig. 1. Le contenu quantitatif des éléments chimiques dans le sol en pour-cents des atomes.

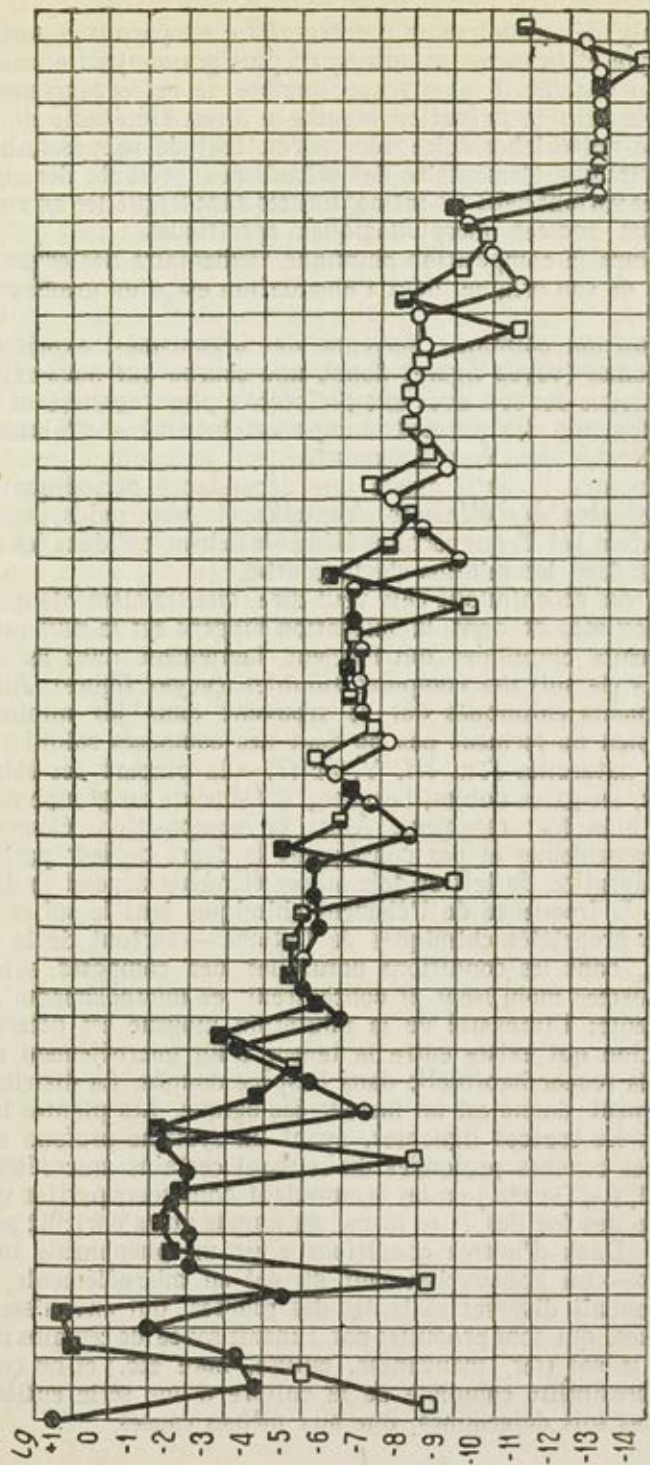


Fig. 2. Le contenu quantitatif des éléments chimiques dans la matière vivante en pour-cent¹⁰⁰ s des atomes.

l'argent, le molybden et beaucoup d'autres. Et c'est parmi ces organismes (Thallophyte et Protozoa et autres, en plus grande partie unicellulaires) que l'on connaît le plus grand nombre de ces organismes spéciaux. Leur rôle dans la migration biogène n'a pas été étudié du tout. Les travaux de notre laboratoire nous permettent de supposer, que la composition chimique élémentaire des organismes, présente des caractères spécifiques variant dans les mêmes limites dans lesquelles on connaît l'oscillation des indices morphologiques spécifiques.

En même temps la composition chimique élémentaire des organismes porte les traits de son origine, dont l'élucidation est d'un grand intérêt scientifique.

7. La composition chimique moyenne des organismes, exprimée en pourcents d'atomes (voyez figure) donne une courbe qui nous rappelle une courbe analogue des sols avec une périodicité plus régulière et troublée dans le domaine des éléments composant les roches d'alumo-silicates et de silicates de l'écorce terrestre.

La courbe montre: 1) qu'il existe une dépendance périodique entre la migration biogène des éléments chimiques et leur poids atomique (resp. nombre atom.) et 2) que certains éléments se trouvent dans les maxima et d'autres dans les minima de la courbe.

Du point de vue géochimique cela veut dire, que les éléments qui présentent des maxima, et dont la migration biogène est la plus intense, sont des éléments chimiques qui forment facilement dans les conditions naturelles (le sol) des composés solubles (voyez figure). Au contraire, les éléments chimiques qui se trouvent dans les minima de la courbe ou bien ne forment pas du tout des composés solubles dans des conditions naturelles (Th, Hf, Y, Sc (?)) — la plupart des éléments rares des terres, les gazes nobles, beaucoup d'éléments du groupe du platine etc.) ou bien fort rarement. Ainsi la composition élémentaire chimique des organismes et par conséquent le degré de leur participation dans la migration de tels ou tels autres éléments dépend 1) dans le cas général de la fréquence de l'élément chimique dans le sol et 2) en particulier des propriétés chimiques de l'atome — surtout de la capacité de former, dans les conditions naturelles des composés solubles.

8. Les organismes mobilisent et concentrent les microéléments d'une manière différente; l'intensité de la migration biogène est déterminée par la corrélation qui existe entre la teneur d'un microélément donné dans le sol et la teneur habituelle dans l'espèce donnée. La distribution d'un microélément donné est un facteur écologique. Les plantes herbacées et surtout les espèces ligneuses, ayant un système profond de racines, tirent des couches profondes du sous-sol certains microéléments (Co, Ni, Mn, B, As, Ge etc.) en les accumulant dans leurs parties vertes. Après la chute des feuilles, il se forme du humus qui s'enrichit par les microéléments. Dans d'autres conditions c'est un phénomène inverse qui se produit — un appauvrissement du sol en microéléments.

Enfin, on connaît diverses maladies des plantes, qui envahissent de grandes étendues, qui sont produites par l'insuffisance de certains microéléments dans le sol (fer, manganèse, cuivre, bore etc.) et on connaît même une impossibilité complète de la culture d'une série entière de plantes dans des sols déterminés, due aux mêmes causes.

D'autre part il existe dans divers pays des zones des maladies endémiques des animaux et de l'homme, se rattachant à l'insuffisance de certains microéléments spécifiques dans le tapis végétal, par exemple le manque du calcium et du phosphore provoque la fragilité des os chez les animaux, celui du fer—l'anémie chez les animaux domestiques; un manque de l'iode cause la formation de goitres, le manque d'autres halloïdes (parfois la surabondance par exemple du fluore) provoque des maladies spéciales; enfin le manque de métaux lourds, comme le cuivre etc., comme on commence à l'élucider à présent, amène l'apparition de souffrances analogues.

L'étude naissante du sol, des solutions des sols, des plantes et des animaux, sur une base géochimique promet de mettre au jour et de donner l'explication de la dynamique fondamentale de ce système si complexe.

En résumant nous tenons nécessaire de faire:

- 1) une étude systématique de la distribution des microéléments dans les sols dans la direction horizontale, de tracer pour ainsi dire une série d'isolignes,
- 2) une étude analogue différenciée de la distribution des microéléments dans les profils verticaux des sols,
- 3) une étude spéciale dans les mêmes directions du contenu des microéléments dans les solutions des sols,
- 4) une étude de la composition chimique élémentaire des diverses espèces de plantes croissant sur ces sols,
- 5) une étude analogue des organismes animaux, se rattachant à des biocénoses végétaux déterminés.

CRITICAL ZONES OF ABSORBED IONS AND THEIR AVAILABILITY FOR PLANT LIFE

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There are two basic points of view regarding those mineral salts in the soil which provide nutrition for plants. According to one the plant receives the nutritive substances from the soil solution, i. e., from the liquid phase of soil. According to the other, as expressed for instance by Truog (10) and also by Parker and Tidmore (7), the plant is able to absorb nourishment from the solid as well as from the liquid phase. This second theory of plant nutrition has not been confirmed experimentally and it is hardly possible to do so; in the process of plant nutrition one cannot form a clear conception either of a dry capillary rootlet of a plant or of a dry soil colloid. In an active state both have water films of some degree of thickness. Therefore the question is, at what thickness of these water films on the capillary rootlets and soil colloid is the transfer of the soil colloid into the capillary rootlet possible, in the process of ion exchange? It is obvious that there are great difficulties in the way of experimental verification of any theoretical solution of such a problem.

We shall assume the soil solution to be the basic source of the mineral nutrition of plants from the soil, or, more precisely, the dissolved salts. But this source cannot be examined isolated from the solid phase of the soil. The plants would exhaust the content of the soil solution with comparative rapidity if a process of replenishment, of regeneration were not continually taking place in this solution. This replenishment takes place in two ways:

- 1) either from the absorptive complex of the soil, by ion-exchange,
- 2) or as the result of the mineralization of raw materials, both by chemical and by biological processes.

The subject of this paper is a brief examination of the part played by the absorptive complex in the regeneration of the soil solution as it is exhausted by plants, especially in relation to the ashy substances. We shall exclude nitrogen from our examination since its basic forms, the nitrates, are firstly, absorbed by the soil only to a very slight degree, and, secondly, have a special biological character in their accumulation and metamorphosis in the soil.

The fundamental thesis which we propose to discuss in this paper is, briefly, this, that under certain conditions the regeneration of the soil solution proceeds better by means of ion exchange, i. e., the absorptive complex, than by means of the mineralization of the raw substance, of complicated compounds which contain nutritive elements. In other words, we regard the absorptive complex as a basic regulator of plant nutrition from the soil. That is to say, those salts which enter the soil solution as the result of mineralization, both chemical and biological, cannot escape the regulatory action of the absorptive complex, i. e., when they have accumulated in excess in the soil solution, they will disturb the equilibrium and shift it towards a higher saturation of the absorptive complex with these ions. The plant, on the other hand, will shift the balance in the other direction, that is, it will lower the degree to which the absorptive complex is saturated by nutritious elements.

The tremendous development of the fertilizer industry in our country and the consequent rapid increase in the use of fertilizers, makes it essential for us to work out a theory which will enable us to use these enormous quantities of mineral fertilizers in the best way. With this aim in mind, we propose to examine in some detail under what conditions the absorptive complex of the soil can most successfully perform its function as a regulator of the soil solution.

We shall not describe here all the experimental work which has gone to prove that the absorbed nutritional ions are an excellent source of plant nutrition. We shall merely cite a few of the authorities on this subject — Chirikov (11), Smirnov (9), Bobko (1), Nostitz (6), Joffe and McLean (5), Gehring and Wehrmann (2), Jenny and Cowan (4), and others. The problem has been studied in special detail in the work of Gehring (3) and Vageler (12), which has thrown much light on this subject.

All the investigators mentioned above have directed their attention to the availability of exchange cations. There has been very much less investigation into the question of the availability of absorbed anions, and we shall, therefore, be obliged to refer as briefly as possible to the work of our own laboratory on soil colloids.

However, although works on the availability for the plant of absorbed ions already exist, few among them bear on the availability of the absorbed ion in relation to the degree of saturation of the whole absorptive complex of the given soil by the given ion. It is just this point which will be emphasized in this paper as being the central one for the scientific establishment of norms and in the technique of applying mineral fertilizers.

Among the few studies of the availability for the plant of the absorbed ion in relation to the degree of saturation of the absorptive complex of the soil with that ion, we must make special mention of the work of Gehring and Wehrmann (2). They studied soil requirements for potassium in relation to the degree of saturation of the absorptive complex with this ion. We have no space here to quote their data, but we regard their results as a convincing solution of the problem which we are discussing. Quite recently Jenny and Cowan have published their work on

the availability for the plant of the absorbed calcium in relation to the degree of saturation of the absorptive complex by that cation. Results of experiments have also given a positive answer to the question — it appears that it is only at a certain degree of saturation that the absorbed calcium becomes completely available to the plant. We must also note the elegant experiments on the availability of exchange cations for the plant described in the works of Nostitz (6). He did not undertake to solve the precise problem which interests us; that is, he did not connect the availability of the exchange cations with saturation. But when he attempted to substitute a finer fraction (less than 0.1 mm.) for the coarser fraction (1—2 mm.) of permutite, then the availability of the absorbed cations decreased sharply, to judge from the decreased yield. Nostitz attributed this result to the fact that it was difficult for the roots to utilize the greatly increased surface of the permutite from which the plant had to take up the absorbed cations. For conditions of pot-culture experiments this explanation does not seem to us entirely satisfactory, and we are inclined to believe that in this case also there was a different degree of saturation of the adsorbent (permutite) with the cation.

We must now pass on to a brief summing-up of our results with regard to the availability of the absorbed phosphoric acid to the plant derived from experiments made by Shtatnov and Odintzova under the author's supervision. In this experiment we used iron gel as an adsorbent. Samples were saturated with the phosphate anion from varying concentrates of NaH_2PO_4 in order to obtain different degrees of saturation of the gel with the same anion. After saturation of the gel of iron from solutions of NaH_2PO_4 of various degrees of concentration, the free electrolyte was removed from the gel by means of dialysis.

In the table which follows, figures are given showing how much P_2O_5 remained in each gel, after the gel was dialyzed from the released NaH_2PO_4 .

Molarity of solution NaH_2PO_4 from which gel has adsorbed PO_4	pH of the solutions		Adsorbed P_2O_5 in mg. per 1 gr. of gel of iron
	Before saturation of gel	After saturation of gel	
0.25	4.5	5.1	16.72
0.10	4.8	5.9	21.21
0.001	5.5	7.0	3.23

As the table shows, we were able to obtain a gel of iron at different degrees of saturation with the phosphate-anion. We must call attention to the fact that, by changing the degree of saturation with respect to the phosphate-anion, we also changed its electro-kinetic properties, as has been shown by the corresponding definitions; that is, at the lowest degree of saturation, we found a positive charge in the gel, while with a medium degree of saturation it became isoelectric, and at the highest degree of saturation it was overcharged — that is, it became negative.

We used samples of iron gel prepared as above described, not containing any free NaH_2PO_4 , and having various degrees of saturation with the phosphate anion as a source of phosphoric acid nutrition in pot-culture experiments with oats. The experiment, as prepared and carried through, was of the type of the isolated nutrition of plants. In one case the free salt of NaH_2PO_4 was given in an isolated form, together with the absorbed phosphate-anion. The absolute amount of P_2O_5 given was the same in all cases — that is, in amounts of 10, 30, 50, 80 and 160 mg. The results are given in the subjoined table:

Doses of P_2O_5 in mg. per vessel.	Free NaH_2PO_4	P_2O_5 bound by the gel of iron in mg. of P_2O_5 per 1 gr. of gel		
		3.238	16.726	21.212
Yield of dried mass in grams per vessel				
10	4.27	2.56	3.0	2.50
30	4.79	2.06	4.44	5.09
50	9.80	2.58	4.79	7.34
80	15.08	4.38	9.37	10.00
160	21.30	—	12.90	—

As this table shows, the availability of the absorbed phosphate-ion is measured, not by its absolute amount in the vessel, but by the degree of saturation of the adsorbent in relation to the anion. We shall, therefore, permit ourselves to introduce a new concept — the critical degree of saturation of the absorbing complex for absorbed nutritive ions. By "critical degree of saturation" we shall understand that level, or better, that zone, below which the absorbed ions pass into the soil solution only in a negligible amount. In other words, nutrition of the plant by the given ion will not be assured and produce a high yield when the given ion is in an absorbed state below a definite degree of saturation which we, accordingly, call the critical degree. Naturally this boundary is indefinite, there is no sharp line of transition. Therefore it is preferable to speak of it as the critical "zone" of saturation¹. In order to illustrate this concept, we refer the reader of the Fig. 1.

In Fig. 1 the degree of saturation with the ion of, let us say, K, is high. Therefore when the plant has taken part of the given ion from the soil solution, the adsorbing complex which has a high degree of saturation, as represented in Fig. 1, will rapidly re-establish a balance — that is, it will replenish the content of the given ion in the soil solution to the degree of concentration necessary to secure a high yield from the plant. In the case of a low degree of saturation, as represented in Fig. 2 when the amount of absorbed ion is lower than the critical zone —

¹ We consider necessary, to emphasize that for various soils the critical levels are different. Thus, according to results of field experiment (Magistad, Soil Science 1934 v. 37 № 2 pp. 99—103), it may be assumed, that in Hawaiian soils the critical level for absorbed sodium is comparatively low, as with a saturation of sodium 0.4—0.5 m, e. those soils are already no more in need of sodium fertilizers (pineapple plant).

that is, in relation to the total capacity of absorption — then the percent of absorbed ion is much lower than in the first case and, the content of the given ion in the soil solution will also be lower. And as the soil solution continues to be depleted by the plant with respect to the given ion, its concentration will constantly diminish more and more as the absorbing complex with a low degree of saturation will not be able to replenish the soil solution as regards this ion. There may even be set up a competition for the given ion between the plant and the absorbing complex. In other words, under certain conditions, the nutritive iron, appearing in the solution either from the fertilizers introduced or as the result of mineralization of the soil itself, will be greedily adsorbed, not only by the root capillaries of the plant, but also by the slightly-

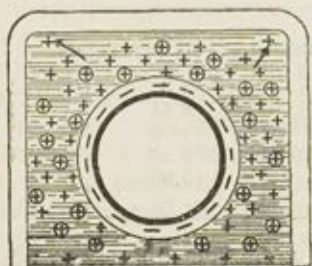


Fig. 1.

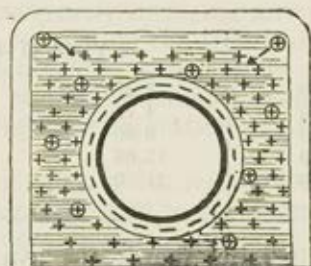


Fig. 2.

saturated absorbing complex. It is this condition that we have attempted to indicate in Fig. 2 by pointing the arrows toward the absorbing complex. It is obvious that our exposition is merely schematic. We must in this case keep in mind the sequence of events, which is now solidly established and described in the works of Gedroiz, Wiegner, Vageler, Mattson, Gehring, Yarussov and others.

Without denying the many theories proposed regarding the absorbing complex, it seems to us timely and expedient to introduce this new concept — that of the “critical zone of saturation” — and to generalize it to apply to all the nutritive ions, cations as well as anions. In other words we apply this concept to all the adsorbing ions. Only NO_2 , NO_3 and Cl are exceptions. These, as is well known, are absorbed by ordinary soils under ordinary conditions only to a very slight degree.

In suggesting the idea of the existence of critical zones of saturation of the absorbing complex by the nutritive ions in connection with their availability for the plant, and while emphasizing the importance of this concept in determining the need of the plant for fertilizer, we nevertheless fully realize the fact that this hypothesis needs further experimental checking. If it could be confirmed on a large scale, then this hypothesis would facilitate the explanation of many phenomena which are now somewhat obscure. Let us give several instances. In Germany many harvests were greatly diminished during the World War because certain fertilizers, especially phosphates, were no more applied. If the high degree of fertility of the German soils had depended on the absolute supplies of nutritive substances in the soils or on the “alte Kraft

des Bodens" (8) as it has been called, then the decrease in the harvests would not have been so catastrophic. But if we assume that the high fertility of German soils is the result of the comparatively high zone of absorbed ions (that is, higher than the critical zone), especially for the absorbed phosphate-anion, then it is quite comprehensible that the harvest should diminish very greatly when these phosphates were no longer applied to the soil. In the light of our hypothesis, it means that the level, or, to use a better term, the zone of saturation of the soil colloids by the phosphate-anions, has decreased, has fallen nearer to the critical level, and that therefore the regeneration of the soil solution by phosphoric acid from the most mobile source — the absorptive complex — has become more difficult. It is true that under these circumstances another factor in the regeneration of the soil solution might have entered into the situation. We have in mind the mineralization of the raw mineral organic and organo-mineral substances of the soil. But it would appear that such a rapid and effective regeneration of the soil solution cannot be obtained from this source as from the absorptive complex, accompanied by a high degree of saturation — higher than the critical zone (which is different for each soil). Of course the quality of the raw material must be taken into consideration. If manure is introduced into the soil, we cannot regard it as completely humous matter of the soil. It is more easily mineralized and therefore more suitable for the regeneration of the soil solution.

But it is obvious that such indirect considerations as the poor harvests in Germany during the War are insufficient to prove our hypothesis. As we have said already, special experiments are required for this, made under the most varied soil conditions and with different cultures.

And finally we emphasize this again to avoid misunderstanding that, the critical level itself is dependent on many conditions, such as, primarily, the precise chemical nature of the absorptive complex of the soil being examined, and the durability of its absorbed ions according to Yarussov; or as the "q-Wert" of Vageler (12). In this case the pH of the medium or soil solution preserves its whole significance, as do also the physiological peculiarities of the culture, the water regime of the soil in relation to the amount of rain or method of irrigation, etc. In other words this new factor which we have suggested must be studied as an inseparable part of the sum total of conditions which govern the efficient fertility of the soil.

It is impossible in the space allotted to us to develop this concept in greater detail, but we desire to call attention to the two following circumstances. In the first place an immediate working out of simpler methods for the determination of the critical zone of absorbed ions is needed. Though in the beginning it may be necessary to work directly with plants, yet later microbiological or purely chemical methods should be worked out which must be inexpensive and simple enough for general use. In the second place, the peculiar conditions of the critical zones of saturation of the absorbing complex in USSR soils must be borne in mind. Many investigators of the soils of Western Europe have stated that they have found exchange potassium present, though in small

amounts, but K. Gedroiz¹ declared in 1916 that in a very large number of Russian soils exchange potassium is completely absent. Now that the fertilizer industry of our country is growing so fast we shall soon be able, especially for those soils on which valuable cultures are grown, to achieve a high degree of saturation with respect to nutritive elements in a shorter time that was the case in other countries which now have high yields.

This means that we must so adjust fertilizer norms as to obtain the maximum effect with the least possible expense. It may very well be that in the beginning it will require high norms of fertilizers to obtain the desired increase of fertility, but later, when the degree of saturation has been raised above the critical zone, we may be able to revise these norms downwards. Starting from our hypothesis we should also take into account one possibility of a more advantageous use of fertilizers on soils with a low degree adsorbed of nutritious substances. We have in mind the technique of introduction. The usual method of mixing rather low norms of fertilizer with the entire arable layer, unavoidably lowers the degree of saturation of each nutritive element; that is, the colloid surfaces per hectare of the arable layer, for example at a depth of 20 cm. per hectare are very large. It is not surprising that on some soils (heavy because of their mineral composition) the usual norms have no effect, especially when these soils are fertilized for the first time. The degree of saturation of such soils still remains below the critical zone. This means that in such cases the absorptive complex does not give nutritive elements to the soil solution but takes them from it into its own surface. In other words with a low degree of saturation the absorbing complex is a rival of the plant in absorbing nutritive substances from the soil solution. In order to avoid such powerful competition with the plant by soil colloids not saturated with nutritive elements, it is important not to mix the fertilizers with the entire arable layer — that is, the contact surfaces of the fertilizer with the soil colloids should be as small as possible. This can be accomplished by placing the fertilizer at a depth of 15 or 20 cm. and then mixing them with only 2 or 3 cm. Obviously if, instead of mixing the fertilizer for an area of one hectare with a layer 20 cm. deep as is usually done, we mix the same amount with a layer only 3 to 5 cm. deep, we shall have a degree of saturation 5 or 6 times as great. The deduction from these considerations is that by introducing the fertilizer locally (in rows), or at a certain depth, without mixing it with the entire arable layer, we may considerably increase the coefficient of the utilisability of fertilizers. This has been directly confirmed by experiment. Over a period of three years we made field experiments (near Perm) with the deep introduction of fertilizers, and as a result obtained a yield that was double and even more than double that obtained by the usual method of mixing fertilizers with the entire arable layer. The amount of such data is now greatly increased and we have reached the point where we can make not only theoretical but, what is more important, practical deductions.

¹ K. K. Gedroiz. *Journal of Agronomy*, Vol. 17. p. 486, 1916.

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In conclusion it should be said that a deeper theoretical basis for the phenomenon of critical zones of saturation is needed from a physico-chemical standpoint. Incidentally it is desirable to clarify in greater detail the reasons why the ion exchange in colloids occurs more easily in the upper, terminal section of the curve of the isotherm of adsorption than it does in the lower, initial one. We can answer this question in a very general way as follows: if we start from the modern theory of the formation of polymolecular layers on the surface of the colloid particles¹, we may suppose that the first layers, lying nearest to the inner wall or coating of the colloid (its granule) are distinguished by the greater stability of the bond. This also confirms Stern's theory of a double electric layer. The following layers, lying farther below the surface of the particle, are less firmly attached. The anti-ions (Gegenionen) of these last layers naturally exchange more easily with other ions. But those ions which abound in the surrounding solution take the places of the diffused ions. It therefore follows that the energy of adsorption of the different ions and their mobility must also be taken into consideration. For this reason, potassium, because of its high energy of adsorption (as Vageler emphatically points out) becomes a deep-lying anti-ion. The same explanation applies also to the phosphate-anion, especially the three-valent one. However, we are, naturally, not wholly satisfied with such an explanation and repeat once more that there should be further, exact investigation.

Summary

1. The author regards the absorptive complex of the soil and its colloids as the chief regulators of the soil solution as regards nutritive substances of plants.

2. However, the absorptive complex supplies the soil solution with nutritive elements when the degree of its saturation with these elements is above a specific limit, i. e., the critical zone of saturation for any given soil.

3. But if the degree of saturation of the absorptive complex of any given soil is below the critical zone, then the absorptive complex will not only supply the soil solution with nutritive ions, but will also remove them from the solution; that is, it will become a rival to the plant as regards the nutritive elements.

4. Based on the hypothesis we have suggested, practical methods have been described to increase the coefficient of utilisability of fertilizers (by placing in a layer below the surface, or in rows, without mixing it with the whole arable layer).

LITERATURE CITED

- 1) Bobko E. V. The assimilation of soil sodium and some silicates by barley in sand cultures. From results of pot-culture experiments and laboratory tests made in D. N. Prjanishnikov's laboratory. Vol. XIII, pp. 128—139, 1923.

¹ These views are derived from the work of Korzin. See Transactions of Faraday Soc. 164 vol. Part 1. January 1935.

- (2) Gehring und Wehrmann. Weitere Untersuchungen über Bedeutung des Kalisättigungsgrads des Bodens. Zeitschr. f. Pflanz., Düng. Bodenkunde. T. A. Bd. XIII, H 1/2, S. 18—28, 1929.
- (3) Gehring, A. Die Bodenabsorption und der Basenaustausch in ihrer Bedeutung für Fruchtbarkeit des Bodens. Handbuch der Bodenlehre. Bd. 8, S. 183—317, 1931.
- (4) Jenny und Cowan. Ueber die Bedeutung der im Boden adsorbierten Kationen für Pflanzenwachstum. Zeitsch. f. Pflanz., Dügn. u. Bodenkunde. T. A., Bd. 31, H 1/3, S. 57—67, 1933.
- (5) Joffe and McLean. Availability of replaceable cations. Proceed. and Papers of the First Internat. Cong. of Soil Science. Commis. II, pp. 256—263, 1927.
- (6) Nostitz, A. Zur Bedeutung der basisch austauschbaren Bodennährstoffe für die Pflanzen und über Einwirkung des Kalkes auf die absorbierenden Bodenkörper. Landw. Vers. Stat., Bd. 103, s. 159—177, 1925.
- (7) Parker and Tidmore. The influence of lime and phosphatic fertilizers on the phosphorus content of the soil solution and soil extracts. Soil Science, v. 21, 6, pp. 439—40, 1926.
- (8) Puchner H. Bodenkunde für Landwirte. S. 448, 1923.
- (9) Smirnov A. I. — Sodium zeolite in sand and water cultures. From results of pot-culture experiments and laboratory tests made in D. N. Prjanschnikow's laboratory. Vol. X, pp. 115—30, 1916.
- (10) Troug.
- (11) Chirikov F. B. Assimilability of K_2O zeolite by plants. Based on pot-cultures and laboratory studies in D. N. Prjanschnikow's laboratory. Vol. VIII, pp. 300—308, 1913.
- (12) Vageler P. Der Kationen- und Wasserhaushalt des Mineralbodens, 1932.

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NOUVELLES RECHERCHES SUR LES PROPRIÉTÉS PHYSICO-CHIMIQUES DES SOLS EN URSS

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Toute une série de vastes entreprises dans notre œuvre de construction socialiste, entreprises agrochimiques, agrotechniques, d'amélioration et autres, telles que: le problème de l'irrigation du Transvolga, la chimisation de nombreux millions de ha des champs des sovkhoz et des kolkhoz, une extension de l'agriculture dans le nord, la vaste mécanisation introduite dans la culture de la terre, l'énorme développement des voies de communication, ont mis en évidence pendant ces dernières années la nécessité d'une étude des problèmes principaux théoriques de la science du sol, se rattachant aux entreprises qu'on vient d'énumérer. Résoudre ces problèmes d'une manière satisfaisante n'est devenu possible que grâce à l'acquisition de connaissances et en même temps au développement des principes théoriques les plus nouveaux, ainsi que des méthodes et de la technique des investigations qui ont atteint aujourd'hui des progrès si brillants dans les sciences fondamentales (la physique et la chimie). La science du sol dans l'URSS s'est enrichie pendant le premier quinquennat de travaux nouveaux en étendant et en approfondissant ceux des laboratoires spéciaux physico-chimiques et colloïdo-chimiques. Les institutions suivantes ont joué le rôle de centres principaux des travaux pédologiques physico-chimiques: 1) le laboratoire physico-chimique de l'Institut des Engrais, de l'agrotechnique et de l'agropédologie de l'URSS (VIUAA) à Moscou (sous la direction de A. F. Tiuline, physico-chimiste E. N. Gapon); 2) le laboratoire physico-chimique et colloïdo-chimique de la succursale de cet Institut à Léninegrad (physico-chimistes: B. P. Nikolsky et B. M. Gortikov et colloïdo-chimistes: A. I. Rabinerson et I. N. Antipov-Karataev); 3) la section physico-chimique de l'Institut du Sol de l'Académie des Sciences, d'abord à Léninegrad et actuellement à Moscou (direction — I. N. Antipov-Karataev); 4) l'Institut de la chimie colloïdale à Voronège (sous la direction de A. V. Doumansky). Cela va de soi que les questions relatives aux investigations physico-chimiques des sols ont été aussi étudiées dans d'autres laboratoires de l'Union (Ukraine — A. N. Sokolovsky, Moscou — S. S. Jaroussov, N. P. Rémésov, Léninegrad — A. A. Rodé, E. N. Ivanova etc.).

1. Composition qualitative des colloïdes dans les sols principaux de l'URSS

Le problème principal de la pédologie en général, et de la physico-chimie en particulier est d'élucider les principes fondamentaux des phénomènes de la formation du sol, afin de pouvoir les diriger conformément aux besoins de la production. Un des meilleurs moyens pour cela est l'étude de la composition minéralogique et chimique des fractions colloïdales du sol. A. A. Rodé¹ a présenté une investigation détaillée de la composition chimique des fractions colloïdales des sols podzoliques et marécageux de la région de Léninegrad. L'élimination des diverses fractions a été effectuée par la méthode de sédimentation² après une saturation des échantillons des sols par le sodium. Dans le processus de formation du podzol Rodé voit deux stades. Au premier stade c'est surtout une décomposition des minéraux primaires qui se produit, les produits de la décomposition formant des minéraux synthétiques secondaires, riches en sesquioxydes, en magnésium et en potassium. Au second stade il se produit une décomposition des minéraux secondaires et des minéraux primaires qui se sont encore conservés. Le quartz est un minéral de reliquat primaire. Cependant plus tard les investigations radioscopiques ont montré, que le quartz peut aussi être un minéral secondaire comme résultat de la cristallisation du silicagène. Dans un profil du sol podzolique les deux stades que nous venons de décrire sont disposés de la manière suivante: le premier stade est concentré dans l'horizon B, le second — dans l'horizon A.

L'auteur du présent article a fait avec ses collaborateurs une étude chimique et radioscopique des fractions colloïdales de différents sols de l'URSS³. Ces fractions ont été séparées selon deux méthodes: 1) la méthode de sédimentation et 2) la cataphorèse d'après le principe de Reifenberg⁴. Comme illustration nous donnons ici une table des résultats obtenus.

On voit d'après la table 1 que la composition des colloïdes, isolés par la méthode de la cataphorèse, diffère de celle de la fraction des particules $<0,25 \mu$, éliminées au moyen de la sédimentation, par une teneur un peu plus élevée en sesquioxydes. Les données de l'analyse radioscopique prouvent que 1) c'est le groupe des montmorillonites qui représente les minéraux prédominants dans la partie cristalline des colloïdes dans la majorité des sols étudiés; 2) moins répandus sont les minéraux du groupe des caolinites, auxquels appartient la seconde place après les montmorillonites. On n'a trouvé la caolinite que dans l'horizon illuvial du sol podzolique septentrional; dans d'autres cas elle est remplacée par des minéraux tels que la nacrite et la diccrite; 3) il est

¹ A. A. Rodé. Travaux de l'Institut du sol de l'Académie des sciences de l'URSS, III, 3, 1931.

² Récemment on a commencé dans nos laboratoires à se servir dans ce but de la centrifuge de Mochev (voyez Travaux du II congrès international de la science du sol, v. I, 66, 1930).

³ Voyez la communication préliminaire dans «Potchvovédénie» № 3, 1934, et «Priroda» № 8, 1934.

⁴ Reifenberg, A. Zeitschr. f. Pflanzen., Düng. und Bodenkunde, 21, 3/4, 1931.

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caractéristique dans la fraction colloïdale de presque tous les sols qu'il y a une grande part qui appartient aux minéraux du mica (mousoïte, biotite) qui peut-être sont aussi d'origine secondaire; 4) l'orthoclase colloïdal dispersé est probablement d'origine primaire: pour ce qu'il est du quartz, son origine peut être secondaire, comme résultat d'une cristallisation du silicagène, mais il n'y a pas de raisons suffisantes pour nier une dispersion du quartz primaire, libéré au cours de la composition des roches; 5) ces données indiquent que l'alumine et le silice forment très facilement des combinaisons secondaires, qui passent en formes cristallines. Ce n'est que le hydrate de l'oxyde ferrique qui reste libre et qui se cristallise sous forme de limonite, ce qui se comprend à cause de la facilité de l'hydrolyse du ferro-ion déjà avec des valeurs faibles du pH; 6) le contenu haussé des sesquioxides dans la composition de la fraction colloïdale du sol (ce qu'on ne peut pas expliquer par la composition des combinaisons cristallines) nous fait supposer, que c'est la partie amorphe de la fraction colloïdale, qui représente le porteur de la qualité augmentée des sesquioxides, principalement de l'aluminium, sous forme de combinaisons labiles. Dans les conditions des subtropiques de l'URSS surtout, une partie assez considérable des colloïdes du sol doit se présenter sous un aspect amorphe; 7) il est difficile de classer et de distinguer les sols podzoliques non seulement dans les limites d'une zone unique, mais encore dans celles de différentes régions (région de Léninegrad et de la côte de la mer Noire au Caucase — Sotchi), d'après la composition qualitative de la partie cristalline de leurs colloïdes. Il n'y a pas de différence frappante même entre les krasnosiomes. Ce fait prouve à notre avis, que les combinaisons cristallines des colloïdes du sol, découvertes par nos recherches, sont les plus stables; elles sont, si vous le voulez, le stade final dans leur genre de la transformation des matières colloïdales des sols dans les vastes conditions thermodynamiques données; 8) les investigations les plus intéressantes (peut-être en appliquant la méthode radioscopique combinée avec la méthode électrographique) seraient celles des processus de transformation des fractions colloïdes amorphes de différents types de sols en colloïdes cristallins. Cette voie, nous paraît ouvrir de vastes perspectives; 9) les investigations de Hoffmann et de ses collaborateurs¹ ont montré que le montmorillonite possède un réseau mobile, et que, selon le degré de la tension de la vapeur et de la température dans son réseau cristallin il absorbe l'eau, l'alcool, l'acétone, l'anhydride acétique, et grâce à cela la distance s'écarte entre les plans du réseau (de 10 à 20 Å). Il faut envisager ce fait comme très important et on doit le prendre en considération quand il s'agit de juger de la nature des réactions d'adsorption métaboliques dans les sols, ayant en vue que le groupe montmorillonite des minéraux représente la masse prédominante de la partie cristalline des sols, tels que les sols jaunes podzoliques de Sotchi, les krasnosiomes de Tchakva, aussi bien que des horizons illuviaux des sols podzoliques septentrionaux.

¹ Hoffmann, Endell et Wilm. Röntgenoskopische und kolloidchemische Untersuchungen über Ton. Angewandte Chemie, 57 Jahrg, 30., 1934; Ztsch. Kristallogr. Mineral. 86, 340, 1933.

Table 1

Données des investigations chimiques et radioscopiques des sols principaux de l'URSS.

(Analyses de I. N. Antipov-Karataev, A. A. Rodé, V. I. Kozine et investigations radioscopiques de B. K. Brounovsky)

Profondeur en cm	Fractions en mm	Eau hygro- scopique en %	Perte feu en %	SiO ₂ en %	Al ₂ O ₃ + Fe ₂ O ₃ en %	Fe ₂ O ₃ en %	CaO en %	MgO en %	MnO en %	Total	SiO ₂ R ₂ O ₃	Résultats des investigations radioscopiques (les minéraux sont rangés d'après la quan- tité décroissante)
Sol podzolique № 26 (région de Léninegrad) sur les argiles à bandes												
5—10	Sol initial 1 mm—2,5 μ 2,5 μ—0,25 μ < 0,25 μ Cataphoré- sate	— — — — 5,47	— — — — 64,44	70,61 76,12 63,80 57,68 50,47	20,85 16,40 25,80 32,73 30,44	3,77 3,00 4,84 5,34 11,35	0,49 0,70 0,22 — 3,39	0,96 0,36 1,98 1,72 0,96	— — — — —	96,68 96,58 96,64 97,47 96,61	— — — 2,69 1,96	limonite, quartz
30—35	Sol initial 1 mm—2,5 μ 2,5 μ—0,25 μ < 0,25 μ Cataphoré- sate	— — — — —	— — — — —	72,98 82,59 64,49 51,72 55,85	16,82 10,48 22,39 30,97 32,35	4,08 1,58 5,32 11,12 9,98	0,65 0,89 0,53 — 0,99	1,09 0,12 2,36 2,54 0,30	— — — — —	95,62 95,66 95,09 96,35 93,47	— — — 2,31 2,44	montmorillonite, quartz, caoli- nites, mouscottes, diacites, montmorillonites
60—65	Sol initial 1 mm—2,5 μ 2,5 μ—0,25 μ < 0,25 μ Cataphoré- sate	— — — — —	— — — — —	68,54 81,62 58,96 46,75 40,02	15,93 10,76 20,77 23,35 30,93	8,40 0,97 11,54 23,47 24,43	0,79 1,15 0,70 — 1,47	1,50 0,45 2,80 2,63 1,12	— — — — —	95,16 94,95 94,77 95,20 97,97	— — — 2,31 1,46	limonites, mouscottes, mont- morillonites, diacites, quartz, orthoclase, biotite
100—105	Sol initial 1 mm—2,5 μ 2,5 μ—0,25 μ < 0,25 μ	— — — —	— — — —	66,07 76,58 61,83	18,78 13,58 21,00	7,09 3,00 7,67	1,03 1,53 1,02	2,03 0,72 2,98	— — —	95,00 95,41 94,50	— — —	montmorillonite, diacite, limo- nite, mouscotte, quartz

100—105	Sol initial 1 mm—2,5 μ 2,5—0,25 μ < 0,25 μ	— — — —	— — — —	66,07 76,58 61,83 50,73	18,78 13,58 21,00 26,19	7,09 3,00 7,67 14,99	1,03 1,53 1,02 —	2,03 0,72 2,98 3,15	— — — —	95,00 95,41 94,50 95,06	— — — —	montmorillonite, diccrite, limonite, mouscoïte, quartz	
Sol jaune podzolique № 1 sur les terrasses marine anciennes													
1—6	Sol initial < 1 μ Cataphoré- sate	— 6,43 7,03	— 19,28 49,57	76,20 63,05 57,45	9,97 13,10 24,13	— 14,16 9,02	5,94 4,64 3,25	0,67 3,98 4,90	0,25 pas déterm. "	— 98,93 98,75	— 9,29 3,21	— — —	montmorillonite, mouscoïte
28—40	Sol initial < 1 μ Cataphoré- sate	— 5,01 7,48	— 10,79 17,13	76,97 55,11 50,50	6,83 27,10 31,67	7,27 12,01 12,73	3,01 1,26 0,98	0,69 1,61 3,82	0,06 pas déterm. "	— 97,09 99,70	— 2,66 2,31	— — —	montmorillonite, limonite, mouscoïte, quartz
Krasnoslones № 21 (Tchakva) sur l'éluvion des roches éruptives													
1—6	Sol initial < 1 μ Cataphoré- sate	— 4,79 5,70	— 21,96 46,25	57,96 44,12 40,43	24,71 23,09 19,75	13,09 28,41 34,65	0,28 2,11 2,91	1,33 1,45 1,04	0,76 pas déterm. "	98,13 99,18 98,78	— 1,79 1,61	— — —	Montmorillonite, diccrite, mouscoïte, limonite, quartz
60—65	Sol initial < 1 μ Cataphoré- sate	— 5,23 4,02	— 11,34 14,32	41,41 41,00 40,70	34,98 25,52 21,52	20,69 30,88 31,99	0,06 1,48 0,96	1,17 0,73 2,13	0,61 pas déterm. "	98,92 99,61 97,30	— 1,52 1,61	— — —	montmorillonite, diccrite, mouscoïte, limonite, montmorillonite, limonite, diccrite, mouscoïte
100—115	Sol initial < 1 μ Cataphoré- sate	— 4,88 2,75	— 12,86 22,62	39,23 37,57 38,19	35,58 22,29 16,47	22,89 33,21 35,47	0,63 3,07 3,39	1,25 0,79 4,11	0,59 pas déterm. "	— 96,93 97,63	— 1,45 1,61	— — —	montmorillonite, diccrite limonite, mouscoïte, montmorillonite, limonite, diccrite, mouscoïte

Notre laboratoire s'est ensuite occupé aussi de recherches sur la structure de l'acide humique retiré de diverses tourbes et des tchernosiomes de l'URSS en employant différentes méthodes (méthode des sels neutres, des alcalis).

Les résultats de ce travail forment le sujet d'un article séparé de I. D. Sedletzky et B. K. Brounovsky¹, et c'est pourquoi nous n'en citons que très brièvement les conclusions. Les spectrogrammes des acides humiques ont exposé les anneaux de Debye caractéristiques pour les combinaisons organiques très polymères (les maximums sont rapprochés au faisceau initial, l'interférence périphérique manque); trois anneaux se font voir; un anneau très intense, un autre—intense et le troisième—d'intensité moyenne. L'analyse comparative des lignines, isolées d'après la méthode de Willstätter, König-Rump, et aussi l'analyse des données littéraires sur les recherches radioscopiques des charbons bruns, de l'anhracite et du graphite ont établi un lien génétique étroit dans la série: lignines—acides humiques—charbon brun—anhracite—graphite. Ainsi on peut à ce qu'il paraît, compter que la théorie sur l'origine des charbons humiques de Fr. Fischer et de Schrader est juste. Le spectrogramme de la cellulose s'est montré très différent de celui de l'acide humique. Ces deux dernières années A. F. Tiuline² a proposé pour la détermination de la quantité et de la qualité de différentes espèces de coagulums la méthode d'une peptisation fractionnée. Cette méthode est basée sur les considérations théoriques suivantes: les divers gels exigent des peptisateurs différents pour passer à l'état de zols—«si les gels électronégatifs se peptisent bien après leur saturation par l'ion de sodium, d'une solution neutre de chlorure de sodium, les gels électroneutres et électropositifs ne peuvent pas être peptisés de cette façon».

D'après l'opinion de A. F. Tiuline l'existence du premier groupe de coagels est due à la coagulation électrolytique, celle du deuxième à la coagulation réciproque des colloïdes. Le laboratoire de A. F. Tiuline isole le premier groupe des coagels par la méthode ordinaire en saturant le sol par du sodium et par une sédimentation ultérieure; le deuxième groupe, celui des coagels électroneutres est isolé après l'élimination du premier du milieu alcalin (0,004-n-NaOH), car il s'établit dans le dernier d'après l'avis de l'auteur de la méthode, une charge négative suffisante de ces coagels. C'est à l'hydrolyse des gels organiques du sol grossièrement dispersés que Tiuline attribue la capacité du sol d'adsorber les cations (jusqu'à 25% de la capacité d'absorption initiale), capacité qui reste après l'élimination des colloïdes des deux groupes. Sont intéressantes ici, les données des analyses sur les coagels des différents groupes. On comprend que dans les tchernosiomes c'est le premier groupe des coagels qui prédomine (jusqu'à 80% de la quantité totale I+II), dans les sols podsoliques I=II; d'après la corrélation: $\text{SiO}_2 : \text{R}_2\text{O}_3$ la différence n'est pas grande, mais d'après la teneur en phosphore et en azote, le premier groupe se montre comme le plus riche, ce qui fait penser que dans les horizons supérieurs P_2O_5 ,

¹ Voyez p. 91.

² A. F. Tiuline et T. A. Malomakhova. La peptisation fractionnée, comme une méthode nouvelle dans l'étude des colloïdes du sol. Chimisation de l'agriculture socialiste, 12, 1934.

aussi bien que l'azote, se rattachent surtout à la matière organique du sol.

II. Échange des cations et acidité des sols

On sait, que les opinions différentes sur la nature de l'échange des bases des sols ont eu pour conséquence des modes différents de formuler au point de vue quantitatif les lois de ce phénomène (Wiegner, Hans, Ramann, Rotmund et Kornfeld, Carr, Wanselow etc).

Chez nous en l'URSS, il faut signaler les travaux de A. I. Rabinerson¹, qui a fait des recherches expérimentales sur la dépendance de l'échange des cations de la pesée de sol et du volume de la solution, de même que les travaux de S. N. Alechine, qui a appliqué l'équation de Langmuire, et surtout les travaux de E. N. Gapon et B. P. Nikolsky. Prenant pour point de départ la supposition que l'échange des ions dans les sols n'a lieu qu'à la surface des particules colloïdales, Nikolsky² a étudié théoriquement le problème de la nature des phénomènes d'échange des bases. En se servant des méthodes de la thermodynamique et de la mécanique statistique il a montré que dans le cas d'un échange équivalent du point de vue de la chimie comme de l'adsorption on aboutit aux mêmes équations, identiques à celles dont se servent Carr et Wanselow. De cette façon on peut considérer comme prouvé que la question sur la nature chimique ou adsorbante des phénomènes d'échange des bases dans les sols et les permoutites, ne peut être résolue d'après la possibilité ou l'impossibilité d'appliquer aux données expérimentales telle ou telle équation de l'isotherme d'adsorption ou la loi des masses, comme le croyaient par exemple Hans et Wiegner.

Le laboratoire de E. N. Gapon³ se sert largement de l'équation de la loi des masses et interprète les matériaux analytiques d'après ce point de vue. Selon Nikolsky l'équation de l'isotherme de l'adsorption d'échange de Gapon pour les ions polyvalents, correspond à la supposition de leur dissociation en ions univalents lors de leur adsorption.

Les travaux du laboratoire de Nikolsky, avec une méthode d'une précision plus grande, ont montré qu'en général l'échange des cations dans le sol est subordonné (approximativement) à l'équation, déduite théoriquement aussi bien pour le mécanisme d'adsorption que pour le même mécanisme «chimique» de l'échange:

$$\frac{y_1^{n_2}}{y_2^{n_1}} \cdot \frac{a_2^{n_1}}{a_1^{n_2}} = K,$$

où y_1 et y_2 représentent les quantités adsorbées du premier et du second cation et a_1 et a_2 — leur degré d'activité dans la solution et n_1 et n_2 , — leur valence. Il faut encore remarquer, que l'énorme majorité des travaux pour la détermination de l'isotherme d'adsorption opère avec des

¹ A. J. Rabinerson. Travaux de la Section de VIUAA de Léninegrad, fasc. 17, sous la rédaction de I. N. Antipov-Karataev. 1934.

² B. P. Nikolsky. Die Eigenschaften der Doppelschicht und die Austauschadsorption von Ionen an nichtmetallischen Oberflächen. Physikalische Zeitschrift der Sowjetunion. 4, 2, 1933.

B. P. Nikolsky. Verhandlungen der II. Kommission der IBG., B. A., 1, 1934.

³ E. N. Gapon. Austauschreaktion des Bodens. Ibidem.

valeurs d'adsorption, obtenues d'après la différence du degré des concentrations avant et après l'expérience ($x=a=c$). Pourtant on connaît les phénomènes de ce qu'on nomme l'anomalie de l'adsorption du dissolvant, grâce à quoi les données ne peuvent souvent pas être placées dans telle ou telle équation. Nos expériences sur la détermination directe de l'adsorption du potassium par les sols ont permis de trouver les concentrations des limites avec lesquelles on peut admettre pratiquement la méthode des différences (jusqu'à 0,1 n KCl quand le rapport entre le sol et le volume de la solution est 10 : 100).

On comprend que la question quant à la nature des réactions d'échange dans les sols n'est point résolue par ces travaux. Ce dernier temps on discute beaucoup sur les problèmes se rapportant à la mobilité des cations.

C'est S. S. Jaroussov (Moscou) qui leur accorde le plus d'attention; il a consacré toute une suite de travaux à leur étude expérimentale¹. Ses études sur les cations ont montré, que la mobilité d'un seul et même cation (H et Ca) lors de son échange avec un autre (K) est différente dans des sols différents: plus le rapport $\text{SiO}_2 : \text{R}_2\text{O}_3$ est petit dans la composition du sol, plus le Ca (et H) est mobile. Une dépendance correlative directe a été trouvée entre la mobilité des cations et la hygroscopicité du sol, ce qui est facile à comprendre: moins le lien entre les cations et le complexe colloïdal est solide, plus la hydratation des cations adsorbés est grande.

Les travaux où varient soit les conditions de la température, soit celles de l'humidité, du temps, ou bien leurs combinaisons (série de recherches américaines) sont intéressants pour résoudre la question quel est le mécanisme de l'adsorption des cations. On a commencé aussi à faire une application en grand des travaux analogues dans l'URSS. Ces travaux ont montré que dans les conditions ordinaires de la température, les phénomènes d'une fixation irréversible de certains cations ne sont presque pas exprimés (travaux de notre laboratoire avec le potassium), les variations de la température jusqu'à 70—100° accélèrent à ce qu'il paraît la cristallisation des coagels amorphes du sol et par cela même fixent le sodium adsorbé (et les autres cations — Mg, par exemple), mais cependant non dans des quantités aussi grandes, que l'a montré par exemple Volk². Ici nous avons en vue les travaux du laboratoire de E. N. Gapon³ et certaines données de notre laboratoire⁴. Les résultats de recherches non encore publiés de notre laboratoire sur les phénomènes de la peptisation et de la coagulation de l'acide humique par les hydroxydes métalliques au moyen des

¹ S. S. Jaroussov und O. I. Dmitrienko. Zur Frage der Beweglichkeit der adsorptiv gebundenen Kationen im Boden. Fragen der Bodenchemie in der UdSSR. Verhandlungen der II. Kommission der I. B. G. Band A. I, 1934.

S. S. Jaroussov. Mobilité des cations adsorbés dans les sols différents, «Chimisation de l'agriculture socialiste», 6, 1934.

² Volk «Soil Science», 37, 5, 1934. Il faut remarquer, que le critérium choisi par cet auteur pour expulser le potassium: 10 g de sol 1 litre d'une solution normale de l'acétate d'ammonium, ne peut pas être reconnu comme étant suffisant.

³ Expériences de N. I. Gorbounov.

⁴ Communication préliminaire dans le journal «Priroda», 8, 1934.

méthodes électrochimiques¹ ont montré que de même que pour les cas de coagulation, dans ceux de la peptisation aussi les sauts de la courbe de titration potentiométrique coïncident, ce qui indique qu'il y a ici des réactions d'échange stoechiométriques (purement chimiques). C'est pourquoi nous nous permettons de considérer que dans les réaction d'échange des sols avec les cations des solutions des processus d'adsorption aussi bien que des processus chimiques d'échange doivent avoir lieu dans les fractions cristallines des colloïdes du sol, des processus, régis par les lois de la cristallogénie.

Pour conclure cette partie de notre rapport disons quelques mots des travaux sur l'acidité des sols. Le phénomène de «Wiegner-Effekt» connu dans la littérature générale est analysé théoriquement du point de vue de l'équilibre de Donan par B. S. Nikolsky². Le laboratoire de Nikolsky a continué l'étude expérimentale de la nature de l'acidité du sol. En se basant sur ces recherches comme sur leurs recherches personnelles les chimistes pédologues soviétiques³ tiennent pour parfaitement établie l'absence dans les sols, de ce qu'on nomme une capacité d'absorption des cations constante. Cette notion doit être envisagée comme un terme de convention car la valeur de la «capacité d'adsorption» dépend avant tout, du pH de la solution, par lequel cette capacité d'absorption est déterminée puisque dans les sols les ions hydrogène sont fixés non seulement par adsorption mais aussi chimiquement et que la valeur de leur dissociation, d'après la loi des masses dépend de la concentration des ions hydroxydes dans la solution.

III. Fixation des anions par les sols

L'état de la question sur la fixation des anions par les sols en URSS a été discutée d'une façon assez détaillée aussi bien théoriquement qu'au point de vue de l'expérience dans nos articles⁴ et dans les travaux de E. N. Gapon⁵ et N. P. Rémésov.⁶ La plupart des chimistes-pédologues soviétiques considèrent actuellement comme établie l'opinion sur la nature ampholitoïde du complexe colloïdal du sol.

Les travaux du fondateur de cette théorie S. Mattson ont été publiés en russe. Nos investigateurs ont continué en l'approfondissant l'étude du mécanisme de la conduite amphotère des colloïdes du sol, sur leurs composants isolés.

W. M. Gortikov avec ses collaborateurs a étudié soigneusement les phénomènes chimiques et d'adsorption qui ont lieu à la surface du carbonate de calcium d'une fine dispersion. En présence d'un excès d'ions du calcium dans la solution, la surface du carbonate de calcium se charge

¹ Travail expérimental de I. A. Khainisky.

² B. S. Nikolsky, loc. cit.

³ Voir p. e. D. L. Askinasi. Sur la question de la nature de l'acidité du sol. «Chimisation de l'agriculture socialiste», 2, 1934.

⁴ I. N. Antipov-Karataev avec ses collaborateurs. Bodenchemie in der UdSSR, Verh. der II. Kommission der I. B. G. B.d.A., 1, 1934.

Le même auteur — «Potchvovédénie», 2, 1934.

⁵ E. N. Gapon. Adsorption des cations et des anions par les ampholitoïdes du sol. Travaux de VIUAA, 2, 1933.

⁶ N. P. Rémésov, «Potchvovédénie», 2, 1934.

positivement, mais s'il y a un excès des ions du carbonate, elle acquiert une charge négative; c'est ainsi que le mode dont se comportent les ions du calcium et les ions du carbonate se montre analogue au rôle des ions hydrogène et des ions hydroxyles sur une surface alumo-silicato-humate. Il fût constaté que des différents carbonates naturels, les uns étaient chargés positivement (calcite, aragonite), les autres négativement (tufs, concrétions dans les sols). La charge négative de bien des carbonates est la conséquence d'une suite de processus secondaires (l'englobement de ces carbonates par des hydrates des oxydes d'aluminium, de fer et par des substances humiques). D'un intérêt particulier a été l'étude de l'action réciproque du carbonate de calcium et des phosphates. Les expériences du même auteur (avec Malinovskaïa) ont montré, que le phosphate recharge négativement le carbonate de calcium positif seulement lorsque les valeurs de pH sont au dessus de 8,8, c'est-à-dire les réactions chimiques entre le carbonate de calcium et les phosphates se produisent énergiquement, lorsque les valeurs de pH sont grandes. Avec des valeurs de pH au dessous de 8,8 dans la solution des phosphates, la charge du carbonate de calcium reste positive, ce qui doit indiquer qu'il n'y a ici que des phénomènes d'adsorption des anions dans la couche de diffusion des particules du carbonate de calcium.

Une place spéciale dans cette série de travaux appartient aux recherches de notre laboratoire, dont le but était de rendre plus intense la solubilité des phosphates à l'aide des «ions des humates». Pourtant, l'action réciproque des phosphates de fer (vivianite y compris) et du calcium (phosphorite et apatite), avec des degrés différents de concentration de l'acide humique et des humates de sodium avec des valeurs variables de pH n'a pas exercé d'influence positive sur le passage des ions des phosphates dans la solution moléculaire, mais la peptisation — le passage des phosphates dans la solution colloïdale est ici très prononcée. De cette façon l'opinion de Mattson quant au faible rôle d'expulsion des ions des humates par comparaison aux ions des phosphates est apparemment juste. Des résultats analogues avec les sols à valeurs neutres de pH dans les matières humiques, ont été obtenus dans le laboratoire de A. F. Tiuline. Nous avons obtenu des résultats aussi négatifs lors d'une action réciproque des phosphates du sol et les zols de l'acide silicique.

IV. Propriétés physico-chimiques du sol

Se rattachant aux problèmes d'une amélioration sur une vaste échelle des sols de l'URSS, et à la technique des machines, actuellement appliquée chez nous dans des proportions grandioses à l'agriculture, les questions relatives au changement des propriétés physico-chimiques du sol, sont devenus l'objet d'une sollicitude particulière pour nos investigateurs.

Les problèmes de la structure du sol ont exigé pour leur étude la mobilisation des forces, non seulement des physiciens, mais encore des colloïdistes. On s'est mis à étudier les causes de la formation d'une structure des sols et de leurs parties composantes en appliquant les méthodes de la chimie colloïdale. A. F. Tiuline a montré par une suite

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de travaux¹ le rôle des sesquioxydes dans la formation des aggrégats stables, des sols. Le laboratoire de A. I. Rabinerson² s'est occupé exclusivement des recherches sur la structure des colloïdes du sol en étudiant les transformations tixotropes et en établissant par des courbes la dépendance entre la viscosité et la pression. Les investigations ont fourni les résultats suivants, se rapportant aux sesquioxydes: 1) la formation de la structure présente le caractère d'une coagulation; 2) l'action des sels neutres est subordonnée non seulement à la règle de Schulze-Hardi, mais manifeste encore une action lyotrope évidente, où les cations comme les anions se montrent d'autant plus capables de participer à la formation d'une structure du sol qu'ils sont plus hydratés; d'où il sensuit que chez les sesquioxydes comme chez les colloïdes hydrophils typiques l'hydratation joue un grand rôle dans la hydratation (de même que la charge); 3) l'échauffement constitue un facteur puissant dans la formation de la structure du sol $\text{Fe}(\text{OH})_3$, en accélérant la hydrolyse des sels ferriques dans le liquide intermicellaire en provoquant par cela même la désorption des ions-stabilisateurs et la baisse de la charge des particules; après le refroidissement, commence partiellement un cours inverse des phénomènes; 4) les colloïdes organiques (l'albumine, les carbohydrates) fixent les ions-stabilisateurs dans le liquide intermicellaire et provoquent ainsi la formation d'une structure; 5) une dilution des solutions colloïdales $\text{Fe}(\text{OH})_3$ avec de l'eau, conduit à un phénomène de destruction. Les données des investigations des sols et des argiles montrent: 1) le rôle important que jouent dans la formation de la structure l'entrelacement des membranes hydratés des particules; correspondant à cela les sols saturés par différents cations, présentent une formation de la structure d'autant plus intense que l'hydratation est plus grande et moins la valence de ces cations est grande³, 2) lors d'une saturation du sol par le potassium l'optimum pour une structure du sol coïncide non avec la saturation complète, mais avec une certaine saturation optimum. Il s'ensuit de là que dans la formation d'une structure la coagulation aussi joue un rôle, coagulation à laquelle contribuent les cations adsorbés ferro-alkalins.

Les changements des propriétés physico-chimiques des sols d'après la composition et la corrélation variable des cations qui s'y trouvent ont fait l'objet des recherches détaillées. Cette partie des travaux étant le thème d'un rapport spécial de l'auteur, nous n'en parlerons ici que très brièvement.

¹ A. F. Tiulin, T. N. Zélénina et N. D. Poustovoïtov. Influence des sesquioxydes sur la stabilité des aggrégats du sol. Travaux de l'Institut des engrais et de la science du sol agronomique, 2, 1933.

² Voyez A. I. Rabinerson et G. I. Fuchs. Travaux de la succursale de Léninegrad de l'Institut des engrais et de la science du sol agronomique. 22, 1933.

³ Il nous faut ici même faire une réserve. Les termes: «structurité» et «formation de la structure», cela s'entend, ne coïncident pas aux notions propres de la pédologie où l'on attache à ces notions la structure des coagels, leur état d'aggrégation. Le laboratoire de A. I. Rabinerson examine le problème du point de vue de l'action réciproque des particules des suspensions et des sols d'un côté et avec le liquide intermicellaire, de l'autre. Plus cette liaison avec le liquide intermicellaire est nettement manifestée, plus la suspension est structurelle. Quant aux coagels, comme on le sait, ce phénomène y mène à une absence de structure plus accentuée.

Un travail particulièrement intense a été poursuivi pendant ces dernières années à l'Institut de la Chimie Colloïdale à Voronège (directeur—A. V. Doumansky) sur les questions de la liaison de l'eau par les sols (et par d'autres matières) en appliquant les méthodes polarimétriques et réfractométriques, développées par A. V. Doumansky^{1, 2}.

C'est encore ici que M. W. Tchapek a étudié d'une manière assez détaillée les différentes chaleurs de mouillage des sols selon la nature de ceux-ci et de leurs composants d'une part et selon la composition des cations échangeables de l'autre. L'inclusion par l'Institut spécial de la Chimie colloïdale des problèmes sur l'étude chimique des sols dans le cercle de ses travaux scientifiques nous promet d'intéressantes perspectives pour le développement ultérieur de la science du sol dans l'URSS.

P. I. Andrianov³ a continué ses études sur la chaleur de mouillage des sols, pour la mesure de leur surface totale. Pour ce qui est de notre laboratoire, il a abordé ce problème du point de vue d'une évaluation de l'énergie de fixation des cations adsorbés isolés, et on est arrivé à la conclusion, que l'opinion de Janert⁴ selon laquelle la chaleur de mouillage est due en une grande mesure à la hydratation des cations échangeables, est apparemment plus justifiée et pour cette raison l'évaluation de la dimension de la surface totale d'après les données sur la chaleur de mouillage peut à peine être considérée juste. En dehors de l'évaluation des chaleurs de mouillage notre laboratoire a fait des recherches sur des sols, saturés après une électrodialyse par différents cations séparés, et par leurs combinaisons et sur les argiles, ainsi que des investigations radioscopiques, électrochimiques et autres. Les résultats obtenus comme on l'a déjà dit feront le sujet d'un article spécial.

V. Au lieu d'une conclusion

La science du sol en URSS s'est engagée d'un pas assuré dans la voie d'une appropriation et d'une application des méthodes des sciences exactes et nous espérons que bientôt nos vieux cadres et en plus des cadres nombreux de jeunes investigateurs bien doués et pleins de talent vont étendre et approfondir l'héritage, que nous a laissé notre grand maître K. K. Gedroiz et réaliser le vœu de notre vénéré investigateur dans le domaine de la chimie colloïdale des sols, le prof. G. Wiegner, que les travaux théoriques sur la science du sol en URSS deviennent encore plus approfondis, le vœu, qu'il a exprimé en 1930 à l'inauguration du II Congrès International de la Science du Sol à Léninegrad. Nous devons réaliser ce vœu comme l'exigent les demandes toujours croissantes de notre oeuvre de construction socialiste, quant à un niveau toujours plus élevé dans les sciences et des études constamment approfondies des problèmes, se rattachant à l'agriculture et aux exigences des sovkhoz et des kolkhoz.

¹ A. Doumansky. Die Bestimmung der Menge des gebundenen Wassers in dispersen Systemen. Kolloid-Zeitschrift, 65, 2 (1933).

² Travaux de l'Institut de la chimie colloïdale. Fasc. 1, 2 (1934).

³ P. I. Andrianov. Journal de la physique technique. v. 3, fasc. 7 (1933).

⁴ Janert. Journ. of Agricultural Science, 1, 1934.

AUFBAU DER HUMINSÄURE UND IHR STRUKTURELLER ZUSAMMENHANG MIT LIGNINEN UND KOHLEN

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Der Boden ist das Resultat höchst komplizierter und mannigfaltiger energetischer Prozesse, die in der Auswitterungskruste sich abspielen und das Gestein in eine ausserordentlich fruchtbare natürliche Formation umgestalten. Von Boden kann nur dann die Rede sein, wenn organische Stoffe vorhanden sind; diese entstehen aus abgestorbenen Pflanzenresten, die beim Bodenbildungsprozess tiefgreifende Umwandlungen durchmachen. Der Einfluss der organischen Substanz auf den Boden ist kolossal. Sie bildet das Nahrungsmedium für zahlreiche Bakterienarten und Pilzchen und ruft eine energische Lebenstätigkeit dieser letzteren hervor. Nicht nur die organischen Verbindungen der Pflanzenreste werden durch die Lebenstätigkeit der Bakterien und Pilze zerstört, — es erleidet auch der mineralische Teil des Bodens unter dieser Einwirkung merkliche Umwandlungen. Der Prozess des Zerfalls dieses letzteren verläuft in einer ganz ebensolcher Weise, infolge der Anwesenheit einer grossen Menge verschiedener organischer Säuren, die in Pflanzenresten enthalten sind, oder bei deren Zerfall neugebildet werden.

Die verschiedene Einwirkungsstärke der organischen Substanz auf den Boden hängt von den Verhältnissen ab, die im Medium herrschen. Viele organische Stoffe der vegetativen (weniger der tierischen) Reste werden restlos mineralisiert (Stärke, Zucker u. a.), einige nur zum Teil (Zellulose) und dritte — zersetzen sich fast gar nicht (Lignin).

In höchst komplizierten energetischen Verhältnissen des Bodens findet nicht nur eine Zersetzung der Verbindungen pflanzlicher Reste statt, sondern es entsteht eine Reihe gänzlich neuer und spezifischer Verbindungen. Die Bodenhumusstoffe sind zweifelsohne, das Resultat der Bodenbildung; viele von ihnen sind nur dem Boden eigentümlich. Es ist zu erwarten, dass die Hauptbestandteile der Humussubstanz Züge einer Konstanz und der Identität ihrer Textur und ihrer Eigenschaften aufweisen.

Studien an den humosen Stoffen des Bodens, die im letzten Jahrhundert von Chemikern-Organikern und Chemikern-Bodenkundlern getrieben wurden, haben zur Ausarbeitung der Methoden der Extraktion der Gruppe der Huminsäuren (durch Alkalien, Neutralsalze u. a.), der

Ausscheidung einer ganzen Reihe individueller Stoffe (Schreiner und Shorey) und der Einteilung der Grundmasse des Alkaliextraktes in mehrere «bedingte» Verbindungen geführt, unter denen die sogenannte Huminsäure quantitativ vorwiegt (4 % des Gesamthumus).

Chemische Untersuchungen haben ferner gezeigt, dass in dem Komplex der organischen Bodenstoffe die Huminsäure durch die grösste Bestimmtheit und Konstanz ihrer Textur und Eigenschaften sich auszeichnet.

Heute kann die chemische Natur der Huminsäure als ausreichend aufgeklärt gelten. Die Anwesenheit von vier Karboxyl- und drei Hydroxylgruppen bedingen, wie aus der von Fuchs und Stadnikow vorgeschlagenen Formel $C_{59}H_{35}O_{27}N[(COOH)_4(OH)_3(CH \cdot CO)]$ ersichtlich ist, die Eigenschaften der Huminsäure, deren molekulares Gewicht zirka 1302—1400 ist.

Weniger aufgeklärt bleibt der Hauptteil der Formel, der die 59 Kohlenstoffatome enthält, d. h. der eigentliche Kern der Huminsäure. Die vortrefflichen Arbeiten von Eller, Fuchs u. a. beweisen die aromatische Struktur der Huminsäure. Als Grundelement, der den Zentralkern der Säure bildet, dient der sogenannte Komplex 1, nach Fuchs (oder was dasselbe ist, der Ligninkern).

Es ist längst bekannt, dass nicht alle Verbindungen der abgestorbenen Pflanzenreste an der Bildung der Huminsäuren teilnehmen. In letzter Zeit wird die Möglichkeit der Umwandlung der Zellulose in Huminsäure in Zweifel gezogen, obwohl dies wohl nicht ausgeschlossen ist, infolge der Umwandlung dieser letzteren beim Humifikationsprozess in eine dem Lignin nahe aromatische Verbindung. Als Hauptquelle der Bildung von Huminsäure wird Lignin bezeichnet, das unter natürlichen Bedingungen sehr widerstandsfähig ist gegen die zerstörende Mikrobentätigkeit und unter Laboratoriumsbedingungen leicht in Huminsäure sich verwandelt, die ihren Eigenschaften und ihrem Wesen nach den natürlichen Huminsäuren identisch ist.

Das Haupttatsachenmaterial über die chemische Untersuchung der Huminsäuren gibt keine volle Lösung der Frage nach der chemischen Beschaffenheit der Huminsäure und des in beträchtlichem Ausmass mit ihr verbundenen Aufbaus dieser Säure. Dies erklärt sich durch die ausserordentlich komplizierte Natur der Huminsäure (analog der Kompliziertheit der Eiweisstoffe; für Verbindungen solcher Art hat die organische Chemie genaue Methoden noch nicht ausgearbeitet. Die Erfolge, die auf dem Gebiete der Anwendung der X-Strahlen zur Untersuchung hochpolymerischer natürlicher organischer Verbindungen erzielt wurden, haben uns dazu bewogen, die aus Torfen und Böden erhaltenen Huminsäuren nach der röntgenospektrographischen Methode zu untersuchen.

Die mit Röntgenstrahlen nach der Debye und Scherrer-Methode untersuchten Präparate der Huminsäure wurden nach der Gedroizschen Methode aus zwei Torfproben ausgeschieden (Moorstation von Minsk und aus dem Leningrad-Gebiet) und nach der Schmuckschen — aus dem Tschernosem aus Woronesch. Es wurden ausreichend deutliche Spektrogramme erhalten, auf dem einen davon sieht man 3 Ringe: einen sehr intensiven, einen intensiven und einen Ring mittlerer Intensität.

Die Spektrogramme erwiesen sich als charakteristische für hoch polymerische organische Verbindungen. Alle Maxima sind in ihnen zu dem Primärstrahl geschoben, die Peripherieinterferenz fehlt. Die Interferenzmaxima sind von ziemlich hohem Diffusionsgrad.

Auf Grund der Angaben dieses Interferenzbildes kann man die Präparate der Huminsäure als eine Verbindung kristallinischer Struktur betrachten, was den herrschenden Vorstellungen von ihrer amorphen Natur gerade entgegengesetzt ist.

Die Tatsache, dass die Spektrogramme der Huminsäuren, die aus verschiedenen Objekten ermittelt wurden, einander gleich sind, weist darauf hin, dass die Struktur dieser drei Säuren identisch ist, dass ihre Grundkerne gleich sind. Die Konstanz der chemischen Eigenschaften und die Identität der Konstitution der Huminsäuren, bei unbedeutenden Schwankungen der chemischen Zusammensetzung erlauben den Schluss zu ziehen, dass die erhaltenen Data die Anschauung der Chemiker bestätigen, und zwar, dass die Huminsäure eine chemisch-individuelle Verbindung ist.

Zwecks Aufklärung eines möglichen strukturellen Zusammenhanges in der Huminsäure wurden auch Ligninpräparate (nach Willstätter und Körnig-Rump dargestellt) einer Untersuchung unterworfen. Sie ergaben ein weniger scharfes Spektrum. Auf ihren Röntgenogrammen konnte man zwei stark zerfliessende und ein sehr schwaches Interferenzmaximum unterscheiden, die auf den Zustand hoher Dispersität des untersuchten Stoffes hinweisen. Die quantitativen Messungen haben aber Werte ergeben, die den Angaben der Huminsäure sehr nahe sind.

Braggische Winkel (φ) für Lignine $\varphi_1 = 13^\circ 59'$, $\varphi_2 = 21^\circ 31'$, $\varphi_3 = 25^\circ 22'$ für Huminsäure $\varphi_1 = 7^\circ 59'$, $\varphi_2 = 12^\circ 58,9''$, $\varphi_3 = 21^\circ 13'$.

Die erhaltenen Angaben setzen einen strukturellen Zusammenhang fest zwischen den Huminsäuren und den Ligninen.

Die Vergleichung der Spektrogramme der Huminsäuren mit den Röntgenogrammen der Zellulose und ihrer Derivate hat einen merklichen Unterschied in ihrem Charakter aufgedeckt, hiervon zeugen z. B. folgende quantitative Angaben der Messungen und Berechnungen für Huminsäure und Zellulose.

Huminsäure		Zellulose
$7^\circ 59' 24''$	mittlere Helle	$7^\circ 21' 30''$ hell
$12^\circ 58' 54''$	sehr hell	$11^\circ 18' 30''$ hell
$21^\circ 13' 0''$	hell	$14^\circ 53' 00''$ schwach
		$17^\circ 11' 30''$ hell

Wir halten den strukturellen Unterschied zwischen Zellulose und Huminsäure für festgestellt, dies schliesst aber, selbstverständlich, die Möglichkeit der Anteilnahme der Zellulose an der Bildung der Huminsäure nicht aus. Dies kann geschehen, wie oben bereits erwähnt, durch Veränderung der Struktur der Zellulose beim Humifizierungsprozess im Sinne der Gewinnung einer, den Ligninen nahen, zyklischen Textur.

Das Zusammenfallen von zwei Interferenzmaxima des Graphits (002) und (100) mit den zwei Maxima der Röntgenogramme der Huminsäure, berechtigt zu dem Schluss, die Huminsäure habe eine Graphitstruktur,

nur mit dem Unterschied, dass das Raumgitter der Huminsäure aus Flächen mit einander verbundener sechswinkliger Benzolringe zusammengesetzt ist, die nach zwei Hauptrichtungen durch die Molekülgrösse begrenzt werden, während dieselben Flächen beim Graphit hinsichtlich Weite und Länge unendlich sind. Der Texturunterschied erklärt sich durch das Vorhandensein peripherer aktiver Gruppen in der Huminsäure und deren Nichtvorhandensein im Graphit. Ebenfalls durch die Anwesenheit dieser Gruppen erklärt sich die bedeutend geringere Kompaktheit der Huminsäure und ihre grosse Reaktionsfähigkeit.

Der angenommene Gittertypus ist hexagonal. Die Elementarzelle der Huminsäure ist dem Elementarkörper des Graphits gleich, mit sehr kleinen Abweichungen in den Dimensionen.

$$\begin{array}{ll} \text{Für Huminsäure} & C=6,85 \text{ \AA}; \quad a=2,39 \text{ \AA} \\ \text{Für Graphit} & C=6,79 \text{ \AA}; \quad a=2,46 \text{ \AA} \end{array}$$

Die festgestellte Verwandtschaft der Struktur der Huminsäure mit dem Graphit weist auf ihren Zusammenhang mit Braunkohle und dem Anthrazit hin. Die vorgenommene Bearbeitung der literarischen Angaben über Kohle und ihre Zusammenstellung mit unseren Daten haben eine erstaunliche strukturelle Verbindung in der Reihe: Lignin-Huminsäuren-Braunkohle-Anthrazit-Graphit aufgedeckt. Die bezüglichen Angaben findet man in Tabelle 1 zusammengefasst.

Tabelle 1

Lignin nach Willstätter <i>d</i>	Lignin nach König <i>d</i>	Huminsäure No.1 aus Torf <i>d</i>	Huminsäure No.2 aus Torf <i>d</i>	Huminsäure des Bodens <i>d</i>	Braunkohle nach Mahadevan <i>d</i>	Kohlen der Tertiärperiode nach Mahadevan <i>d</i>	Anthrazit nach Turner a. Andersson <i>d</i>	Graphit nach Ott <i>d</i>
3,76\AA(3,8)	3,66 \AA	5,52 \AA	5,52 \AA	5,52 \AA			6,54 \AA	3,41 \AA
2,10 \AA	2,03 \AA	3,43 \AA	3,39 \AA	3,43 \AA	3,5 \AA	3,5 \AA	3,6 \AA	(3,39) \AA
1,80 \AA		2,08 \AA	2,18 \AA	2,13 \AA	2,12 \AA	2,22 \AA	2,16 \AA	2,05 \AA

Es deutet sich eine Gesetzmässigkeit an, die auf eine mit dem Uebergange vom Lignin zum Graphit vor sich gehende Verdichtung hinweist. Die Grösse die für Lignin = 3,8 \AA beim Graphit ist nur = 3,39 \AA. Der hinsichtlich der Verdichtung gezogene Schluss wird durch eine ganze Reihe spezifischer Gewichte bestätigt.

Lignin=1,02; Huminsäure=1,26; Anthrazit=1,6; Graphit=2,23.

Tabelle 1 zeigt, dass die zyklische Struktur in der Reihe der Umwandlungen, die beim Prozess der Humifizierung vom Lignin bis zum Graphit vor sich gegangen sind, völlig erhalten geblieben ist, beim Prozess der Humifizierung erleiden die Seitenverbindungen (Ketten) qualitative Änderungen und werden quantitativ zerstört, die aromatischen Kerne

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der Lignine kondensieren sich (polymerisieren sich) und erreichen im Graphit in der Fläche der Benzolringe kolossale Dimensionen.

Der durch die röntgenographischen Untersuchungen aufgedeckte strukturelle Zusammenhang in der Reihe Lignin-Huminsäure-Humin-Kohle-Graphit bestätigt die Theorie von der Herkunft der Humus Kohlen von Fr. Fischer und Schrader.

Der Diffusionszustand der Interferenzmaxima spricht von einem hohen Dispersitätsgrad des untersuchten Stoffes. Die weiter angeführten Grössen müssen aber wegen der grossen Breite der Maxima der Photometerkurve nur als grobe Annäherung betrachtet werden. Die Ausrechnung geschah nach der Laueformel und ergab bei einem orthorombischen Achsenkreuz für $m_2c = 8,9 \text{ \AA}$ und für $m_1a = 16,5 \text{ \AA}$, m_2b liess sich nicht wegen Fehlen der nötigen Interferenz ausrechnen. Die Kristallite haben eine Plattenform, was ziemlich gut mit den Beobachtungen der Chemiker in Einklang gebracht werden kann, die festgestellt haben, dass die Huminsäure beim Austrocknen Mikroplättchen bildet.

Die Huminsäure besteht aus Myzellen (anysotrope Kristallite im Sinne von Nägeli). In Wassermedien befindet sich die Huminsäure in kolloider Auflösung. Die Kolloidteilchen müssen als ein Aggregat von Kristalliten betrachtet werden, die durch das zwischen die Myzellen eingedrungene Wasser auseinander geschoben sind. Jedes Myzell verändert weder seine Struktur noch seine Grösse. Die Erscheinung der molekularen Auflösung der kolloiden Huminsäure bei deren Titrieren mit Alkalien weist auf den Prozess der Zerlegung der einzelnen Kristallite in Molekeln, die sie zusammensetzen, hin, wobei durch die letzteren mit den Metallen Verbindungen des Salztypus' gebildet werden. Die Wiederherstellung der Kristallite stellt einen langwierigen Prozess dar, der auf eine langsame Orientierung der Molekeln in der Verbindung hinweist.

Das Vorhandensein peripherer reaktionsfähiger Gruppen in der Huminsäure, die an der Oberfläche der Kristallite liegen, soll unter den natürlichen Bodenverhältnissen, mit den Mineralkolloiden höchst komplizierte organo-mineralische Bildungen ergeben, die spezifische Bildungen des Bodens vorstellen. Diese werden sicherlich neue Bodenminerale bilden, die im Prozesse der Bodenbildung entstehen.

Die Perspektiven der Anwendung der röntgenospektrographischen Analyse zur Untersuchung des organischen Teils des Bodens sind kolossal weit. In Verbindung mit den chemischen und physikalisch-chemischen Methoden wird die X-Strahlen-Methode in nächster Zeit das Wesen der humosen Stoffe im Detail aufklären helfen.

Vorliegende Arbeit wurde unter allgemeiner Leitung von Prof. I. N. Antipow-Karatajew ausgeführt.

Aktiven Beistand bei der Ausführung der Arbeit haben geleistet: die korrespondierenden Mitglieder der Akademie der Wissenschaften A. W. Schubnikow und B. B. Polynow, die Prof. Prof. N. A. Orlov und I. W. Tjurin und Dozent W. I. Simakow.

LITERATUR

- (1) Fuchs, W. — Die Chemie des Lignins. Berlin, 1926.
- (2) Fuchs, W. — Die Chemie der Kohle. Berlin, 1931.
- (3) Orlow, N. — Skizzen über die Chemie der Kohle. Leningrad, 1933.
- (4) Stadnikow, G. — Die Chemie der Kohle. Moskau, 1932.
- (5) Stadnikow, G. — Die Chemie der Kohle. Moskau, 1932.
- (6) Stadnikow, G. — Der Ursprung der Kohlen und der Naphta. Moskau, 1931.
- (7) Naiwald. — Handbuch der Bodenlehre von Blank. Berlin, 1930.
- (8) Trussow, A. — Materialien zur Untersuchung russischer Böden. Lfg. 24.
- (9) Schmuck, A. A. — Abh. des Kubanschen landwirtschaftlichen Instituts. Bd. 1. Lfg 24, UdSSR.
- (10) Schmuck, A. A. Bülletins des Bodenkundlers, 5-7, Moskau, 1930.
- (11) S. Oden — Die Huminsäuren. Leipzig, 1922.
- (12) Mahadevan — Fuel in Sci. a. Pract. № 8, 462, 1929; № 10, 1929; № 5, 574, 1930; № 12, 1930.
- (13) Turnera. Anderson — Fuel in Sci. a. Pract. № 7, 1932. № 11 262, 1932.
- (14) Ebert E., Die Anomalien der Pulveraufnahmen nach der Debye-Scherrer-Methode. 1925.
- (15) Maignin, Ch. — Structure du graphite. Saint Avand, 1926.
- (16) Trollat, J. J. — Les applications des rayons X. Paris, 1930.
- (17) Ewald, P. — Kristalle und Röntgenstrahlen. Berlin, 1923.
- (18) Geiger, H. — Negative und positive Strahlen. Zusammenhängende Materie. Berlin, 1927.
- (19) Meyer u. Mark — Der Aufbau der hochpolymeren organischen Naturstoffe. Berlin, 1931.
- (20) H. Standiger — Die hochmolekularen organischen Verbindungen. Berlin, 1932.
- (21) Anwendungen der Röntgen- und Elektronenstrahlen. Ergebnisse der technischen Röntgenkunde. Bd. IV, Leipzig, 1934.

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METHODS OF A DIRECT STUDY OF SOIL MICROFLORA

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I

In the course of the last decade soil microbiology has doubtlessly entered a new era. Quite recently it was dominated by the methods of classical bacteriology hardly suitable for the study of life in this peculiar environment. About ten years ago Winogradsky was the first to suggest the necessity of leaving the traditional path. By a series of brilliant researches he founded a new soil microbiology. Under his influence and partly under that of the American bacteriologist Conn began a revision of the methods of soilbacteriological research. The old methods are reevaluated and worked out anew from the point of view of the closest possible approach to the natural conditions existing in soil. The same principle is laid at the base of some of the new methods, especially in that field which must, it seems to me, become the foundation of new soil microbiology. I bear in mind the direct study of soil microflora under the microscope, its detailed study in its natural environment. As in the world of higher plants direct investigation of the flora in its natural environment, in all the complexity of its mutual relations with its surroundings, including under this term both the living and the non-living nature, is an indispensable premise for a further and deeper analysis of the life of the vegetable kingdom, so to form an idea of the no less intricate phenomena of the world of microorganisms inhabiting soil, it is necessary first of all to accumulate data; a vast purely descriptive work is necessary, which should give us reliable starting points for successful progress in this difficult and little accessible field of research.

During the last 5-6 years several different methods have been suggested for the direct microscopic investigation of soil microflora. We should mention in this connection the works of Koffman, Rossi, Kubena and my own. Of all the suggested methods the one met with the greatest interest was the method of «overgrow slides» proposed by me.

Its substance is as follows. A vertical slit several centimeters deep is made in soil and a clean slide is introduced into it. Soon the surface of the slide is covered with soil solution, solid soil particles adhere to it and in this medium begin to develop various microorganisms, so that the slide is gradually overgrown by them. After a certain time (from

3 to 14 days) the slide is extracted from the soil with special precautions so as not to harm so far as possible the microflora covering one of its sides, the preparation is fixed, the larger soil particles washed off, the preparation stained with phenol erythrosin and studied under the microscope. It appears that a considerable part of soil microorganisms (fungi, actinomycetes, bacteria, protozoa), may live, grow and multiply on the clean surface of glass, obtaining their food-supply either from the soil solution or from the small particles of solid remnants adhering to the glass. This part of the soil microflora can be very well observed on overgrow slides. Of course the microorganisms living inside of soil conglomerates are less accessible to observation.

This method has been described by me in detail in two articles published in 1930 (Cholodny, 1930, a, b,) to which I refer the reader interested in the technical details of this method of soil microflora research and in the results obtained with its help.

We shall dwell now on some later works the authors of which have tried to apply the method of overgrow slides to the solution of various problems of soil microbiology.

Conn (1932) was one of the first to draw the attention of bacteriologists to the method proposed by me and applied it to the investigation of three questions: 1) in determining the differences in the microflora of different soils; 2) in the study of the effect of manure and varying moisture of soil on its microflora; 3) in the investigation of the formation of colonies in sterilized soils inoculated with pure cultures.

This author obtained very promising results in respect of the first two questions: the method revealed distinct differences in the flora of different soils even in those cases in which the usual method of inoculating solid nutrient media with subsequent microscopic analysis did not reveal any differences. Introducing into soil fertilizers and varying its moisture he also succeeded to note distinct alterations in the microflora on overgrow slides. Pointing out some defects of the new method (impossibility of obtaining a fully typical picture of the soil in question on one preparation; impossibility of a precise identification of the forms observed, particularly of the bacterial ones) Conn at the same time prophesies a great future to it, as to a means for «the successful solution of various enigmas of soil microbiology».

A year later appeared the work of Demeter (in collaboration with Mosel—1933). This author set himself the purpose, similarly to Conn, first, to establish, whether it is possible to detect with the aid of overgrow slides qualitative differences in the microbic population of different soils, both in their natural condition and after manuring; and, second, is it not possible to approach by means of the same method the quantitative evaluation of these differences.

Demeter introduced slides into two different soils under potatoes and beet; one part of the plots was left without manuring, into the others he introduced manure in the shape of dung, of nettolin (peat humified at 80°—90° C with the addition of lime) or of a mixture of mineral salts, containing N, K and P.

From a detailed analysis of the obtained results Demeter draws the conclusion that the method of overgrow slides allows to detect with ease

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the differences in the composition of soil microflora both in the non-manured plots and in the plots supplied with different manures, these differences having not alone a qualitative, but also a quantitative character. Thus in the experiment with potatoes cultivated on a comparatively poor sandy soil he notes the absence of *Azotobacter*-like cells in the plot without manure, while in the plot with fertilizers they appeared in great numbers; sporing forms were frequently observed in the plot without manure, they were absolutely lacking in that with nettolin; fertilizers eliminated the usually abundant flora of actinomycetes but favoured the multiplication of Protozoa; the development of fungi was increased under the influence of dung etc.

It proved further that the changes caused in the microflora by the introduction of various manures into soil were different under potatoes and beet resp. Demeter registers also a similarity of biologic effect of fertilizers and nettolin, seeing in it a proof of the sensitiveness of the method, as both nettolin and the mineral manure applied by him are equivalent as regards their mineral contents. Besides this Demeter stresses particularly the fact that only the method of overgrow slides allows to detect some fine distinctions in the response of different soils to the same kind of manure. Thus, e. g., introduction of dung into the heavier clayey soil under beet provoked an increased development of blue-green and some other algae, capable of assimilating the nitrogen of organic compounds. At the same time in the poorer sandy soil under potatoes no algae whatever were found after the introduction of the same manure. Demeter, like Conn before him, indicates that with increasing soil moisture the development of bacteria increases, while that of fungi and actinomycetes is depressed.

Summing up all his observations Demeter points out the following advantages of the new method: simultaneous embracing of the whole soil microflora, possibility of its quick differentiation by morphological characteristics; accessibility to observation of organisms and of the natural combinations (coenoses) formed by them in situ; ease of determination of the qualitative and partly of the quantitative changes of the characteristic groups of microbes under the influence of various external factors, and finally the simplicity of its application. The defect of the method consist according to Demeter mainly in the impossibility of a precise diagnosis of bacteria, the impossibility to isolate pure cultures, and finally in that the qualitative characterization of the microflora observed is possible only as a rough approximate judgement. Some of these defects may be, in the opinion of this author, eliminated with accumulation of experience and further improvement of the method. Demeter conceives this further development of the method mainly as the application of pure or mixed cultures of various typical microorganisms introduced into sterilized soil and subsequent investigation of overgrow slides introduced into this soil. In this way, as he thinks, it will be possible to obtain an idea of the behaviour of various known beforehand microorganisms in their natural environment this making easier the task of their identification on slides obtained from unsterilized soil.

Of the works published in 1934 I shall note first of all the detailed

study of the Australian bacteriologist Jensen (1934). This author set himself the task of comparing the overgrow method with the usual method of cultivating and growing colonies of soil microorganisms in artificial solid media and subsequent counting of these colonies. The experiments with the burying of slides were conducted not in the field, but, similarly to those of Conn, in the laboratory with soil samples placed in Koch's plates. Two soils were investigated: one from a flower-bed, clayey, rich in organic matter and lime, with a $\text{pH}=7.3$; the other from an uncultivate grass-plot, also clayey, still richer in organic matter, with a $\text{pH}=5.4$. Both soils were used without any additions and with the addition of various organic and inorganic compounds (mannitol, cellulose with NaNO_3 , keratin, liquid paraffin with NaNO_3 , etc.).

Without dwelling on Jensen's results I shall say only that this author found a far-going parallelism between both methods, both in respect of the qualitative composition of the microflora observed and in that of quantitative relations between the various groups of soil microorganisms. Besides those defects of the overgrow slide method which had attracted the attention of the other previously mentioned authors, Jensen points to the difficulty of counting the number of microorganisms in the preparations obtained by this method due to their irregular distribution over the surface of the slide, and to the impossibility of the determining the exact time of the development of microbic agglomerations, particularly in the case of lengthy experiments. At the same time data obtained by the microscopical study of overgrow slides form, according to Jensen, in many cases a valuable supplement and corrective for the results of the usual solid media method. Therefore he recommends to use in soil microflora researches both methods simultaneously.

Among other works by foreign authors we should note also a small but interesting article by Kamerman (1934) of Pretoria, South Africa. Kamerman indicated that the character of the microflora developing on overgrow slides depends not alone on soil but also on the chemical composition of the glass of which the slide is made. If his observation will be confirmed it will be a good illustration of the extraordinary susceptibility of microorganisms to the so-called oligodynamic action to which our attention was recently drawn by Nadson, M. A.—U.A. Sci. The practical conclusion which must be drawn from the observations of Kamerman is that in comparative researches of the soil microflora by the method of overgrow slides it is necessary to use glass of one and the same sort.

Simultaneously with Jensen's work appeared the article of Kriuchkova (1934), which is an attempt of applying the method of overgrow slides to the solution of questions of soil agronomical diagnostics. At the same time we find in this work the first attempt to realize the idea, suggested as we have seen by Demeter (1933) and still earlier and in a more precise form by E. E. Uspensky (1932) of the necessity of utilizing in soil bacteriological research microbes-indicators selected from among the forms most typical for the soil in question and simultaneously particularly susceptible to the presence or absence of the factors determining the fertility of soil. An ideal indicator — according to

the idea of E. E. Uspensky — is such a form which responds to the soil conditions, interesting the agronomist, by definite morphological changes easily accessible to observation.

A new element in comparison with the researches of earlier authors is presented in the work of Kriuchkova by the fact, that she did not fixate the overgrow slides but obtained a culture from them covering them with a thin layer of nutrient agar, applying in this manner the media of Ashby, Conn, Hutchinson and peptone-glucose-agar. This author's opinion is that this modification of the method allows a «quantitative registration of the activity of the microflora by means of counting the number of colonies», permits to differentiate the microflora by physiologically different groups, to study the effect produced by manures on these groups and, moreover, to isolate pure cultures of various characteristic microorganisms.

The experiments were conducted in the laboratory in podzolized loam. Their chief purpose was to study the mutual relations of the microflora and the chemism of soil, the chemical changes in soil being achieved by introducing manures into it — nitrophoska and mixture of mineral salts containing N, P and K. We cannot dwell in more detail on the results of this thorough and valuable investigation, but must note that an increased overgrowing of the slides was observed in the experiments with nitrophoska, in comparison with the controls and with the slides from soil manured with the mineral mixture, as this was established by direct counts of microorganisms per 1 cm² of the preparation's area. The qualitative composition of the microflora also changed visibly under the influence of different manures. Not only the nature of the manure but also the period of its action and the distance between the slide and the place of the introduction of manure (when it was introduced into the soil in rows) affected the development of the microflora.

Two of the forms, found on overgrow slides, were isolated in pure culture — a large-sized coccus and a small rod, — both very sensitive to changes of nitrogen concentration in the medium. Both these cultures were utilized in further experiments as indicators for nitrogen. In these experiments nitrogen was added in varying amounts and in the shape of different compounds to the soil under investigation, and into the same soil after its sterilization this author introduced one of the above mentioned cultures and a slide for overgrowing. On the preparations, after their termination, Kriuchkova counted the number of colonies per 1 cm². In the experiments with the coccus which were particularly numerous, she registered besides this, the alterations in the shape and structure of cells as well as in the character of colonies. From an analysis of her results the author draws the conclusion that it is too early to speak of the utilization of the isolated organisms for practical purposes, still she is of the opinion, that further work in this direction may bring us closer to the solution of questions connected with soil diagnostics and, consequently, to the control of soil dynamics.

We should mention also the work of the Polish author Marszewska-Ziemiecka (1934), who applied the method of overgrow slides to the investigation of the microflora of soils enriched by various organic

compounds. Soil was placed in pots and the following substances were added to it: glucose, starch, cellulose, xylan, urea, asparagin; alanine, peptone; stearic, palmitic, oleinic, acids; agar and phenol. After the introduction of overgrow slides soil was kept in the laboratory at 30° C. Several experiments were also arranged for the study of thermophilic and anaerobic microbes. The conclusions of the author are as follows:

The method applied revealed a very specific character of the microflora attacking one or other of the organic substances after their introduction into soil. It seems that only one specific for each substances microbic species takes part in this process in its first stages, attracted by the chemotactic action of the substance and forming uniform agglomerations, which may be regarded as pure cultures.

In fertile soils, abounding in bases, these microbes-pioneers of the decomposition of organic substances — are usually represented by bacterial species, while in poor and acid soils (pH=4—4.5) this rôle is executed in most cases by moulds.

Later-on this primary microflora is substituted by a secondary one composed mainly of fungi and actinomycetes. The process finishes by the development of a tertiary microflora represented by several species of bacteria feeding on the remnants of the microorganisms of preceding vegetations. Sometimes the preparations abound in Protozoa.

It proved possible to study by means of overgrow slides also the thermophilic and anaerobic microflora of the soil.

Finally Marszewska-Ziemiecka indicates that, while the first stages of the decomposition of organic substances are achieved by bacteria and fungi, the main part in the later stages of humification belongs to actinomycetes.

Such are, most summarily, the chief results of several works, the authors of which tried to utilize the method of overgrow slides for the solution of various questions of soil microbiology and evaluate the measure of its fitness for researches of this kind. As we have seen all the authors cited above arrived at positive conclusions in this regard and evaluated the possibility of the new method sufficiently high.

It seems to me, however, that the hopes laid on this method are somewhat exaggerated, and that may be some of the authors demand from it more than it can give. There can be no doubt, of course, that attentive study of overgrow preparations from various soils and under most varying conditions will aid us to enrich our knowledge of soil microflora, especially in the purely descriptive, morphological aspect. As a bacterioscopic, or, to be more precise, microbioscopic method the method of overgrow slides represents a doubtless progress in comparison with the other methods applied before, as it permits to avoid almost totally any disturbance of the natural structure of soil and of the biocoenoses characteristic of it. Suffice it to say that before the application of the technique proposed by me we had no idea of the actual aspect of bacterial colonies in soil, of the natural forms of growth of the soil actinomycetes, of the ecological relations between bacteria and fungi, while our information on the numerical prevalence of individual groups in the microflora of different soils was far

from correct etc. Now we already know something on all of these questions.

However, in spite of all its generally accepted advantages the method of overgrow slides has essential defects which have been noted by the investigators who applied it. We must note particularly the static character of this method; the preparations obtained with its help reflect only one definite moment in the life of the soil, or to be preciser, present the picture formed by the moment of the extraction of the slide from the soil as a result of a number of previous changes inaccessible to observation. Thus even those external phenomena of soil dynamics, which under other conditions could be detected without difficulty, escape our attention. We meet here with another essential defect of the method, with its unfitness for *in vivo* observations of soil microflora; and with this is bound in its turn the impossibility of isolating pure cultures at the experimenter's choice and of their subsequent thorough investigation. It is true, Kriuchkova made an attempt to override this obstacle by covering the preparations with nutrient agar and letting them germinate, but it is evident that this mode of action is in substance no different than the commonly used inoculation with soil samples of solid nutrient substrates in Petri plates. In both cases the experimenter lacks the possibility of choosing beforehand a definite microorganism from the mixture under the microscope and is obliged to act blindly. Inoculation of Petri agar plates with soil simultaneous with the extraction of slides from soil as in the experiments of Jensen is, in my opinion, even preferable, because in this case we may achieve by means of preliminary dilution better isolation of individual microbes, obtain larger colonies and keep them longer from contamination or from merging with other adjacent colonies.

Several times the question has been raised, whether the method of overgrow slides can be used for a quantitative determination of the soil's microbic population. Some research-workers considered it unsuitable for this purpose (e. g. Waksman, 1931), others, as Kriuchkova, made attempts to count the number of colonies per 1 cm² of the slide's area and obtained data comparable to the results of counts made by other methods.

It is of course evident that for the determination of the number of microbes per 1 g of soil, i. e., for the purpose which is pursued e. g. by the method of Winogradsky and its various later modifications, overgrow slides can be of no use. However for a comparative evaluation of the density of the microbic population in different soils or in one and the same soil under different conditions this method can be successfully used. In this case I think the common practice of counting individual cells should be substituted by counting the number of colonies in usual not-germinated preparations. By this figures would be obtained characterizing the active microflora of the soil in question under the conditions existing in it at the moment, as evidently only those microbes, which find in soil everything necessary for their development, will be able to multiply and give rise to colonies on a clean glass slide.

It remains to answer the question in what measure the method of

overgrow slides may be utilized for purposes of agronomical soil diagnostics alone, without the simultaneous application of other supplementary methods. The idea of determining the properties of soil on the ground of an analysis of the microflora inhabiting it deserves undoubtedly great attention. Its successful realization could be of great use in the reclamation of virgin land for agricultural purposes, and — as a more distant prospect — for the control of the current condition of soil and that of the dynamics of soil processes.

Contemporary geobotany presents a number of instances, how it is possible to form a rough idea of the quality of soil on the areas covered by plant communities by the character of these communities. This principle has been particularly well elaborated in forest research. It is, further, well known, that among higher plants there are many forms, typical for saline soils, for soils containing calcium, for various values of pH etc. All these facts induce us to think that in the microflora of soil, so rich in various representatives of the lower classes of the vegetable kingdom, it should be possible to find in the course of closer analysis many forms, which might serve as indicators for the evaluation of the chemical composition and physical condition of soil. It is quite easy also to imagine that, given a further, more deep and thorough, knowledge of the microbic population of soil, the investigation of the «microbic landscape» on overgrow slides might serve to the microbiologist as a base for judging of one or other property of soil at least in the same degree, in which this is within the reach of the geobotanist on the ground of his analysis of natural associations of higher plants. The variety of the pictures presented by the overgrow slides from various soils is, indeed, so great that there is nothing improbable in this idea. Work in this direction is extremely desirable, and it should begin, as I think, with a systematic study of the microbic landscape of different soils in their natural condition without complicating research in its first stages by the interference of the experiment.

Much is expected, as we have seen, in regard to soil diagnostics and to the evaluation of their current condition, from the so-called indicator forms in the sense of Uspensky. We have acquainted the reader with one of the attempts to find such forms among the soil's bacterial population in summarizing the experiments of Kriuchkova.

Without denying the great scientific and practical value of the idea laid at the base of these experiments, I must, however, say that the choice of bacteria as indicator forms cannot, in my opinion, be considered fortunate. What had to be done was to find such microorganisms which would respond to a definite condition of their surroundings, not only by an increase in growth and multiplication but by «morphological alterations» as well. Judging by Kriuchkova's description of her experiments with the two cultures she had isolated (cocci and rods), special importance was ascribed to this latter feature, i. e. to the morphological alterations. At the same time everyone, who has taken some interest in the morphology of bacteria, knows how little ground there exists for connecting various alterations in the structure, shape or size of bacteria with the action of some isolated definite external factor. The morphological language of bacteria, one might say figura-

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tively, is too poor to be useful as a ground for answering the questions of soil diagnostics. To be clearer, one and the same change of the shape of bacterial cells or of their structure may be produced by a great variety of causes. On the other hand the great susceptibility of microorganisms to the finest, almost too delicate for us, external changes may also become a source of serious mistakes in drawing conclusions in regard to the physiological condition of bacteria from their morphological characteristics. The bacterial «physiology of form» or the experimental morphology of bacteria, upon which, as Kriuchkova correctly observes, research of this kind should be founded, — is a science of the future and we cannot expect any great progress in this field in the next few years. One can but regret that the indicator forms were not chosen from among the microorganisms of other groups, more accessible to morphological analysis. We shall return to this question later.

After summing up the work of different authors with overgrow slides we arrive at the conclusion that up to the present moment this method proved sufficiently effective only in the investigation of a relatively narrow sphere of problems, that of the morphology and partly of the ecology of soil microflora. There are grounds to expect that it will prove useful also in the study of the correlations between the physical and chemical properties of soils on one hand and the character of their «microbic landscape» on the other. Such, it would seem, are the limits of the sphere of this new method's independent application. Further widening of this sphere implies its supplementing by other methods, as has been also noted almost by every author cited above.

II

The indicated above defects of the method of overgrow slides are mostly inherent to it and cannot be eliminated by any improvements or modifications. This circumstance induced me of late to work out another method for the direct observation of soil microorganisms which I described under the name of the method of soil chambers (Cholodny, 1934).

A small square soil plate 18×18 mm. in size is prepared on the surface of a slide with the aid of a special apparatus — the soil press — from the soil under investigation. The perfectly smooth upper surface of this soil plate is covered with a cover-slip. The plate is 1–2 mm. thick and has in its middle a cylindric cavity without soil, some 4 mm. in diameter. In this way a small chamber, filled with air and surrounded by soil, is formed between the slide and the cover-slip. If such a preparation is left for several days in a humid place at room temperature or in an incubator at 25° – 30° C, soon various microorganisms begin to grow into it; locating themselves partly on the inner surface of the cover-slip, where they can be without difficulty observed in vivo under the microscope at the greatest magnifications.

The soil chamber method has been as yet tested only by myself and in the Laboratory for Mycology of the Botanical Institute of the Ukrainian Academy of Sciences by Z. K. Gizhickaja with my close collaboration. This limited experience allows, however, to judge of the advantages and the defects of the new method and to draw some

conclusions in respect of its possible sphere of application to soil microbiology.

The chief advantage of the soil chamber method over that of overgrow slides consists, of course, in the possibility of observing the soil microflora in its living condition and to do this all through a considerable period of time, in the course of which take place the different phenomena of the growth and multiplication of microbes, their transference from one place to another, their death and destruction of their cells through autolysis or under the influence of other organisms, the displacement of one form of microbes by others etc. In short, the picture of soil life with all its intricate dynamics, with all the riches and variety of its phenomena is unfolded before the eyes of the observer, — it is true — only on a limited area and under the peculiar conditions of a contact of soil conglomerates with a clean glass surface. I think I shall not exaggerate the significance of this new method if I say that it makes for the first time soil transparent, allowing to the observer's eye, armed with a powerful objective glass, to penetrate its most intimate mysteries.

Even superficial acquaintance with the microflora of soil chambers is sufficient to make one see another advantage of this method. The obtaining of overgrow preparations involves the separation of the slide from the adjacent soil. With whatever care we shall execute this operation it will inevitably be bound with the harming and tearing of the larger soil microorganisms possessing thread-like organs, i. e. of fungi and, to a lesser degree, of actinomycetes. Sporangia of fungi, usually formed in cavities filled with air which are so abundant in almost every soil, are but rarely encountered in the overgrow preparations in the well preserved condition indispensable for the identification of their species. Soil chambers present ideal conditions for the development of fungi and actinomycetes and for the formation of their reproductive organs. Therefore in soil chambers we can not only see the natural, undistorted forms of growth of these microbes and achieve various delicate morphological observations, but can also identify them with the greatest convenience. This led us to the idea of utilizing soil chambers for the systematic study of soil microflora.

The first experiments in this direction were arranged in the Laboratory of Mycology of the Botanical Institute of the Ukrainian Academy.

The chambers used in these experiments were 1.5 mm. deep. The area of the soil layer on the preparation was 18×18 mm. This layer was covered with a cover-slip of the same or of a somewhat larger (e. g. 24×24 mm) size. In the latter case the edge of the cover-slip protruded beyond the soil layer and the fungi obtained the possibility to grow not only inside the chamber but also on the periphery of the soil layer, between the slide and the cover-slip. This slight modification allowed to detect also those forms which because of their higher need in oxygen could not successfully develop inside the soil chambers with their somewhat lower content of this gas, especially in the case of a compact ramming of the soil layer.

Usually 1 p. c. of citric acid was added to the soil before the experiment. Simultaneously with the preparation of soil chambers the soil

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was plated on glucose-peptone-agar, acidified with citric acid. The soil with which these experiments were conducted had been taken in a foliage forest in the neighbourhood of Kiev (Golosseyevo). By means of chamber investigations 18 forms of fungi belonging to 15 different genera were found in it. The majority of these forms were hyphomycetes (Hyphales — 11 genera) and even their species could be identified. Five forms, belonging to the genera *Mucor*, *Penicillium*, *Aspergillus* and *Fusarium* could be identified only as far as their sections as the identification of these fungi is based on such characteristics which can be established only by means of their cultivation in artificial nutrient substrates (e. g. colour of the colonies, pigmentation of agar etc.). Particular interest is presented by the fact that among the forms found in the chambers there were two (*Coëmansia reversa* Van Tiegh and *Helicomyces candidus* Corda), which had been never and under no conditions found in agar plates, either of the above described composition or on any of its modifications. On the contrary no forms, which were not encountered in the chambers, could be found on agar plates.

Thus, judging by this first experience, the soil chamber method may be successfully applied to the study of soil microflora and permits to detect in it forms, which we are unable to find by plating soil on nutrient agar. At the same time this method makes the task of the research-worker much more rapid and facilitates it, ridding him of a number of operations involved by the preparation and sterilization of nutrient solutions and of the necessity to wait till visible colonies develop on the plates, to transfer them into separate test-tubes and to make many preparations for microscopic study, preparations which moreover, never present such unimpeached pictures, as soil chambers do. Attentive study of one—two chambers can perfectly substitute the investigation of 10—20 preparations made in the usual way. Only in one respect the method of plating on solid nutrient substrates cannot be substituted by the method of soil chambers — in that of the identification of those species which are identified on the ground of characteristics observed macroscopically in pure cultures.

What has been said above about fungi is to a high degree just of the actinomycetes. The matter stands worse with bacteria because these have to be observed chiefly in the narrow ring-shaped zone immediately contiguous to the soil edge, and only few bacterial forms penetrate in the course of time into the central part of the chamber utilizing as their path for this migration the dying off hyphae of the fungi. However, I was able by comparing the bacterial flora of soil chambers with that of overgrow slides from the same soils to establish a far going similarity of the pictures obtained by each of these methods.

It should be noted that the prevalence of one or other form observed in soil chambers prepared from the same soil sample depends first of all on the soil's moisture. As a rule fungi prevail at low moisture, and bacteria at a high one. The same is just of overgrow slides.

Already in my first communication on the soil chamber method I mentioned that artificial alterations of the soil's chemism provoke sharp changes in the character of the microflora observed. To compare both my methods in this respect I investigated in what manner pro-

ceeds the composition of cellulose in the soil chamber — a process which I had studied earlier in its bacterioscopic aspect on overgrow slides (Cholodny, 1930). For this purpose a certain amount of filaments were scratched with the point of a lancet off a bit of dry Swedish filtering paper, laid on a clean glass slide. The filaments were carefully transferred by means of pincers to the surface of a soil plate, prepared in the press immediately before, and placed on the edge of the chamber so that one part of each bit would lie on soil while the other would protrude into the chamber. After the chamber was covered as usual with a cover-slip and the preparation placed in a space saturated with water vapour. Observing such preparations day by day I was able to follow under conditions of excellent visibility all the stages of the process of decomposition of the cellulose filaments by soil microbes invading them. Without dwelling in greater detail on these observations I shall indicate only that in different soils as might be expected, this decomposition proceeded differently both in regard to its rate and in respect of the character of microorganisms decomposing cellulose. In some soils the main work fell to the part of fungi, in others it was chiefly executed by bacteria and actinomycetes. In one and the same soil the character of the process varied depending on external conditions (temperature and moisture). Sometimes the destruction of the filament was begun by one microbe and ended by another. The possibility of observing all these changes as oculos and to follow it step by step fixing the attention at will on one and the same filament is an invaluable advantage of the soil chamber over all other methods applied before in this field of research including that of overgrow slides.

Is it possible to apply the soil chamber method to soil diagnostics? As we have seen several paths for the mastering of this difficult and intricate problem are arising in modern microbiology. On one hand it is the study of the "microbic landscape", i. e. the study of the soil's microbic population in its totality and the finding-out of the most characteristic of the tested soil's biocoenoses, colonies and forms of growth of various microorganisms; on the other — the isolation and establishing of particularly typical for this soil microbic species, indicators of its content in various substances, and finally — the study of the "form physiology" of the individual indicator species, i. e. of their morphological changes in connection with definite changes in the factors of their soil environment. In respect of enlarging our knowledge of the natural associations of microorganisms in soil the chamber method may hardly give much new in comparison with that of overgrow slides. But in respect of the two other directions mentioned above one may, it seems to me, expect from it considerably more. The excellent development of various fungi in soil chambers and the relative easiness of their identification and isolation induce us to think it is just in this group of soil microorganisms that the indicator forms, on the thorough investigation of which rational microbiological soil diagnostics are to be built, should be sought. There is hardly any need to argue the point that fungi deserve preference to bacteria in this regard. Piercing by its hyphae relatively larger amounts of soil the organism of a fungus may form a more reliable indicator of its average content of one or

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other substance which we are interested in, than bacterial colonies: abundant or scarce development of the latter on the overgrow slide may depend on purely local causes, e. g. on the presence of "local foci" of certain nutrient substances. On the other hand, if we should seek approaches towards soil diagnostics in the experimental morphology of the microorganisms inhabiting soil according to the scheme of Uspensky, in this case also fungi represent a doubtlessly more suitable object of research thanks to the comparatively large size of their cells and the greater ease with which their morphological characteristics may be distinguished.

The method of overgrow slides has been tested in the course of the last four years by many bacteriologists in different countries; it begins apparently to enter into the practice of wider agrobacteriological researches. Experience of work with the soil chamber method is as yet too limited for a sufficiently grounded evaluation. This however was not my purpose. I would desire only that my communication would be a stimulus for further experiments in the indicated direction. I am sure that the methods of direct observation of soil microflora will play a not unimportant part in the progress of soil microbiology and that they deserve the serious attention of all scientific working in this field.

LIST OF REFERENCES

- Cholodny N. Ueber eine neue Methode zur Untersuchung der Bodenmikroflora. Arch. f. Mikrobiol., I, 4, 1930.
- Cholodny N. To the study of soil microflora (Ukrainian). Papers of the phys. math. section of the Ukr. Academy of Sc., V, 1930.
- Conn H. J. The Cholodny technic for the microscopic study of the soil microflora. Zbl. f. Bakt., II Abt., 87, 1932.
- Demeter K. J. Ueber die Brauchbarkeit von Cholodnys mikroskopischer «Aufwuchsplattenmethode» bei mikrobiologischen Bodenuntersuchungen. Zbl. f. Bakt., II Abt., 88, 1933.
- Jensen H. L. Contributions to the microbiology of Australian soils. II. Proc. Linn. Soc. of New South Wales, 59, p. 3—4, 1934.
- Kammerman P. Note on the effect of the type of glass in studying the microflora of the soil by the Cholodny technic. Soil Research, IV, 1, 1934.
- Kriuchkova A. P. On the study of the ecologic variability of microorganisms in connection with agronomic diagnostics. (Russian) Microbiology, III, 2, 1934.
- Marszewska-Ziemiecka J. New methods for the study of microorganisms decomposing organic substances in soil (Polish). Roczniki nauk rolniczych i lesnych. T. 33, 1934.
- Uspensky E. E. Results and problems of microbiological research of soil and manure in connection with the works of the Fertilizer Research Institute. Transact. of Inst. on Fert. 108, 1933.
- Waksman S. Principles of Soil Microbiology, 2-nd Edition, 1931.

SOIL MICROFAUNA — AN INDICATOR OF SOIL ACTIVITY

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One of the most fundamental problems, on the solving of which the successful development of human society largely depends, is that of soil fertility.

Fertility may be defined as the resultant of the activity of soil processes directed by man toward their greatest efficiency.

The methods of determining the quantitative and qualitative aspects of soil activity which have been in vogue up to the present suffer from one-sidedness and have failed to solve questions of soil evaluation.

While it has been theoretically recognized that the soil is a complicated biocomplex, in practice soil science has included the data of the vegetational components of this complex only to a very small extent, and has almost entirely neglected the data regarding its animal components. But an understanding of the intensity of soil dynamics and of its character can only be arrived at by an analysis of all the components of the soil, including also the zoo-components.

The zoo-components of the soil biocomplex include a great many groups. Among these the protistofauna have been much more completely subjected to biological analysis than the others; so much so, in fact, that their behavior may now be used as an additional indicator for the dynamics of soils.

Notwithstanding numerous discoveries of protozoa in the soil by many investigators, beginning with 1837, up to the present time, the protistofauna has been almost completely ignored. Those who deny the significance of protistofauna take the position that the soil protozoa are introduced into the soil from manure and water. However, experiments with manure have shown that fresh animal manure is almost free from protozoa. Analysis shows that groups of soil protozoa occur in differing proportions in the composition of different soils, (see Table 1) and that these proportions seldom correspond to the proportions characteristic of the water representatives of those groups. The morphological features of the soil protozoa also distinguish them from other protozoa; as a rule they are very small, and this must be regarded as a feature of adaptation. Moreover, many of these protozoa which populate the soils of Middle Asia must be assigned to species not found in water. Finally, experiments in watering the soil with water from

Table 1

Ratio between groups of protozoa in the soils of Middle Asia (in percents).

	Fl.	Rh.	Cil.
I. On the territory of Middle Asia as a whole	32.7	35.6	31.7
II. The Golden Horde	50	35.5	14.5
III. Kara Kum Desert	35.7	42.8	21.5
IV. Valley of the Murgab River	22.6	25.8	51.6
V. The Kaplanbek tract	36.7	36.7	26.6
VI. The Valley of Ferghana	31.8	36.4	31.8
VII. The State Farm of Pakhta-Aral	35.3	41.2	23.5
VIII. Valley of the Chirchik River	35.9	39.1	25.0

irrigation systems have proved that the soil is not enriched by protozoa from the irrigation water (see Table 2). Similarly tests of 67 varieties

Table 2

The effect of distilled and irrigation water on the qualitative and quantitative composition of soil protistofauna (According to Belyayeva).

	Ak-Kavak		Pakhta-Aral	
	No. of Individuals	No. of Species	No. of Individuals	No. of Species
Air-dried soil	102500	15	12350	9
Watered from irrigation system	216000	17	276000	14
Watered with distilled water	116000	21	214000	14

of soil have shown that the upper horizon is very seldom richer in protozoa than the horizons lying below the surface, and this excludes the possibility of the enrichment of the soil by cysts falling from the air.

The question as to whether the protozoa in the soil are in a physiologically active state must be answered affirmatively. A proof of this is the variation in the number of protozoa in soils protected from any accessions of cysts from air or water, that is, protozoa in the soil are capable of reproduction (see Table 3). When drops of protozoa culture are introduced into sterile soil, the protozoa are capable of spreading through the soil in various directions and at varying rates of speed. This indicates capacity of movement—that is, their activity. The author has arrived at the conclusion that it is only under conditions of exceptional dryness (e. g., the summer season in the scorching sands of the Kara-Kum Desert), that the soil protozoa remain in an encysted state; as a rule soil protozoa are found in a physiologic

Table 3

Variations in the number of protozoa in the soil of a cotton field of the State Farm of Pakhta-Aral (Golodny Steppe).

Date	Horizon 0 — 3	Horizon 3 — 20	Horizon 20 — 30
27/V	60000	105500	
16/VI	50000	152500	60500
11/VII	113650	66100	52150
22/VII	116600	202750	116050
1/VIII	116200	112000	70100
11/VIII	211100	76000	11000
21/VIII	212000	120000	15000
1/IX	166200	162000	100000
24/IX	207200	107000	
1/XI	268200	221000	

active state. The constant activity of the protozoa in the irrigated soils of Middle Asia is beyond doubt.

We must wholly discard the idea of the existence of soils lacking in protozoa investigations of an enormous number of different kind of soil comprised within the vast territory of Middle Asia (1,200,000 sq. km.) disclose protozoa in the soil everywhere in the following regions: the sandy deserts of Kara-Kum and Kizyl-Kum, the clayey desert of Bedpak-Dala, the fine earth virgin soils of the Golodny Steppe, the oases of Tashkent, Ferghana and Samarkand, the arid foothills with wormwood vegetation, alkali soils (solonetz) and salines (solontchaks) etc. The absence of protozoa in soil is a phenomenon quite as rare as the absence of protozoa in any water basin. The soil protozoa do not fit into any zoo-geographical scheme owing to their high biotic potential. However, it is necessary to note that it is not impossible that further investigation may demonstrate the existence of zoo-geographic subdivisions for protozoa as well. A comparison of the composition, according to species, of the soil protistofauna of Eurasia and North America, shows that 15 per cent of the forms found on these two continents are the same. An analysis of the groups shows that 10.6 per cent of the common forms are Flagellata, 19 per cent — Rhizopoda and 16.7 per cent — infusoria. Thus two of the zoo-geographical regions, the Palearctic and the Nearctic, are characterised by a difference in their soil protistofauna.

In the distribution of soil protozoa, biotopes and microtopes hold an important position, that is, factors of an ecological order. The author has studied 67 different orders of biotopes, a greater number than has hitherto been identified in the literature of the subject. Among the representatives of soil protistofauna which have been discovered in Middle Asia, 50 per cent have been found in only one place (see Table 4). The number of forms common to two, three, four, five or more points decreases rapidly; no one common form is found in Middle Asia in as many as seven different places. An analysis of the distribution of soil protozoa within narrow territorial boundaries pro-

Table 4

The distribution of soil protozoa by biotypes on areas of different sizes in Middle Asia, in percentages of the total number of all forms.

	№	Protozoa	Flagel- lata	Rhizo- poda	Ciliata
In Biotypes of large areas	1	49	44	48.5	54.5
	2	19.3	14.5	27	15
	3	13.4	18	11.4	12
	4	4.9	3	1.7	25
	5	11.5	15	11.4	26
	6	1.9	5.5	0	0
	7	0	0	0	0
In different soils of the Kara-Kum	1	78.5	60	83	100
	2	10.7	20	16.4	0
	3	3.6	0	16.4	0
	4	3.6	10	0	0
	5	3.6	10	0	0
	6	0	0	0	0
In different soils of the Murgab River Valley	1	73.3	69.2	66.7	100
	2	11.5	7.7	22	0
	3	3.8	7.7	0	0
	4	3.8	0	11.1	0
	5	3.8	7.7	0	0
	6	3.8	7.7	0	0
	7	0	0	0	0
In different soils of the Chirchik River Valley	1	54.7	39.1	56	75
	2	20.3	26	20	12.5
	3	7.8	8.7	12	0
	4	4.7	13	0	0
	5	0	0	0	0
	6	3.1	4.4	0	6.3
	7	1.6	0	4	0
	8	1.6	0	4	0
	9	1.6	4.4	0	0
In different soils of Pakh- ta-Aral (Golodny Steppe)	1	25.5	22.2	33.3	16.6
	2	23.5	16.6	28.9	33.4
	3	13.8	11.2	5	25
	4	37.2	50	33.3	25
In different soils of the Valley of Ferghana	1	18.2	0	37	19
	2	22	14	13	43
	3	4.6	0	13	0
	4	14	29	0	14
	5	0	0	0	0
	6	14	14	25	0
	7	9	14	0	14
	8	5	0	0	14
	9	5	14	0	0
	10	0	0	0	0
	11	0	0	0	0
	12	5	14	0	0
	13	0	0	0	0
	14	5	0	13	0
	15	0	0	0	0

Horizon	Kara-Kum				Valley of Murgab R.				Golden Horde				Pakhta-Aral			
	Pr	Fl	Rh	Cil	Pr	Fl	Rh	Cil	Pr	Fl	Rh	Cil	Pr	Fl	Rh	Cil
0-3	—	—	—	—	18	4	5	9	—	—	—	—	58	18	22	18
0-10	14	10	4	2	—	5	3	3	18	8	6	4	—	—	—	—
1-15	—	—	—	—	19	7	4	8	—	—	—	—	—	—	—	—
1-15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3-20	—	—	—	—	9	4	2	3	—	—	—	—	51	18	16	17
10-20	7	4	2	1	—	—	—	—	17	8	8	1	—	—	—	—
25-30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20-30	—	—	—	—	—	—	—	—	14	6	4	4	33	13	13	7
30-40	—	—	—	—	10	4	4	2	—	—	—	—	—	—	—	—
40-50	—	—	—	—	—	—	—	—	13	7	4	2	—	—	—	—
50-55	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50-60	3	1	1	1	7	4	2	1	—	—	—	—	—	—	—	—
60-70	6	4	2	—	—	—	—	—	13	7	4	2	—	—	—	—
70-80	4	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—
80-90	3	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—
90-100	2	2	—	—	11	4	6	1	12	8	2	2	—	—	—	—
150	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
200	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Kaplan Bek				Savai				Uch-Kurgan				Combinat				Harpai				Bukhara			
Pr	Fl	Rh	Cil	Pr	Fl	Rh	Cil	Pr	Fl	Rh	Cil	Pr	Fl	Rh	Cil	Pr	Fl	Rh	Cil	Pr	Fl	Rh	Cil
—	—	—	—	12	4	5	3	14	5	5	4	8	3	3	2	8	5	1	2	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	—	4	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
31	11	12	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	13	5	5	3	9	3	3	3	4	2	1	1	9	5	2	2	16	6	5	5
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15	5	5	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
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—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	11	6	2	3
—	—	—	—	8	4	3	1	5	2	2	1	5	3	1	1	5	4	—	4	—	—	—	—
11	5	5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
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—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	2	2	—
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1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	2	—
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vides a high percentage of „singlets”. Thus, in the comparatively limited area of the clay semi-desert of the Golodny Steppe which abounds in microbiotopes, the percentage of “singlets” rises to 75. It appears, then, that representatives of soil protozoa are not cosmopolitan — ubiquists — as some investigators have tried to maintain, and they may, therefore, serve as indicators of the ecological condition of the soil, which they populate. Among the animal forms three ecologic categories stand out from among the other groups of soil protozoa — pedobionts, pedophils and pedoxens. The first category includes those forms which only inhabit soil with its specific conditions. It is not over bold to state that such an ecological group does exist. The second comprises those forms which find the conditions in the soil equally favorable to life as those in the water. The third includes those forms which fall into the soil (out of the air or the water), and are able to survive in the soil only when it has a high percentage of moisture. The author estimates that the pedobionts represents 12.2 per cent of the total number of soil protozoa, the pedophils, 26.4 per cent and the pedoxens, 61.8 per cent. It is evident, therefore, that the soil lags far behind water in which the number of hydrobionts is incomparably greater. The protozoa are distributed, in accordance with the systematic groups, within the three ecological categories as follows: of the pedophils, the Flagellata constitute 46 per cent, the Rhizopoda 30 per cent and the Ciliata 24 per cent; of the pedoxens 31.3 per cent are Flagellata, 38.9 per cent Rhizopoda and 31.8 per cent Ciliata.

Among the pedoxens the Ciliata are apparently absent; the Flagellata and Rhizopoda occur in equal percentages.

An interesting fact is the absence from the composition of the soil protistofauna of the forms of the species *Paramecium*, *Coleps*, and others which are so widely distributed in water biocenoses.

The data regarding the distribution of soil protozoa according to elevation above sea level are still inadequate. However, we have, some information up to considerable heights — over 4,000 m. (Pamir).

The number of species of protozoa varies, depending on the number of microbiotopes in a biotope. The largest number of species found in any one biotope is 60, but it is usually somewhat less in the soil biotopes of Middle Asia. A comparison of the species composing the various biotopes and microbiotopes of water in Middle Asia with similar ones in the soil shows that the soil biotopes and microbiotopes are poorer in species than those of the water. This must be explained by the general poverty of the soil protistofauna in species.

The qualitative and quantitative composition of the protistofauna depends largely upon the depth at which the layer inhabited by them lies; soil protistofauna is distributed in layers. In Middle Asia the soil protozoa, in distinguishable quantities, extend down to a depth of from 160 to 180 cm. Their presence at greater depths — to as much as five to ten ms, depends upon the activity of earth borers — termites, ants and earth worms (see Table 5.) The greatest number of species in the soil biocenoses is adapted to the upper horizon—that is, from 70 to 80 per cent. Deepest of all, and preserving a considerable number of species, are the Flagellata; somewhat higher the Rhizopoda push

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in, Ciliata disappear from the soil biocenose, very rapidly with depth. The composition by species of any horizon or of any variety of soil is not stable, but subject to variation.

The number of individual protozoa in the soil is subject to very great variation and depends upon a whole sequence of factors — soil, variety, its horizon, the season of the year, the vegetation, the manner in which the soil is worked, etc. In the soils of Middle Asia the author observed great differences in the quantitative composition of protozoa; in rare cases the maximum may rise to 1,030,000 per gram of soil, while the minimum may fall to 10 individuals per gram — that is, practically none. However, in Middle Asia soils with a minimum below 100 individuals per gram are very rare exceptions. The greatest density of protistofauna in the soils of Middle Asia falls far short of the theoretically computed maximum density; for the Flagellata $125,10^6$ per gram, for the amoeba, 10^7 and for the infusoria, 450,000 per gram.

The density of the protistofauna decreases as a rule in a downward direction. The protistofauna of horizon 0—20 or 0—30 cm. is the most dense. Usually horizon 20—25 or 25—30 differs sharply in the density of its population from the layers lying both above and below, thus constituting a "biological leap". In a soil which has been subjected to long-continued tillage, the boundary between the layer of the "biological leap" and the layers lying above is somewhat ironed out. In some soils, such as the sands of the Kara-Kum Desert, a second layer with the character of a "biological leap" is observed at a depth of 70—80 cm. The density of the protistofauna is subject to considerable variation, but for each variety of soil there is a certain amplitude of density characteristic of it, within which the variations occur (see Table 6). In the majority of cases the Flagellata are strongly represented

Table 6

Variations in the density of protistofauna in Pakhta-Aral (Golodny Steppe) during a period of six months.

Horizon	Group	Virgin Land	Cotton, 1st yr.	Cotton, 4th yr.	Alfalfa, 4th yr.
0—3	Pr	130000	142000	210000	315000
	Fl	50000	53000	110000	151000
	Rh	63500	83000	87000	102000
	Cil	17000	6000	13000	61000
3—20	Pr	85000	124000	182000	225000
	Fl	34000	63000	85000	145000
	Rh	46000	61000	94000	79000
	Cil	5000	460	500	1000
20—30	Pr	3500	50000	30000	30000
	Fl	2500	22000	52000	45000
	Rh	1000	27000	27000	35000
	Cil	10	50	700	700

numerically; next come the amoeba and the infusoria are usually fewer than the first two groups. In the soils of Middle Asia an inverse ratio between the number of species and the number of individuals of protozoa, as is the case with water biocenoses, has not been observed (Table 7).

Table 7

Ratio between number of individuals and number of species by groups of soil protozoa, in Pakhta-Aral (Golodny Steppe).

Horizon	Virgin Soil						Cotton, 1st yr.					
	Fl		Rh		Cil		Fl		Rh		Cil	
0—3	48000	10	66000	10	16000	6	52000	7	100000	13	600	6
3—20	32000	4	45000	6	5000	4	60000	12	51000	9	500	3
20—20	2500	7	1000	6	20	1	20000	5	27000	9	60	1

Horizon	Cotton, 4th yr.						A l f a l f a					
	Fl		Rh		Cil		Fl		Rh		Cil	
0—3	130000	10	95000	11	14000	10	148000	15	101000	16	60000	15
3—20	94000	12	123000	10	600	8	143000	16	79000	11	1000	13
20—30	52000	10	27000	9	700	3	50000	9	50000	10	800	6

Other conditions being equal, the degree of concentration of mineral salts is a factor which greatly influences both the qualitative and quantitative composition of soil protistofauna (see Table 8). The greatest

Table 8

Density of protistofauna in two soil samples from the State Farm "Yussupov's Combinat" in the Ferghana District.

No. of Sample	General characteristics	Dense residue	Horizon	Pr	Fl	Rh	Cil
84	Virgin meadowland	2.32	0—3	110500	100000	5000	5500
			3—20	100000	50000	50000	
			20—30	1150	600	500	
168	Virgin meadow solonchak	4.82	0—3	600	550	50	
			3—20	600	600		
			20—30	600	600		

resistance to high concentrations of mineral salts (within the maximum) show the Flagellata in the soils of Middle Asia, especially the two forms, *Oicomonas termo* and *Oicomonas mutabilis*. The Rhizopoda are less resistant to high concentrations of salts. In some cases the density of the distribution of the protistofauna may be divided according to the content of salt in the soil into two groups. Thus, in the semi-desert serozems (gray soils) densities from 300—1,000 individuals per gram correspond to 28—138 tons of salts per hectare; 20,000—60,000 individuals to 15—28 tons; 300,000—400,000 to a much lower content of salts in horizon 0—25 cm. The qualitative content of mineral salts has an influence on the density of the protistofauna. In the soils of Middle Asia the influence of Na_2SO_4 on protozoa is the most noticeable.

The organic components of the soil also affect the species and numerical composition of the protistofauna. The density of the protistofauna increases in proportion to the increase in the content of organic matter. The markedly increased density of the protistofauna in those parts of the soil where the holes of termites, ant and earth worms pass, is explained by the presence of organic matter. The amoeba show a special sensibility to the content of organic substances in the soil, when they have not yet been disintegrated to any considerable degree. In the presence of simple products of the disintegration of organic matter, the Flagellata develop rapidly in the soil.

Moisture is a factor which has a decisive influence on the development of soil protozoa. When the moisture falls below 15 per cent, the protozoa become encysted. In this state soil protozoa may live for a very long while and exhibit an enormous endurance. In unirrigated, virgin soils the protozoa show a sharp increase of density during rainy periods. In the irrigated soils of Middle Asia, each watering calls forth a sharp increase in the number of protozoa several days later, with a subsequent fall in their number. The influence of watering is clearly shown by the high points of the curves of propagation of protozoa in the upper horizons; the peaks of these curves flatten out more and more with depth. The results of watering are usually cumulative, so that with each watering the peaks of the curve of multiplication rise constantly higher and higher.

The influence of temperature on the density of soil protistofauna is also very great. Representatives of the soil protistofauna endure heat within wide limits. In the sand of the Kara-Kum Desert the cysts of the protozoa survive temperature higher than 65°C; this indicates a high temperature adaptability of the protozoa of the hot zone. The most favorable horizon as regards temperature is that from 15 to 20 cm. where the temperature does not rise above 25 to 27°C. In regions where periods of moisture with low temperatures alternate with long periods of little moisture and high temperatures, the protozoa employ the encysted state for the process of reorganisation of their cell apparatus, and often for intra-cyst reproduction. This explains the different times at which the soil protozoa emerge from the cysts when the latter are placed in a nutritive solution.

High temperatures combined with a high degree of moisture favor the reproduction of the soil protozoa; therefore in irrigated soils the

protistofauna increase spontaneously in density from spring to the late autumn. If the moisture is insufficient, the high temperature has no such effect; therefore in irrigated soils the density of the protistofauna reaches its maximum at the end of spring, decreases during the entire summer and rises to a second maximum at the beginning of autumn. Thus the curve of the development of the soil protistofauna is an index of the degree of moisture in the deep horizons of the soil.

The texture of the soil is reflected in the qualitative composition of the protistofauna. Soils with fine pores provide shelter only for very minute forms of protozoa, chiefly Flagellata. Soils with large pores are inhabited by large forms. Thus the qualitative composition of protozoa in any horizon of the soil or in any of its varieties, may serve as an indicator of the true texture of the soil and of the distribution and size of the soil pores, whereas by other methods it is possible to determine only the general porosity of the soil.

Among the protozoa found in the soils of Middle Asia, the method of nourishment is known with any degree of approximation for only about 40 per cent of all the forms. The Ciliata absorb nourishment in the greatest variety of ways; next follow the Flagellata and Rhizopoda. The Flagellata include the greatest number of true bacteriophages, while the Rhizopoda are, to a considerable degree, polyphage, showing a high percentage of mixed feeding (see Table 9). There are

Table 9

Distribution of groups of soil protozoa according to methods of feeding.

	Bacteriophages	Flagellata	Infusoria	Mixed feeding	Feeding on algae	Osmotic
Flagellata	37.50%			28%		33%
Rhizopoda	25%			65%	10%	
Ciliata	13%	6.5%	10.5%	44%	19.5%	6.5%

a considerable number of forms of soil Flagellata of very great importance which are nourished exclusively by osmosis. We may assume that among the soil Flagellata there are from 60 to 70 forms which are nourished exclusively or chiefly by osmosis. Among the Rhizopods the phagocysts or forms nourished by bacteriae greatly predominate. The proportion of these or of other forms in the soil biocenoses furnishes an indication of the content in the soil of soluble or insoluble organic matter and of the extent to which it has been enriched by vegetable and animal detritus.

It is not only the soil factors properly which have a selective influence on soil protistofauna, but also the plants which are rooted in the soil. In the sands of Kara-Kum the density of the protistofauna in the area of the root systems of *Arthrophyton haloxylon* and of *Arth. perdicum* is different. The same phenomenon may be observed in the semi-desert fine-earth soils planted to cotton and alfalfa.

The soil protistofauna, while affected by the mutual action of the factors which surround it, is itself a source of various influences upon

the soil. There can be no doubt, for example, that the protistofauna influences the character of soil dispersity. In comparing a number of stages of soil dispersity, such as: the increase of dispersity with increase of moisture, the different periods required by different soils to change their dispersity, the definition of the greatest coefficient of dispersity in alfalfa plots at a horizon of 0—12 cm. (a horizon of a low density of protistofauna in alfalfa fields) — all this leads to the conclusion that the soil protozoa may alter the dispersity of the soils in which they live. This change proceeds from the influence of the protozoa on the bacterial flora as well as from the rapid reproduction of the very minute Flagellata which have a body diameter of less than 5μ .

The soil protistofauna may serve as an indicator for the degree and character of activity of the soil. It has been established by the author that tilling the soil and introducing fertilizer into it not only increases its productivity but also stimulates the reproduction of the protozoa which populate this soil. On the other hand, when the productivity of soil becomes less, it is accompanied by a decrease in the number of protozoa. By calculating the increment in the number of protozoa in proportion to the years that the soil has been under cultivation, it is possible to establish a "coefficient of activity" for the soil. This "coefficient of activity" changes according to the kind of soil and the horizon. For cotton fields in one of the regions of Middle Asia this "coefficient of activity" was found to equal 1.33 (see Table 10). This

Table 10
Coefficient of soil activity in the soils of Pakhta-Aral.

Horizon	Virgin Soil	Cotton, 1st yr.	Cotton, 4th yr.
0—3	1	1.33	1.7
3—20	1	1.7	2.3
0—20	1	1.33	2.3

coefficient does not remain stable but decreases rather rapidly with the years that the soil is under cultivation. With good tillage the "coefficient of activity" remains positive for a number of years, but with poor tillage the "coefficient of activity" may even be a negative one. Similarly changes in density at various times of the year may provide an index of the activity of the soil during this period of time as well as of its trend. The "coefficient of activity" of the soil may thus serve as a kind of "soil pulse" indicating the intensity and direction of soil dynamics. This "pulse", by calling timely attention to the character of the soil processes makes it possible to anticipate a decrease of soil activity.

As the result of a determination of the number of protozoa in a definite volume of soil at fixed periods of its life, considered as a measure of soil activity, the author has divided all the soils of Middle Asia into five categories.

1. Extremely inactive soils with a content of 1,000 individuals per gram of soil.
2. Somewhat inactive soils with not over 20,000 individuals per gram.
3. Moderately active soils, with not over 100,000 individuals per gram.
4. Active soils, with a content of not over 500,000.
5. Very active soils, with a content of over 500,000 individuals per gram.

Soil protistology is only one of the chapters of a synthetic discipline — pedobiology — which studies the laws of a specific complex — the soil. It is necessary to approach systematically the problem of the development of pedobiology (as has already been done for hydrobiology). The subject is not exhausted by the study of one component of the soil biocomplex but embraces the biology of many vegetable and animal organisms which inhabit the soil and determine its dynamics.

It is important to give systematic consideration to the science of pedobiology in the soil institutes (especially in the Soil Institutes of the Academy of Sciences and the Lenin Academy of Agriculture), to establish standardized methods of pedobiological analysis and to begin to prepare staffs of specialists — pedobiologists — as has already been done for hydrobiology.

Soil Type	Number of individuals per gram	Number of individuals per gram	Number of individuals per gram
1. Extremely inactive	1,000	1,000	1,000
2. Somewhat inactive	20,000	20,000	20,000
3. Moderately active	100,000	100,000	100,000
4. Active	500,000	500,000	500,000
5. Very active	Over 500,000	Over 500,000	Over 500,000

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EVALUATION OF THE PHOSPHORIC ACID AND POTASSIUM IN THE SOIL BY MEANS OF A MOULD CULTURE

W. S. BUTKEVICH

Moscow

About thirty years ago, in 1906, a microbiological method for measuring the phosphoric acid and potassium in the soil was proposed for the first time by the author of this article. The method suggested consisted in substituting for the vegetational culture commonly used for this purpose, a mould culture in a nutrient solution, to which a known amount of the soil under test was added as a source of phosphoric acid or potassium. It was assumed that since the mould, like the higher plants, demanded phosphorus and potassium for its growth, the content of these elements in the soil tested would be reflected in the weight of the growing film in the same way as in the development of plants in vegetational cultures. Therefore it seemed possible to replace the cumbersome vegetational tests, requiring large amounts of soil and a considerable expenditure of time, by other tests requiring relatively little space, soil and time.

During the same period (1907—09) the method was studied by A. Kostseletsky in the laboratory of the author, from the standpoint of its practical application, and it was definitely demonstrated that, after elaborating some details, it could be used with success for determining at least two agriculturally important elements of the soil — phosphoric acid and potassium. Kostseletsky's work was not, however, completed, and did not give the method a final shape.

Recently this method has again attracted some attention — first in Germany where two modifications of it have been proposed, a simplified one by Benecke and Söding, and another, more precise and elaborate, by Niklas. Later, a further modification of the method, uniting some features of the modifications of both Benecke and Niklas and influenced by them, was proposed in our own country in the work of Simakova and Bovshik published in 1932.

All these experimenters, beginning with Kostseletsky, in elaborating this method, used cultures of *Asperg. niger*. The investigations made more recently by Rubin and Naidina in our laboratory have showed that this mould may be substituted by another, *Asperg. oryzae*, which possesses some advantages over the former. It produces less acidity and causes a greater increase in the weight of the mycelium per unit

of phosphoric acid consumed, and therefore its growth detects and reflects more precisely differences in the phosphoric acid of the substratum being tested. This fact was established both for soils and for phosphate fertilizers.

The relatively low acidity peculiar to *Asp. oryzae* (pH about 4) does not allow its cultivation without preliminary sterilization of the substrata to be tested as in Niklas' method with *Asp. niger* cultures. However, the sterilization of air-dry soils in the autoclave, as our experiments show, is an operation which is perfectly admissible in this case and causes no considerable changes in the condition of the substances tested. This is further confirmed by the data of Simakova and Bovshik. Working with sterilized substrata is also more reliable when *Asp. niger* is employed. According to our observations and to the data reported by Niklas himself, the high acidity recommended by him when working with the latter mould, does not guarantee full security against the development of foreign organisms.

A comparison of results obtained by determining the supply of phosphoric acid and potassium by means of *Asp. oryzae* cultures with those obtained from vegetational and field tests of the same soils, shows that in most cases they coincide sufficiently and that *Asp. oryzae* cultures—so far as the problem of the presence in the soil of the two elements referred to is concerned—may successfully be substituted for vegetational tests. In some cases this problem can be better solved, even within a wider range, by mould cultures than by vegetational tests, as the latter solves it only within the limits of the plant's need for the substances investigated. From this point of view the evidence furnished by the mould culture may serve as an essential supplement to the data obtained by vegetational tests. The mould culture method has a supplementary significance also in cases where the influence of the substances tested on the development of the plant is limited by other factors besides the content of these substances in the soil. In such cases the difference in the data from the two tests may supply valuable indications of the presence of such limiting factors and of the necessity of investigating and eliminating them.

Experiments conducted on carbonate soils have shown that though the presence of calcium carbonate does not affect the mould's absorption of potassium, it does considerably decrease its capacity to utilize the phosphoric acid present in the soil. Therefore, in testing carbonate soils for phosphoric acid it is necessary, in addition to the regular cultures, to run parallel tests on soil in which the carbonates have been previously destroyed by its treatment with acid.

In adapting this method for practical use, the question of a standard measure for evaluating the results obtained deserves special attention.

Niklas suggests a scale of limit myceliums, based on preliminary tests of soils containing phosphoric acid and potassium in varying amounts, which could be used to evaluate the results obtained from mould cultures. Objections may be made to this method from various points of view. In the first place, it would always be necessary to provide exactly the same experimental conditions for every test made by the scale of standard myceliums established—which is difficult to ensure in prac-

tice. In conducting experiments on the same soil at different times, the absolute values obtained for the mycelium weight often show considerable divergence, though the relative order of distribution within their range is usually maintained. Moreover, the method proposed by Niklas does not take into consideration the as yet insufficiently investigated but possible influence on the development of the mould of other qualities of the soil tested besides its content of the substances in question.

As regards the identity of the conditions under which the tests for establishing standards of quantity, and an examination of any given soil are made, it is evident that this is possible only if both tests are made simultaneously. It remains, however, to settle the question of the character of the standard cultures.

Benecke and Söding were the first to attempt to solve this problem. They proposed to accompany cultures on soils being tested for their phosphoric acid content, by other cultures on solutions containing different quantities of soluble phosphate, and on that basis to draw conclusions as to the amount of phosphoric acid absorbed by mould films from soil, by comparing the films developing on the soil with those developing on the solutions. A further development of this method was proposed by Simakova and Bovshik who substituted actual weighing for the approximate comparison by observation. But this method, as well as that proposed by Niklas, requires the establishment of standard values by special preliminary tests on soils whose content of the substances in question has already been well established, before the value of its results can be finally accepted. Thus, all that has been said regarding Niklas' method, applies also to this one.

Even by the technique of Benecke and Simakova, an accurate quantitative determination of the phosphoric acid extracted from the soil is not assured. The percentage of this acid in the mycelium, when developed on soil and on soluble phosphates, may differ considerably, as Kostseletsky has shown.

In working out a suitable method, we must take into consideration the possibility already mentioned that the soils to be tested may possess properties not directly connected with the substance which is the subject of the test as regards content or condition, which may affect the development of the mycelium. The data on which to base an estimate of the possible extent of such influences are still inadequate, and until this question is cleared up it seems more expedient to investigate soils in groups which include soils of districts more or less definitely uniform in character, and to include in each series of tests for the study of such a group, one standard test of a soil from such a district which has already been thoroughly studied with respect to its content of the nutritive substances for which the other soils are to be tested. Of course the soil taken as a standard must not be one which contains an excess of the substance for which the other soils are to be tested. The value obtained for such a standard sample in simultaneously conducted experiments, will serve to measure the degree to which the other soils in the same series of tests contain the substance in question.

When such a culture on a standard soil is included in a series of tests for the study of soils by mould cultures, the experimenter enjoys the

important advantage of greater freedom in setting up his experiments, and is not bound by the necessity of conforming to strictly defined conditions, as is inevitable in the other modifications of the method discussed. But in the method suggested here some variation in the conditions of the experiment are permissible, such as the duration of cultivation, the size and shape of the vessels used, the temperature, etc. As the effect of these variations will be the same on all the cultures — both those on the test and on the standard soils — the relations between them, by which the final evaluation of the soils tested is determined will remain unchanged and the results will not be materially affected, since the variations will affect all the cultures equally.

On the basis of our experiments and of the considerations above discussed, the following scheme may be suggested for determining the supply of phosphoric acid and potassium in the soil by means of *Asp. oryzae* cultures.

The soils are examined in groups, each of which includes soils of a single type from a single, definite soil district. One soil must be included in each of these groups which has already been thoroughly tested by vegetational and field tests to determine its content of the substances in question (P and K). This standard soil must not possess an excess of the substances for which the soils are being tested.

All the soils to be included in the experiment are air-dried and then passed through a sieve of 1 mm. mesh. Three or four parallel cultures are run on each soil sample for every test. The cultures are made in Erlenmeyer flasks with a capacity of 60 to 100 cc. The weighed samples of air-dried soil — 5 g. for the phosphoric acid test and 1 g. for the potassium — are introduced into the flasks.

When carbonate soils are being tested for phosphoric acid, it is best to make two series of cultures, one with and one without the destruction of carbonates. In this case double the number of flasks containing 5 g. weighed portions of soil must be prepared.

All the flasks containing weighings of soil are stoppered with cotton and autoclaved for 30 minutes at a pressure of two atmospheres (i. e. 120° C.). The respective solutions, which have already been sterilized by twofold heating in the Koch apparatus or by autoclaving for 20 minutes at a pressure of 1.5 atmospheres, are then introduced in a sterile condition into the flasks which contain the soil.

To each of the flasks intended for the phosphoric acid test (i. e. containing 5 g. of soil), 30 cc. of the following solution is added, after sterilization as described above:

Cane sugar	10 per cent	MgSO ₄ · 7H ₂ O	0.05 per cent
Ammonium tartrate	1.25 " "	Fe (in the shape	0.001 " "
Potassium chloride	0.1 " "	Zn (of sulfate)	0.001 " "

To each of the flasks to be used for the potassium test (i. e. those containing 1 g. of soil) is added 20 cc. of a solution differing from the one described above only by the substitution of potassium chloride by phosphate of ammonia amounting to 0.075 per cent of P₂O₅ (0.1 2NH₄H₂PO₄).

If carbonate soils are to be tested, then the double series of flasks prepared with soil and solution in the way indicated for the phosphoric

acid test is divided into two parts. To one half of the flasks a water solution of tartaric or citric acid is added proportional to the carbonates contained in the soil, but in concentrations such that not over 1 cc. of the solution shall be introduced into any one flask. These flasks are carefully shaken from time to time and are left standing, like the rest of the flasks, for 24 hours. Acid for the destruction of the carbonates is added in amounts equivalent to the amount of calcium carbonate contained in the soil, i. e., 1.4 g. of citric or 1.5 g. of tartaric acid per 1 g. of carbonate.

The flasks, prepared in the manner described, are then inoculated copiously, and as far as possible equally, with conidia from a slant agar culture of *Asper. oryzae* in which the conidia are well developed.

After inoculation the flasks are kept in an incubator for from six to ten days, at a temperature of about 30°C. The cultures are then killed by heating for ten minutes in Koch's apparatus, the films are extracted from the flasks by means of a glass hook, thoroughly washed in hot water and the water pressed out with filter paper (the film being folded with the conidia on the inside). The films are then placed on weighed drying glasses, dried at 80°C. (to get an unvarying weight, this takes about 10 hours), and then weighed with precision to one milligram.

On the basis of the data thus obtained it is possible to determine the extent to which the soils tested contain phosphoric acid and potassium, starting from the value determined for the culture on the standard soil, for which the content of phosphoric acid and potassium has been previously established by pot-culture or field tests. Thus, for instance, if the mould film for the standard soil, the phosphoric acid content of which has been established as 60 per cent, weighs 0.3 g., and the films from two other soils examined in the same experiment, weigh respectively 0.4 and 0.2 g., then the extent to which they contain phosphoric acid will be:

$$\frac{60 \times 0.4}{0.3} = 80 \text{ per cent, and } \frac{60 \times 0.2}{0.3} = 40 \text{ per cent.}$$

In this way we obtain figures which possess a perfectly genuine significance, at least for that plant about which pot culture and field tests were run characterizing the supply of P_2O_5 and K in the standard soil.

The data at our disposal at the present moment indicate the possibility of successfully applying the method of mould cultures (under the experimental conditions above described) to establish a certain classification in grouping soils according to the degree to which they contain phosphoric acid and potassium, at least for practical purposes, i. e., in estimating the requirements of soils for the corresponding fertilisers.

REFERENCES

- Butkevich — Chemization of socialist agriculture, 1, 64, 1932.
Butkevich and Naidina, Chemization of socialist agriculture, 4, 62, 1933; 5, 56, 1933.

In these articles references to the literature of the problem may be found.

STUDIES ON THE MAIN ECOLOGICAL FORMS OF *B. MYCOIDES*

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The object of investigation

Ecological study of the soil-microflora is an almost untouched field of microbiology. We have no idea of the chief biotypes of soil bacteria, of the strains formed by them under the natural conditions of their habitat, of their peculiar characteristics and mutual relations.

The object of the present investigation was to study not the laboratory and museum strains of *B. mycoides* but those natural forms under which the life activities of this bacteria reveal themselves in different soils.

Isolation of strains

The strains of *B. mycoides* have been isolated from various soil samples during the summer of 1933. The isolation was done in the usual way by the method of pouring on meat-peptone agar plates. From many samples of soils, besides the normal forms of *B. mycoides*, also smooth forms without the characteristic curls may be isolated. As these smooth forms were difficult to distinguish from the *B. megatherium* group we limited our study to the normal forms with symmetrically bent curls. It is very essential for a study like this one to have not one but many strains of *B. mycoides* from each soil sample. This study was fulfilled on 27 strains, isolated from 9 soils. Table 1 shows the characteristics of the soil samples and the NN of strains corresponding to each of these.

Thin, medium and thick forms of *B. mycoides*

The strains isolated from soil must be subjected to a microscopic study immediately after their isolation. In this case it is possible to note that some of the strains consists of cells whose cross-section is thicker than that of the cells of the majority of other strains (Fig. 1 shows living cells of a medium strain of *B. mycoides*, in the dark field; Fig. 2—living cells of a thick strain of *B. mycoides* in the dark field).

Films of 24-hour cultures stained blue according to Manson were made for a more detailed study of this phenomenon. The transverse dimension of 50 cells of each strain was measured with the greatest possible precision. Measuring was done with the aid of a Zeiss screw ocular micrometer, each of whose points was equivalent to 0.07μ . The

Table 1

Soil samples and the №№ of *B. mycoides* strains isolated.

№ of soil sample	Characteristics	№№ of isolated strains
1	Moderately podzolized loam. Kotelnichi	1, 2, 3, 4, 5, 14
2	Moderately podzolized heavy loam. Kotelnichi	7, 8, 9, 12, 17
4	Thick heavily loamed chernozem. Central Chernozem Region. Kasak Steppe	23, 24, 25, 26
11	Red soil. Batoum-Chakva	30, 31, 32, 33, 34, 35
14	Dark-coloured swampy soil. Torzhok	27
15	Dark gray, heavily loamed forest-steppe soil	28, 29
16	Meadow-bog soil. Kotelnichi	11, 13
17	Podzolized gley. Moscow, Dolgoprudnoye Experimental Field	38
18	Ordinary chernozem, transitional to Southern chernozem. Boguchary Experimental Station	37

results of these measurements are registered (in points of the micrometer's scale) in Table 2.

25 strains out of 27 produced a regular variation curve characterizing their cell dimensions. Only 2 strains (№№ 12 and 5) were composed of cells of varying dimensions in a rather motley quantitative ratio.

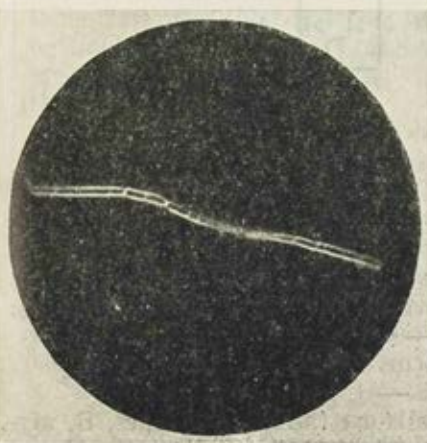


Fig. 1. Live cells of medium *B. mycoides*. Dark field preparation.

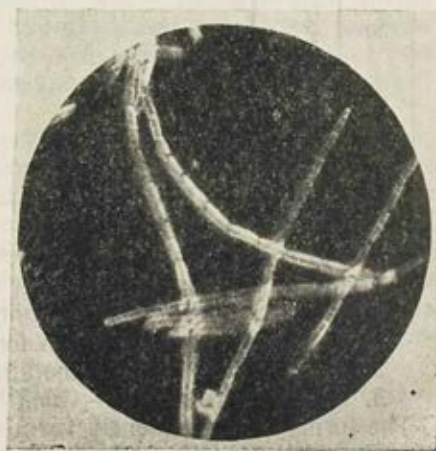


Fig. 2. Live cells of thick *B. mycoides*. Dark field preparation. Microphotographs 1 and 2 have been taken with object glass 60 $\times$ and Homal.

Table 2

Results of measurement of cell diameter in different strains of *B. mycoides*

№ № of strains	Form	Diameter of cells in points of ocular micrometer																									
		9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26								
24 38 23	B. mycoi- des "a" thin	1	2	2	19	16	9	1																			
			1	2	8	22	4	5	6	2																	
				2	11	15	17	5																			
13 4 25 2 7 29 35 26 11 9 1 27 28 14 8	B. mycoides "b" medium					1	9	13	25	2																	
					1	2	2	17	22	5	1																
							5	10	25	14																	
						1	5	10	21	11	2																
							3	11	24	9	3																
						1	1	15	19	6	5					1											
							2	12	26	7	3																
							3	13	16	15	3																
						1	2	9	22	11	3	2															
								9	24	10	7																
						1	3	8	20	12	3	1				1											
							1	5	24	14	5	1															
								2	16	14	8	10															
								1	19	13	10	4	3														
							3	—	8	18	14	8	1														
30	B. mycoides "c" thick										7	5	11	14		4	8	1									
32 17 3 34 33																1	19	9	10		5	4	1	1			
																3	7	9	11	12	3	2	3				
																4	4	4	9	15	7	3	3				
																	2	4	16	20	8						
																1	3	11	11	10		11	1	1	1		

The data of Table 2 show that there exist three forms of *B. mycoides* characterized by the following transverse dimensions of their cells:

1. *B. mycoides* "a" — thin forms — 0.8–1.0 μ (Fig. 3).
2. *B. mycoides* "b" — medium forms — 1.05–1.2 μ (Fig. 4).
3. *B. mycoides* "c" — thick forms — 1.4–1.5 μ (Fig. 5).

The forms most frequently found in soils are the medium ones, *B. mycoides* "b". The thick forms, *B. mycoides* "c" are much rarer. Rarest of all are found the thin forms, *B. mycoides* "a". Among our 25 strains 3 were thin, 15 — medium, and 7 — thick.

In podzols we found *B. mycoides* of all the three forms. In chernozems only thin and medium ones. In red soils — medium and thick ones.



Fig. 3. *B. mycoides* "a" — thin form. Strain 23.



Fig. 4. *B. mycoides* "b" medium form. Strain 1. Microphotographs 3—7 have been taken with object-glass 90X and Homal.

Physiological characteristics of the thin, medium and thick forms of *B. mycoides*

Physiological study of the thin, medium and thick forms revealed a number of characteristic distinctions of these forms.

On usual meat-peptone media of a pH = 7.7 thin forms develop most intensely and speedily, the medium ones — somewhat slower, and the thick forms show the slowest development. A few thick strains during some time after their isolation from the soil refused completely to grow on liquid and solid (agar) meat-peptone media. Thin and medium forms are capable of developing on these media within a wider range of pH than thick ones.

Thin and medium forms of *B. mycoides* ferment glucose, galactose, saccharose and maltose with acid formation approximately with equal intensity. Thick forms (except one strain) showed pronounced abnormalities of the activity of their fermentation complex. Various thick strains lacked the ability of fermenting various carbohydrates, chiefly saccharose. In those cases, where the carbohydrates were assimilated by the thick forms, much less acid was accumulated than in the case of thin or medium forms. In respect of gelatine liquefaction no difference was found between the various forms of *B. mycoides*.

Spores were formed by the thin strains on meat-peptone agar (pH = 7.7; t° —29°C) after 24—48 hours. Approximately within the same time sporing began in the medium strains (with the exception of two strains in which a delay of spring up to 4 days was observed). In thick forms the process of sporing takes a quite different way from that of the other forms. While some thick strains formed spores already during the first 2 days and some other ones — during the first 4 days,

some of them produced no spores whatever. All the non-sporogeneous strains of *B. mycoides* were thick.

The heat resistance of the spores of different forms was also different. The spores of thick forms (where they were formed) proved the least stable. Those of medium forms showed greater thermostability and the spores of thin forms were the most stable.

The rate of spore germination was the highest in thin and medium forms. The spores of thick *B. mycoides* show a delayed germination.

All these data indicate that the thin, medium and thick forms of *B. mycoides* are not casual occurrences but actually reflect the natural physiological types of this bacterium.

Mutual relation of the thin, medium and thick forms of *B. mycoides*

E. E. Uspensky has shown on various species of *Spirogyrae* that both under natural conditions and in artificial cultures in which a number of factors has been adjusted in a definite way the volume of cells may be doubled, this size increase being accompanied by deep changes in the physiological characteristics of these organisms. Such hereditary changes of *Spirogyrae* lead to the transition of the organism from one ecotype into another. E. E. Uspensky suggests that apparently many of the lower organisms are able to change their cell volume in multiple ratio, this forming one of the modes of origin of the "conjugated forms" (see "Microbiology", Moscow, v. III, 1934). These conceptions served us a guide-post for our study of the forms of *B. mycoides*.

It is easy to see that the ratio of the cross-dimensions of thin, medium and thick cells of *B. mycoides* is not casual, but follows a definite law. If the volume of a cell is twice as large as the another, the diameter of the first cell will be $\sqrt[3]{2}$ times that of the second. And, indeed, if we multiply the dimensions of thin *B. mycoides* by $\sqrt[3]{2}$ we obtain the dimensions of the medium forms of thick bacterium, and multiplying the latter by $\sqrt[3]{2}$ we obtain the approximate dimensions of the thick forms.

Form of <i>B. mycoides</i>	Diameter observed	Calculated diameter
Form "a" (thin) . .	0.8—1.0 μ	—
Form "b" (medium) .	1.05—1.2 μ	1.0—1.2 μ
Form "c" (thick) . .	1.4—1.5 μ	1.3—1.5 μ

Some other observations confirm the regular character of this change of the cell diameter. Thus in one of the thick strains (strain 17) besides thick cells of the usual size (1.4—1.5 μ) other still thicker cells were noticed, often their shape was round and their content granular. Their diameter equalled 2.1—2.4 μ , i. e. it was $\sqrt[3]{2} \cdot \sqrt[3]{2}$ times that of the thick forms (Fig. 6). In the first generation of strain 17, i. e., directly after its isolation from soil there were many such ultra-thick cells. In further transfers they disappeared. It seems that they proved little viable in in the media we used.

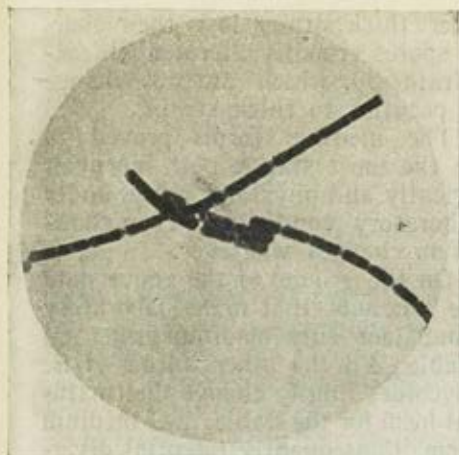


Fig. 5. *B. mycoides* "c"—thick form. Strain 17.



Fig. 6. Strain 17 with cells of much greater thickness than usual— $2.1\text{--}2.4\mu$ in diameter. Some cells have the shape of swollen balls.

All this induces us to think that the thin, medium and thick forms of *B. mycoides* are not autonomous but represent a series of "conjugated forms" in the sense of E. E. Uspensky, i. e., of forms originating one from the other.

Transition of the forms of *B. mycoides*

Attentive study of cultures under the microscope shows that both in thin and in thick forms threads can be found which consist of cells of a varying thickness. Such threads are encountered but rarely. In some cases this thickening of cells is gradual (Fig. 7). In others already two adjacent cells show a sharp difference in thickness. Only in medium strains almost no such transition could be observed. These observations show that characterizing a culture by the average size of its cells we in certain cases, particularly in regard to thick strains, undoubtedly simplify the actual condition. On the other hand they seem to indicate the possibility of transition of the thin, medium and thick forms from one to another.

Such transformations occurred to a number of our cultures as they gradually turned into "laboratory" strains, passing through a series of reinoculations on the same media.

All the thin forms after 6 months of laboratory life were transformed into typical medium forms. This fact was established not only by comparing the former variation curves with the new ones, but also by attentive comparison of microphotographs. Simultaneously with their transformation into medium forms the thin forms lost their characteristic rate and intensity of development.

Many thick forms after 6 months of laboratory life also turned into medium forms. Some of them however, e.g. strain 30, did not change.

After their transformation the former thick strains lost their characteristic properties, began to form spores speedily, fermented saccharose with acid formation etc. Strain 30, which did not change its size, kept also all the properties peculiar to thick strains.

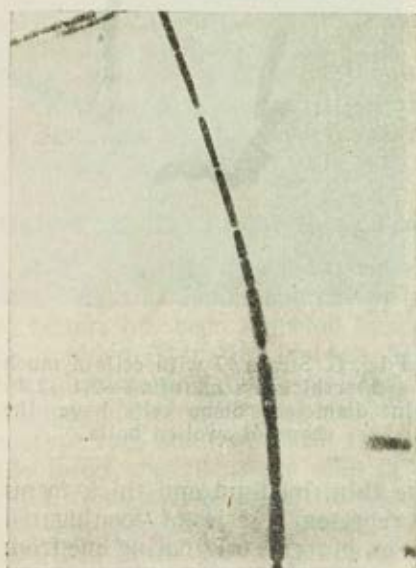


Fig. 7. Strain 17. A thread of *B. mycoides* with gradually thickening cells.

The medium forms proved to be the most stable, both morphologically and physiologically, under laboratory conditions. They showed no changes whatever.

On the ground of the above data we conclude that under laboratory conditions only medium forms are stable. All the other forms of *B. mycoides* finally change their natural form for the stable, i.e. medium form. Consequently essential divergence may arise between the strains of *B. mycoides* recently isolated from soil and the same strains after they have been kept for a long time in the laboratory.

Summary

1. The species *Bacillus mycoides* Flügge is a medley of different forms of this microbes ("a", "b" and "c") — thin, medium and thick forms, which may exist side by side under natural conditions.

2. The thin, medium and thick forms of *B. mycoides* are different biotypes of this microbe.

3. These forms being cultivated in artificial media under laboratory conditions, at first keep their peculiar features in a number of generations. After prolonged cultivation in the same artificial conditions takes place the transformation of the thin and the most thick forms into medium forms.

4. The regular quantitative relation existing between the cell dimensions of the different forms permit to think that the biotypes studied represent a "conjugated series of forms" (in the sense of E. É. Uspensky) originating one from the other¹.

¹ A more detailed report of this work has been published in "Microbiology", Moscow, v. IV, 1935.

THE HIGHER PLANTS AS A SOURCE OF CARBONACEOUS NUTRITION FOR AZOTOBACTER

A. SHELOUMOVA and R. MENKINA

In pure cultures the azotobacter develops and fixes nitrogen, using mannite, glucose and a number of other similar substances as a source of carbon. In the absence of available carbon, the azotobacter ceases to fix nitrogen and, as Kostychev and Sheloumova (1) first showed, disintegration of the nitrous substances of the body of the microbe itself occurs under the influence of the desaminative capacity of the azotobacter.

In the soil the development of the azotobacter and fixation of nitrogen also must naturally proceed at the expense of easily available carbon. The sources of carbon in the soil may be, on the one hand, the products of the disintegration of vegetable remains, or, on the other, the root secretions of the higher plants.

The variety of plants involuntarily suggests that the root secretions must differ in different plants both qualitatively and quantitatively. The degree of development of the plants must, of course, influence the character of the secretion.

That this is really so may be proved by the unequal amount of microflora in the zone around the roots of the plants. Starkey (3) has pointed out the zonal distribution of bacteria in relation to the roots of the plant. The root zone is exceedingly rich in microorganisms as compared with points at a greater distance. Krassilnikov (2) notes that during the period of development of plants, bacterial flora predominate in the root zone, while as the plants gradually mature, the bacteria are replaced by actinomyces and others.

Mashkovtzev (4) has shown that the root secretions of rice are different at stages of its development. When rice is under water, the amount of organic secretion is very great. The moment the rice rises above the water, the amount is sharply reduced.

In another of his studies (5) Mashkovtzev has described the specific kinds of bacteria peculiar to the root zone.

Changes of microflora or the presence of permanent kinds, depend, of course, on the character of the substances secreted by the plant roots.

The object of our paper is to establish the difference of the root secretions in different plants by the relation to the azotobacter as the only source of carboniferous nutrition. The degree of development of the plant,

which gets nitrogen only as a result of the work of the azotobacter, as well as the increase of nitrogen in the environment, might serve as a criterion of the availability of the root secretions as a source of nutrition for the azotobacter.

The suitability of plants for experiment was determined by the following method.

Seeds of maize, millet, oats, buckwheat, flax, etc., were allowed to germinate in Koch's dishes on silica gel with Prjanischnikow's or Ashby's solution, but without mannite. When the root system of the seeds selected had formed, a culture of azotobacter was introduced into the dishes without adding any energizing material, but with the addition of chalk, if the reaction was lower than 6. We were able to judge by the development of slime and the formation of pigment, and putting these slimy formations under the microscope, we could see that some plants call forth a good growth of the azotobacter, while others give none.

It appeared that the azotobacter developed best of all on the roots of maize and buckwheat. Oats and millet gave negative results.

Prjanischnikow's solution was taken as a nutritive medium into which nitrogen enters in the shape of nitrate of ammonium. Moreover, both the plants and the azotobacter grew well in it (silica gel permeated with Prjanischnikow's solution). The experiment was made under sterile conditions, in water cultures by Shulov's method, and in sand by Bessonov's method (6). Parallel with the sterile experiments others were set up by Bessonov's method which were not sterile. We were unable to achieve absolutely sterile conditions notwithstanding repeated trials and a great number of parallel cultures. It seems that the cotton batting stoppers cannot protect the contents from external contamination for very long periods. When the experiment was completed, containers which seemed quite clean, when planted on meat-pepton agar, showed the presence of a number of microorganisms which formed strongly fluorescent colonies. Those containers which were evidently contaminated were not included.

We took for the experiment seeds of maize and buckwheat which could be completely sterilized, and did not lose their germinative capacity after remaining 15 minutes in one per cent Br and washing for two hours with sterilized water.

Experiment with maize in flasks, by Shulov's Method

Under the experiment's conditions, both in the control containers and in the containers with azotobacter, maize developed very feebly. Analyses of the condition of the azotobacter during the period of vegetation showed it to have normal appearance.

The experiment lasted two months.

A calculation of the azotobacter gave the following results:

Initial amount	422 million
In containers without maize	557 "
In containers with maize	1,432 "

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We see that maize even in a bad condition gave to the azotobacter the possibility of developing.

An analysis of the plant and the liquid showed that the azotobacter during that time had nevertheless fixated the nitrogen at the expense of the root secretions, but of course to a very small extent. Results of the analysis are given in Table I.

Table 1

Analysis of experiment with maize in flasks in liquid.

Scheme of experiment	Height of growth in cm.	Wt. in gr. of dry mass of nitrogen in mg. in the seed	Nitrogen in mg. in plant	Nitrogen in mg. in solution	Balance of N in mg.	pH in experiment		Cn. of $\frac{1}{10}^n$ N KMnO_4 taken for the titration for the entire solution
						Initial.	Final	
Initial Liquid . .				0.41		6.83		
Control without maize				0.41 0.41		6.83	6.51	0
Azotobacter without maize . . .				0.28 0.45	-0.04	6.83	6.12	4.0 4.5
Control of maize .	41 40	0.73 0.60	2.06	2.35 2.27	0.12 0.18	0 + 0.08		14.0 15.0
Azotobacter and maize	41 41	0.87 0.77		3.08 2.73	0.62 2.63	+ 1.23 + 0.89		11.0 11.0

The poor development of the maize was also reflected in the work of the roots. The secretion of organic substances by the roots was very small (titration with KMnO_4). With the weak root secretion it was impossible for the azotobacter to develop in any considerable degree the work of fixing nitrogen. Moreover, the acidification of the medium by the maize created unfavorable conditions for the fixation of nitrogen.

According to Burck's data (7) for the fixation of nitrogen by azotobacter, it is necessary to have pH higher than 6 in the nutritive medium. When pH is lower than 6 its development only will take place; that is what happened in our experiment.

Experiment with maize by Bessonov's method

The set-up by Bessonov's method made it possible to obtain a marked increase of nitrogen in the nutritive medium. In addition, there was found an increase in organic substances in the containers with maize, which of course indicated the presence in the medium of root secretions from the maize.

The containers with the azotobacter gave even greater values of titration of KMnO_4 , which was the result of a greater development of the plant.

However, notwithstanding the increase of nitrogen in the medium resulting from the presence of azotobacter, the maize did not attain its normal growth. The idea suggests itself that all these conditions do not make it possible for maize to develop and completely use the azotobacter even though the azotobacter has already begun to manifest activity at the expense of the root secretions.

We obtained similar results in a number of experiments mounted under unsterile conditions by Bessonov's method, both as regards the condition of the azotobacter and from analysis of plants and medium. We do not give the figures.

Experiments in flasks with the addition of glucose (10 g. per litre) gave no essential differences. It is true that under these conditions the azotobacter developed freely in the liquid without maize as well. In the containers with maize it was chiefly concentrated on the roots of the plants. The maize, with the addition of glucose, did not differ in any way from the maize without glucose; the tiny, sickly plants had poorly developed root systems. The increment of nitrogen in the medium was no greater than in the first experiments in flasks.

Experiments with maize with the addition of Nitrogen

The addition of nitrogen, creating conditions for the normal development of plants and their root systems, and together with it of the roots, should act favorably on the life activity of the azotobacter. The experiment was made with maize in Prjanischnikow's complete nutritive solution, under sterile conditions, in flasks, by Shulov's method, but it gave no satisfactory results. The maize developed normally, and made an equally good growth in the absence as well as in the presence of the azotobacter. An analysis of the medium showed no differences except the fact that during the first few days of the presence of the azotobacter in the medium, much formation of HNO_2 from HNO_3 went on, evidently chiefly at the expense of the reduction capacity of the azotobacter. After a month, the experiment was brought to an end. The azotobacter in the containers had perished everywhere, both in the liquid and on the roots.

The microscope revealed only dead cells (much vacuolated or quite torn). The destruction of the azotobacter was evidently caused by the acid medium. There remained very little of the liquid under the vigorously grown maize. pH of the solution was 3.5—2.80.

The following experiment was set up in the same way, but azotobacter was not introduced. When approximately half of the solution remained, and the maize was growing normally, the solution was poured off in sterile conditions and the roots were washed with a solution without nitrogen. After selecting entirely similar pairs of containers, we infected one of each pair with a usual quantity of azotobacter. We had 6 such pairs. Analysis of the solutions when poured off showed a complete absence of nitrates, nitrites and ammonia. No fixed nitrogen was found. Thus we may consider that the plant had taken most of the nitrogen provided at the beginning of the experiment.

Table 2

Analysis of Experiment with Maize by Bessonov's Method.

Scheme of Experiment	Height of growth in cm.	Wt. in g. of dry mass	N in seeds in mg.	N in maize in mg.	N. in solution in mg.	N in sand in mg.	N balance in experiment	Amount of liquid remaining	Organic substance in cc. $\frac{1}{10}$ NKMnO ₄	On sand pH		Solution pH	
										Beg.	End	Beg.	End
Initial	—	—	—	—	1.21	51.20	52.41	3,000	236.0	6.86	—	6.83	—
Control without maize	—	—	—	—	2.59 1.79	32.52 33.81	-17.30 -16.81	775 700	234.5 225.9	6.86	6.80	6.83	6.69
Azotobacter without maize	—	—	—	—	1.99 1.25	35.51 35.36	-14.91 -15.80	1,475 780	234.9 233.3	6.86	6.80	6.83	6.74
Maize	42 36	4.05 3.57	2.05	19.25 18.30	0.35 0.31	26.51 30.95	8.36 4.91	790 620	273.4 275.5	6.86	6.76	6.83	6.80
Maize with azotobacter	45 48	4.48 1.22 roots	2.05 roots	20.80 12.25 roots	1.19 1.87	43.43 45.51	+10.95 + 5.19	740 740	298.1 305.1	6.86	6.89	6.83	6.81

After the change of solutions and the introduction of the azotobacter, the control plants ceased to grow. The plants in the containers into which the azotobacter had been introduced far outstripped the control plants in their growth. It was clearly evident that they had received a definite stimulus to their growth by the presence of the azotobacter.

Photos 1 and 2 give a visual representation of the result of the introduction of the azotobacter. All the 6 pairs showed the same marked difference between the controls and the plants which had received the azotobacter. A month after the introduction of the azotobacter the experiment was brought to an end. The sowing of 1 cc. of solution on MPA showed the presence of from 1 to 110 colonies of microorganisms. The azotobacter in the cultures gave a strong growth on silica gel.



Fig. 1.



Fig. 2.

Cultures taken from the roots showed very good growth of the azotobacter on all parts of the roots. The microscope showed the presence of considerable amounts of mobile rods. When we examined the roots, the azotobacter resembled figure 8s or large zoogly located on the tissue of the root itself, though there were also some dying cells. There was little azotobacter in the liquid when examined under the microscope; the cultures of root particles and of the solution on the gel clearly showed that the azotobacter had been concentrated almost entirely on the roots.

It is not possible to wash off the azotobacter even by shaking violently. Therefore the count of the cells is only approximately correct. Nevertheless, in calculating the azotobacter, nine million of the cells introduced were found, while about four million remained in the liquid.

The figures in Table 3 show that the solutions were acid, and perhaps for this reason they acted destructively on the cells of the azotobacter so that this also contributed to the decrease in the amount of azotobacter. However, the balance of nitrogen indicated a considerable activity of the azotobacter which very possibly was checked by the lowering of the content of pH. In all the containers with azotobacter a greater in-

Table 3

Analysis of experiment with maize.

Scheme of experiment	Height of growth	Wt. of dry mass in g.	In % of control	N given in mg.	N in maize in mg.	N in solution in mg.	N balance in mg.	pH		Organic subst. in cc. of 1/10 nKMnO ₄
								Beg.	End	
Initial Solution . .	—	—	—	72.97	—	—	Average taken by maize 6.89	6.89	—	—
Maize										
1) control	69	6.76	100	72.97	61.9	0.6	— 64	6.89	5.0	27.5
2) azotobacter . . .	75	8.20	121	72.97	76.5	2.06	+ 9.6	6.89	5.8	35.7
3) control	75	6.25	100	72.97	68.0	0.86	— 0.1	5.0	5.2	27.2
4) azotobacter . . .	82	8.00	128	72.97	78.4	1.6	+ 11.1	5.0	5.9	36.8
5) control	75	7.21	100	72.97	70.5	0.42	+ 1.0	5.0	5.4	26.8
6) azotobacter . . .	82	9.21	127	72.97	79.8	2.8	+ 13.7	5.0	6.1	38.2

Table 4

Analysis of experiment with buckwheat under non-sterile conditions by Bessonov's method.

Scheme of experiment	Height of growth	Wt. of dry mass in g.	N in seed in mg.	N in buckwheat in mg.	N in sand in mg.	N in solution in mg.	N balance in mg.	pH sand		pH solution	
								Beg.	End	Beg.	End
Initial	—	—	—	—	—	—	52.01	6.86	—	6.83	—
Control without plant	—	—	—	—	29.34 33.43	4.85 3.40	— 17.82 — 15.18	6.86	6.80	6.83	6.83
Azotobacter	—	—	—	—	27.02 27.58	4.68 4.18	— 20.31 — 20.25	6.86	6.80	6.83	6.81
Buckwheat											
1) Control	8.0	0.65	0.21	5.95	27.30	2.73	— 17.06	6.86	6.22	6.83	5.78
2) Azotobacter . . .	7.5	0.91	0.21	9.27	24.67	3.75	— 14.34	—	6.85	—	6.22
3) Control	6.0	0.43	0.21	3.85	27.89	3.15	— 17.12	—	6.18	6.83	5.35
4) Azotobacter . . .	6.5	0.51	0.21	4.72	27.30	4.15	— 15.84	6.86	6.85	—	6.02

crement of nitrogen was obtained than in the controls. There was also an increased acidification of the solutions by the action of KMnO_4 , which indicates the presence of organic matter in the solutions. There was more organic matter in the containers with azotobacter than in the controls.

Experiments with buckwheat

The experiments with buckwheat were made in the same way as those with maize, but though maize did grow, after a fashion, in the flasks without nitrogen, the buckwheat promptly died under these conditions. In the experiment by Bessonov's method under non-sterile conditions, the buckwheat lived about a month. It had a very miserable appearance, but nevertheless we were able to complete the analysis in this experiment, both as regarded the condition of the azotobacter and the development of the buckwheat. (See Table 4).

It is interesting to note in this case that the buckwheat which received azotobacter yielded entirely healthy and mature seeds, while the control plants produced only flowers. The nitrogen balance in this experiment showed a loss for all containers, but least in those with buckwheat which had received azotobacter. The buckwheat, owing to its weak development, could not provide the conditions which were present in the similar experiment with maize.

An analysis of the condition of the azotobacter gave the following results:

Initial amount	8,861	million
Without plants	7,779	"
	4,739	"
With buckwheat	5,609	"
	Single cells	

There was no difference in the amount of azotobacter in the containers with and without buckwheat; the azotobacter decreased everywhere and apparently most in the containers with buckwheat.

Experiments with buckwheat with the addition of nitrogen also showed worse results than those with maize.

The experiment with the complete nutritive solution resulted in the destruction of the azotobacter in the same way as in the experiment with maize. There was no difference in the plants in this case. We did not make with buckwheat the experiment with the change of solutions. An experiment with a half dose of nitrogen in Prjanschnikow's complete solution was also made. When the buckwheat began to develop leaves, azotobacter was introduced as usual.

The arrangement of the experiment with the half dose of nitrogen allowed the buckwheat to develop, the addition of the azotobacter at the moment when the nitrogen of the solution was about exhausted, must have served as an additional source of nitrogenous nutrition. After the buckwheat had grown three weeks, when an analysis of the nitrogen in the solution showed that there remained from 13 to 15 mg. of nitrogen, the containers were sorted into pairs and the azotobacter was introduced

into one container of each pair, the other serving as a control. The buckwheat which received the azotobacter began to grow rapidly and yielded mature seeds, while the control plants grew slowly and only flowered. The seeds that matured were incomparably fewer than on the buckwheat which had received the azotobacter.

Analysis for azotobacter after the experiment was concluded (a month after the introduction of the azotobacter), showed that in cultures on silica gel only the roots showed its presence, there were none at all in the liquid. The microscope showed much on the roots and its appearance was normal. The calculation for the liquid gave the following results:

Initial number of azotobacter . . .	4,466 million
In containers without plants	$\left. \begin{array}{l} 267 \\ 213 \end{array} \right\}$ "
In containers with buckwheat . . .	$\left. \begin{array}{l} 500 \\ 639 \end{array} \right\}$ "

There was no such sharp fall in the number of azotobacter in any of the experiments with maize. It is true that it is very difficult to judge of the true number of azotobacter in the containers with plants as the azotobacter live chiefly on the roots where it is very difficult to make a quantitative count. Nevertheless, in this experiment with buckwheat it must be said that, notwithstanding a quite evident reduction, the count showed that in containers with buckwheat there remained nearly twice as many azotobacter as in the containers without. Sterility in these containers was relative. Cultures of one cc. of liquid from 500 cc. on MPA yielded from 23 to 192 colonies.

The analyses of the plants and solution are summed up in Table 5.

Analysis of experiment with buckwheat in flasks
(1 L. of solution with Nitrogen).

Table 5

Scheme of experiment	Height of growth	Wt. of dry mass in g.	N in seed in mg.	N in buckwheat in mg.	N in solution in mg.	N balance in mg.	pH	
							Beg.	End
Initial liquid	—	—	—	—	36.50	36.50	6.84	—
Control without plants	—	—	—	—	23.24 29.16	— 13.26 — 16.34	6.84	5.18
Azotobacter without plants	—	—	—	—	19.32 19.24	— 17.18 — 17.26	6.84	4.75
Buckwheat control .	70 75	1.65 1.76	— 0.21	35.17 35.35	0.36 0.52	— 1.18 — 0.84	6.84	4.84
Buckwheat azotobac- ter	79 81	1.81 1.82	— 0.21	36.05 37.01	1.05 1.40	+ 0.39 + 1.70	6.84	5.52

Experiments with maize, wheat and buckwheat in soil

As visual evidence of the different behaviour of the azotobacter in relation to different plants, an experiment was started as follows: Clay pots filled with coarse sand were used for an experiment by Bessonov's method. After sterilization, wheat, buckwheat and maize were planted in them and they were regularly watered with distilled water. The pots had an opening in the bottom, and were all set in boxes full of soil in which they were sunk to one-fourth of their height. The soil was taken from a vegetable garden with a high content of azotobacter.

The plants grew badly, especially the buckwheat. The wheat grew better than the others. The experiment was continued for one month. The roots of none of the plants penetrated into the earth through the hole in the pot. Nevertheless analysis revealed a great quantity of azotobacter on the roots and in the sand of those plants the root systems of which had developed strongly. The grains of sand in the pots of wheat, when spread on silica gel, produced a dense culture of azotobacter. The roots washed with distilled water were covered with a very abundant slimy mass of the azotobacter.

The maize roots were less developed than those of wheat, but nevertheless a culture from them on silica gel gave large slimy increments of azotobacter; but in the sand their growth was weaker than in the experiment with wheat.

In this case also the buckwheat showed a weaker growth of azotobacter cultures on the roots and in the sand than the wheat. The roots of the buckwheat developed more strongly than of the maize. This experiment demonstrated the presence of root secretions in these plants which actively attracted azotobacter from the soil, notwithstanding the fact that there was much organic matter in it. Among all the plants taken it appeared that the wheat stood higher than the maize. This may be so; but we are inclined to think that in this instance the maize only lagged behind the buckwheat and wheat in the development of its root system and therefore the azotobacter germinated more weakly in the sand under it than in the other pots. Of course our test was very primitive; it is possible that an uneven distribution of moisture also played some part, but nevertheless the migration of the azotobacter to the roots is an undeniable fact.

However, this close connection between the azotobacter and the maize may not exist at all stages of its development. In all the experiments with maize described above with nitrogen, we have seen either a decrease in the amount of azotobacter or sometimes a complete disappearance just as the maize began to flower. In experiments with soil, cultures of the azotobacter at various stages in the development of the maize showed a different state of the azotobacter. In the first stage of the development of the maize, the azotobacter grew on the silica gel. When the maize was about to flower, its roots no longer developed a growth of azotobacter on the plates of gel, though it still went on in the soil.

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Conclusions

1. The presence of root secretions of maize can provide carbon nutrition to the azotobacter. The development of the latter takes place at the expense of the root secretions and the fixation of the nitrogen of the air. The fixation of nitrogen by the azotobacter does not occur when pH is lower than 6.

2. The presence of azotobacter in the root zone of maize causes an increase in the yield under conditions necessary for the development of the azotobacter and the fixation of nitrogen.

3. A marked acidification of the medium resulting from the growth of maize, especially just as it flowers, stops the fixation of nitrogen by the azotobacter and kills it.

4. The root secretions of different plants vary in their action on the azotobacter. Maize has a stronger effect than buckwheat.

5. Even in the presence of organic substances in the soil (garden soil), the azotobacter actively migrates to the roots of wheat, maize, and to some extent, buckwheat.

The conditions of the experiment did not, however, allow us completely to elucidate the work of the azotobacter. The presence of acidification of solutions in water cultures retarded and sometimes, apparently, completely stopped the fixation of the nitrogen (pH sometimes fell to 4.5).

We are confident that when arrangements can be devised to reduce the possibility of acidification, it will be possible to verify experimentally the powerful work of the azotobacter.

In any case our results already indicate a considerable work by the azotobacter. Our experiments have confirmed the correctness of S. P. Kostychev, M. A. S., when he spoke of the interrelation between azotobacter and the higher plants.

LITERATURE CONSULTED

- (1) Kostychev, S. P. and Sheloumova, A. M.—Bulletin of the Acad. of Sci., 1931.
- (2) Krassilnikov, N. A.—Microbiology, 3, 1934.
- (3) Starkey—Soil Sci. XXVII, 1929; XXXII, 1931.
- (4) Mashkovtsev—Proceedings of the Cent. Exp. Rice Station of the People's Commissariat of Agriculture of the USSR. Part 7, 1934.
- (5) Mashkovtsev—Proceedings of the Inst. of Tobacco Culture.
- (6) Truffaut et Bessonoff—La Science du Sol, 5, 1926.
- (7) Burck, Zineweaver and Horner—Journ. of Bact. XXVII, 1934.

METHODS OF PROCEDURE IN DRAWING UP AN AGRO-CHEMICAL MAP OF THE DISTRICTS OF FERTILIZER APPLICATION, AND THE MAIN RESULTS OF THE WORK

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Moscow

1. The task of a planned distribution of mineral fertilizers according to territory and branches of agriculture, viewed in connection with the powerful development of the Soviet fertilizer industry and the wide mechanization of the collectivized agricultural industry, had already, during the last years of the First-Five-Year Plan acquired the significance of a great national economic problem.

One of the main principles on which planned distribution of fertilizers is based is the effectiveness of fertilizers as expressed at the same time in the raising of the yield of individual crops in the creation of stable yields and in the improvement of the quality of the produce, all on the indispensable condition that the fertility of soil itself is at the same time increased.

2. The effectiveness of fertilizers depends on the type and variety of the crops and their rotation, on the soil, on weather conditions, and on the agro-technical background, of the technique of fertilizer application. To show the influence of these factors in their mutual relations is the most important problem of agro-technics and of agronomical soil-science. This problem can be solved by a complete complex of laboratory and field investigations, the field investigations being both territorial and stationary. To these investigations also belongs the drawing up of an agro-chemical map of the districts of fertilizer application.

3. The purposes of drawing up this agro-chemical map are:

a) To show the principles governing the effectiveness of fertilizers in their dependence of varieties of soil and climatic peculiarities under the conditions of production in collective and state farms, and to estimate the effectiveness of fertilizers for the next few years taking into consideration the dynamics of agro-technical development.

b) To create a geography of the effectiveness of fertilizers on the basis of these principles and on a study of the soil and climate of the territory—to draw up maps of fertilizer effectiveness (agro-chemical maps) of regions, districts and individual farms.

4. The work on this agro-chemical map was conducted during 1932—34 in chernozem and podzolized soil zones of the European part of the

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USSR and also in the irrigated districts of the desert-steppe zone of Transcaucasia and Middle Asia.

5. The chief method used in determining the effectiveness of fertilizers was the field experiment.

The distinctive characteristics of the method of procedure in the field experiment were determined as follows:

a) A very limited number of fertilizer variants were included in the schemes of experiments dealing with each crop, and in the main these were variants of those kinds of fertilizers or of their combinations, which can be considered suitable for the given crop in the near future.

b) All field experiments were made on state or collective farms directly on fields carrying the regular crop in the cycle of crop rotation with the application of such experimental methods (in respect to size of plots, their number and location), as were possible to apply. So long as there was a sufficient degree of typicality and no great difficulties the methods of tilling, cultivation and harvesting commonly used on the given collective (or state) farm, were observed on the experimental plots.

Due to this the indices of effectiveness obtained in this work must be considered as the most probable under the present conditions of production.

c) Moreover, in connection with every field experiment a detailed soil inspection was made with subsequent agro-chemical analysis of soil samples.

6. The reliability of the conclusions, giving the effectiveness of fertilizers for each definite complex of soil, climatic, and agro-technical conditions was assured not only in that each individual experiment was set up at least in duplicate (for cotton often 3—4 parallel similar experiments were conducted), but also in that experiments in each subject, for each culture, on each variety of soil and on if possible in identical conditions of cultivation were annually conducted simultaneously on several adjacent spots (collective or state farms). Experiments accepted as satisfactory were united into uniform groups with identical soil and agro-technical conditions, and the average indices were calculated for each group separately.

7. The main lines of effectiveness of fertilizers proved fairly stable in the course of all three years during which mass experiments were conducted, in spite of the extremely varying weather conditions of these three years in most of the investigated districts.

8. As a result of this work the effectiveness of fertilizers with respect to technical and fodder crops has been determined for different varieties of soils. Soil types and varieties of a different genesis (podzolized soils, gray forest-steppe soils, varieties of chernozems) differ with respect to the effectiveness of fertilizers applied to them. This effectiveness (particularly that of potassium fertilizers) is considerably influenced by the mechanical composition of the soil.

9. Several grades of effectiveness have been distinguished for each crop. A definite group of varieties of soil corresponds to each such grade.

Thus, for instance, for flax after clover the following five effectiveness grades have been distinguished:

a) Podzolized loamy sand on fluvio-glacial and ancient alluvial deposits. Marked effectiveness of potassium.

b) Podzolized sandy (light) loams and coarse-pulverescent (light) loams on moraine and loesslike rocks. Marked effectiveness of potassium and phosphorus applied both separately and in combination. The effectiveness of complete mineral fertilization is considerable. Increase of flax straw yield from NPK reaches 50 percent.

c) Podzolized heavy pulverescent loams. Slight effectiveness of potassium.

d) Slightly podzolized medium and heavy loamy sands on carbonate rocks and washed off soils. Slight action of potassium and phosphorus.

e) The districts in the Eastern section of the podzolized zone form a separate group. The action of fertilizers in these districts is less constant than in the Western and Central regions. Phosphorus fertilizers, however, are here more active than potassium ones.

The fertilizers produce a considerable increase in the yield when applied to potatoes, beet, cotton; the yield increase, due to the addition of complete mineral fertilizer, reaches 50 per cent, and in some cases even more. For these crops also, grades of effectiveness have been established depending on the variety of soil (from the point of view of genesis) and its mechanical composition.

10. The degree of cultivation or "cultivatedness" of the soil considerably influences the effectiveness of fertilizers. By "cultivatedness" we understand the totality of changes in its properties brought about by agro-technical measures.

We must distinguish a number of types of "cultivatedness". That which has arisen chiefly under the influence of continuous application of dung manure must be considered a special type. This type represents only an individual case and is often called cultivatedness in the narrow sense of the word. It is connected with deep changes in the absorbing complex and in the supply of nutritive substances and (in the case where the influence of dung manure has acted over a long period of time) is well revealed by agro-chemical analyses, especially by the determination of P_2O_5 soluble in citric acid by the method of Arrhenius. This type of cultivatedness shows considerable differences in individual plots in a series of hemp and suburban (vegetable) farms, in many state sugar-beet farms and in some potato farms. This considerable variation in the supply in the soil of citric soluble P_2O_5 as determined by the Arrhenius method (varying from 3 to 35 and more) is to a great degree explained by the difference in their manuring in the past.

Other types of cultivatedness, resulting from a systematic application of other agro-technical measures, may have great importance in connection with effectiveness of fertilizers; for instance perennial grasses, the system of tillage, liming, systematic treatment with mineral and organic manure etc.

Besides the influence of the cultivatedness of the soil, the effectiveness of fertilizers is considerably influenced by the "state of cultivation of the field", created by the agro-technical measures of the current year and by those of the few preceding ones.

The state of cultivation of the field may be determined by the study of the history of the plot in recent years (and in the current one). The effectiveness of fertilizers rises with the increase of the state of cultivation of the fields.

11. In order to present a geography of effectiveness based on the principles found, i.e. in order to extrapolate the data obtained from field tests to a definite territory, soil investigations accompanied by mass agro-chemical analyses, have been conducted over the territory of technical crops.

These investigations have made it possible, utilizing extensively the soil data gathered from former years, to draw up regional soil maps (scale: about 1/100,000). In 1932—1933 a selective investigation of certain definite farms (totalling 1,500,000 hectares) was conducted (scale: 1/25,000). In 1934 100 cotton and sugar-beet Machine and Tractor Stations, uniting some 30—40 collective farms each, were subjected to a detailed investigation (scale: 1/25,000).

A new element in these territorial soil investigations was the wide application of agro-chemical analyses, making it possible to find out a number of characteristics which are important in production — e.g. acidity and saturation with bases for different varieties of soils, and also to make more precise the delimitation of the varieties of soil themselves (especially with respect to cultivatedness).

The following agro-chemical analyses were used on a mass scale: determination of the total replaceable bases and of the hydrolytic acidity by the Kappen method; pH of salt extract (to establish the need in liming of the soil); mobile phosphoric acid (by the methods of Arrhenius, Truog and Kirsanov); absorbed potassium (Peive method).

12. The most important results of this work are the agro-chemical plans of collective and state farms which form the basis for drawing up annual schemes of fertilization and plans for chemization.

All the principles established as a result of the drawing up of the "agro-chemical map" must serve as guides for the determination of the effectiveness of fertilizers on definite farms.

The following three cases must be distinguished:

a) According to the available data, varieties of soil found on a given farm territory which are related in their origin show practically no difference with respect to effectiveness. The history of fields and the results of agro-chemical analyses show the lack of any sharp divergence between individual plots from the point of view of cultivatedness (in the narrow sense of the word). In these cases the prognosis of the action of fertilizers may be differentiated for the various plots of the farm territory only on the basis of a study of the state of cultivation of fields. This case is often met with in districts of podzolized soils on mantel and loesslike rocks, in ordinary chernosems etc. (for collective farms).

b) Where varieties of soils found on the farm territory differ sharply, they show great divergence with respect to effectiveness of fertilizers. There are no divergences between individual plots in respect of their "cultivatedness" (in the narrow sense).

This case occurs in collective farms in the districts of loamy sands and sandy soils, in forest-steppe districts etc. For the prognosis of the

effectiveness of fertilizers the varieties of soil and the state of cultivation of fields must be taken into consideration.

c) The various plots of the farm differ in their "cultivatedness" mainly as a result of differences in dung manuring over a number of previous years. The agro-chemical indices of "supplies" show considerable diversity. This case occurs in hemp farms, suburban farms, state sugar-beet farms etc. To determine the effectiveness of fertilizers in different parts of the farm territory, it is necessary to be guided among other things to a considerable degree by the results of the mass agro-chemical analyses. The agro-chemical plans of such farms must be drawn up in the greatest detail.

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METHODS OF PROCEDURE IN DRAWING UP AGRO-CHEMICAL MAPS FOR THE SUGAR-BEET CULTURE REGIONS OF THE USSR

I. I. KANIVETZ

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1. Attention has long been focused on the questions of study of soil cover and classification of soils, but it is only since the October Revolution that with the growth of socialist soviet economy, the demands made upon soil science, upon its scope and direction, have so greatly increased, that these questions have received due consideration both in range and depth of theoretical thought. During the period following the Revolution especially important work has been performed by the Soil Institute of the Academy of Sciences, by the All-Union Institute of Fertilizers and Agriculture Chemistry (VIUA) (a survey of soils covering over 25 million hectares) and by the All-Union Scientific Research Institute of the Sugar Industry (V.N.I.S.) (an elaboration of the methods of procedure in agro-chemical survey on state sugar-beet farms).

At the same time, the organized body of soil scientists, agrochemists and agronomists of the V.N.I.S., in order to meet the needs of socialist sugar-beet farming, carried out a large-scale survey of soils at state sugar-beet farms, systematizing the results of this work in the form of agro-chemical maps of the sugar-beet regions of the Ukrainian Socialist Soviet Republic (1 : 42,000), and providing each separate state sugar-beet farm with agro-chemical maps, scientific methods of fertilization and plans of chemization. These maps of the state sugar-beet farms are made out in great detail (1 : 10,000 and 1 : 25,000), and show the peculiarities of each field comprised in the crop rotation system. Accordingly, the rôle of the soilscientist, the agro-chemist and the agronomist has greatly increased and the results of their joint scientific research work, in the form of maps, systems of fertilization, and plans of chemization have found themselves a really useful field of application in Glavsakhar (Main Administration of the Sugar-Beet-Industry) Narkomzem (People's Commissariat of Agriculture), various trusts, Machine and Tractor stations, state and collective sugar-beet farms etc., where these materials have been incorporated as part of agricultural recommendations and standards. The object and content of these maps, systems of fertilization and plans may be determined as follows:

a) The agro-chemical map shows the basic genetic and agronomical characteristics of the original soil considered as the object and the basic means of production for agricultural activities, and enables the execu-

tive workers of socialist agriculture to plan agro-technical measures with greater precision and more accurate prognosis, this being especially important for drawing up systems of fertilization and agro-chemical plans for actual crop rotation.

b) The system of fertilization, being the sum-total of all measures connected with the use of fertilizers in crop rotation, is drawn up for the full rotation (taking in consideration the time when the farm has been introduced into the crop rotation) and is worked out in full agreement with the following factors: the requirements of the plan; the need for increasing labour productivity; the necessity of cutting costs; the requirement of increasing in quantity and quality the yield of all crops forming part of the rotation, and at the same time preserving and increasing the fertility of the soil and carrying out in good time all the agrochemical measures scheduled.

c) On the basis of the planned development of the system of agrochemical measures, a plan of applying chemical methods is made for each separate state and collective farm which must duly provide for the available organizational and economic conditions, as well as the peculiarities of crop-rotation for each section of the farm area and the constituent land-plots. Available stocks of fertilizing materials, the extent of cultivation of the soils in question and of the former conditions of cropping must also be duly accounted for.

2. Thus the carrying out of soil surveys and the drawing up of agrochemical maps demand a profound knowledge of the genesis and development of soils, of their productivity characteristics, while a study of all attendant factors involved in soil formation is of no less significance. The methods of procedure adopted for this kind of work should promote the knowledge of the most essential features and peculiarities of soils.

The following table gives an idea of the characteristic features pertaining to the methods of procedure adopted in the work of the All-Union Scientific Research Institute of the Sugar Industry.

Study of general questions of soil formation

№ Sections	Contents
1. Geomorphology of the region.	Characteristics of general relief, as well as macro-, meso-, micro-, and nano-reliefs. Combination of relief elements in conditions of placor bedding, terraces, gullies and the flooded plains of rivers.
2. Hydro-geology of the region	Soil-forming rocks and the nature of weathering. Regions where tertiary and quaternary deposits occur. Regioning of loess. Depth of ground-water tables. Nature of soil-moisture and its circulation. Nature and depth of upper water tables. Water-bearing strata suitable for supplying the population with water. Ground and artesian waters.

3. Climate of the region.

Precipitation. Number of days on which precipitation occurs. Soil climate and weather according to working seasons in agriculture. Sum-total of various conditions warranting the maximum effectivity of agronomical measures taken for the growing of sugar-beet and winter wheat.

4. Plant-covering, and part played by microorganisms and animals in soil formation.

A geo-botanical survey of steppe and forest-steppe zones. Nature of the existant vegetation, and its relation to tendencies in soil formation. Part played by microorganisms, fungi, algae, and animals in soil formation.

5. Influences of a social, economic and technical order.

a) Physico-chemical improvements: lime-dressing, addition of gypsum, various methods of tillage and fertilization.

b) Physico-mechanical improvements: deep digging, terracing, draining, spray watering, irrigation etc.

c) Deforestation, and in connection with this, nature of erosion, state of ground waters etc.

A close study of the peculiarities of land surface with due account of those factors which are at power to radically change the nature of soil formation processes, provides full possibilities for a detailed discussion of the history of soils, their origin and development, these problems being put on a solid theoretical foundation. Such studies at the same time contribute to a more accurate understanding of soil properties from the point of view of productivity, and permit to find a correct approach to the question of working out a rational soil classification in sugar-beet regions.

B. The nature of the original soil, and its productivity constitute the second and especially important division of the methods of procedure in map-drawing. In our work, this section takes the following form:

№ Section

Contents

1. Classification and nomenclature of soils.

Principles of classification. Taxonomical units: type, process, stage. Conception of complexity and of the elements forming the soil complex. Soil series and regions of soil occurrence. Nomenclature of soils.

2. Physico-chemical and morphological characteristics of soils.

Combination and relation of elements in the soil complex. Characteristics of the soil profile, differentiation of horizons, mechanical composition, grass and water-soluble humus, stability and form of structure, porosity, water-holding capacity, form of moisture,

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| | air holding capacity, plasticity, coefficient of expansion, state of absorbing complex, degree of saturation, hydrolytic acidity, pH, nature of salinization, solonchok, nature of carbonates and amount of CO ₂ . |
| 3. Chemico-biological characteristics of soils. | Total supply of phosphorus. Mobility of phosphates including both mineral and organic forms. Nature of compounds with Ca, Mg, Al, Fe and other bases. Total supply of nitrogen. Nitro-amides, amido-acids, and melanins. Nitrification capacity and dynamics of nitrates in fallow land, and as well under winter wheat, sugar-beet or grasses. Growth of azotobacter, quantity of microorganisms and their group composition (fungi, actinomycetes, bacteria) protozoa and algae. Fermentation processes in the soil. Supply of potassium in the soil, and its bio-dynamics. |
| 4. Agricultural effectiveness of chemical methods applied in the nutrition of cultivated plants and in soil improvement. | Types, kinds, forms, and doses of fertilizers applied to sugar-beet, winter wheat and grasses. Methods, place and time of fertilizer application. Changes in the quality of crops under the influence of chemization. Effect of physico-chemical improvements (application of gypsum, lime, acids) and mechanical land betterment (drainage, irrigation spray-watering etc.). |
| 5. Agrotechnical and general management conditions influencing the effectivity of proposed methods of chemization. | Configuration and relief of fields. Condition of roads and transport facilities. Provision of labour force. Draught animals. Kind and quality of tillage. Supply of manure and fertilizers. Supply of agricultural machines. Rotation of crops, history of fields, and yield of sugar-beet, winter wheat, grasses, barley and oats over a series of years. |

Although the economic considerations proving the effectivity of the recommended measures form the most conclusive and fundamental part of the work, yet, in the survey so far conducted too little material on the given question appears to be collected, and insufficient attention paid to it. The methods of procedure for this work are as yet but little familiar. The basic questions in this division may be summed up as follows:—The principles laid down as criteria to judge of the effectiveness of the measures recommended for the chemization, the index of effectivity, the amount of yield obtained (sugar-beet, winter wheat, grasses etc.), fulfilment of plan, labour productivity, production costs, outlays itemized, effectivity of outlays, of amount of socialist accumulation.

D. The question of generalization of the material obtained is exceed-

ingly important, and this not only for an individual sugar-beet farm. The material must be synthesized for use on a regional, district, republic and all-union scale. We have carried out the generalization of the materials obtained along the following basic lines:

№ Subject	Contents
1. Regional distribution of soils and fertilizers.	Principles of laying down regional distribution of soils. Characteristics of: soil series, macro- and micro-regions. Characteristics of soils from the farm view point. Regional distribution of fertilizers.
2. Methods of tillage and land betterment.	Regional distribution of methods of tillage. Terms and water-values in irrigation. Nature of tillage, time, depth and direction of ploughing. Efforts expended in tillage, and methods for making the soil more mellow classified according to kind of crop and type of soil, crust-forming etc. Areas suitable for tractor-cultivation. Adaptability of agricultural implements to land surface.
3. Distribution of animal and insect pests and plant diseases, in connection with the peculiarities of surface features and soils.	Occurrence. Kinds of pests and weeds and degree of infestation of areas with varying types of soil. Principal means of control.
4. Regional distribution of different varieties of sugar-beet, winter wheat and grasses.	Where to be sown. Reaction of different varieties of crops to fertilizers and methods of tillage. Grading varieties in accordance with soil complexity, especially in salinized regions and on irrigated lands.

The methods of procedure as described in the above sections can be seen to be exceedingly complicated and varied, so that the performance of the work not only exceeds the forces of individual workers but even falls short of the potentialities of a specialized laboratory: accordingly, it was decided to summon the greater part of the laboratories within the system of V.N.I.S. as well as the laboratories of the Geology and Botany Research Institutes of the USSR Academy of Science which were jointly called upon to take part in the activities.

The results of the whole work have been laid down in the form of an agro-chemical map of the sugar-beet regions of the Ukrainian Socialist Soviet Republic. The map has an accompanying text the contents of which corresponds to the tables given above. Specimens of work conducted at state sugar-beet farms are also given, consisting of tabulated maps, maps of sections, fertilizer systems and separate monographs.

A STUDY OF THE FERTILITY OF THE DEEP HORIZONS OF THE SOIL OF THE USSR

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1. Review of literature

Both in the statement of its problems and in their solution the study of soil fertility continually changes, depending on the extent of our knowledge of soils, of the requirements of plants, and on the interdependence between soil and plant on the one hand and the demands of agricultural production and the social and economic conditions on the other.

Our study of the deep horizons of the soil of the USSR has been, and still is, governed by several considerations: 1) a more fundamental approach to the whole soil profile from the point of view of genetic soil science; 2) the establishment of a connection between the various genetic horizons and the permanent exchange between them of moisture and of organic and mineral substances in the soluble (soil solution), finely dispersed and hard phases (activity of worms); 3) a better understanding of the deep penetration of the root system of our cereal plants far below the limits of the arable and sub-arable layers (Rotmistrov, Modestov and others); 4) the more widely spread cultivation of deeply rooted technical plants; 5) an intensive development of various kinds of reclamation work — irrigation, draining, terracing, etc.

In evaluating the fertility of soil, generally the first thing done is to estimate the supply of nutritive substances contained in it. However it would be a more correct procedure to evaluate the physical properties and the micro-biological factors of soil fertility at the same time, and not only from a static point of view but also from a dynamic cross-section. Nevertheless, in the following pages we shall have in view chiefly the chemical fertility of the soil.

The fertility of the deep horizons has been studied in the USSR by the following methods: 1) in the laboratory, chiefly by chemical analyses, 2) by pot and 3) field experiments. In the course of these investigations nearly all the chief types of soils have been covered, but especially the chernozems and podzolized soils.

The laboratory methods included the study by layers of the easily soluble P_2O_5 in 2% citric, 2% acetic and other acids (Gedroiz, Lebedyantzov and others); of the nitrates and their dynamics (Sazanov and

many others); of the physical properties of soil (Kachinsky and others) and of their microbiological peculiarities (Kostychev, MAS, and his fellow-workers).

Pot tests were made, using Wagner's vessels, according to the 5-fold and 8-fold schemes, with a number of variants (Levitsky, Stchussiev, Gedroiz, Bychikhin, Lebedyantzev, Zakharov, Kirichenko and others).

Field methods were used comparatively seldom as they were complicated by certain difficulties (Stchepanovsky, Egorov, Klimov and Ivanov). To these workers must also be credited the original method of the "spread profile", first suggested by S. Zakharov in 1923. Farther on we shall briefly summarize the results of the study of the fertility of deep horizons, classified according to different soil types.

When the podzolized zone was studied in the laboratory it became evident that such soils are richer in citric-soluble P_2O_5 at the depth of from 27 to 50 cm. of the illuvial horizon B (0.0286%) than in the upper layer from 0 to 22 cm. (0.265%), while still deeper the percentage decreases slightly (0.184). Nevertheless «no parallelism exists between the solubility of phosphoric acid compounds and their availability for plants (oats and clover) in different horizons of the same soil» (Gedroiz) — though with some exceptions.

Pot-culture experiments (Gedroiz) with podzolized soils reveal a sharp decrease (as high as 75%) of the yield with depth. The yield of grain decreased with the depth more noticeably (30, 10 and 6 g. of grain) than that of straw. In all soils N was reduced to its minimum first and P second; the deficiency of N and P is more evident in the deep horizons, and fertilization greatly increases the yield (77, 33 and 40 g. of grain). This corresponds to the decrease in the content of humus and nitrogen with depth.

Field experiments near Moscow with deep spading of the soil (Egorov) show that on sub-arable soils the yield is reduced by one third in the case of some plants (barley, mustard, beets) and very little in the case of others (oats, flax), but of course this can hardly be considered a generalization. Comparative study (Stchepanovsky) at the Engelhard Experiment Station on field plots of the fertility of a normal profile of strongly podzolized soil with a humus horizon, and of the same soil without horizon A but with an exposed podzolized horizon, showed a tremendous difference in germination, development and yield of oats on both plots when various mineral and organic fertilizers were added. On the podzolized plot the plants were sickly with quite yellow leaves and the yield was only one twentieth of the yield from the humus horizon. The introduction of complete mineral fertilization and of double amounts of stable manure increased the yield from the podzolized horizon so that it equalled that from the control plot on the normal profile. The great difference in the yield is explained by the removal together with horizon A of most of the humus and of the N and P connected with it, as well as by a considerable worsening of the physical properties. By the cultivation of lupine and the simultaneous introduction of fertilizer, A. D. Stchepanovsky was able radically to improve the fertility of a barren podzolized horizon in four years; the yield was increased from eight to ten times, and a crop of oats of 27 centners per hectare

was harvested. This certainly opens up possibilities and prospects for reclaiming wild podzolized soils!

The study of the physical properties of podzolized soils of the genetic horizons by Kachinsky gave a clear picture of their change for the worse in the podzolized horizon A_2 ; he also cleared up the regularity of the distribution of the root system of plants connected with the physical properties of the soil.

The study of the biodynamics of the various genetic horizons of podzolized soils has shown that only the upper sod horizon is microbiologically active, and that tillage makes it much more active, the various physiological groups of bacteria are not equally distributed in the different horizons. For example, the denitrifying and butyric acid bacteria penetrate into horizon C also.

For the soils of the chernozem zone, laboratory study has shown that the solubility of P_2O_5 in 2% citric acid generally decreases in the second horizon B , and sometimes increases in horizon D . This also coincides with the availability of P_2O_5 in the two upper horizons. V. Sazonov made investigations in 1906 into the dynamics of nitrates in various chernozem horizons which showed a considerable shifting of the nitrogen available to the plant along the soil profile during the year. Since then the number of similar observations has greatly increased.

Pot tests (Levitsky, Stchussiev, Gedroiz, Sazonov, Lebedyantzev, Bychikhin, Zakharov, Pushkarev and others) have shown a rapid decrease with depth of the yield of oats (16; 8.3; 3.8 g. or 25, 12 and 8 g.) clover, millet, barley and wheat, and the unequal response of the plants grown on different horizons to the introduction of various kinds of fertilizers. The arable layer reacts best to N , and the deep layers to P or to N plus P . The amount of N assimilated decreases with depth, and the assimilative capacity of P also in nearly all soils. The fertility of the different horizons is evened up to a considerable degree by the introduction of fertilizers. The fertility of leached chernozem of the Shatilovo Experimental Station (A. N. Lebedyantzev) decreases with the depth of the horizon (A_1 , A_2 , B_1 , B_2 and C) thus: 15.25; 5.05; 3.55; 5.35 g. of millet per pot. In Lebedyantzev's opinion the periodical drying out of the upper horizon is an essential factor in its increased fertility.

As the result of pot experiments the conclusion was reached that in calculating soil productivity in relation to N we cannot limit ourselves to the arable layer only because the nitrates penetrate deep into the soil and are used there by the plant roots. This fact may explain the continual lack of co-ordination between the results of pot and field experiments (Stchussiev, 1906). The plants did not give a maximum yield because of the lack of assimilable P_2O_5 especially in the sub-arable horizon (Bychikhin, 1912). Recently, in connection with the problem of the mobilization of the richness of the chernozem, it has been shown (Avdonin, 1934) that the sub-arable horizons of the chernozem, which are very rich in nutritive substances and have an ideal structure, have a very low productivity. This must be attributed to the low mobility of the nutritive substances of the sub-arable horizon, which requires cultivation.

Special experiments made at the Shatilovo Experimental Station (Lebedyantzev) indicate that the fertility, not only of the different horizons of the chernozem, but even of the upper and lower parts of the arable horizon, differ very definitely, that this change is dynamic and that the fertility of the arable horizon increases very markedly during the growing season.

Somewhat different results were obtained (S. Zakharov and A. Nikonetz) with different layers and sub-horizons of the humous horizon A of a thick, strongly leached North Caucasian chernozem; the sub-arable horizon was found to be the most fertile (for barley and maize).

The fertility of the deep horizons of the chernozem was studied by the field method at the Kuznetsk Experimental Field (Klimov and Ivanov) by means of cultures on arable and sub-arable layers, and in the Northern Caucasus (S. Zakharov, K. Kirichenko and others) by the method of a "spread profile" to a depth of from two to three m, various plants (cereals, root plants, legumes, row crops.) being used. The fertility of the layers and horizons was found to decrease gradually with depth, most sharply in horizon C₁, but at a greater depth it began to increase again. Different plants react unequally. Millet and beans are most sensitive to the deep horizons, buckwheat the least and beet roots only to a certain extent. These last gave the same yield up to a depth of 80 cm.

It is interesting to observe the dynamic potentialities of the fertility of the deep horizons. When placed on the surface, and exposed to daylight, the yield of all the plants grown on them gradually increases, and the yield of alfalfa on deep horizons becomes even higher than on the arable one in the course of time. It is evident that the potential fertility of these horizons passes into effective fertility under the influence of atmospheric and geological agents as well as of tillage.

It is instructive also to observe the different behavior of cultivated plants on deep horizons during years when the meteorological conditions are different, the relative changes of the grain and the straw, (barley) and between the aboveground and underground organs (beets).

The study by layers of the agro-physical properties of chernozems has shown their gradual change with depth (Lebedev, Maslova and L. S. Zakharova).

Study of the biodynamics of chernozem horizons has shown that the number of active microorganisms is large only in the very surface layers and that with depth it rapidly decreases. The nitrification of soils changes similarly; but some kinds of bacteria, such as the denitrifying, putriferous and butyric acid ones, are found in all horizons.

Pot and field experiments (on a "spread profile") with sandy, chestnut loams under irrigation gave a gradual fall in the yield from horizon A to horizon B, and a rapid one in horizon C (99; 58; 5.3 g. of sunflower seeds), but an increase in horizon D (59). On brown sandy loams (hors. A, B₁, B₂ and C) similar results were obtained for oats (150; 100; 60 and 10 g.); for beans, and especially for potatoes, the decrease in the yield with depth was more gradual (1170; 1040; 1030 and 640 g.). On chestnut soils of a loamy mechanical composition probably quite different results would be obtained.

Pot experiments with several different horizons of gray soils (serozems) (Negodnov) showed a comparatively slow and even decrease in the yield of oats with depth (12.5; 8 and 6.5) which corresponds to the small differentiations of the soil profile.

Pot experiments with eikommia (rubber bearing tree) on horizons A, B and C of a podzolized krasnozem (red soil) near Batum showed (Znamensky) a rapid decrease in the growth of transplanted seedlings (63; 32; 16 cm.), in their leaf surface and dried leaf mass (11.95; 3.45, 1.60 g.) on deep horizons. Similar results were obtained with tea seedlings at the All-Union Institute of Tea Culture. This lag in the growth and development of plants must be attributed to a reduction in the nutritive substances and a change for the worse in the physical properties as depth increases. The stunted development of tea shrubs on plots with washed-off soil also illustrate and confirm the results of the pot experiments, while the analyses of the content of P and N by horizons explains the correctness of the deductions.

A biodynamic study of krasnozem (red soil) (Harder) disclosed a very intensive nitrification of the arable horizon of the plantation, ten times as great as that of the virgin soil (2.89 and 0.29 mm.), but a complete absence of it at a depth of 45 cm.

Field observations in the region of the complex cover of the chernozem zone (Gedroiz) indicated that oats developed badly or not at all on micro monticulees of chernozem alkali-soils (solonetz). Pot experiments have shown that the arable horizon of the chernozem-solonetz produces hardly any yield even with the introduction of mineral fertilizers. However, the deep horizons B, 20—50 cm., and C, 60—70 cm., are more productive, especially when complete fertilization is introduced. Observations in the chestnut zone show that horizon A of solonetz is comparatively fertile, while the columnar horizon B is nearly sterile because of its bad physical properties. Under the influence of tillage the nitrifying activity in horizon A is much increased.

Pot experiments with different horizons of plawni soils show very different changes in these soils with depth. Rice responds differently to the introduction of mineral fertilizers (Kirichenko).

In peaty soils the energy of nitrification and the fixation of atmospheric nitrogen, falls gradually and evenly with depth to 60 cm., where it ceases altogether.

In summing up the results of these studies of the fertility of the different genetic horizons of the principal soil types of the USSR, although up to the present this work has not been systematic or in accordance with any general plan, it is nevertheless possible to make the following deductions:

1. The very top horizon — humous and arable — is distinguished by the greatest effective fertility, with certain exceptions, when the sub-arable layer is richer.

2. Fertility decreases more or less sharply with depth and this takes place differently with different plants.

3. However, at a certain depth some increase of fertility is again observed, for instance in horizon C and D of the chernozems or in

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horizon *B* of chernozem-solonetz. This must be associated with the washing into them of nutritive substances from the upper horizons.

4. The infertility of the deep horizons may be explained in several ways: by a general lack of nutritive substances (horizon A_2 in podzol soils) or because they are in a condition insufficiently available for the plants (the subsoil horizon of chernozem); by their bad physical properties (chestnut solonetz); by their containing injurious compounds (large amounts of soluble salts or toxic substances — products of the life activity of organisms).

5. The low fertility of the deep horizons may be increased by introducing fertilizers, chiefly P and N, and by subjecting them to the action of atmospheric and biological agents.

6. The potential fertility (richness) of sub-arable horizons may be activated by agronomic measures, fertilizing them and bringing them gradually into contact with the atmosphere and the biosphere.

These deductions concerning the fertility of the deep horizons of the soil become intelligible in the light of our modern knowledge of the genesis, evolution and dynamics of the earth's soil cover; to some extent they may be deductively (synthetically) and differentially, foreseen, starting from the same state of knowledge afforded by the soil science of today.

1. Horizon *A*, humous-accumulative, is formed by a process of gradual humification and mineralization of decaying vegetable remains as a result of which the humous substances, together with N and the ash are accumulated in it, it is also a carrier of the more useful microorganisms. When it is brought under cultivation the life-activity of the microorganisms is activated, and once it has become the arable layer, this horizon is naturally found to be the most fertile.

2. The elluvial horizons (horizon A_2 of podzol, the transitional horizon *B* of chernozem and some others) contain less humus, ash and fewer microorganisms. This is the cause of the sudden or considerable decrease in their fertility.

3. The illuvial horizons (horizon *C* of chernozem, horizon *B* of podzol and solonetz) constitute that part of the soil profile where the descending solutions discharge some of the substances and isolate them together with CaCO_3 and P_2O_5 , P, K and others also being fixated here. The toxic substances and easily soluble mineral salts (in solonchaks) which are injurious to plant life may be isolated along with them. This causes the change in the fertility of these horizons.

4. The differentiation of the soil horizons is accompanied by changes in their dispersity and in their physical, as well as in the air, water and other properties which change regularly along the profile and, correspondingly influence the fertility of the different horizons.

5. As the soil-forming process gradually progresses, the differences in fertility of the individual, even contiguous genetic horizons increase (e. g. A_1 and A_2 of podzolized soil and horizons *A* and *B* of chestnut solonetz), and the zone of potential fertility may be shifted along the profile.

The study of the fertility of the deep horizons gives a clue to certain possibilities of transforming the potential fertility (richness) of our

soils into effective fertility, of reconstructing the soil cover of our Union, of creating cultivable soil out of our virgin and half-wild lands by taking various measures, of reconstructing the agriculture of our country on a socialist foundation by utilizing new lands, improving them, increasing the yield from land already under cultivation, deepening the arable layer — in general, increasing the yield of the Union's agriculture during the second Five-Year Plan.

The study of the fertility of the sub-arable soils and of the deep horizons has so far been insufficiently organized and haphazard, depending on the initiative of individual workers and departments. We must carry on the further study of this problem more systematically and include in it all the principal soil-climatic and agricultural zones and regions of the USSR. We must ask our agricultural experiment stations to include in their programs problems and topics arising from this work so that they may throw light upon them by various methods from the point of view of chemistry, physics and the microbiology of the soil.

2. Field experiments by the method of "spread profiles" for determining the fertility of deep horizons

In 1921, at the suggestion of the author, a special field method for the study of deep soil horizons was given a practical test at the Kuban Experimental Station. It has been proposed to call it "the method of spread profiles". The theory on which this method is based is that of a monolith of soil, laid horizontally, on which plants used in the experiment are sown and grown. In this way the germinative capacity of the seeds, the development of the plants and their appearance as affected by the fertility of the different horizons can be clearly observed.

In practice, a trench or pit is excavated in a field two or three m. wide, seven or eight m. long (one meter for each horizon) and with a depth of 0.5 to 1.0 m. This trench is faced with brick and divided by brick partitions into compartments or sections. A consecutive row of bottomless "lysimeters" is thus obtained. These compartments are then filled with equal amounts of soil from each separate horizon or sub-horizon taken from a neighbouring pit. This can be best done in autumn. In the spring the seeds are sowed, phenological observations of the plants are then made and the yield calculated. A control plot is planted alongside and there is also a protective strip. Between 1921 and 1934 the author and his collaborators (K. S. Kirichenko, V. S. Dibrova, Z. S. Kuvika) carried out a number of experiments with a large number of agricultural plants by this method of spread profiles, both with the leached chernozem of the Northern Caucasus (near Krasnodar) and with some soils of arid regions (Kazakstan).

These experiments have confirmed the positive value of this method and have made it possible for us to make many interesting and constructive deductions. We summarize the most important.

1. The fertility of the independent horizons of the leached cherno-

¹ Data compiled with the collaboration of K. S. Kirichenko and V. S. Dibrova.

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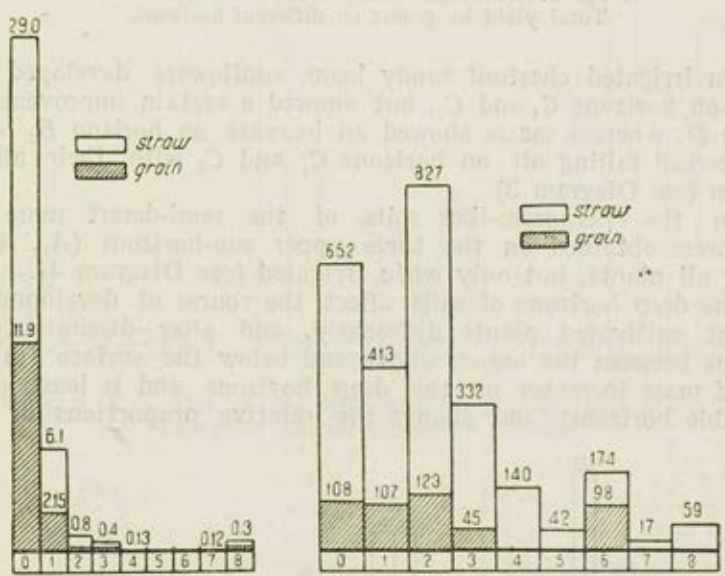
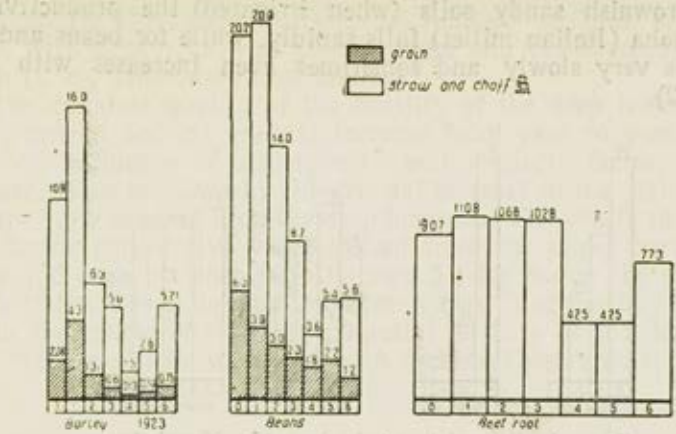


Fig. 1. Fertility of various horizons. First series of experiments 1922—1923, North Caucasian leached chernozem.

zem of the Northern Caucasus decreases more or less rapidly with depth down to the illuvial carbonaceous horizon C, where it increases somewhat.

2. Most of our agricultural plants draw their mineral food chiefly from the upper horizons of the chernozem (K. S. Kirichenko).

3. Different agricultural plants differ as regards the energy of their root systems in assimilating nutritive substances from the deep horizons of the chernozem. Buckwheat has the most active root system; next come beets, maize and barley. The least energetic is that of barley which is probably more sensitive to the slightly alkaline reactions of the deep horizons. Maize develops best on the sub-arable horizon (see Diagram 1).

4. On brownish sandy soils (when irrigated) the productivity of oats and moha (Italian millet) falls rapidly, while for beans and potatoes it falls very slowly and sometimes even increases with depth (Diagram 2).

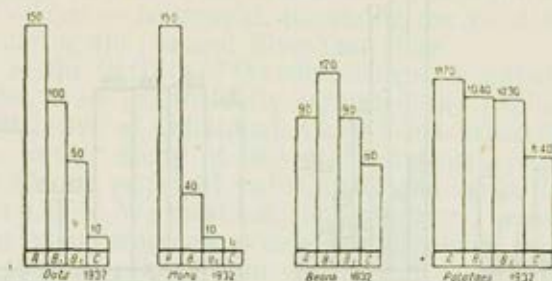


Fig. 2. Brownish sandy loam in Kazakhstan.
Total yield in grams on different horizons.

5. On irrigated chestnut sandy loam, sunflowers developed very poorly on horizons C_1 and C_2 , but showed a certain improvement on horizon D , whereas maize showed an increase on horizon B_2 and a very marked falling off on horizons C_1 and C_2 with their alkaline reaction (see Diagram 3).

6. On the chernozem-like soils of the semi-desert more even yields were obtained on the three upper sub-horizons (A_1 , A_2 and B_1) for all plants, but only when irrigated (see Diagram 4).

7. The deep horizons of soils affect the course of development of different cultivated plants differently, and alter dissimilarly the relations between the organs above and below the surface (in beets the leaf mass increases on the deep horizons and is least on the sub-arable horizons) and change the relative proportions of grain

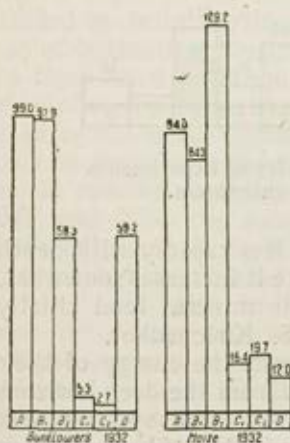


Fig. 3. Chestnut sandy loam in Kazakhstan.

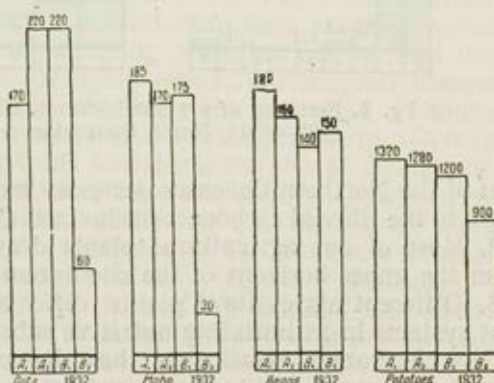


Fig. 4. Chernozem-like loam in Kazakhstan.

and straw (in the case of barley the relative amount of straw increases with depth), as well as the shape and development of the root system (i. e., sunflowers and alfalfa).

8. The dynamic quality of the fertility of the deep horizons should be emphasized and its gradual increase from year to year, evidently under the influence of atmospheric and biologic factors as well as of tillage. This is shown by the gradual increase in the yield of cereals, and especially of alfalfa, on the deep horizons. For alfalfa the maximum yield during consecutive years shifted from the upper horizon to the middle and deep horizons (see Diagram 5); for barley the yield on the deep horizons was somewhat more even (see Diagram 6).

9. In the course of time the potential fertility of the deep horizons (their "richness") is mobilized with considerable rapidity and passes

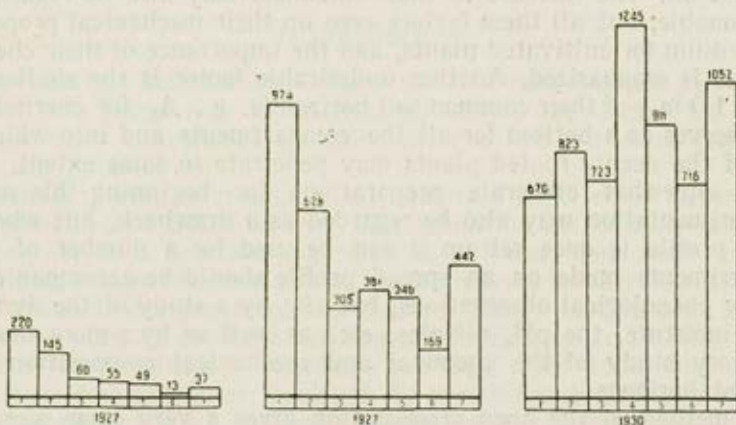


Fig. 5. Dynamics of the fertility of various horizons of North Caucasian leached chernozem. Alfalfa.

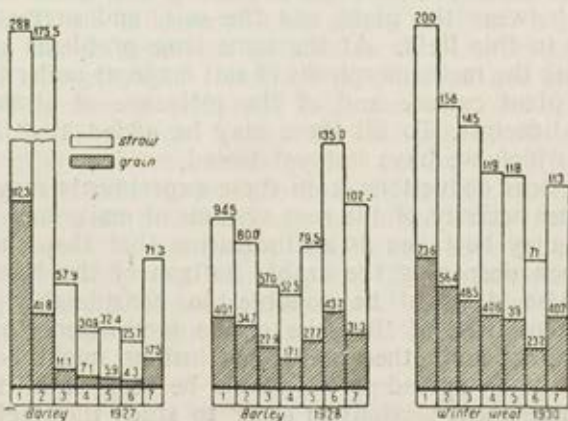


Fig. 6. Dynamics of the fertility of various horizons of North Caucasian leached chernozem. Barley and winter wheat.

over into effective fertility. Simultaneously, under the influence of the atmosphere and the biosphere, a profound change takes place in the properties and composition of the different horizons. A certain metamorphosis occurs; they are leached, acquire structural qualities, become loose and friable, etc.

The method of spread profiles occupies an intermediate position between field and pot culture methods as regards its special characteristics. Some of the artificial and objectionable factors of pot-culture are eliminated, such as the small volume of soil, the deformed development of the roots, the exclusively optimal conditions of moisture and temperature, etc. By this method the plant has a more natural field environment. The unavoidable loosening of the different horizons may be regarded as an undesirable factor, but it is approximately equal for them all. The increase in their thickness may also be regarded as objectionable; but all these factors even up their mechanical properties, as a medium for cultivated plants, and the importance of their chemical qualities is emphasized. Another undesirable factor is the shallow bed (0.5 to 1.0 m.) of their common soil horizon (e. g., A_3 for chernozems), which serves as a bottom for all the compartments and into which the roots of the deeply rooted plants may penetrate to some extent.

The somewhat elaborate preparations for beginning this method of experimentation may also be regarded as a drawback, but when the spread profile is once set up it can be used for a number of years.

Experiments made on an spread profile should be accompanied not only by phenological observations, but also by a study of the dynamics of the moisture, the pH, nitrates, etc., as well as by a more thorough laboratory study of the chemical and mechanical composition of the different horizons.

The method of the open cross-section gives a very clear picture of the fertility and yields of the different horizons as the plants used for the experiments develop. Observations of the plants and analyses of the yields obtained enable us to make a number of deductions regarding the relations between the plant and the soil, and suggest many new considerations in this field. At the same time problems arise and are solved regarding the metamorphosis of soil horizons under the influence of tillage, of plant culture and of the influence of atmospheric and microbiological factors. To all these may be added also the influence of fertilizers, which we have not yet tested.

Several practical deductions from these experiments may be pointed out. The greater activity of the root systems of maize and beets in the deep horizons may be taken as an indication that they should receive precedence when deepening the arable horizon of the North Caucasus chernozem. Also it might be possible to considerably deepen the arable horizon of most of the soils of the semi-desert complex when they are irrigated; and other useful conclusions might be drawn.

The method of an spread profile should be used at all the principal agricultural experiment stations in order to study the chief plants used in the rotation of crops in various soil zones and regions of the USSR, and also in other countries.

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LA RÉPARTITION DU POTASSIUM DANS LES FRACTIONS DU SOL ET SON ASSIMILATION PAR LES PLANTES¹

MASLOVA A. L., STOLIAROVA A. A. et OUVAROVA A. V.

I. Introduction

Nos Instituts scientifiques d'agriculture s'intéressaient peu jusqu'à présent à la question de la nutrition potassique des plantes, car on considérait, dans la pratique agricole, que nos sols n'avaient pas besoin d'engrais potassiques.

Cependant, avec la croissance du nombre d'expériences faites sur les champs de toute l'URSS, et avec l'accumulation des faits sur les engrais potassiques, on a constaté que certaines cultures, dans toute une série de régions, présentent une réaction très nette avec les engrais potassiques. Dans une série d'expériences aux champs, aussi bien que dans les expériences en pots, la conduite des engrais potassiques se manifeste d'une manière très originale, — conduite provoquée par toute une série de conditions concomitantes: le degré de saturation des sols, la composition mécanique du sol, le fond présenté par d'autres engrais minéraux (Droujinine; 2, Maslova, 3).

Le désir d'établir plus nettement les régions de l'action des engrais potassiques, de même que le désir de mettre en évidence toutes les conditions existantes qui aideraient à en mieux profiter, ont obligé les savants à fixer leur attention sur la question de l'engrais potassique. Nous savons, par exemple, que l'Institut scientifique des engrais, NIU, à Moscou, s'est beaucoup occupé de cette question, ces dernières années, et l'examen de 25 millions ha fait en 1932 par l'Institut Panunioniste des Engrais et de la Science du Sol, avait comme but principal d'établir l'efficacité de l'engrais potassique dans différentes régions de l'Union. Les études ayant pour but de trouver des méthodes de recherches agrochimiques sur l'équilibre potassique dans le sol, se sont sensiblement développées récemment, on a beaucoup traité les questions des formes du potassium dans le sol, de ses formes les plus accessibles à la plante, c'est à dire des méthodes servant à déterminer l'efficacité des engrais potassiques.

¹ Le travail a été fait à l'Institut Panunioniste des Engrais et de la Science du Sol (Moscou) sous la direction de M-me A. L. Maslova. Le 2-me chapitre «Répartition du potassium par les fractions du sol» a été écrit par M-me A. A. Stoliarova et le 3-me chapitre «Assimilabilité du potassium des fractions mécaniques» — par M-me A. V. Ouvarova.

Un aperçu sommaire des travaux agrochimiques, qui, par leur synthèse, doivent servir de base à l'application productive des engrais potassiques dans l'économie pratique nous montre qu'en étudiant la fertilité naturelle du sol à l'égard du potassium, nous pouvons arriver à connaître la dépendance complexe de l'efficacité des engrais potassiques de toute une série de facteurs: de la composition mécanique du sol, du stock total de potassium et de sa répartition dans les fractions, du degré de l'assimilabilité de ces formes différentes de potassium dans le sol, de la solidité de la fixation du potassium introduit dans le sol avec l'engrais.

Tout ceci a en grande partie imprimé la direction à nos travaux sur le potassium.

En premier lieu, il nous a semblé évident qu'à côté des méthodes de détermination du potassium, absorbé dans le sol, nous devions élaborer des méthodes pour une détermination du potassium non-échangeable, lequel, d'après les données de beaucoup d'auteurs fournit les réserves de potassium échangeable; par conséquent, les deux espèces de potassium réunies, fournissent des formes de potassium mobiles, assimilables par les plantes, et qui garantissent le rendement.

Voilà pourquoi l'un de nos premiers travaux a été un travail méthodique; ce travail, avait en vue non seulement l'élaboration d'une méthode simplifiée pour déterminer le potassium absorbé, mais se posait comme but la création d'une méthode de détermination des formes du potassium solubles dans les acides citrique et chlorhydrique, avec une détermination ultérieure iodométrique du potassium dans les extraits obtenues (v. l'ouvrage de A. L. Masslova et Z. V. Tchernychova, livr. 5. Ouvrages de l'Institut des Engrais et de la Science du sol).

Ensuite, si nous étudions la dépendance entre la composition mécanique et la fertilité des sols et le potassium, nous croyons qu'il serait insuffisant de se borner à une comparaison de la composition mécanique, et du «stock» de potassium «mobile», dans le sol, que ce soit le potassium soluble dans les acides ou bien le potassium absorbé, puisque cette quantité est excessivement variable, inconstante pour l'espèce du sol envisagée, ce qui dépend des conditions existantes; par ex.: cela dépend de ce que le champ est emblavé ou non, s'il est fumé ou non, etc.

Nous trouvons nécessaire de donner une caractéristique approfondie de la composition mécanique des fractions même du sol, cette caractéristique doit d'un côté, définir la quantité globale du potassium et du potassium accessible aux plantes dans les fractions, de l'autre, en définir la valeur nutritive.

C'est pourquoi, nous avons accordé une attention particulière à la question de savoir quelles sont les fractions du sol qui sont assimilées par les plantes, et dans quelle mesure elles le sont. Pour cela, nous avons introduit des fractions de sols comme source d'alimentation potassique, dans les expériences sur la végétation, sur celles d'après Neubauer et dans les expériences sur la champignon *Aspergillus oryzae*.

II. La répartition du potassium par fractions du sol

Nous avons pris pour l'étude 9 échantillons de sols représentant des groupes d'origine génétique différente, notamment 4 espèces de sol pod-

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zolisé, 3 espèces de tchernosiome, le sol gris (le sérosiome) de l'Asie Centrale et le sol gris forestier.

Voici la caractéristique sommaire de ces sols:

1. Sol podzolisé de la région de Moscou: — fortement podzolisé, terrain argilo-limoneux, léger.

2. Sol podzolisé de la province Occidentale: — fortement podzolisé, argilo-limoneux, reposant sur un sous-sol de loess puissant.

3. Sol podzolisé de la province d'Ivanovo — terrain argilo-limoneux, moyennement podzolisé, à sous-sol de loess.

4. Sol podzolisé du champ d'expérimentation de Dolgoproudny: — sol fortement podzolisé, portant des traces de marais. Par sa composition mécanique — terrain argileux, avec une teneur en humus de 1,87%. Capacité d'absorption — 6,3 mil équiv.

5. Tchernosiome du district de Krasnozorsinsk de la Région Centrale du Tchernosiome (Terres Noires): — faiblement lessivé, argileux, de puissance moyenne.

6. Tchernosiome lessivé de la station d'expérimentation Mironovka, de puissance moyenne.

7. Tchernosiome argileux puissant de la station d'expérimentation Kaménno-Steppes. La teneur en humus — 8%, capacité d'absorption — 50 mil. équiv.

8. Sérosiome (sol gris) de la région Kershinsk. Non-salin, sur un sous-sol d'une composition mécanique diverse dans les dépôts, légèrement marécageux; (eaux sous-terraines à partir de 245 cm).

9. Sol forestier gris, argilo-sablonneux, — état de bonne culture. District de Gloukhov de la Région Centrale du Tchernosiome (Terres Noires).

Tous les échantillons ont été pris des parcelles témoins (sans engrais) de la couche arable.

Dans tous les échantillons la teneur globale de potassium fut établie par la calcination du sol avec le chlorure d'ammoniaque, et le carbonate de chaux avec une précipitation ultérieure du potassium par le $\text{CO}_3(\text{NO}_2)_6$ (méthode de Milné).

Ensuite, les échantillons du sol (passés au tamis de 2 mm), de 100 g furent divisés en fractions mécaniques d'après la méthode de Williams et celle de Gedroiz.

Les données analytiques sont données dans la table 1.

Les données de la table 1 nous montrent, que pour les sols podzolisés les deux méthodes appliquées par nous donnent à peu près les mêmes résultats, en ce qui concerne le dégagement des fractions qui nous intéressent. Or, pour les terres noires, riches en humus, de la station expérimentale de Kaménno-Steppes, la quantité des fractions d'argile obtenue par la méthode Gedroiz, constitue presque le double de la quantité obtenue par la méthode Williams, — ce qui rendait la quantité des grandes fractions suivant la méthode Williams, surtout pour le limon grossier, considérablement supérieure en % à celle obtenue par la méthode Gedroiz.

Tant soit peu différent est le pourcentage de potassium dans les fractions dégagées d'après la méthode Gedroiz.

Table 1

S o i l	Teneur en K ₂ O du sol et des fractions en %/100									
	%/100 des fractions									
	F	r	a	c	t	i	o	n		
1	> 0,25	0,25—0,01	0,01—0,005	0,005—0,001	< 0,001	Sol	0,25—0,01	0,01—0,005	0,005—0,001	< 0,001
	2	3	4	5	6	7	8	9	10	11
Méthode Williams										
Podzol de la région de Moscou . . .	4,8	47,9	40,8	—	4,9	1,37	1,10	2,00	—	0,59
Podzol de la région Occidentale . . .	1,3	56,4	38,2	—	3,0	1,25	1,92	2,50	—	1,56
Podzol de la région Ivanovo . . .	7,3	65,1	19,5	2,83	4,3	1,98	1,74	2,52	2,59	2,79
Podzol du champ d'expérience Dolgoproudny . . .	0,84	39,3	46,5	4,8	7,6	2,72	2,54	2,94	3,22	3,11
Tchernosiome de la région Centrale des Terres Noires . . .	1,5	33,2	51,5	—	11,3	1,77	1,73	1,58	—	0,89
Tchernosiome du district Romachkovo . . .	1,0	56,9	32,3	—	8,6	1,50	1,81	1,81	—	1,77
Tchernosiome de la station d'expér. de Kamennno-Steppes . . .	2,75	28,3	42,6	7,6	22,3	2,00	1,70	1,96	2,35	3,43
Sérosiome de l'Asie Centrale . . .	1,2	37,4	41,2	—	9,65	2,30	2,48	1,56	—	3,26
Sol forestier gris du district de Gloukhovo . . .	18,6	64,4	9,6	3,5	4,7	1,38	1,55	3,19	3,07	3,08
Méthode Gedroiz										
Podzol de la r. Ivanovo . . .	7,9	64,1	22,2	2,4	3,4	—	1,86	2,33	2,63	3,53
Podzol du champ d'expér. de Dolgoproudny . . .	2,2	42,9	40,8	7,3	11,9	—	2,44	2,75	3,02	2,83
Tchernosiome de la station de Kamennno-Steppes . . .	0,27	13,7	35,2	5,85	41,4	—	2,36	1,90	2,24	2,09
Sol forestier gris du district de Gloukhovo . . .	22,5	61,1	11,4	1,59	4,1	—	1,14	2,40	2,64	2,95

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Cependant les deux méthodes présentent la même caractéristique des sols étudiés en ce qui touche la proportion du potassium dans chaque fraction, ainsi que le bilan de tout le potassium du sol (voir la table 2).

Quant à la répartition du potassium par fractions, le point de vue généralement accepté est, que le pourcentage du potassium augmente avec la diminution des diamètres des fractions. Suivant les données, obtenues par nous, cette tendance n'a lieu que dans les limites de la transition du limon grossier au limon fin, — cependant, il arrive souvent que les sols indiquent un pourcentage égal de potassium pour toutes les trois fractions de limon (voir la table 1, terres noires lessivées et sérosiomes).

L'argile présente d'habitude un pourcentage de potassium plus bas que celui de la fraction précédente (limon fin), à l'exception du sol podzolisé de la région d'Ivanovo, du tchernosiome de la station de Kamenno-Steppes et du sérosiome.

Dans la table 2 nous donnons les chiffres du potassium de chaque fraction pour 100 g de sol en mg de K_2O .

Vu que le pourcentage du potassium dans les argiles, obtenues de sols différents, n'est pas égal, et varie entre 0,59 et 3,53%, et étant donné, que le pourcentage de la fraction argileuse elle-même varie fortement entre 3 et 22%, il est tout naturel que la quantité de potassium qui revient à la part de cette fraction sur 100 g de sol, varie aussi fortement.

On y observe, cependant, une certaine régularité, notamment en ce que le chiffre est très bas pour les sols podzolisés sablonneux, les sols gris forestiers et le tchernosiome lessivé, tandis qu'il s'élève considérablement pour les sols podzolisés argileux, et pour le sérosiome et atteint son maximum dans le tchernosiome puissant de Kamenno-Steppes.

Alors que la quantité de potassium calculée pour les limons grossiers, moyens, et fins, démontre que dans tous les sols, la masse principale du potassium du sol se trouve précisément dans ces fractions (dans les sols argileux les fractions des limons moyens et fins sont plus riches en potasse que le limon grossier), dans le tchernosiome de la station de Kamenno-Steppes, le poids total du potassium de l'argile et du limon fin et moyen, est presque égal.

Sur la même table 2, nous montrons le pourcentage du potassium des fractions différentes par rapport à la teneur globale en potassium du sol.

Comme le démontre la table 2, dans les sols limoneux-sablonneux podzolisés, légers, la fraction argileuse ne contient que 2—6% de potassium, par rapport à la quantité globale de potassium dans le sol. La plus grande partie du potassium de ces sols revient au limon moyen et fin (59,5%), et le reste au limon grossier.

Dans le sol podzolisé limoneux de Dolgoproudny le pourcentage du potassium se rapportant à la fraction de l'argile, s'élève jusqu'à 8—12%, quoique la masse principale du potassium reste encore concentrée dans les fractions du limon moyen et fin. Par la répartition du potassium dans les fractions, c'est le tchernosiome lessivé qui se rapproche de très près du sol podzolisé limoneux, tandis que la conduite du potassium dans tous les autres sols est toute différente. Tandis que dans le sol forestier gris, par exemple, la part revenant au potassium de la fraction argileuse, 9—10%, égale approximativement celle contenue

Table 2

S o i l	K ₂ O des fractions différentes par 100 g du sol en milligrammes						Proportion du potassium dans chaque fraction en %/100, par rapport au potassium global du sol					
	F		r	a	c	t	i	o	n			
	0,25— 0,01	0,01— 0,005	0,005— 0,001	0,005— 0,001	< 0,001	0,25— 0,01	0,01— 0,001	< 0,001				
Total	2	3	4	5	6	7	8	9				
Méthode Williams												
Podzol de la région de Moscou	1 373	528	816		29	38,4	59,5	2,1				
Podzol de la région Occidentale	2 085	1 083	955		47	51,8	46	2,2				
Podzol de la région Ivanovo	1 815	1 131	491	73	120	62,3	31,0	6,7				
Podzol du champ d'expér. de Dolgoproudny	2 756	998	1 367	155	236	36,3	55,2	8,5				
Tchernosiome de la Région Centrale des Terres Noires	1 489	574	814		101	39,4	54,6	7,0				
Tchernosiome du distr. Romachkovo	1 770	1 032	585		153	58,3	33,1	8,6				
Tchernosiome de la st. d'expér. de Kamennno-Steppes	2 260	481	835	179	765	21,1	45,0	33,9				
Sérosiome de l'Asie Centrale	1 509	5 553	643		313	37,0	42,5	20,7				
Sol forestier gris	1 555	998	306	107	144	64,2	26,5	9,2				
Podzol de la rég. Ivanovo	1 886	1 190	513	63	120	63,7	30	6,3				
Podzol du champ d'expér. de Dolgoproudny	2 726	1 047	1 122	220	337	38,5	49,2	12,3				
Tchernosiome de la st. d'expér. de Kamennno-Steppes	1 998	323	669	131	875	17,2	40,0	43,8				
Sol forestier gris	1 132	695	274	42	120	62,3	27,9	10,6				

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dans les sols du groupe précédant, la masse principale du potassium, 62—64%, revient déjà à la fraction grossière.

Dans le tchernosiome de Kamenno-Steppes, la masse principale du potassium revenant à l'argile constitue 34—44%, aux fractions du limon moyen et fin — 40—45% et une part insignifiante appartient au limon grossier.

Dans le tchernosiome 20% de la quantité globale de potassium du sol revient à la fraction argileuse, et à peu près une quantité égale aux deux autres fractions plus grossières.

On peut souvent voir dans la littérature, des indications que le potassium assimilé par la plante se trouve dans la fraction argileuse du sol.

Nos données montrent, que la quantité de potassium dans le sol, revenant à la part de cette fraction dans les différentes variantes des sols, varie considérablement dans les chiffres tant absolus que relatifs.

Les sols podzolisés sablonneux sont surtout pauvres en potassium et, au contraire, le sérosiome et le tchernosiome puissant en sont riches.

Le sol podzolisé argileux et le tchernosiome lessivé occupent une place intermédiaire.

Conclusions

1. La teneur en potassium des fractions n'augmente pas toujours avec la diminution du diamètre des particules du sol. Nos résultats ont montré que cette tendance n'est constatée que dans les limites des fractions qui passent du limon grossier au limon fin. La fraction argileuse marque très souvent une baisse dans la teneur en potassium global, par comparaison avec les autres fractions.

2. La teneur en potassium de la fraction argileuse par rapport au potassium global du sol, varie beaucoup autant dans les chiffres absolus que relatifs. Aussi, cette part de potassium, par rapport au potassium global du sol dans les espèces podzolisées et le tchernosiome lessivé, n'a constitué que 2—8%, tandis que dans le tchernosiome et le sérosiome elle s'est élevée jusqu'à 20—40%.

3. La composition qualitative des argiles est différente, puisque les argiles de divers sols ont présenté un pourcentage différent pour le potassium global, qui variait de 0,5% à 3,5%.

III. L'assimilabilité du potassium des fractions mécaniques

1. Expériences d'après la méthode de Neubauer

Pour deux sols, notamment le tchernosiome de la station d'expérimentation de Kamenno-Steppes, et le sol podzolisé du champ d'expérimentation de Dolgoprudny, les fractions suivantes ont été dégagées par la méthode de Williams:

Limon grossier — 0,25 — 0,01 mm.

Limon moyen — 0,01 — 0,005 mm.

Limon fin — 0,005 — 0,001 mm.

Argile colloïdale — <0,001 mm.

Toutes les fractions (à l'exception de l'argile) furent recueillies après la lévigation sur un entonnoir, où on les amenait à l'état sec à l'air.

L'argile fut recueillie dans des capsules en porcelaine évaporée à sec au bain-marie.

Dans les fractions séparées on détermina la teneur globale en potassium.

On s'est servi pour ce dosage du procédé de l'agglutination du ol , avec le chlorure d'ammonium et le carbonate de calcium; ce procédé fut suivi par un dosage du potassium dans le filtrat selon la méthode par le cobalt-nitrique, avec la modification de Milné. Les résultats de l'analyse sont donnés sur la table 3.

Les fractions obtenues furent introduites dans les cristallisoirs de Neubauer en qualité de source de nutrition potassique, en une quantité correspondant à 75 mg de K_2O pour chaque vase.

Un mélange de la fraction étudiée, et de sable en une quantité de 200 g fut placé en couche unie au fond du cristallisoir (dimensions du cristallisoir — 14 cm $\times$ 7 cm), et recouvert d'une couche également unie de 200 g de sable pur.

Avant l'emblavement, le sable dans les pots fut humecté par 50 cm³ d'eau.

Dans les vases ainsi préparés on procédait à l'ensemencement.

On prenait pour l'ensemencement des graines de seigle de Petkuss.

Neubauer recommande de prendre le grain, dont le poids absolu de 1000 graines, atteint 40 g. Nous avons employé du grain dont le poids n'était que de 29 g, c'est pourquoi nous avons pris pour chaque pot non 100 graines, comme Neubauer, mais 120.

Les 120 grains choisis furent traités, durant une demi-heure avant l'ensemencement, par une solution de 0,1% d'uspuline (chloro-phénolate de mercure), en une quantité de 5 cm³ par 120 graines. Le grain ainsi traité, fut séché sur du papier filtre, après quoi on le plaçait en couches régulières dans le pot préparé, le recouvrant de 50 g de sable et l'arrosant ensuite d'eau à l'aide d'une pipette.

La quantité totale d'eau par pot était de 80 cm³. Les pots utilisés pour l'ensemencement n'étaient pas recouverts d'un verre, comme chez Neubauer, mais on les plaçait dans une armoire vitrée, dans laquelle une température de 20—16° était assurée préliminairement.

L'arrosage était fait tous les jours. Date de l'ensemencement — 1 décembre. La durée de l'expérience — 16 jours. Le 17-ème jour, les plantes furent coupées à la racine. On compta ensuite le nombre des plantes dans chaque pot: leur nombre était en moyenne 113 par pot.

Les racines furent soigneusement débarrassées du sable dans un tamis par un courant d'eau pris au robinet, après quoi les racines, débarrassées du sable, furent lavées à l'eau distillée. Les racines et les parties aériennes des plantes furent séchées à une température de 60° jusqu'à un poids constant, toute la masse végétale fut ensuite incinérée dans des capsules en platine placées dans un moufle. La cendre obtenue fut traitée par 3 cm³ de HCl (25%). Après la précipitation de l'acide phosphorique et des sesquioxides, on a déterminé la potasse dans le filtrat, par la méthode cobalto-nitrique, avec la modification de Milné. Les résultats de l'analyse sont donnés sur la table 3. Comme on le voit sur la table, les variations dans les rendements de la récolte étaient insignifiantes.

Table 3

1-ère expérience selon la méthode Neubauer.

	Poids en grammes			Total de K_2O assimilée en mg	K_2O assimilée des sols ou fractions en mg
	Paille	Racines	Masse totale		
Sable quartzueux	0,6674	0,8057	1,4731	25,0	—
Sable + P	0,6113	0,8473	1,4586	23,3	—
Sable + PK	0,8380	1,0179	1,8559	85,2	60,2
Podzol du champ d'expérimentation de Dolgoproudny					
Sable + sol naturel	0,6264	0,8580	1,4844	24,3	0,7
Sable + limon grossier	0,6715	0,8278	1,4993	25,3	0,3
Sable + limon moyen	0,8125	0,8101	1,5226	29,0	4,0
Sable + limon fin	0,7254	0,8579	1,5833	26,0	1,3
Sable + argile	0,8216	0,8726	1,6942	51,3	26,3
Tchernosiome de Kamemno-Steppes					
Sable + sol naturel	0,700	0,8051	1,5051	28,0	3,0
Sable + limon grossier	0,6900	0,8837	1,5737	27,3	2,3
Sable + limon moyen	0,700	0,8712	1,5712	29,0	4,0
Sable + limon fin	0,711	0,8596	1,5706	28,0	3,0
Sable + argile	0,8274	0,8027	1,6249	52,0	27,0

Par l'assimilation du potassium l'argile se distingue nettement de toutes les autres fractions.

Alors que pour les fractions grossières, la potasse fut assimilée en quantité de 1,3 jusqu'à 4 mg de la quantité introduite de 75 mg, la potasse de l'argile fut assimilée en quantité de 26,3 et 27 mg par pot.

Dans le pot contenant le sable et le sol podzolisé, le potassium ne s'assimilait pas du tout, quoiqu'une certaine quantité de la fraction argileuse contenant du potassium, y ait été introduite avec le sol.

Dans le tchernosiome il n'a été assimilé que 3 mg de K_2O .

Etant donné que dans le tchernosiome 34% du potassium introduit revient à la part du potassium de l'argile, nous devons admettre qu'avec notre pesée du tchernosiome, nous n'avons introduit que 26 mg K_2O sous forme d'argile, c'est à dire, que dans ce cas aussi, ne furent assimilés que 3 mg sur 25 mg.

Nous voyons que de la fraction argileuse introduite avec le sol ne fut assimilée qu'une quantité relativement moins grande de potassium, moins que de la fraction argileuse séparée du sol lors de l'analyse mécanique. Dans ce dernier cas il s'assimile évidemment quelque partie faci-

lement déplaçable du potassium que nous n'avons introduit qu'en quantité très insignifiante dans les expériences avec la pesée du sol; tandis que dans le cas de la fraction argileuse nous avons introduit cette forme assimilable en quantité suffisante pour que les plantes aient pu utiliser 26,3—27 mg de K₂O dans l'expérience selon Neubauer.

On pouvait naturellement supposer que cette forme facilement assimilable du potassium fût précisément le potassium échangeable qui doit se concentrer dans la fraction argileuse. En outre la possibilité n'était point exclue d'un enrichissement de cette fraction en potassium échangeable pendant le processus de l'analyse mécanique, au dépens du potassium des minéraux du sol.

La détermination du potassium échangeable dans les argiles non-séparées du sol fut effectuée au moyen de son dosage dans le sol et ensuite en attribuant la quantité obtenue de potassium absorbé à la fraction argileuse du sol. Dans l'argile séparée par l'analyse mécanique, le potassium échangeable fut déterminé de la même manière que dans le sol, au moyen de sa lixiviation par le chlorure d'ammonium.

Potassium absorbé en $\frac{0}{0}\frac{0}{0}$ de K_2O

	Sol podzolisé	Tchernosiome
Sol	0,040	0,054
Argile non séparée du sol .	0,626	0,233
Argile séparée par l'analyse mécanique	1,2	0,95

Comme on le voit, il y a eu un enrichissement considérable de l'argile en potassium échangeable, après sa séparation selon la méthode de Williams. En tenant compte des pesées des argiles utilisées pour l'expérience de Neubauer, nous avons calculé que dans le cas de l'argile du sol podzolisé, nous avons introduit de fait 26 mg de potassium échangeable.

Les quantités correspondantes pour l'argile du tchernosiome étaient 20 mg de K_2O . Avec les pesées du sol, nous avons introduit en tout 1,3 mg (sol podzolisé) et 2 mg (tchernosiome) de potassium absorbé par pot.

Le pourcentage relativement élevé de l'assimilation du potassium des argiles, établi par l'expérience de Neubauer, s'explique par la présence d'une grande quantité de potassium échangeable, introduit avec les argiles. Pour le sol podzolisé, les quantités du potassium échangeable introduites avec l'argile (26 mg) et celles du potassium assimilé de l'argile par la plante (26,3) coïncidaient entièrement. Dans le tchernosiome il a été assimilé un peu plus de potassium de l'argile (27 mg) qu'il n'a été introduit (20 mg) de potassium absorbé avec la pesée du sol.

Les dernières comparaisons font voir que le potassium échangeable des argiles en tout cas n'était pas moins bien assimilé et l'était même mieux que le potassium du chlorure de potassium introduit dans le pot témoin, si, toutefois, nos calculs sont parfaitement justes. Par conséquent, l'assimilation du potassium absorbé des limons était entière; en même temps des 75 mg de potassium qui avait été introduit sous forme de chlorure de potassium, furent assimilés 60 mg de K_2O , soit 80% (voyez la table).

Pour établir le rôle que jouent les particules argileuses elles-mêmes, en qualité de sources de nutrition potassique, nous avons cru utile d'obtenir des argiles et aussi des sols, entièrement privés de potassium absorbé.

À cette fin, les limons et les sols que nous étudions après un traitement par une solution de chlorure de sodium, jusqu'à ce que soit complètement éloigné le potassium absorbé, étaient lavés à l'alcool pour éloigner le chlore dans les pesées.

Les argiles et les sols ainsi préparés, furent de nouveau étudiés par nous comme les sources de nutrition potassique dans l'expérience de Neubauer.

On procède à cet effet, au mois d'avril 1934 à une seconde expérience. Les procédés de l'expérience d'après Neubauer ont été maintenus, tels que cela a été décrit plus haut, pour la première expérience.

Les résultats de la seconde expérience sont donnés sur la table 4.

Table 4

2-me expérience par la méthode Neubauer.

	Poids en grammes			Assimilation totale de K_2O en mg.	Assimilation de K_2O en mg.
	Paille	Racines	Masse totale		
Sable quartzeux .	0,5519	0,6400	1,1919	20,7	—
Sable + P_2O_5 . .	0,7556	0,5077	1,2633	74,7	54,0
Sable + K . . .	0,6335	0,6457	1,2792	21,8	1,1
Sol podzolisé de Dolgoproudny					
Sable + sol . . .	0,5353	0,5970	1,1323	21,5	0,8
Sable + sol saturé par Na	0,4855	0,6298	1,1153	20,2	—0,5
Sable + argile . .	0,7032	0,6048	1,3080	54,7	34,0
Sable + argile saturée par Na . .	0,5437	0,7000	1,2537	24,5	3,8
Tchernosiome de la station d'expérimentation de Kamenno-Steppes					
Sable + sol . . .	0,6280	0,5913	1,2193	26,2	5,5
Sable + sol saturé par Na	0,4842	0,6739	1,1581	20,1	—0,6
Sable + argile . .	0,7036	0,5774	1,2810	46,4	25,7
Sable + argile saturée par Na .	0,4883	0,6684	1,1767	19,1	—1,6

De même que dans la première expérience, les données du rendement variaient faiblement dans la deuxième expérience, et se distinguèrent de nouveau nettement par le potassium assimilé, les argiles non-privées de potassium absorbé. De l'argile du sol podzolisé, 34 g furent assimilés, de celui du tchernosiome, 25,7 mg. L'argile du sol podzolisé privé de potassium absorbé ne donna que 3,8 mg de potassium par pot et l'argile du tchernosiome donna une quantité négative.

Le même phénomène a été observé pour les sols naturels et pour les sols privés de potassium échangeable. Si les sols naturels ont encore présenté des chiffres peu élevés pour l'assimilation du potassium des pots respectifs les sols privés de potassium absorbé ont tous les deux donné une quantité négative par rapport au potassium assimilable.

Par conséquent les sols et les limons privés de potassium absorbé perdent toute valeur nutritive, ce qui est démontré par les jeunes pousses des plantes cultivées d'après la méthode Neubauer.

2. Expériences avec le champignon *Aspergillus orizae*.

Nous avons emprunté en entier les méthodes de culture du champignon *Aspergillus orizae* à l'ouvrage de Naidina en nous écartant un peu des recommandations faites dans cet ouvrage à propos des pesées. Dans la première expérience nous avons pris pour les argiles et pour les fractions 0,5 g pour chaque dosage et dans la deuxième expérience nous avons pris différentes pesées des argiles et des fractions, en les égalisant d'après la teneur du potassium introduit. La souche du champignon *Aspergillus orizae* provenait du laboratoire du professeur W. C. Butkevitch.

Au cours de la première expérience on soumit à l'analyse les argiles ordinaires et les fractions isolés d'après la méthode de Williams, en même temps que les argiles dans lesquelles le potassium absorbé avait été remplacé par un ion d'ammonium.

Les résultats de l'analyse sont donnés plus loin sur la table 5 où est indiqué le poids du mycélium du champignon *Aspergillus orizae*, qui a poussé sur un substrat nutritif, dans lequel différents argiles et des fractions en quantité de 0,5 g par pot, servaient en qualité de source de nutrition potassique.

Table 5

Poids du champignon en milligrammes.

Mélange pur	404
Argile du tchernosiome de Kamenno-Steppes .	475
Argile du podzol du champ d'expérimentation de Dolgoproudny	467
Argile du podzol de la région d'Ivanovo . .	501
Argile du tchernosiome saturée NH_4Cl . . .	97
Argile du podzol saturée NH_4Cl	65
Limon moyen du tchernosiome	71
Limon du podzol	23
Limon grossier du tchernosiome	77
Limon du podzol	10

Comme on le voit dans la table 5, un développement intensif du mycélium n'est signalé que dans les argiles qui n'avaient subi aucun traitement. Une quantité particulièrement grande de la masse fut obtenue dans le limon du podzol de la région d'Ivanovo, laquelle dépassa de 100 mg (25%) la masse obtenue dans le mélange nutritif contenant du chlorure de potassium.

Les argiles saturées par l'ammonium ont donné une petite masse de mycélium. L'enlèvement des argiles du potassium absorbé a été évidemment suivi d'une baisse immédiate de leur valeur, comme source potassique de nutrition.

Faut-il porter cette masse insignifiante de 65—97 mg obtenue dans ce cas, au compte de l'utilisation du potassium des minéraux qui constituent les particules du sol? En nous basant sur les deux analyses mentionnées ici, nous ne pouvons pas naturellement tirer une conclusion pareille, d'autant plus que les chiffres de la deuxième expérience (voir la table suivante) n'indiquent aucune assimilation du potassium

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des argiles privées de potassium échangeable. Quant aux chiffres obtenus dans les expériences avec des fractions mécaniques plus grossières, nous croyons qu'il est bien possible, que l'assimilation du potassium s'y était produite au dépens de l'encombrement de ces fractions par des fractions colloïdales, encombrement particulièrement fort pour les grandes fractions, dégagées du puissant tchernosiome de Kamenno-Steppes. Les fractions grossières séparées de ce sol, ont présenté un excédant considérable de mycélium par comparaison avec les fractions correspondantes, isolées du podzol. Dans la deuxième expérience les pesées des argiles et des fractions furent égalisées au point de vue de la quantité de K_2O , introduit dans le pot en qualité de source de nutrition. Nous avons pris 20 mg de K_2O pour chaque pot, en nous basant sur le fait, qu'approximativement, une telle quantité du potassium total est contenue dans 1 g de sol, d'après la méthode ordinaire, élaborée par Butkevitch. Cette expérience a montré qu'aucune croissance du mycélium ne fut constatée dans les limons saturés par le sodium et l'ammonium; le même phénomène fut observé pour toutes les trois fractions plus grandes, saturées également par Na et NH_4 .

Toutes les autres variantes de l'expérience ont donné les résultats suivants:

Table 6
Poids du champignon en milligrammes¹.

Argile du tchernosiome de Kamenno-Steppes non altérée	209
Argile du podzol du champ d'expérimentation Dolgoproudny	229
Argile du sol forestier gris	174
Argile du tchernosiome de Kamenno-Steppes saturée par K.	349
Argile du podzol de Dolgoproudny saturée par K.	345
Argile du sol forestier gris saturée par K.	220

Comme nous le voyons, ce ne fut que le potassium des argiles qui s'assimilât, et encore l'assimilabilité des argiles n'était pas égale. C'est le limon du sol forestier qui est considérablement inférieur au point de vue de la qualité. L'enrichissement du limon en potassium fit monter immédiatement sa valeur nutritive.

3. Expériences sur la végétation

Il serait cependant tout naturel de supposer que les plantes adultes se comporteraient tout autrement quant à l'utilisation des fractions grossières en qualité de nutrition potassique que cela n'a été observé pour les jeunes plantules dans l'expérience d'après Neubauer et dans les expériences avec le champignon.

On a procédé donc à une expérience sur la végétation dans des cultures de sable, pour laquelle on employa comme source de nutrition potassique, les mêmes fractions des mêmes espèces de sol dont on s'était servi pour les expériences mentionnées plus haut.

¹ Le poids total du mycélium y est considérablement plus bas que dans la première expérience, vu que, par erreur, on avait employé la moitié de la dose de P_2O_5 .

Les autres substances nutritives furent utilisées en quantités optimum sous forme de sels solubles NH_4NO_3 , MgSO_4 , Fe_2Cl_6 . L'acide phosphorique fut employé pour une série d'expériences sous forme de phosphate monocalcique et pour une autre sous forme de phosphate dicalcique.

Toutes les substances nutritives furent introduites dans la quantité de 0,1 g de tel ou tel autre élément (N , K_2O , P_2O_5) pour un kilogramme de sable.

Ainsi, en tenant compte du potassium totale, on a donné pour un pot d'une capacité de 4 kilos de sable les quantités suivantes de différentes fractions:

	Podzol	Tchernosiome
Limon grossier	19,04	23,52
Limon moyen	15,4	20,4
Limon fin	12,0	17,2
Argile	11,92	11,68
Sol	17,08	20,4

Pour le contrôle on a pris des pots avec un mélange normal complet, où le chlorure de potassium était employé comme la source du potassium, ainsi que des pots avec un mélange normal incomplet, d'où le potassium était entièrement exclu.

Pour l'ensemencement on utilisait l'avoine au nombre de 16 plantes par pot. L'arrosage s'effectuait par en haut et par en bas avec de l'eau distillée.

L'ensemencement de la première série, avec le phosphate monocalcique a eu lieu le 28 mai.

Les pousses ont paru normalement le 28 mai.

Cependant après 4—5 jours, en même temps que se manifestait un grand effet dans les pots à mélange normal et dans les pots où les argiles servaient de source à la nutrition potassique, les extrémités des feuilles de l'avoine dans tous les pots commencèrent à se flétrir.

Ce phénomène résultait de ce que la plante souffrait de la présence du phosphate acide.

Les pots avec le mélange normal, ainsi que ceux avec les limons présentaient pourtant un développement satisfaisant, alors que tous les autres pots n'indiquaient presque aucune augmentation de la masse verte.

L'ensemencement de la deuxième série des pots contenant du phosphate dicalcique a eu lieu le 25 juin. Les pousses ont paru le 30 juin.

Dans 4—5 jours, de même que pour la première série, un effet marqué se manifesta dans les pots avec le mélange normal et l'argile.

Dans la deuxième série de pots, la flétrissure des extrémités des feuilles ne fut point observée et les pots avec le mélange normal et l'argile présentèrent par la suite un développement parfaitement normal, tandis que la croissance des plantes dans tous les autres pots cessa rapidement.

Le 23/VII les pots de la première et de la deuxième série, qui contenaient de grossières fractions et le mélange normal sans potassium, furent enlevés, parce que la croissance de la masse verte n'y augmentait absolument pas.

Les autres pots furent conservés jusqu'à la maturité du grain, ce qui eut lieu le 25/VIII, pour la première série, et le 20/IX pour la deuxième.

La table 7 ci-jointe donne les chiffres de la récolte.

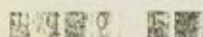
Rendement en grammes; moyennes de deux répétitions.

Table 7

	I série		II s é r i e					
	Podzol		Tchernos.		Podzol		Tchernos.	
	Grain	Paille	Grain	Paille	Grain	Paille	Grain	Paille
Mélange normal	3,68	7,52	—	—	7,95	10,99	—	—
Mélange normal sans potassium	—	1,1	—	—	—	0,17	—	—
En qualité de source de nutrition potassique:								
Sol	—	1,46	—	1,75	—	0,38	—	0,48
Limon grossier	—	1,10	—	1,68	—	0,38	—	0,45
Limon fin	—	1,51	—	2,09	—	0,28	—	0,44
Argile	2,1	7,5	3,0	10,5	6,29	9,44	6,96	9,09

Comme on le voit, les pots où des quantités insignifiantes de potassium échangeable seulement pouvaient s'introduire, n'ont donné que des rendements insignifiants, ne dépassant que de peu, la récolte du pot avec le mélange normal, privé de potassium. Ce ne furent que les pots avec les argiles dans lesquels nous avons introduit près de 120 mg de potasse échangeable, qui présentèrent une croissance normale des plantes.

Cela veut dire que l'expérience sur la végétation confirme également le fait que dans les conditions des cultures de sable, la plante adulte aussi n'a pu utiliser que des quantités minimum de potassium, de la quantité relativement petite des minéraux potassiques que nous avons employés pour les pesées (les sols et les fractions grossières).



Conclusions

1. Les expériences d'après la méthode Neubauer, qui furent faites avec diverses fractions du sol, étudiées comme sources de nutrition potassique, ont démontré que dans la méthode Neubauer ce n'est que la fraction argileuse du sol qui peut servir de source pareille, tandis que les autres fractions, notamment celle du limon grossier moyen et fin, n'ont absolument pas pu être utilisées comme sources de nutrition potassique.

2. La fraction argileuse du sol, privée de son potassium absorbé, au moyen du remplacement de l'ion du potassium par le sodium ou l'ammonium, perdait également alors sa valeur nutritive quant au potassium.

3. L'examen des mêmes fractions au moyen d'une culture sur ces fractions du champignon *Aspergillus orizae* aboutit aux mêmes résultats quant à la valeur nutritive des fractions du sol. La croissance normale du champignon ne fut constatée que dans les variantes pour lesquelles on s'était servi de la fraction argileuse comme source de nutrition potassique:

les argiles privées du potassium absorbé, perdaient toute leur valeur nutritive pour le champignon *Aspergillus orizae*, tandis qu'au contraire, les fractions argileuses saturées artificiellement par l'ion du potassium constituaient une source très riche en potassium assimilable.

4. Les expériences sur la végétation de l'avoine dans des cultures de sable, où l'on s'était de nouveau servi des mêmes fractions du sol en qualité de source de la nutrition potassique, ont confirmé les résultats des expériences précédentes, qui avaient montré que c'est le potassium échangeable de la fraction argileuse qui constitue pour les plantes le stock principal de potassium assimilable; ce potassium échangeable détermine en même temps le rendement. En même temps dans les plus grosses fractions, même les plantes adultes ne sont capables d'assimiler que des quantités des plus insignifiantes de potassium.

IV. Conclusion générale

Les conclusions du dernier chapitre démontrent que c'est le potassium échangeable qui constitue dans le sol la source assurant aux plantes une nutrition potassique directe. Nous ne nous arrêterons pas ici sur la question de savoir si le potassium échangeable ne sert ici que de transmission, à la solution dans le sol, ou bien si l'assimilation du potassium échangeable du sol se produit directement.

D'ailleurs, la solution de la question en supposant le premier cas, n'affaiblirait nullement l'importance du potassium échangeable, dans le bilan total de la nutrition potassique.

Il est hors de doute que le potassium échangeable ne constitue une source de potassium qui passe rapidement, d'une manière ou d'une autre dans la plante. Mais il serait tout à fait erroné de caractériser la fertilité du sol quant au potassium rien que par sa teneur en potassium échangeable.

Nous savons qu'on peut rarement trouver dans les sols de grandes réserves de potassium échangeable. Ce stock varie en moyenne de 5 à 15 mg K_2O par 100 g de sol, et selon nos calculs, ne pourrait suffire que pour 4—5 ans, dans le cas d'une alternance normale des cultures.

Il est donc évident qu'il existe dans les sols des processus qui ont pour résultat que l'ion du potassium se détache des minéraux du sol et prend une forme échangeable.

Les particules de la fraction argileuse détachent en même temps plus facilement l'ion du potassium que les particules des autres fractions.

Comme résultat de l'électrodialyse¹ nous avons obtenu pour deux espèces de sol, notamment le tchernosiome de la station d'expérimentation de Kamenno-Steppes, et le podzol du champ d'expérimentation de Dolgoprudny, ainsi que pour l'argile de tchernosiome pris pour l'expérience, les quantités suivantes de potassium électrodialysé:

	Argile	Tchernosiome	Podzol
Durée de l'électrodialyse en heures . . .	12	18	12
K_2O en %/0 de la matière utilisée . . .	2,393	0,0943	0,0619

¹ On se sert pour la dialyse de l'appareil à 3 chandres du système Pauli, avec la distance des électrodes de 4,5 cm, et une tension ininterrompue du courant de 200 volts.

Si l'on déduit de ces nombres les nombres du potassium échangeable des échantillons correspondants on obtient les quantités suivantes de potassium, provenant de la désagrégation des silicates de potassium au cours de la dialyse (en pour cent de K_2O de la pesée utilisée): pour argile — 1,443, pour tchernosiome — 0,0423, pour podzol — 0,0219.

Comme on le voit, — l'ion du potassium se détachait avec une intensité particulière lors de la dialyse de la fraction argileuse. Les nombres cités pour les sols doivent apparemment être également portés en entier, au compte des particules argileuses contenues dans les pesées du sol utilisées pour l'analyse.

En tout cas les fractions grossières détachaient au cours de la dialyse des quantités infiniment petites de potassium.

C'est pourquoi la présence dans le sol de la quantité totale de la fraction limoneuse, ainsi que de la quantité totale du potassium qui y est contenu, acquièrent une importance toute particulière.

Plus la fraction argileuse est grande, plus elle est riche en potassium, d'autant plus, naturellement, les stocks de potassium échangeable dans le sol seront abondamment fournis.

C'est pourquoi sans doute les sols, contenant une grande quantité de fractions argileuses à grande teneur en potassium, sont indubitablement les sols les plus fertiles sous le rapport du potassium.

Les sols du type podzolisé et les tchernosiomes lessivés, qui ne contiennent que 2—8% de potassium de la fraction argileuse dans le bilan total du potassium du sol, doivent être placés à cause de leur fertilité naturelle sous le rapport du potassium, dans la catégorie des sols moins fertiles que les tchernosiomes et les sérosiomes qui contiennent 20—40% du potassium de la fraction argileuse par rapport au potassium total du sol.

De même que pour la caractéristique des sols au point de vue du bilan de l'azote disponible pour les plantes, nous devons connaître non seulement les réserves des nitrates dans le sol, mais encore les conditions de leur accumulation, la faculté nitrificatrice du sol, la perméabilité du sol pour les sels solubles etc, mais il faut aussi, pour caractériser la fertilité naturelle du sol, à l'égard du potassium, connaître non seulement les quantités du potassium échangeable mais aussi celles du potassium total de la fraction argileuse et la quantité de cette dernière dans le sol. On obtient ainsi la caractéristique du sol au point de vue de sa capacité de mobiliser des quantités de potassium plus ou moins grandes, destinées à remplacer le potassium assimilé par les plantes.

BIBLIOGRAPHIE

1. Gehring. Handbuch der Bodenlehre. Herausg. v. Dr. Blanc. B. VIII 106—148.
2. Drujinine. Résultats des expériences sur la végétation dans les conditions de culture.
3. Maslova. Edition de la Station Expérimentale de Kieff, № 64 et journal Chimisation de l'agriculture Socialiste 1932.
4. Bogdanoff. Agriculture et sylviculture. 1900.
5. Nemeč. Zeitschrift für Pflanz. Düng. und Bod. A, H. 5/6, 1931.

6. Dirks. Deutsch. Zuck. Industr. B. 81, 1931 u. Landwirtsch. Jahrbuch. B. 72 H. 5.
7. Wrangell. Landwirtschaft. Jahrbuch. B. 71, 1930.
8. Bair. Théorie et application des engrais minéraux.
9. Rammann. Internat. Mitteil. f. Bodenk. B. VI, H. 1, 1916.
10. Ehrenberg u. v. Zijl. Internat. Mitteil. f. Bodenk. B. VII, H. 3/4, 1917.
11. Wrangell. Landwirtschaft. Jahrbuch. B. 71, 1930.
12. Soboleff et Dratscheff. Journ. d'agronomie scientifique. № 2, 1926.
13. Travaux principaux de la station expérimentale de Kieff, № 60.
14. Lemmermann u. Fresenius. Zeitschr. f. Pflanz, Düng. u. Bodenk. T. A. H. 4/5, 1930.
15. König u. Hasenbäumer. Verh. der Zweit. Komis. der Intern. Bod. Gesellsch. B. A. 1929.
16. Fraps. Texas Agr. Exp. Station. Bull. 391.
17. Kirsanoff. Chimisation de l'agriculture socialiste. № 12, 1933.
18. Smirnov. Résultats des expériences sur la végétation dans les conditions de culture. v. X.
19. Tchirkov. Ibid. V. VIII et X.
20. Bobko. Ibid. v. XXI.
21. Brezee. Arizon. Univers. Bull. № 21, № 24.
22. Nostitz. Die Landwirtschaft. Vers. Stat. B. CIII, III u. IV.
23. Gedroiz. Engrais et récolte. № 6, 1930.
24. Stewart. The Journ. of agric. Scien. v. XIX. 1929.
25. Penseler. Kühn. — Archiv. B. 26.
26. Wheeting. Soil Science, v. 29. № 1, 1930.
27. Volk and Truog. Journ. of the amer. Soc. of agron. v. 26, № 7, 1934.
28. Bamberg. Zeitschrift für Pfl., Düng. und Bodenk. B. 14, T. A. 11, 4/5.
29. Mehlich, Truog and Fred. Soil Science v. 25, № 4, 1933.
30. Hoagland and Martin. Soil Science v. 36, № 1, 1931.
31. Magisted. Universit. Arizona. Bull. № 22.
32. Martin. Soil Science v. 27, № 2, 1929.
33. Volk. Soil Science v. 37, № 4, 1934.
34. Vageler. Der Kationen- und Wasserhaushalt des Mineralbodens.
35. Barbier. Annales agronomiques № 5, 1933.
36. Schreiner u. Failyer. Bur. of Soils Depart. Bull. № 3.
37. A. N. Puri. Soil Science v. 30, № 6, 1930.
38. Diehl. Die Ernähr. der Pflanz. K 20, 1930.
39. Kötzen. Die Ernährung der Pflanze, B. 30, H. 7, 1934.
40. Antipov-Karataev et Krassikov. Trav. de l'Institut pédologique de Dokoutchaev. v. VIII, fas. 8.
41. Magistad. Soil Science v. 27, № 2, 1934.
42. Murphy. Jour. of the amer. Societ. of Agr. v. 26, № 1, 1934.
43. Barbier. Annales agronomiques № 5, 1932.
44. Nyhdal. Neddelande № 421 från Centralanstalten för föröksvösendet p. jordvr. somraadet.
45. Russell. Soil Conditions and Plant growth.
46. Dumont. Comptes Rendus 1904.
47. Roudinsky. Nouvelles de l'Institut agricole, v. IX.
48. Beliakova. Recueil consacré à la mémoire de Glinka, 1928.
49. Rodé. Composition chimique des fractions mécaniques. Académie des Sciences, 1933.
50. Ludorff. Landwirtsch. Jahrbuch. B. LXV, 1927.
51. Puchner. Landwirtsch. Versuchstat. B. LXVII, 1907.
52. Zolcinsky. J. de l'agronomie expérimentale. 1908.
53. Wagner. Anwendung künstlich. Düngemittel.
54. Piatenko. Station expérimentale de Mironowka, forc. III.
55. Naidin. Chimisation de l'agriculture socialiste. № 10, 1934.
56. Weibull. Journ. f. Landwirtsch., 1907.
57. Opitz. Landwirtsch. Jahrbuch. B. 36, 1907.
58. Naidina. Bulletin de l'Institut de l'Industrie sucrière, f. 5/6.
59. Seidel et Pavlovitchi. Annales Agronomiques № 4, 1932.

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THE INFLUENCE OF INCREASING AMOUNTS OF EXCHANGE SODIUM IN THE SOIL* ON THE GROWTH OF PLANTS AND ON THEIR ASSIMILATION OF PHOSPHORIC ACID FROM DIFFICULTLY SOLUBLE PHOSPHATES

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I

Pot-culture experiments made with oats and spring wheat on chernozem soil artificially enriched with increasing amounts of exchange sodium, show that the yield of these plants, on the basis of complete mineral fertilization, did not change noticeably when the sum total of the exchange bases of the soil was replaced by sodium up to 50 per cent. The plants showed no outward evidence of suffering from such an amount of exchange sodium in the soil except a retardation in the germination of the seeds.

A further increase of exchange sodium in the soil causes a decrease in the yield, reaching the final limit (the death of the plants) when 60 to 70 per cent of the total exchange bases have been thus replaced.

Experiments carried out with horizons A and B of natural carbonateless solonchaks from the zone of chestnut soil in the European part of the USSR (the Trans-Volga Region and Chongar) also show that the amounts of exchange sodium in these soils amounting to from 10 to 45 per cent of the total exchange bases, do not exercise any marked negative influence on the growth of plants, under the conditions of pot-culture.

A further analysis of the problem by studying artificial substrata—artificial humus acid and permutite—gives us reason to assume that in soils poor in organic matter, the upper limit, at which the content of exchange sodium in the soil is harmless to plants, is even higher than in soils rich in organic matter.

Thus all the data quoted tend to show that the physiological limit to which plants will tolerate exchange sodium in carbonateless soils is very high.

Under field conditions the adverse influence of exchange sodium on the yield from cultivated plants must appear when there is a smaller content in the soil, than under the conditions of pot-culture experiments, because in the first case the indirect influence of increasing amounts of exchange sodium on the yield must have some effect owing

to the sharp change for the worse in the physical properties of the soil which takes place even with comparatively small amounts of exchange sodium.

The data quoted above from pot-culture experiments, when compared with data regarding the influence of exchange sodium on the physical properties of the soil, incidentally illustrates the complete falsity of the idea still held by some authorities, based on pot-culture experiments, regarding the importance to plants of the physical properties of the soil. As a matter of fact, saturation of chernozem soil by sodium up to 50 per cent was only very slightly reflected in the yield, although the filterability and capillarity of the soil were reduced almost to zero, while its dispersability and capacity to swell had reached its maximum. In other words the yield was not affected, under the conditions of pot-culture, by the disintegration of the macrostructure of the soil, nor even by the disintegration of the microstructure, the importance of which for the harvest cannot be questioned.

II

Attempts to establish experimentally the reason why plants die in pot-culture experiments when the content of exchange sodium in the soil exceeds a certain definite limit, lead to the conclusion that, in the case of carbonateless soils, the death of the plants cannot be explained either by alkalization of the reaction, nor by accumulation of soda in the soil, nor by the immobilization of micro-elements in the soil, nor, finally, by the physical properties of the soil.

The cause of the death of the plant seems rather to be the immobilization of the exchange calcium as the result of the predominance in the soil-absorbing complex of another exchange cation, in this case, sodium. An insufficiency of calcium, as we know, prevents the normal processes of plant development.

III

We made a study of the influence of exchange sodium on the mobility in the soil of phosphoric acid from difficultly soluble phosphates. The soil samples were taken from horizons A and B₁ of deeply columnar solonets on the Valuiki Experimental Station and on the Saratov Experimental Station on the Lower Volga. We were interested in these soils, firstly, as being representative examples of solonets and solonchous soils of the region below the projected Kamyshin Dam, with the aid of which it is planned to irrigate the vast area of five million hectares in the Trans-Volga Region; and, secondly, because they are soils containing exchange sodium within limits physiologically harmless to plants. These solonets soils are carbonateless in their upper horizons, are comparatively poor in humus and contain exchange sodium up to 20 per cent of the total exchange bases in horizon A, and up to 40 per cent in horizon B₁.

In order further to increase the content of exchange sodium, soil samples were treated with a 1-n solution of NaCl until about 70 per cent of the total exchange bases had been replaced with sodium, and also until a practically complete replacement by sodium of all the exchange

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bases. On the other hand, some of the soil was treated with gypsum and water to remove the exchange sodium contained in the original soil sample.

The phosphorites FePO_4 and AlPO_4 were selected as the difficultly soluble phosphates, and superphosphates were also introduced into the experiment for the sake of comparison.

The experiments showed that, as the content of exchange sodium in the soil increased, the solubility in water of the phosphoric acid of the soil itself also increased greatly, as well as that of the phosphoric acid of all the phosphates used in the experiment.

This influence of exchange sodium was most marked in the case of the phosphate of aluminium. When all the exchange bases of the soil were completely replaced by sodium, the solubility in water of the phosphoric acids from this phosphate nearly equalled the solubility of phosphoric acid from the superphosphate.

In the case of the phosphate of iron, the increase of mobility of its phosphoric acid under the influence of exchange sodium in the soil was much weaker than in the case of the phosphate of aluminium, but nevertheless it was fairly well marked even with the smallest amounts of exchange sodium which occurred in our soil samples (about 10 per cent of the total exchange bases).

As regards phosphorite, the presence in our soil samples of exchange sodium up to 35 per cent of the total exchange bases was not sufficient to increase the mobility of its phosphoric acid. When about 70 per cent and about 100 per cent of the exchange bases was replaced by exchange sodium, the mobility of the phosphoric acid was considerably increased, but much less than the mobility of the phosphates of iron and aluminium.

Thus the laboratory tests showed that in the solonets and solonchaks soils of the chestnut zone, the mobility of the phosphoric acid of the phosphates of iron and of aluminium increases in the presence of small amounts of exchange sodium in the soil, while the mobility of the phosphoric acid of phosphorite increases only when the amounts of exchange bases are already so large as sharply to change the properties of the soil as a medium for the growth of plants.

At the same time these experiments showed that the saturation of the soil with calcium creates very unfavorable conditions for the mobility in the soil of sesquioxide phosphates, especially the phosphates of iron.

IV

Pot-culture experiments with oats and spring wheat, using the same phosphates and the same soils as in the laboratory experiments described above, as well as analyses of the plants grown in these experiments to determine the amount of phosphoric acid taken up by them from those phosphates, gave results which completely confirmed the laboratory investigations.

With the amounts of exchange sodium which our soils contained (from 10 to 35 per cent of the total exchange bases), phosphorite was found to be an unavailable source of phosphoric acid for the plant, while the

phosphates of iron and aluminium were well assimilated by the plants even with the smallest amounts of exchange sodium used in the experiments. The replacement in the soil of exchange sodium by calcium (by treatment with gypsum and water) markedly decreased the availability for the plant of the phosphoric acids of those phosphates, especially the phosphate of iron.

It is essential to emphasize the fact that under the influence of exchange sodium there was a marked increase in the availability for the plants even of those phosphates of iron and aluminium which contain a great excess of R_2O_3 in respect to P_2O_5 , and which, in the soil treated with gypsum, were found to be quite unavailable sources of phosphoric acid for the plants.

Thus the combined results of the laboratory and pot-culture experiments indicate that in solonets and solonchaks as well as in reclaimed sodium solonchaks, the phosphates of iron and more especially of aluminium, must be the most valuable sources of phosphoric acid for plants. As regards phosphorite, there is little prospect of its effective utilization on the solonets and solonchaks soils of the chestnut zone, so far as appears from these experiments.

V

Further study of the part played by the different factors in the increase of mobility of phosphoric acid of phosphorite under the influence of exchange sodium, has shown that the richness of the soil in organic matter has special importance in this respect. In the experiments described on the slightly humous solonets of the chestnut zone, the exchange sodium increased the mobility of the phosphoric acid of phosphorite only when there was a very large amount of it in the soil, but in the chernozem this effect of exchange sodium was already clearly evident even when it replaced less than 10 per cent of the total of exchange bases of the soil.

The part played by organic matter stands out still more conspicuously in experiments with artificial humic acid and permutite saturated with sodium. With the mutual action of phosphorite and amounts of humic acid and permutite equivalent as to content of exchange sodium, the amount of P_2O_5 passing over into the solution from the phosphorite was many times greater in the case of humic acid than with the permutite.

The data given open a prospect of the efficient application of phosphorite on solonets and solonchaks soils rich in organic matter (for example, on the solonets soils of the chernozem zone).

VI

The increase of the availability to the plant of the phosphoric acid of sesquioxide phosphates under the influence of exchange sodium, cannot be wholly explained by the increase of the alkaline hydrolysis of these phosphates resulting from the increased pH in the solonets, but must to a considerable degree be ascribed also to the direct cation

exchange between those phosphates and the sodium of the absorbing complex.

Thus, for example, in the case of horizon A of our solonets, the reaction of the soil did not exceed pH 7 and changed but little after treatment of the soil with gypsum, while the availability to the plants of the phosphoric acid from phosphate of iron was substantially decreased as the result of this treatment.

VII

The content of exchange magnesium in the soil has a certain positive effect on the mobility of phosphoric acid of the sesquioxide phosphates; nevertheless the action of the exchange magnesium is much weaker than that of the exchange sodium.

In experiments with artificial humic acid saturated with different cations — H, Ca, Mg, Na — the influence of these cations on the mobility of the phosphoric acid of phosphate of iron may be expressed by the series $\text{Na} > \text{H} > \text{Mg} > \text{Ca}$. The series for phosphorite is $\text{H} > \text{Na} > \text{Mg} > \text{Ca}$.

In the case of permutite, taken in amounts equivalent to the humic acid with respect to exchange capacity, the same series was obtained for phosphate of iron as for humic acid. But for phosphorite, the predominant part played by the absorbed hydrogen was not detected. This must be explained by the partial destruction of the permutite when saturated with hydrogen by treatment with 0.03-n-HCl.

The amounts of P_2O_5 passing over into the solution from the phosphate of iron and the phosphorite were, with all the exchange cations, considerably greater in the case of humic acid than in the case of permutite containing the same amounts of exchange cations. (The exchange capacity of permutite and humic acid was expressed by approximate values — about 130 M-equiv. per 100 g. of matter.)

ON THE DETERMINATION OF DISTANCE BETWEEN DRAINS

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The problem of establishing the proper distance between drains is of great importance not only in draining practice but also in that of irrigation, as it is necessary to compute the drainage of irrigated lands.

In American and British literature empirical data prevail as yet in the consideration of the dependence of the distance between drains on the main factors. On the continent, especially in Germany, of late was widely utilized the formula, proposed in 1924 by Prof. Rothe:

$$E = 2h \sqrt{\frac{k}{q_0}} = 2(t-H) \sqrt{\frac{k}{q_0}} \quad (1)$$

In this formula, E is the distance between drains; t — the depth of the drain; h — the distance between the level of the drain and that of the ground waters at mid-distance between two drains; H — the distance of the ground-water level from the surface at mid-distance between two drains; k — the coefficient of filtration of the soil-ground, q_0 — average amount of water entering the soil and eliminated by drainage per unit of time and area (draining modulus). As may be gathered from this formula the distance between drains, other conditions (k and q_0) being equal, increases with the increase of the depth of the drains t and with the decrease of distance of the ground water level H from the soil surface. This conception is in accordance with the generally accepted theory of action of draining.

In 1931-32 Prof. Setinski (Yugoslavia) came forward with a new theory of draining.

The theoretical construction on which Prof. Setinski bases his formula for computing the distance between drains can be summarized as follows.

He considers two pairs of drains lying at the same distance E , but at different depths: t and t_1 (Fig. 1). If as a result of the action of both pairs of drains the ground water levels will lie equally higher than the levels of the drains in both cases ($h=h_1$), assuming that before draining the ground water level was at the soil surface, — the t -deep drain would drain the soil layer $abcd$, while the t_1 -deep drain would drain the layer $a_1b_1c_1d_1$. But as $abc_1d_1 > abcd$, Prof. Setinski concludes that the time needed for draining in the case of the

deeper drain (t_1) will be longer than in the case of the less deep one (t), and from this he draws the conclusion that to achieve drainage of the soil by means of a deep lying drain in the same lapse of time as by means of one lying less deep, it is necessary to leave a corresponding smaller distance between drains in the first case. If the distance between drains is E , the length of one drain — 0.33 m., the depth

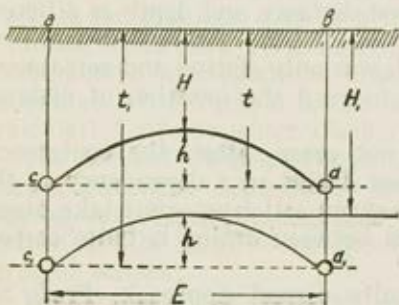


Fig. 1.

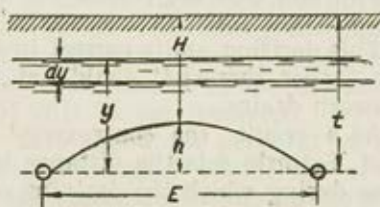


Fig. 2.

of the drain — t and the coefficient of water filtration k_x , than the volume of water entering each drain will be $k_x \cdot E \cdot 0.33 l$. The rate at which the ground water enters the drain Prof. Setinski expressed by the formula

$$v = \varphi_x \cdot \sqrt{2gt} \quad (2)$$

Designating the area of the aperture between two drains as μF_o , Prof. Setinski finds that the amount of water, entering the drain at the time T equalizes $T \cdot \mu \cdot F_o \cdot \varphi_x \cdot \sqrt{2gt}$.

This amount of water must be equal to that passing from the drained layer of soil if it is drained in the time T . Therefore Setinski sets down the following equation:

$$T \cdot \mu \cdot F_o \cdot \varphi_x \cdot \sqrt{2gt} = k_x \cdot E \cdot 0.33 \cdot t \quad (3)$$

From this equation he obtains his formula for determining distances between drains. This formula is:

$$E = \frac{\varphi_x T \cdot \mu \cdot F_o \cdot \sqrt{2gt}}{k_x \cdot 0.33 \cdot t} \quad (4)$$

where E is the distance between drains; t — their depth; μF_o — the area of aperture between two drains; T — time needed for the ground water level to fall from the soil surface to the depression curve cd (Fig. 1); φ_x — coefficient for the rate at which ground waters move towards the drain; k_x — coefficient of porosity or of water filtration of the given soil-ground. Evident from the above formula of Prof. Setinski the distance between drains does not increase with their depth but on the contrary decreases in proportion to the square root of their depth. This thesis, contradicting both the generally accepted theoreti-

cal conceptions and experience of practise naturally gave rise to a quite lively polemic, both in special press and at the International Conference of the VI Commission of the I. S. S. S. on soil-melioration, meeting in Holland in July 1932.

As well known the conference did not accept the theses of Prof. Setinski and passed a decision, proving that the distance between drains in the same soil must be increased according to the increase of their depth, and that the correlation between distance and depth is different for different soils.

This decision, quite correct in itself, was only stating and corroborating earlier theses; it could not help forward the question of distance between drains.

As a result the controversy did not cease after the conference. Prof. Setinski sets the distance between drains in a dependency to the time during which the draining of the given soil layer must take place. This way of approaching the distance between drains is quite correct in principle.

However, in spite of his theoretically correct approach, Prof. Setinski builds all his considerations on a fallacious hydrodynamic conception of the phenomenon and on equally mistaken premises and in result comes to incorrect conclusions.

On the other hand the opponents of Prof. Setinski, basing their arguments on Prof. Rothe's formula of distance between drains, practically proceed from a single and particular case when the water-tight layer lies immediately below the level of the drains. However the hydrodynamic picture of the movement of water in the drain will be different depending on the depth of the water-tight layer below level of the drains.

These hydrogeological conditions of drainage and the varying in accordance with them hydrodynamic model of the process of water filtering into the drains have not been taken into consideration when establishing the distance between drains. This led to the contradictory conclusions of various authors. Neither have these circumstances been taken into consideration in the discussion of Prof. Setinski's theory.

As mentioned above, the amount of water, flowing into the drain per unit of time and length is determined according to Setinski by the formula:

$$q = \frac{1}{0.33} \mu F_0 \varphi_x \sqrt{2gt} \quad (5)$$

in which t is the depth of drains; 0.33 — the length of one drain pipe in meters and μF_0 — the area of the aperture of the abutement of two pipes. Thus, assuming that at the starting of drainage the ground waters reach the soil surface, Setinski accepts that the amount of drain water 1) is proportional to the square root of the depth of the drains, and 2) does not vary with time till the ground waters' level is continuing to descend. Both these assumptions are incorrect from hydrodynamic point of view.

If we assume the initial position of ground water level coinciding with the surface of the soil, then with the decrease of this level as

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a result of drainage the actual head of ground water, initially equal to the depth t at which the drains lie, will permanently decrease and with it will decrease the inflow of ground water into the drains. Further, from the theory of movement of ground water in the soil-grounds of the type commonly drained, which obey the law of Darcy, we know that the rate of this motion is in direct proportion to the gradient of the head. Only in pebbly rock or in rock in fissures the water motion obeys the law of Chezy, i. e. is proportional to the square root of the gradient, but as a matter of course such rock does not need draining. Therefore even assuming the author considering the case of atmospheric precipitations soaking through the thick of the ground saturated with water from its surface to the depth of the drains, his calculation of the water discharge (5) will be yet incorrect.

The amount of ground water flow into the drain per unit of time and pipe-length depends 1) on the hydrological conditions of the laying out of the drainage and 2) under these conditions on the properties of the drained soil-ground and the condition of the head of ground waters.

We shall consider here two extreme cases of hydrogeological conditions of drainage: 1) when the watertight layer is bedded deeply below the level of the drains, and 2) when this layer lies immediately below this level.

In the first case the amount of ground water flow into the drain (per unit of time and pipe-length) may be expressed as follows¹:

$$q = \frac{\mu_1 \pi k h}{l g_n \frac{E}{d}} \quad (6)$$

in which h is the actual head of the ground waters, i. e. their highest level above that of water in the drain; k — the coefficient of filtration of the soil-ground being drained; d — the diameter of the drain; E — the distance between drains; μ_1 — the coefficient < 1 , showing the influence of the compression of the water-thread at its entering the drain.

In the second case, i. e. when the water-tight level lies near to that of the drain, the amount of water flowing into the drain per unit of pipe-length, is expressed by the formula:

$$q = \frac{2 \mu_2 k \cdot h^2}{E - d} \quad (7)$$

in which the designations are the same as above but the coefficient of compression μ_2 is < 1 but $> \mu_1$. This expression is in accordance with the formula (1) of Prof. Rothe, in which q_0 is the average amount of water penetrating the soil per unit of time and of area, and according to the conditions from which this formula is deduced $q = 0.5 \cdot E \cdot q_0$.

From the above formula (6) and (7) it may be seen that the value of

¹ For hydrodynamic grounds of the method I propose for calculating drainage in this case and for the deduction of the above formula see book on «Elements of melioration».

the inflow of ground water into the drain does not remain constant and that it varies in the course of time together with the variations of the head h i. e. the height of the level of ground waters. This head reaches its maximal value when the ground water level coincides with soil surface and it decreases with the depression of the ground water level (under action of drainage, evaporation etc.). The amount of water entering the drains will be constant if the head remains constant (e. g. under the influence of a stable inflow of ground waters, of continuous precipitations, of thawing weather). When the ground water level falls its head h and together with it the water discharge q decrease gradually during the whole time of the level descend, and it is quite inadmissible to assume, as Prof. Setinski does, q as constant during the whole period.

Let us consider now, what will be the time during which the decrease of the ground water level will take place in the drainage-area under both extreme types of hydrogeological conditions of the depth of drains described above.

1. Deep bedding of water-tight layer

Let us assume that at a certain moment the highest level of ground waters lies y meters above that of the drains, and that during the time dT the ground water level descends to dy . In such a case a layer of soil $E \cdot dy$ will be drained. If the total water-capacity of the ground is A p. c. and its lowest water-capacity, showing the amount of water remaining after draining, is C p. c., then the amount of water which penetrated into the drain from the layer $E \cdot dy$ at the time dT per unit of drain-length will be:

$$\frac{A-C}{100} \cdot E \cdot dy \quad (8)$$

in which $\frac{A-C}{100}$ is the coefficient of the drained ground's water discharge. The amount of water, which penetrated into the drains per unit of their length at the time dT will be:

$$\frac{\mu_1 \pi \cdot k \cdot y}{\lg_n \frac{E}{d}} dT \quad (9)$$

And as this amount of water has penetrated into the drains, achieving thus the draining of the soil layer $E \cdot dy$ we can set down the equation:

$$\frac{A-C}{100} E \cdot dy = - \frac{\mu_1 \pi k y}{\lg_n \frac{E}{d}} dT \quad (10)$$

Integrating this equation within the limits $y=t$ to $y=h$ we obtain:

$$T = \frac{A-C}{100} \cdot \frac{E}{\mu_1 \pi k} \lg_n \frac{E}{d} \lg_n \frac{t}{h} \quad (11)$$

where T is the time of the ground water level descending from t to h (see fig. 2), i. e. will decrease by $t-h=H$.

2. Water-tight layer bedding near to the drain level

In the case of the water-tight layer bedding at the level of the drains we can write the following equation, analogous to the preceding one:

$$\frac{A-C}{100} \cdot E \cdot dy = - \frac{2\mu_2 k \cdot y^2}{E-d} dT \quad (12)$$

Integrating this equation within the limits $y=t$ to $y=h$ we obtain:

$$T = \frac{A-C}{100} \cdot \frac{E(E-d)}{2\mu_2 k} \left(\frac{1}{h} - \frac{1}{t} \right) = \frac{A-C}{100} \cdot \frac{E(E-d)}{2\mu_2 k} \cdot \frac{t-h}{th} \quad (13)$$

in which T is the time of the level of ground waters descending from t to h , i. e. will decrease by $t-h=H$.

The results obtained show that the time necessary for the ground water level to descend the same distance H at equal depth of drains t , distance between drains E and soil characteristics $\left(k \text{ and } \frac{A-C}{100}\right)$ will be different, in dependence on the location of the water-tight layer relatively to that of the drains, i. e. on the hydrogeological conditions of drainage.

In the following table we bring an example, of influence of hydrogeological conditions of drainage on the duration of the elimination of ground waters.

Depth of drains	Depth of ground water level	Maximal head of ground waters	Deep of water-tight layer		Water-tight layer close to drain level	
			E = 10 m.	E = 20 m.	E = 10 m.	E = 20 m.
$t = 2.0$	0.5	1.5	0.44	1.00	0.83	3.30
	1.0	1.0	1.10	2.50	2.45	9.90
$t = 1.5$	0.5	1.0	0.64	1.46	4.62	6.60
	1.0	0.5	1.75	4.00	3.30	13.20

Time needed for draining a layer of soil of the depth H is expressed in relative figures, assuming as unit time needed for draining under the condition of a deep bedding of the water-tight layer and at $E=20$ m. $t=2.0$ m. and $H=0.5$ m. The value of the coefficient μ_1 is assumed to be 0.8 and that of $\mu_2=1.0$.

We see that time needed by ground waters to descend to the same depth H (other conditions — E and t — being equal) increases with the decrease of distance between water-tight layer and drains, and that the difference depending on this may be quite considerable. We see moreover, that the time of draining increases with the decrease of depth of drains (with an equal fall of the ground water level H), and with the increase of distance between drains E .

After determining of time needed for the decrease of ground water level to a certain value H depending under given soil and hydrogeolo-

gical conditions on the depth of drains and on the distance between drains, we can attempt to fix the distance between drains. This problem must be set as follows: it needs to establish the distance between drains (their depth and conditions of soil and hydrogeology being given) at which the ground water level would be lowered to the value H (according to utilization of the soil under drainage) and in a fixed time T .

Under these conditions the distance between drains is to be calculated as follows:

1. In the case of deep bedding of the water-tight layer we obtain from formula (11):

$$E = \frac{\mu \cdot \pi \cdot k \cdot T}{\frac{A-C}{100} \lg_n \frac{E}{d} \lg_n \left(\frac{t}{t-H} \right)} \quad (14)$$

The distance E can be calculated from this by establishing gradual approximative values, as the denominator of the right side of this equation contains $\lg_n \frac{E}{d}$.

Within the range of the values of E and d usually applied in draining the value of $\lg_n \frac{E}{d}$ varies within a limited range between 4.0 and 6.1.

2. In the case of water-tight layer lying near to the drain level we obtain from formula (13):

$$E = \sqrt{\frac{\mu_2 2 k T \cdot t (t-H)}{\frac{A-C}{100} \cdot H}} \quad (15)$$

in which the ratio E we assume to approach 0, because of the very small value of d in comparison with E .

We see that in the case of both sets of hydrogeological conditions the distance between drains, given the same time T for the depression of the ground water level to the same value H , increases with the increase of depth of drains. However the relation between t and E is different under different hydrogeological conditions. The nearer to the drain level the water-tight layer is bedding, the less must be the distance between drains if their depth remains unaltered. Moreover in the case of the water-tight layer lying near the drain level the distance between drains increases at a greater rate than in the case of its deep location. This may be seen from the following example for the same soil, whose $k=1.0$ m. per day and $\frac{A-C}{100}=0.08$, the relations of the distance between drains and their depth for obtaining the decrease ground water level to the value $H=0.5$ m. from the surface within 3 days must be as follows:

Depth of the drainage	1.0 m.	1.5 m.	2.0 m.	1.5 m.
Distance between drains:				
1. In the case of deep water-tight layer . .	20.0	32.0	41.0	53.0
2. In the case of the water-tight layer near to drain level . . .	8.2	14.2	20.1	25.9

If the ground water at its highest does not reach the soil surface by a meters, in the above formulae we must substitute for t and H respectively $t=t_0-a$ and $H=H_0-a$, where t_0 stands for the drains' depth and H_0 —for the depth to which the ground water level has descended as a result of the drain's work.

The following conclusions may be drawn from the above:

1. The action of drainage may be considered equally effective if it produces an equal lowering H of the ground water level during equal time T , i. e. the ratio $H:T$ may be accepted as the measure of the practical effectivity of drainage.

2. Suitable depth of drains and suitable distances between them are the main means for achieving the necessary effectivity of drainage under given soil and hydrogeological conditions.

3. The relation between depth of drains and distance between them, needed for obtaining the necessary effectivity (i. e. the ratio $\frac{H}{T}$) depends

not on soil conditions (coefficients of filtration and of water discharge) alone, but on the hydrogeological conditions of the drainage (the depth of water-tight layer and the dimension—vertical—of the water-bearing layer). These latter conditions up to the present were not taken into consideration in the theory and practice of draining.

4. The nearer to the drain level lies the water-tight layer, in which no movement of ground water takes place, a) the less (other conditions, particularly the drain depth, being equal) must be the distance between drains for obtaining an equal practical effectivity of drainage, and b) the more does this distance increase for obtaining an equal effectivity with increasing depth of the drainage.

Further study of the problem of drainage should be conducted on the base of the above theses. In such studies, besides scrupulously taking into consideration the hydrogeological conditions of the drains, it is very important to investigate the variations of the water discharge of soil-grounds in the depth of the drained layer, as this will permit to bring greater precision into the problem of the correlation of the distances between drains and their depth.

RESULTS OF EXPERIMENTS WITH MECHANICAL SPRAY IRRIGATION IN THE ARID ZONES OF THE U S S R

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The purpose of this experimental work with sprinklers was to study the possibility of using them, and their effectiveness, in the arid zones of the Soviet Union, especially the principal irrigated areas. As a result of the work done during the last three years, we now have experimental data on the use of mechanical sprinklers for cotton in Middle Asia, for grain in the Northern Caucasus, for tobacco and vegetables in the Crimea, and finally, for summer wheat in the Trans-Volga region. We have deliberately limited ourselves to a study of this data only, as all work with spray irrigation previous to the last three years was of a purely exploratory character, done in order to familiarize ourselves with the technique of mechanized sprinkling and to master it. During the last three years our main aim has been to obtain largest statistics for the yield of a number of the most important crops from the standpoint of national economy.

Central Asia. Cotton. The experiments were made in the widely-known Golodny Steppe district at Pakhta-Aral, one of the best State cotton farms. We shall discuss the data for the three years from 1932 to 1934, inclusive. The soils of the Golodny Steppe are very uniform in type. They are typical serozem, light (loesslike) loams, porous in texture, poor in humus and with the water table at a depth of from three to six metres. The ground water is strongly mineralized, and this causes salinization of the surface horizons as the result of its rapid rising after irrigation. The phenomenon of salinization is a serious menace to the Golodny Steppe district. In planning the experiments, the existence of irrigated land where the ground water is found less than four metres below the surface, and of unirrigated land where the water table is below four metres, and occasionally reaches ten metres or more, was taken into consideration.

The average annual precipitation for this district is 247 mm. From the 15th of May to the 15th of October there is practically no rain. The average monthly temperatures for the last 25 years in this district are:

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
0.7	1.0	7.5	15.6	22.8	26.3	29.1	24.5	17.4	12.9	7.5	2.3

The results of experiments on land where the ground water was 3.5 to 4.0 m. below the surface are shown in the following table

Table 1

Yields of cotton on lands with high ground water table (3.5—4.0 m.)

N.º of variants	Method of watering	Number of watering	Watering standard	Irrigation standard	Distance between rows	Yield of raw cotton in 100 kg. per ha
Experiments of 1932						
1	Spray irrigation	5	150—200	800	80 cm.	7.46
2	» »	5	200—300	1 200	80 »	8.99
3	» »	5	300—400	1 600	80 »	10.39
4	» »	8	300—400	2 800	80 »	24.00
5	» »	8	300—400	2 800	40 »	36.9
6	» »	8	300—400	2 800	20 »	49.8
Experiments of 1933						
1	Spray irrigation	5	400	2 000	80 cm.	24.5
2	Flooding	2	2 000	4 000	80 »	23.4
Experiments of 1934						
1	Spray irrigation	5	400	2 000	80 cm.	10.1
2	» »	5	400	2 000	65 »	16.7
3	Flooding	2	2 000	4 000	65 »	14.4

In the course of these three years the yields obtained with spray irrigation were higher than those obtained with the usual method of watering by flooding. These increased harvests, when mechanical sprinklers are used, are obtained with a smaller expenditure of irrigating water. The economy, amounts to as much as 30 or 40 per cent.

This last circumstance is of great practical value on account of the high cost of water in the principal irrigated districts and because the water saved can be used for irrigating additional areas. In districts suffering from swamping and salinization resulting from the usual methods of watering, spray irrigation will contribute to a radical solution of the problem of preventing salinization because the excess hydrological balance in such districts will be corrected both by the lowering of the water norms and by reducing the network of small ditches which exert a harmful effect through filtration. By reducing the capacity of the irrigational network, spray irrigation considerably lessens filtration.

However, though the yields of cotton with spray irrigation were high both absolutely and in comparison with crops watered in the usual

way, on land with a relatively high water table, — when the water table was from five to seven metres or even more below the surface, the yields when sprinklers were used were somewhat lower than when the usual system was employed. At the same time the economy of irrigation water decreases. The explanation of this phenomenon is to be found in a less favourable soil moisture condition. In the spring time the water

Table 2

**Yield of cotton on lands with a deep lying ground water table (5—7 m.)
Experiments of 1934**

Nº of variants	Method of watering	Number of waterings	Watering standard	Irrigation standard	Yield of raw cotton in 100 kg. per ha.
1	Spray irrigation	6	300	1 800	8.5
2	» »	6	400	2 400	9.4
3	» »	6	500	3 000	9.3
4	» »	7	300	2 100	8.9
5	» »	7	400	2 800	9.1
6	» »	7	500	3 500	10.4
7	» »	8	300	2 400	10.6
8	» »	8	400	3 200	12.6
9	» »	8	500	4 000	13.9
10	Flooding	2	1 500	3 000	11.5
11	»	3	1 500	4 500	14.4
12	»	4	1 500	6 000	13.1

supply in the surface layers of land with a high water table is considerably greater than in land with a deep water table. This original stock of ground water has a decisive effect on the yield, as when the original stock of water decreases, the depth to which the ground is moistened by artificial watering also diminishes. It is possible to improve the water regime of soils with a deep lying water table by means of spray irrigation before the spring sowing in order to increase the stock of water. The reduced water permeability of the soil after the first watering considerably diminishes the depth of moistening. An increase in the watering norm only runs off the surface.

Hoing the soil after each watering might produce an increase in the permeability and a levelling of the rows and furrows would reduce the surface drainage. The above-described results obtained by watering cotton plantations in a Central Asian oasis, justifies the statement that spray irrigation, as a method of watering, is adapted to extremely dry regions such as the Golodny Steppe district certainly is.

Trans-Volga Region, Grain Culture. Experiments with spray irrigation for wheat were made at three points in the Trans-Volga Region in 1934. First, in Bezenchuk, near the Samara Bend of the Volga River, which lies farther north than the other two, the soils are southern chernozems. This district is not so dry as the other two which are farther south. The annual average rainfall in Bezenchuk

is 357 mm. The second point, 300 km. south of Bezenchuk is located on chestnut soils near the town of Ershov. The average yearly precipitation is about 300 mm. The third point, 120 km. south of the second, is also on chestnut soil, but has pronounced solonetsous features, the alkali soils blotting the area in patches.

Table 3

Yield of grain of summer wheat in 1934

№№ of plots	Watering standard	P o i n t s		
		Bezenchuk	Ershov	Dobryninsky
1	400	9.6	—	—
2	600	—	14.8	—
3	800	12.9	20.5	—
4	1 000	—	21.9	17.7
5	1 200	22.3	23.7	20.4
6	0	6.3	8.9	11.2

In spite of the fact that in the experiments made in 1934 no irrigating could be done, during the period of branching the sprinkling greatly increased the yield as compared with the unirrigated wheat. The crops from the Trans-Volga areas, which were watered in the usual way, were similar to those from the sprinkled areas, but the expenditure of water was greater. Observations of the micro-climate of the air layer adjacent to the earth, both when watered by the various methods employed, and when unwatered, showed that a considerable effect was produced on the micro-climate by watering — the moisture of the air increased, and the temperature of both air and soil was decreased after sprinkling. These observations allow the assumption that it is not only possible to control the moisture conditions of the soil by sprinkling, thus achieving the direct object of watering, but that the moisture and temperature of the air are affected as well. This fact, judging by recent physiological investigations, should play an important part in increasing the yield, and reveals a new aspect of the results of sprinkling in dry areas, where one of the factors limiting the yield is frequently the dryness of the air. It will suffice to recall the deleterious effect of dry winds in the Trans-Volga Region. Of course we cannot claim that the present, technique of spray irrigation would make it practicable to use this method to improve the micro-climate. It has, in fact, several essential defects which make it unsuitable for such use; but it may be supposed that if attention is paid to this matter, there will be decisive improvements in the design of the mechanical sprinklers which will make these effects practically realisable on a large scale. The results of the experiments in sprinkling in the Trans-Volga Region justify the statement that sprinkling, as a method of melioration, will have a real value both in this region and in other similar territories.

The effects of sprinkling on tobacco and other crops in arid regions in the U.S.S.R. with very varied soils, corroborate the conclusions that mechanical sprinkling can be used in many types of arid regions.

THE ACTUAL PROBLEMS OF GROUND INVESTIGATION IN THE LIGHT OF SOCIALIST CONSTRUCTION IN THE USSR

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About 18—20 years ago soil science began the study of soil formation in a new direction. The soil scientist in our country has been called to solve problems, connected not with agronomy alone but with building-engineering science as well, as may be seen from the voluminous literature accumulated in this field during the indicated period.

This is not all; investigations conducted on the base of natural historic soil science, mainly for purposes of road-building and hydrotechnical construction, have at the present time taken the shape of a complex of knowledge which has obtained in our country a special name — that of *ground science*. The integrity and preciseness of the works of soviet scientists in the field of ground science permit to define the contents of this young science and to formulate its objects.

Ground science studies soils and grounds from the natural historical point of view, having as its object the creation of a corresponding base for building-engineering, road-building and hydromelioration. According to this definition, forming a logical sequel of all the accumulated ground-scientific literature, ground science does not coincide with engineering geology, as this latter science studies mostly geologic processes taking place in the areas of engineering constructions and supplies the builders with the necessary prognostications and indications as to their probable course.

In regard to the immediate object of its study ground science deals in our country with the superficial horizons of rock, which are partly already transformed into soil, and partly form the sub-soil layers composing together with the soil the contemporary weathering crust.

Construction works conducted in the USSR, such as for instance the White-Sea canal, the Moscow Subway, numerous civil-engineering works, aero- and hydroaerodromes, stadiums for physical culture, prospecting in the Great Volga problem and other no less important and large-scale works have indicated the main lines along which the study of the grounds is to be conducted.

These lines are the following: 1) physico-chemical, 2) physico-mechanical and 3) technological. It is evident that ground science, having in its composition the three sections just named, is on the one hand a

branch of soil science and geology and on the other is bordering upon engineering geology. Let us turn to a short consideration of each of the three just named sections of ground science.

The physico-chemical direction has to do with uncemented grounds, both cohesive (argillaceous complexes) and uncohesive (sandy complexes). It considers grounds as dispersion systems, whose distinctive properties are the processes conditioned by the surface energy. Special importance belongs in it to works devoted to the rôle of adsorption and other bonds, reacting to stresses applied to the grounds. In this field a number of investigations are planned at present by the Geological Institute of the Academy of Sciences of the USSR and by the Soil Institute of the Moscow State University. The various constructive works conducted now in the U.S.S.R. must form the base of these investigations.

Recent investigations have established the immense influence of the colloidal part of grounds on their physico-mechanical properties (the works of Prof. A. F. Lebedev), Prof. M. M. Filatov, of the soil scientist and chemist Tolstopiatov, of Prof. V. V. Austin et al.). At the present moment one can say without exaggerating that, the physico-chemical character of grounds and their physico-mechanical properties are inseparable. As is well-known numerous methods of technological treatment of grounds have been created by this time in our country on the base of their physico-chemical study. We shall speak of these methods later. In the just mentioned respect the rôle of this section of ground science appears to be particularly important. It opens wide horizons for building-engineering, e. g. in road-construction.

The second, i. e. the physico-mechanical direction considers grounds as systems or combinations of granulometric elements, the variety of which for the sake of simplification and convenience of calculations is brought down to two types of complexes: the argillaceous and the sandy ones. The first of these is characterized according to principal schemes as a gathering of particles of a lamellate shape (about 2μ in diameter and 0.1μ thick), the second consists of «compact» elements of more or less equal dimensions.

According to recent investigations (K. Tertzaghi, N. M. Ghersevanov, N. V. Ornatsky et al.) in the field of mechanics the shape of ground particles is considered one of the most essential factors, determining the physico-mechanical character of grounds. However, under the influence of mainly Soviet Russian scientists, this fundamental principle of the section of ground science under consideration has now been subjected to considerable corrections. As a result we have at our disposal a scientific analysis of the theory of the relation between the shape of ground-particles and the ground's physico-mechanical constants. This relation consists in that:

1. Lamellate argillaceous particles and such particles of other shape reveal the presence on their periphery of a compact zone — pellicle capable of reacting to mechanical stress (Prof. M. M. Filatov).

2. Argillaceous complexes possess a special micro-structure arising in the process of ortho- and perikinetic coagulation, taking place in the very beginning of the formation of deposit rock (Prof. K. Tertzaghi and Prof. M. M. Filatov).

3. Elastic deformations in relatively moist argillaceous grounds depend primarily on the elastic properties of the air engaged by the ground during the period of structure formation, secondly — on the elastic properties of the colloid pellicles covering the ground-particles, and thirdly — on the elastic properties of the solid ground grains; the last named occurs mainly in the sandy complexes.

4. Non-elastic (persisting) deformations in the same argillaceous complexes are determined by the breaking of the integrity of the ground's «structural cells» and pores under the action of the load.

5. Non-elastic deformations in sandy grounds take place at the expense of the breaking of the integrity of the grain and of the displacement of particles in relation to one another under the action of the load (Prof. K. Tertzaghi, Prof. N. V. Ornatsky et al.).

6. The theory of fold formation and of catastrophic displacements of particles in argillaceous grounds during their deformation under the action of the load has not been confirmed experimentally. Likewise no confirmation was obtained for the conclusions of Prof. D. P. Krynin whose experiments tended to prove the lamellate shape of argillaceous particles (investigations of the Moscow Automobile Road Institute; Prof. N. V. Ornatsky; the Moscow Institute of Road Construction etc.).

The turn towards studying ground samples with intact structure and construction must be considered as the most important moment of modern methodics of ground investigation. It is now irrefutably established that a large number of constants important for calculations cannot be based on data obtained in the laboratory on artificially prepared samples alone. Among other works on ground mechanics, possessing a keystone significance for this branch, we must indicate the numerous investigations on: 1) the determination of the fundamental constants of ground (the angle of internal friction and cohesion); 2) the elaboration of the methods for obtaining the compression curve; 3) the methods for determining side-pressure and 4) those for determining ground swelling. Our Soviet Russian literature has become richer by a considerable number of investigations of each of these problems. Their analysis, conducted in the light of the demands of our constructive works, brings us to the following conclusions:

1. The majority of the methods available at present for obtaining quantitative indexes of the technical characteristics of grounds cannot warrant that the values obtained with their help will be actually those constants which the author of the method had in view.

2. Up to the present no adequate scientific analysis, has been undertaken as yet, which would permit to establish a list of the necessary physico-mechanical indices for the technical characterization of grounds. The available indications of this kind (K. Tertzaghi, N. N. Ivanov, Zitovich et al.) bear a rather dogmatic character.

3. The relation between the mechanical constants of grounds remains as before insufficiently elucidated; this is limiting their application in practical work.

The above shows that Soviet Russian ground mechanics must urgently undertake a revision of the existing fundamental methods of ground investigation. These methods pertain to the: 1) investigation

of the physico-mechanical condition of grounds and establishing of adequate indices characterizing this condition; 2) study of the character and distribution of stresses in the grounds under the action of external forces; 3) investigation and determining of ground deformations under the action of loads and other external forces.

The third, i. e. the technological direction of ground science develops in our country very intensively. It considers the ground as an object of technological action (granulometrical additions, cement treatment, bituminous treatment, heat treatment etc.).

The level reached at present by ground technology in our country is almost entirely due to road-building, which first made the approach to the natural ground from this point of view necessary. At present the Soviet Russian ground scientists think that every local ground may be transformed into a road surfacing («ground-surfacing») of the necessary character and fortified in the road's foundation by radical changes of its properties achieved by methods of technology. This conclusion is of immense importance for the liquidation of our lack of road and opens limitless horizons to road construction.

A quite exceptional importance belonged and belongs at the present moment in the development of ideas of the just mentioned character to the conception of ground as a dispersion system. On the base of this conception the theory of the cohesive action of bituminous solutions on the ground was created and the conditions of artificial ground petrification elaborated in our country. A particularly fruitful part was played in this field by the theory of the soil adsorbing complex of K. K. Gedroiz, Member of the Academy of Sciences of the USSR.

A number of investigations, executed recently by various research organizations in the Soviet Union convince us with irrefutability that by acting in various ways on the adsorbing complex of the soil ground we can change its properties in the direction desired. Almost all the methods of a radical fortification of the ground in the road platform are based on this conception.

Thus, according to the investigations of the Moscow University Soil Institute and of the Moscow Automobile Road Institute, even the introduction of granulometric additions into the ground (the so-called «claying» and «sanding» of the road) is most closely connected with the adsorption phenomena. Thanks to adsorption a mutual coagulation of highly disperse elements (mechanical clay) and the enveloping of sand-dust aggregates by films of clayey substance take place during the mixing of the granulometric fractions. This circumstance led to the necessity of including into the calculations of granulometric mixture a special coefficient registering the influence of adsorption in the cohesive action of argillaceous particles. The theory of the phenomena, connected with the disperse character of the non-cemented grounds, introduced most essential corrections into the theory of ground treatment by organic and inorganic colloid substances (bituminous treatment, silicate treatment and other technological processes).

The purpose of the introduction of cohesive substances of the colloid type, e. g. bitumes and bitume-like substances, into grounds is to lime its particles together into a monolith mass and make in this manner

the ground cohesive, unsoakable, impermeable. Investigation shows that ground treated in this manner does not represent a uniform monolith mass, but is an aggregate porous substrate the particles of which are bound by films of a «bituminous-argillaceous» substance (the «cohesive substance» of Filatov and Sakharov). Such a constitution of bitumized ground is the result of the phenomena of coagulation and adsorption of the dispersion systems arising in the ground during its technological treatment of the character named above. Further investigations revealed that the process of bitumizing ground may be controlled both in regard to the character of the bonds formed in the ground as a result of such treatment and to the quantity and character of the cohesive ingredient. In other words, ground fortifying has passed in our country from the realm of crude empiricism to the level of a scientifically grounded technological process.

Without dwelling on other achievements of our ground technology we shall allow ourselves to register that cement treatment as well as thermic treatment of soil-grounds have also been subjected to thorough scientific analysis and corrections possessing by the present time a profound theoretical and practical significance.

We see thus that the technologic direction of ground science, like the two others described above have achieved in our country an adequate form and preciseness of purpose.

The outlined tasks and trends of contemporary ground investigation in their building-engineering aspect, in connection with the wide development of construction in our country permit at present to give a concrete form to the problems demanding immediate consideration by our scientific research organisations. The main of these are:

1. The establishing in the genesis, dynamics and static of ground.
2. The investigation of the water's rôle in cohesive grounds.
3. The study of physico-chemical and physico-mechanical processes, taking place in grounds under the influence of thermic changes (including freezing and thawing).
4. The establishing of a list of obligatory tests permitting a technical characterization of the ground first of all for purposes of road-making and hydrotechnical construction.
5. The standartization of the methods of mass analyses and testing of grounds.
6. The elaboration of the methods of ground sample taking without disturbing their constitution and the devising of the apparatus for the physico-mechanical testing of such samples.
7. The establishing of the correlations existing between the various physico-mechanical constants and the physico-chemical character of grounds.
8. The investigation of the nature of bonds arising in grounds after treatment with cohesive substances.
9. The elaboration of methods for the fortifying of grounds for purposes of hydrotechnical construction, road-making, aerodrome and stadium construction.
10. The precisation and further elaboration of the existing in ecology and science field technic of soil and ground investigation for application to the tasks of our constructive work.

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DIE MOORFORSCHUNG IN DER UdSSR

Die hauptsächlichsten, nach 1931 durchgeführten Arbeiten

W. S. DOKTUROWSKY

Die Untersuchung der Moore wird in der UdSSR in verschiedenen Richtungen geführt. Es wird einerseits an der Aufklärung einer Reihe theoretischer Fragen gearbeitet, und zwar der Prozesse der Bildung der Torfmoore, der Versumpfung im Zusammenhang mit den Veränderungen des Bodensubstrats, vorwiegend vom chemischen Standpunkt aus; des Wesens, der Zusammensetzung und Bildung der Huminstoffe, der Ergründung der Azidität der Torfe; keine geringere Rolle spielen die Untersuchungen, die nach der Methode der Pollenanalyse zur Bestimmung des Alters der Moore vorgenommen werden. Andererseits wird grosse Aufmerksamkeit Fragen der Praxis gewidmet: vorzugsweise auf dem Gebiete der landwirtschaftlichen Ausnützung und der Torfgewinnung, die in der UdSSR eine bedeutende Entfaltung genommen hat; eine ganze Reihe spezieller Fragen steht auf der Tagesordnung — Katastrieren der Moore (erschöpfende Katalogisierung), Bonitierung der Lager vom Standpunkte der in ihnen vorhandenen Torfarten, Fragen spezieller Untersuchungen der Torfmoore—Torf als Streu, in Anwendung zur Gasbereitung usw. Besonderes Interesse erregen Fragen der Bestimmung des Zersetzungsgrads des Torfes u. a. m.

In vorliegender kurzer Uebersicht ist es nicht möglich alle aufgezählten Themata zu besprechen; es seien hier nur die hauptsächlichsten erwähnt, die auf der bevorstehenden Allunionskonferenz der Bodenkundler, 1935, zur Diskussion bestimmt sind.

Aus der Zahl der theoretischen Fragen wurden vor allen anderen die Fragen nach den chemischen Eigenschaften der verschiedenen Arten der Waldstreu und der Waldtorfe einer eingehenden Untersuchung unterworfen. Die Arbeiten von B. D. Zaitzew (10,11) haben Licht verbreitet über die mit ihrer Adsorptionsfähigkeit verbundenen Reagierungseigenschaften der Böden, und die Wirkung der Salzlösungen auf die organische Substanz der untersuchten Waldstreu- und Torfarten. Es wurden bestimmt: hygroskopisches Wasser, Glühverlust, Wasserstoffionenkonzentration, hydrolytische Azidität, die austauschfähigen — Wasserstoff, Kalzium und Magnesium (nach Gedroiz). Es stellte sich die Notwendigkeit heraus, zwei Versumpfungstypen herauszuscheiden: unter Bedingungen einer stark ausgeprägten Ungesättigkeit an Basen des adsorbierenden Komplexes und bei Sättigung dieses letzteren mit Kalzium

(und Magnesium). Es wurde festgestellt, dass die Waldstreu der Laubbestände, beim Vorhandensein bodenbildender Anschwemmungen die «besten» chemischen Eigenschaften besitzt; so ist z.B. der Koeffizient der Ungesättigtheit bei Fichte — 0,20 und 0,56, bei Laubarten — 0,08 und 0,38; die Kiefer nimmt eine Uebergangsstelle ein zwischen Fichte und Laubarten — der Ungesättigtheitskoeffizient beträgt 0,12 und 0,48. Die Fichte besiedelt vorwiegend Böden mit torfigen Horizonten, die eine beträchtliche Menge Kalzium und Magnesium in sich führen; die Kiefer wählt zum Standort Böden mit torfigen, schwach mit Basen gesättigten Horizonten. Dies gilt besonders für torfige und torfig-gleiige Böden. Der Uebergang von den letzteren zu den ersteren wird durch die Steigerung des Einflusses der Salzverhältnisse des Grundwassers bestimmt, welche unabhängig von den anderen Faktoren auch die chemischen Eigenschaften der Torfe bestimmen. Beim Anwachsen der Mächtigkeit des Torflagers können die sich neubildenden Torfschichten aus dem Bereiche der Einwirkung des Grundwassers heraustreten, so dass die oberen Schichten einen schwachen Sättigungsgrad aufweisen.

B.D. Zaitzew hat gefunden, dass zwischen der Natur des adsorbierenden Komplex und der botanischen Zusammensetzung kein Zusammenhang besteht (das Kosnowsche Moor); der Forscher meint, obwohl die Vegetation mit der Art der organischen Substanz im Zusammenhang steht, kann die Geschichte der Entwicklung des Moores von Veränderungen der Eigenschaften des adsorbierenden Komplexes begleitet sein. Somit kann die Zusammensetzung der austauschfähigen Kationen des Torfes, bei der Aufklärung der Geschichte der Versumpfung nur teilweise als dynamischer Faktor in Frage kommen. Ferner bestimmt die Verschlechterung der organischen Substanz zu Beginn der Versumpfung ihren weiteren Weg nicht — dieser wird von den Salzverhältnissen der zu den oberflächlichen Schichten heraufsteigenden Boden- und Grundgewässern vorgezeichnet. Entsprechende Salzverhältnisse in diesen Wassern, die zu den organischen Horizonten strömen, bedingen wohl auch die Natur des adsorbierenden Komplexes.

Beljajewa (2) widmet ihre Arbeit der Rolle der Bodenlösungen, als Anzeiger der Gesetzmässigkeit, die bei den Uebergängen von den mineralischen Böden zu den torf-moorigen beobachtet werden. Beträchtliche Mengen löslicher Verbindungen in Bodenauszügen findet man in dem Gleichhorizonte. Der Prozess der Mobilisation der Salze und ihrer Vertragung durch den Gleichhorizont der Senkung entlang, sichert die Versorgung des an die trockene Wasserscheide grenzenden Torfmoors mit Salznahrung. Die alkalische Reaktion und die grosse Elektroleitfähigkeit der Gleichhorizonte zeichnen sich dadurch aus, dass die Salzvorräte nicht erschöpft sind, insofern sie allmählich in das benachbarte Torfmoor übertragen werden; die Mobilität der Salze steigt in der Nähe des Moores. In den an das Moor grenzenden Böden (podsoligen) zeichnen sich die Salze des Eisens durch grosse Beweglichkeit aus, Aluminium und SiO_2 dagegen — durch eine geringe (letzteren findet man mehr in den hoch lagernden Böden). Mit dem Näherkommen zum Moore fällt der Gehalt an SiO_2 , Al_2O_3 und Fe_2O_3 stärker als der von CaO und P_2O_5 , insbesondere in dem Grundwasser.

Einige Angaben über diese Fragen findet man auch bei Dosmanowa

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(8). Was den organischen Teil des Torfes betrifft, so sehen wir hier nur wenig Prinzipiell-Neues; einige Fragen aber wurden einer eingehenderen Untersuchung unterworfen. Im Einklang mit den Arbeiten von Waksman, Fischer, Liske u.a. wurden folgende Untersuchungen durchgeführt: 1) von Begak (17) über die Menge der Mikroorganismen in Hochmooren, 2) von Belikowa (17) über die Veränderungen der chemischen Zusammensetzung der Sphagneen unter der zerstörenden Tätigkeit von *Merulius lacrimans* (die Anhäufung des Lignins mit fortschreitender Zerstörung der Torfbildner hat eine Bestätigung gefunden) und 3) von Kurbatow (17) über die chemische Untersuchung der Torfe; dieser letztere Forscher vertritt die Meinung, dass die in den oberen Schichten des Torflagers vor sich gehenden torfbildenden Prozesse, in der Hauptsache der mikrobiologische, im Weiteren bereits zu einem chemischen Prozesse der Veränderung und Umwandlung organischer Verbindungen wird.

Eine grosse Bedeutung wird den Fragen der Untersuchung des Zersetzungsgrads des Torfes beigemessen (selbstverständlich im Zusammenhang mit einer ganzen Reihe «technischer» Merkmale des Torfes, wie Aschegehalt, Feuchtigkeit, Menge der in ihm vorhandenen Mikroorganismen usw.). Fragen der Bestimmungsmethode des Zersetzungsgrads unterliegen einer speziellen Durcharbeitung. Die weiteste Verbreitung und grösste Anwendung geniesst in den Laboratorien der UdSSR die sogenannte mikroskopische Methode; nach dieser Methode wird in dem Gesichtsfeld des Mikroskops «nach Augenmass» die Menge des Humus (zersetzte Masse) und die Menge der Fasern mit der nicht-humifizierten Masse in %% bestimmt (die Aufzählungen werden mehrmals vorgenommen und daraus das Mittel gewonnen) (Warlygin, 3). Zur Vergleichung führt Warlygin verschiedene Methoden an, doch auf Grund ihrer Angaben — nur nach der Färbung mit Reagenzien und der Vergleichung dieser Data mit dem Humifikationsgrad, der ebenfalls «nach Augenmass» bestimmt wird — kann man noch keine endgültigen Schlüsse ziehen über die Menge der in den Torfen vorhandenen Mengen an Lignin und Zellulose.

Die Fragen der Untersuchung der Eigenschaften des Torfes müssen natürlich mit den Hauptausgangsgründen — den Arten des Torfes und den Torfbildnern — im Zusammenhang gebracht werden. Diesen Fragen wurde in der UdSSR immer sehr viel Aufmerksamkeit gewidmet; die Entwicklung der Stratigraphie der Moore (Anufrijew, Zerow, Dokturowsky u.a.) ging immer gleichen Schritts mit der Untersuchung des Zersetzungsgrades des Torfes, seines Aschegehalts, seiner Feuchtigkeit, Wärmeerzeugungsfähigkeit u.a.m., mit der Untersuchung der botanischen Zusammensetzung des Torfes, mit der Bestimmung der einzelnen in ihm vorhandenen Arten der Sphagneen, Hypneen, Seggen u.a. Bestandteilen des abgelagerten Materials. Einzelne Gebiete sind vom Standpunkte der Stratigraphie bereits mit ausreichender Fülle erforscht (1,5). Von grosser Bedeutung sind die Arbeiten von Markow, die in Fragen des Aufbaus der Moore eine präzise geologische Orientierung gebracht haben (parallel mit der Analyse der botanischen Zusammensetzung und der Pollenbestimmung wird eine Analyse der Diathomeen eingeführt).

Eine richtige geologische Datierung des Alters der Moränenterrassen und die Charakterisierung der jüngsten Quartärablagerungen hat Markow

u.a. erlaubt, die Fehler, welche Gerassimow bei der Bestimmung des Alters der Leningrader Moore begangen hat, zu korrigieren. Es erwies sich, dass diese Torfmoore älter sind als Gerassimow dachte, seine «boreale» Periode, d.h. die Periode der ersten beobachteten Besserung des Klimas gehört tatsächlich zu der «subarktischen» Periode, die der arktischen nachfolgte usw.

Von nicht geringerem Interesse ist die Frage nach den Torfarten.

Bereits in den Arbeiten von Weber über das Augustumalmoor finden wir eine eingehende Analyse der Torfarten mit einer genauen Bestimmung seiner Zusammensetzung. Letzteres spielt eine grosse Rolle bei der Bestimmung der Genesis des Torflagers (der Etapen seiner Entwicklung in der Zeit). Bei der Festsetzung einer gewissen «Litogenese» (in vorliegendem Fall — der Elemente der Torfarten), bei der systematischen Gruppierung der Organismen muss man in den Lebensbedingungen, unter denen das Sediment — der Torf sich abgelagert hat, passive und aktive Bildner unterscheiden. Man hat eine ausserordentlich schwierige Aufgabe zu lösen — die Paläoökologie der Vergangenheit aufzudecken, mit Aufklärung der Lebensweise der Pflanzen, um die ehemaligen Lebensbedingungen wiederaufzubauen, unter welchen die eine oder die andere Assoziation existiert hat, und zwar vom Standpunkte der «Vergangenheit», wo andere Verhältnisse im Kampfe ums Leben herrschten — im Chemismus des Bodens, in der Zusammensetzung des Wassers, in den Temperaturbedingungen und den biologischen Wechselwirkungen. Das Medium des gegenwärtigen Lebens ist ein anderes als das Medium des Todes. Die Biozönose ist der begrabenen Tonatozönose nicht ähnlich. Es genügt nicht, wenn wir für ein Torflager bestimmte genetische Verhältnisse finden; es ist ferner eine vergleichende Untersuchung ein und derselben Torfart, an Proben aus geographisch verschiedenen Gebieten, unbedingt notwendig. Erst dann wird das allgemeine Bild klar, das in der gegebenen Ablagerung sich abspiegelt. Beim Studium der Gegenwart pflegt man aber der Vergangenheit nur geringe Aufmerksamkeit zu schenken.

In der Geschichte der Ablagerungen spielt z.B. ein solcher Faktor, wie das Klima eine grosse Rolle; es hat aber im Laufe der Jahrtausende vielfache Veränderungen erfahren, so dass auch im Torflager Ablagerungen vorhanden sind, die eher von sekundärer Natur sind (Prozess der Einwirkung der Salzlösungen zu verschiedenen Zeiten, Art der Verwitterung usw.). Es kann sich auch erweisen, dass das «Grundgewebe» das «Skelett» des Torfes (ein Teil davon) als «Schwamm» wirkt, der Chemismus eines solchen Torfes hängt aber von der wasser-mineralischen Ernährung ab. So behauptet z.B. Zaitzew (s.oben), dass zwischen der Natur des adsorbierenden Komplexes und der Zusammensetzung der Torfvegetation kein Zusammenhang besteht.

Von diesem Standpunkte aus betrachtet, geben uns die von einigen Forschern (L.F.Post, Granlund, D.A. Gerassimow) vorgeschlagenen natürlichen Klassifikationen der Torfarten nur wenig.

Vom Interesse sind also: die Zusammensetzung des Pflanzenbestandes, der Zersetzungsgrad der durch diese Vegetation gebildeten Ablagerung und die sukzessiven Veränderungen, die sich in ihr abspielen. Von diesem Gesichtspunkt aus sind für uns die älteren Formationen — die inter-

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glazialen Torfe sehr wichtig, denn ihr Studium ermöglicht sozusagen, eine Brücke von den älteren Pflanzengruppierungen zu der gegenwärtigen Vegetation zu schlagen.

Den interglazialen Ablagerungen wurden in letzter Zeit zahlreiche Arbeiten gewidmet. 20 interglaziale Ablagerungen wurden untersucht (7). In 15 Punkten nordwärts und südwärts von der Grenze der Würmverglatscherung (nach Miröink) wurde gefunden: *Brasenia* (*Brasenia purpurea*), seltene Arten der Wassernuss (*Trapa*) und eine ganze Reihe von Vertretern der wärmeliebenden Flora im Hypnumtorf (aus *Drepanocladus Sendneri* u.a.). Die Pollenanalyse hat gezeigt, dass die Funde dieser Flora laut der Pollenanalyse mit dem Maximum der Hasel, der Erle und des Eichenmischwaldes, im Moskau Gebiet, oder dem Maximum derselben Hasel mit dem an erster Stelle stehendem Eichenmischwald in Weissrussland zusammenfallen. Eine solche Kombination der Baumarten mit der *Brasenia*flora weist darauf hin, dass in der Riss-Würm-Periode (mindestens während eines Bruchteils dieser Periode) eine relativ hohe Temperatur geherrscht hat. Schwach zersetzter Torf ist an Stellen zu finden, wo Hypnum sich reichlich angehäuft hat. Wo die anderen Torfarten sich in Lignin umgewandelt haben, mit eigenartigen Verbindungen der Pflanzengruppierungen, die in den oberen Teilen der Ablagerungen in *Sphagnum*gruppierungen übergehen.

Ausreichende Aufmerksamkeit wird bei der Untersuchung gegenwärtiger Torfe der Pollenmethode gewidmet. Als richtige Altersdatierungen werden folgende anerkannt (auch in der ausländischen Literatur): von Markow, Anufrijew, Dokturowsky, Neustadt und Zerow.

Die mikroskopische Analyse (ebenso wie auch die Pollenmethode) wird heute auch bei Bodenuntersuchungen angewandt (im Auslande besonders Beijerinck).

Ein besonders reiches Material liefern die begrabenen Humus- und Torfschichten und Zwischenschichten. Die Pollenmethode, mit allgemeiner Analyse verbunden (Funde und statistische Aufzählungen der Diatomeen u. a.) gibt wertvolle Resultate (Tichejew, z. T. auch bei Markow, 17,10).

Es seien hier noch einige allgemeine Angaben erwähnt, die sich auf den Kataster der Moore und der versumpften Territorien überhaupt beziehen. Das Ziel eines Katasters (nach Drubach) ist: «Charakteristiken der versumpften Territorien, womöglich für jedes Objekt einzeln, aufzustellen, zwecks präliminärer Lösung der Frage nach der zweckmässigsten wirtschaftlichen Ausnützung dieser Ländereien, mit orientierender Bestimmung der quantitativen Seite dieser Ausnützung». Das Objekt der Untersuchung bilden sowohl trockengelegte Moore, mit einer nicht weniger als 30 cm mächtigen Torfschicht (mit Einteilung in Nieder-, Hoch- und Uebergangsmoore), als auch versumpfte Areale mit nicht trockengelegtem Torf (0–30 cm mächtig) und versumpfte Areale ohne Torf—Plawni (*Phragmiteta*), Limane der Seeufer und Solontschaks (Salzböden). Resultate der Katastrierung: Kapitel über Moore in den hydrologischen Nachschlagebüchern (aus der Zahl dieser letzteren sind bereits erschienen: Kazakstan, Unter-Wolga, Mittel-Wolga-Gebiet und Nord-Gebiet); Katalog der versumpften Gegenden, nebst Karten, und hydrologischer Atlas. Der Kartenkatalog für einzelne Ob-

jekte wird wegen seines zu grossen Umfangs nicht veröffentlicht. Die Arbeit wird in dem Zentralen Büro für Wasserkataster, dem hydrologischen Staatsinstitut in Leningrad und dem Gebiets-Wasserkatasterbüro durchgeführt.

In einer seiner Arbeiten (15) spricht M. I. Pawlow über die Klassifikation der Torfmoore und äussert sich gegen die angenommene Einteilung der Moore nur nach der Mächtigkeit der Schichten — in Hoch- und Niedermoore: wenn mehr als die Hälfte der Schicht, ihrer Mächtigkeit nach, zu dem Hochmoortypus gehört, wird das Moor zu Hochmooren gerechnet; wenn diese Schicht die Hälfte der Tiefe des Lagers nicht übertrifft — wird ein solches Moor zu dem Uebergangstypus, oder besser gesagt, zu dem Mischtypus gezählt. Man muss das Verhältnis der Kubatur kennen und die Vorräte des Hoch- und Niedermoors bestimmen, schichtenweise, im Verhältnis zu dem ganzen Lager, sonst entsteht eine Zergliederung des Plans des Moores in eine grosse Anzahl von Parzellen («Typen»), die den Plan überhäufen und seine Handhabung erschweren. Die qualitative und quantitative Charakterisierung darf nicht nach typischen Parzellen sondern unmittelbar nach den natürlichen Schichten des Hoch-, Uebergangs- oder Niedertorfs zusammengefasst werden. In der Praxis des Torfwesens wird eine solche Schichtencharakterisierung zur Ausscheidung der unterlagernden Schicht bereits seit langem angewandt, doch für das gesamte Lager ist es nicht üblich. Die Aufzeichnung von Profilen mit Auftragung detaillierter stratigraphischer Data ist ebenfalls notwendig (hieraus kann man auch die Kubatur in %% entsprechender Torfarten ermitteln). Die Schilderung der Torfarten muss durch Isolinien des Zersetzungsgrads oder der Humifizierung, des Aschgehalts u. a. Eigenschaften des Lagers ergänzt werden.

Die Methode der schichtenweisen Untersuchung trifft mit der Methode der stratigraphischen Untersuchung der Torfmoore, den Profilen nach, zusammen, sie muss aber als eine wissenschaftlich mehr ausgebildete bezeichnet werden. Die Untersuchung der Stratigraphie nach Profilen wird in letzter Zeit im Torfinstitut der Weissrussischen Akademie der Wissenschaften durchgeführt, so wie sie teilweise früher in anderen Torfforschungsanstalten der UdSSR ausgeführt worden ist.

L I T E R A T U R

1. Anufrijew, G. I. — Aufbau der Moore des Rayons von Leningrad. Abh. d. wiss. Torfinstituts. Lfg. 9. Moskau, 1931.
2. Beljajewa, E. N. — Ausgangslösungen als Indexe der Gesetzmässigkeit der wechselseitigen Uebergänge der Mineralböden in sumpftorfige. Abh. d. Zentr. Torfinstituts. Lfg. 3. Moskau, 1933.
3. Warlygin, P. D. u. a. Bestimmung des Humifikationsgrads des Torfes mittels der mikroskopischen Methode und nach anderen Verfahren. «Torfjanoje Delo» № 10, («Torfwesen») Moskau, 1934.
- 3.a. Hecker, R. F. — Prinzipien und Anleitung für paläoökologische Untersuchungen. Moskau-Leningrad, 1933.
4. Gerassimow, D. A. — Der Torf, seine Genesis, Lagerung und Verbreitung. Moskau, 1932.
5. Dokturowsky, W. S. und Anufrijew, G. I. — Materialien zur Stratigraphie der leningrader Torfmoore. Abh. des wiss. Torfinstituts, Lfg. 9. Moskau, 1931.
6. Dokturowsky, W. S. — Torfmoore. 2. Ausg. 1935.

7. Dokturowsky, W. S. — Ueber interglaziale Torfe. Büll. der Moskauer Ges. d. Naturforscher. Geol. Abt. Bd. IX, 1-2. Moskau, 1931 und Mitt. d. Weissruss. Akad. d. Wiss. 3. Minsk, 1934.
8. Dosmanowa O. P. — Materialien zum Studium der Gleibildungsprozesse. Abh. d. bodenk. Inst. d. Akad. d. Wiss. Bd. IX, 1934.
9. Dubach, A. D. — Uebersicht der Arbeiten der Katastrierung der versumpften Territorien der UdSSR. (Materialien zur Allunionskonferenz der Bodenkundler, 1935).
10. Zaitzew, B. A. — Bodenkundliche Bedingungen der Standorte der Kiefer und der Fichte. Moskau, 1931.
11. Zaitzew, B. A. — Wald und Böden des Nord-Gebiets. Archangelsk, 1932 und Materialien in Manuskriptform zur Allunionskonferenz der Bodenkundler 1935.
12. Zerow, D. — Postglaziale Geschichte der Wälder und des Klimas der n.-w. Ukraine. Beih. z. Botan. Zentralbl. Bd. LII, 1934.
13. Neustadt, M. — Einige Resultate von pollenstatistischen Untersuchungen im Westen des Gouv. Wladimir. Geol. För. Förh. V-X, 1928.
14. Markow, K. K. — Spät- und postglaziale Geschichte der Umgebungen von Leningrad. Abh. d. Kommission zur Erforschung der Quartärperiode Akad. d. Wiss., IV, Lfg. 1. L. 1934.
15. Pawlow M. I. — Beitrag zur Frage der Klassifikation und Bewertung der Torfmoore (Vorgetragen vor der Moorkommission der Sowjetsektion der Int. Bodenk. Ges. am 13/II—1935).
16. Tichejewa, L. W. — Begrabene Bodenbildungen in den Umgebungen von Leningrad. Abh. d. Bodenk. Inst. d. Akad. d. Wiss. Lfg. 6.
17. Abhandlungen des wissenschaftlichen Torfinstituts, Lfg. 14. Moskau, 1934.

ZUR CHARAKTERISIERUNG DER CHEMISCHEN EIGENSCHAFTEN VON WALDSTREU UND TORF

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Der Boden ist in chemischer Hinsicht ein höchst komplizierter Körper. Dieser chemisch-komplizierte Körper besitzt Reaktionsfähigkeit, die in Waldböden besonders stark in organischen Horizonten ausgeprägt ist. Diese Reaktionseigenschaften des Bodens hängen in hohem Masse von der sogenannten Adsorptionskapazität des Bodens ab, deren theoretische Begründung in letzter Zeit K.K. Gedroiz, Mitglied der Akademie, gegeben hat. Da der Boden in chemischer Hinsicht einen komplizierten Körper darstellt, wird seine Reaktionsfähigkeit in der Hauptsache bei Untersuchung jener Veränderungen untersucht, die in den Salzlösungen bei deren Einwirkung auf den Boden stattfinden. Eine solche Untersuchung der Wechselwirkung von Boden und verschiedenen Salzlösungen (darunter auch der alkalischen und sauren) ist von ausserordentlichem Interesse, da sie Licht breitet über die sich im Boden abwickelnden Prozesse und Material zur Charakterisierung des Bodens als eines Milieus zur Pflanzenansiedlung, liefert.

Dies sind die Gründe, die mich bewogen haben, bei meinem langjährigen Studium der Wechselwirkung von Wald und Boden, mein Augenmerk auf diese Seite der Frage zu richten. Das im Laufe dieser Zeit angesammelte Material zeigt, dass die organische Substanz der Waldböden ausser einer scharf ausgeprägten Reaktionsfähigkeit noch eine ausserordentliche Buntheit der chemischen Eigenschaften, quantitativ und qualitativ, aufweist. Die chemischen Eigenschaften der Waldstreu und des Torfes variieren in Grenzen der Genesis sowohl nach verschiedenen Bodenarten, als auch im Bereiche ein und desselben Bodentypus. Dies muss wohl dadurch erklärt werden, dass die organische Substanz der Waldböden sich leicht verändert unter Einwirkung von Faktoren, die auf Mineralböden ganz einflusslos bleiben können, oder nur eine schwache Wirkung ausüben.

Als Grundmomente, welche die chemischen Eigenschaften der organischen Substanz der Waldböden im Bereiche ein und derselben Bodenzone regulieren, sind folgende zu nennen: 1) Art der sich abspielenden bodenbildenden Prozesse, 2) Art der bodenbildenden Alluvien, 3) Art der Vegetation.

Diese Erwägungen wiesen auf die Notwendigkeit hin, die von mir gesammelten 80 Proben von Waldstreu und verschiedenen Torfarten nicht

nur in chemischer Hinsicht zu untersuchen, sondern sie mit der Art des bodenbildenden Prozesses, des bodenbildenden Alluviums und der Vegetation in Verbindung zu setzen.

Die Waldstreu und Torfproben wurden im Bereiche des Nordgebiets, in Karelien, in Leningrad und im West-Gebiet entnommen. Bei der Untersuchung jeder Probe wurde folgendes bestimmt: hygroskopisches Wasser, Glühverlust, Wasserstoffionenkonzentration (elektrometrisch beim Verhältnis Boden : Wasser = 1 : 25), hydrolytische Azidität (Spülen, auf Trichtern, mit Natriumazetat bis zum Verschwinden der Reaktion), austauschfähiger Wasserstoff, Kalzium und Magnesium (nach Gedroiz). Die Analysendaten wurden, um vergleichbare Werte zu erhalten, auf die organische Substanz umgerechnet (Glühverlust). Die erhaltenen Daten wurden summiert; die Mittel wurden berechnet nach Art des bodenbildenden Prozesses, nach Art des bodenbildenden Alluviums (bei podzoligen Böden) und nach Art der Waldbestände. Der Bodenbildungsprozess wurde in drei Hauptformen eingeteilt: podzoliger, podzolik-mooriger und mooriger. Die bodenbildenden Alluvien wurden in Alluvien, die arm an austauschfähigen Basen sind (austauschfähiges Kalzium und Magnesium in einer Menge von 0,2 bis 7,7 ME je 100 g Boden vorhanden) und in an austauschfähigen Basen reiche Alluvien (austauschfähiges Ca und Mg entsprechend in einer Menge von 10,1 bis 23,2 ME vorhanden) eingeteilt. Bei Waldbeständen unterschieden wir Kiefer-, Fichten- und Laubwälder.

Allgemeiner Charakter der Analysenresultate

Die erhaltenen Ergebnisse zeugen von einer ausserordentlichen Bunttheit der chemischen Eigenschaften der Waldstreu- und Torfarten der podzoligen Zone, obwohl wir mit Zahlen zu tun hatten, die auf organische Substanz umgerechnet waren. Die einzelnen Werte der oder jener Bestimmungen variieren sehr stark. Die hydrolytische Azidität schwankt im Bereiche von 88,6 bis 281,7 M.E. je 100 g organischer Substanz. Die Austauschazidität gibt entsprechend Zahlen im Bereiche von 0 bis 81,6 M.E.; der Gehalt von austauschfähigen Ca und Mg schwankt — des ersten im Bereiche von 6,4 bis 232,1 M.E., des zweiten von 0 bis 62,4 M.E. und die Summe dieser Kationen (S) — von 7,0 bis 294,5 M.E.; die Austauschkapazität nach Gedroiz ($H_{\text{aust.}} + S$) schwankt zwischen 25,0 und 294,5 M.E. je 100g organischer Substanz. Die Summe der hydrolytischen Azidität und des austauschfähigen Kalzium und Magnesium ($H_{\text{hydr.}} + S$) zeigt Zahlen von 88,6 bis 354,4 M.E. Die Grössen

$\frac{H_{\text{aust.}}}{H_{\text{aust.}} + S}$ und $\frac{H_{\text{hydr.}}}{H_{\text{hydr.}} + S}$ variieren entsprechend im Bereiche von 0 bis 0,93 und von 0,09 bis 0,97. Die Wasserstoffionenkonzentration zeigt Zahlen von 3,2 bis 7,0 (pH). Es muss dabei darauf hingewiesen werden, dass einzelne Zahlen öfters, mit der Art von Boden, Alluvium und der Holzvegetation in gewisse Verbindung gebracht werden können. Im Bereiche eines jeden dieser Faktoren sind bedeutende Schwankungen der chemischen Eigenschaften der verschiedenen Waldstreu- und Torfarten zu bemerken. Dies erschwert die Betrachtung der Analysenresultate in jedem einzelnen Falle und erfordert eine Gruppierung der erhaltenen

Tabelle 1

Veränderung der chemischen Eigenschaften der Waldstreu und des Torfes je nach der Art der bodenbildenden Prozesse.

Bodenbildender Prozess	Zahl der analysier- ten Proben	pH	Je 100 g trockener organischer Substanz in M. E.							$\frac{\text{H}_{\text{hydr.}} + \text{S}}{\text{H}_{\text{hydr.}}}$	$\frac{\text{H}_{\text{aust.}} + \text{S}}{\text{H}_{\text{aust.}}}$
			Hydroly- tische Azidität H hydr.	Aus- tausch- fähigkeit H aust.	Austauschfähige Basen (S)		S	H aust. + S	H hydr. + S		
					Ca	Mg					
Podsoliger	46	5,0	129,7	18,5	44,5	11,6	56,1	74,6	185,8	0,31	0,71
Gemischter podzolgmoor- riger	20	4,3	134,7	31,3	31,9	7,5	39,3	70,7	174,0	0,46	0,78
Mooriger	14	4,2	97,1	21,7	72,8	13,0	85,8	107,5	182,9	0,34	0,59
Durchschnittsresultate für alle Böden . . .	80	4,5	125,2	22,3	46,3	10,8	57,1	79,3	182,3	0,35	0,70

Tabelle 2

Veränderung der chemischen Eigenschaften der Waldstreu je nach Menge der in bodenbildenden Alluvien vorhandenen austauschfähigen Basen.

B o d e n	Zahl der analysier- ten Proben	pH	Pro 100 g trockener organischer Substanz in M. E.							H _{aust.} + S	H _{hydr.} + S
			Hydroly- tische Azidität H _{hydr.}	Aus- tausch- fähi- gkeit H _{aust.}	Austauschfähige Basen (S)		S	H _{aust.} + S	H _{hydr.} + S		
					Ca	Mg					
Podsolige auf an aus- tauschfähigen Basen armen Alluvien . . .	23	4,8	146,9	26,7	24,9	6,3	31,2	57,9	178,0	0,82	
Podsolige auf an aus- tauschfähigen Basen reichen Alluvien . . .	23	5,3	112,3	10,4	64,0	17,0	81,0	91,4	193,0	0,59	
Mittel für podsolige Bö- den	46	5,0	129,7	18,5	44,5	11,6	56,1	74,6	185,8	0,71	

Daten nach den Grundmomenten, die auf die chemischen Eigenschaften der Waldstreu und des Torfes einwirken, und eine Analyse der erhaltenen Mittel. In unseren Tabellen werden daher die Mittel von einer ganzen Reihe von Beobachtungen angeführt.

Einfluss der Art der bodenbildenden Prozesse auf die chemischen Eigenschaften der Waldstreu und des Torfes

Ueber den Einfluss, den die Art des Bodenbildungsprozesses auf die chemischen Eigenschaften der Waldstreu und des Torfes ausübt, kann man auf Grund der in Tabelle 1 zusammengefassten Daten urteilen. Wie bereits erwähnt, unterscheiden wir drei Formen des Bodenbildungsprozesses: der podsolige, der gemischte podsolig-moorige und der moorige Prozess (S. Tabelle 1).

Die Zahlen der Tabelle zeigen deutlich, wie stark der Einfluss des bodenbildenden Prozesses auf die chemischen Eigenschaften der Waldstreu und des Torfes ist. Der gemischte podsolig-moorige Prozess zeigt ein starkes Anwachsen der Azidität nach dem pH-Wert und dem der Grösse H_{aust} im Vergleich zu den podsoligen Böden; dementsprechend wachsen

die Grössen $\frac{H_{\text{aust}}}{H_{\text{aust}} + S}$ und $\frac{H_{\text{hydr}}}{H_{\text{hydr}} + S}$ an und fällt dabei der Ge-

halt an austauschfähigen Basen (S). Es wird somit unsere früher ausgesprochene Meinung über die Verschlechterung der Eigenschaften der organischen Substanz bei eintretender Versumpfung des Podzols bestätigt. In anmoorigen Böden ist das Bild anders: im Vergleich mit den podsoligen Böden zeugen hier die Durchschnittszahlen, mit Ausnahme des pH-Wertes, von einem relativ schwachen Anwachsen der Azidität. Dieser Umstand kann dadurch erklärt werden, dass man in der Gruppe der Moorböden zwei Torfarten unterscheiden kann: sehr wenig mit Basen gesättigte Torfarten und solche, die gänzlich mit Basen gesättigt sind. Diese beiden Torfgruppen unterscheiden sich ziemlich scharf voneinander bezüglich ihrer chemischen Eigenschaften und des Salzregimes der

zufließenden Grundwasser ($\frac{H_{\text{aust}}}{H_{\text{aust}} + S}$ dieser beiden Torfgruppen ist

— 0,66 und 0,10). Auf Grund des angeführten Materials kann man sich den Einfluss der bodenbildenden Prozesse auf die chemischen Eigenschaften der Waldstreu und des Torfes in folgender Gestalt denken — der Podsolbildungsprozess sichert durchschnittlich eine ziemlich grosse Azidität der verschiedenen Waldstreuarten, bei Versumpfungsprozessen; wo mit Versumpfung zugleich auch Podsolbildung stattfindet, werden die chemischen Eigenschaften der organischen Substanz der Waldböden viel schlechter; beim Versumpfungsprozess wirkt sich der Einfluss der Salzverhältnisse des Grundwassers sehr stark aus; dies fördert die Bildung bald stark mit Basen gesättigter Torfarten, bald solcher, die stark ungesättigt sind. Für vorliegende Untersuchung ist die Schlussfolgerung wichtig, dass die Art des bodenbildenden Prozesses einen grossen Einfluss auf die chemischen Eigenschaften der organischen Substanz der Waldböden hat.

Einfluss der Art der bodenbildenden Alluvien auf die chemischen Eigenschaften der Waldstreu

Das hinsichtlich des Einflusses der Art des Bodenbildungsprozesses auf die chemischen Eigenschaften der Waldstreu und des Torfes Gesagte veranlasst uns den Einfluss der bodenbildenden Alluvien nur im Bereiche der podsoligen Böden zu betrachten. Bei unserer Untersuchung teilten wir die podsoligen Böden in zwei Gruppen je nach der grossen oder kleinen Menge der in mineralischen Alluvien vorhandenen austauschfähigen Basen (Ca und Mg). Diese Menge schwankte in den an Basen armen Alluvien im Bereiche von 0,2 bis 7,7 M.E. je 100 g Boden und in den an Basen reichen — von 10,1 bis 23,2 M.E. Tabelle 2 zeigt Durchschnittszahlen der Analysen der Waldstreu auf den an austauschfähigen Basen armen und reichen mineralischen Alluvien (s. Tabelle 2).

Die Zahlen der Tabelle 2 zeigen, dass zwischen den chemischen Eigenschaften der Waldstreu und der Art der bodenbildenden Alluvien ein sehr deutlich ausgeprägter Zusammenhang besteht. Die Waldstreuarten, die sich auf den an austauschfähigen Basen armen Alluvien gebildet haben, zeichnen sich durch eine bedeutend grössere Azidität aus, als jene, die sich auf reichen Alluvien formierten. Von Interesse ist, dass nach Mittelwerten die Austauschkapazität ($H_{\text{aust.}} + S$) der Waldstreu auf armen Alluvien bedeutend kleiner als auf den reichen — 57,9 und 91,4 M.E., — und das Verhältnis $H_{\text{aust.}} : H_{\text{hydr.}}$ bedeutend enger ist — 1 : 5,5 und 1 : 10,8.

Somit zeigen die erhaltenen Resultate darauf, dass die chemischen Eigenschaften der Waldstreu von der Art der bodenbildenden Alluvien abhängen.

Einfluss der Art des Waldbestandes auf die chemischen Eigenschaften der Waldstreu

Die eben dargelegten Untersuchungsergebnisse berechtigen uns zu behaupten, dass bei der Betrachtung des Einflusses, den die Baumarten auf die chemischen Eigenschaften der Waldstreu ausüben, man auch den Einfluss der Bodenbildungsprozesse und der bodenbildenden Alluvien in Rücksicht ziehen muss. Dies erklärt die Tatsache, dass wir den Einfluss der Baumarten nur in Hinsicht der podsoligen Böden betrachtet haben — dabei differenziert — bezüglich der an austauschfähigen Basen reichen und der an diesen Basen armen Alluvien. Die Durchschnittswerte, die bei Untersuchung des Zusammenhangs zwischen Waldart und bodenbildenden Alluvien erhalten wurden, sind auf Tabelle 3 zusammengefasst. Der Laubwald wird nicht nach einzelnen Baumarten eingeteilt. Wir verfügen noch nicht über genügend reiches Material, um den Einfluss der Birken-, Epen- und Erlenbestände einzeln betrachten zu können.

Wenn man die Zahlen der Tabelle 3 nur in Abhängigkeit von der Art der Baumarten betrachtet, ohne die Art des bodenbildenden Alluviums in Rücksicht zu ziehen, sieht man, dass die günstigsten chemischen Eigenschaften die Waldstreu der Laubwälder besitzt, dann kommen die Fichtenwälder, an letzter Stelle in bezug auf die chemischen Eigenschaften

Tabelle 3

Veränderung der chemischen Eigenschaften der Waldstreu je nach der Art des Waldbestandes.

Waldbestand	Reichtum und Armut des bo- denbildenden Alluvium an austauschfä- higen Basen	Zahl der analysier- ten Proben	pH	Pro 100 g trockener organ. Substanz in M.E.						S	H _{aust.} + S	H _{hydr.} + S	H _{aust.} + S	H _{hydr.} + S
				Hydro- lyt. Azi- dität	Aus- tauschazi- dität	Austauschfähige Basen (S)								
						Ca	Mg							
Kiefer	arm	15	4,5	155,7	27,4	25,0	6,4	31,4	58,6	187,1	0,48	0,83		
	reich	2	6,1	122,2	10,3	60,0	15,1	75,1	85,4	197,3	0,12	0,62		
	durchschnitt- lich	17	4,8	151,2	25,4	29,1	7,5	36,6	61,8	188,4	0,44	0,81		
Fichte	arm	4	4,7	139,2	31,8	19,5	3,4	22,9	54,7	162,1	0,56	0,86		
	reich	10	5,0	124,0	14,2	49,5	14,9	64,4	78,6	188,4	0,20	0,66		
	durchschnitt- lich	14	4,9	128,4	19,3	41,0	11,5	52,5	71,8	180,8	0,30	0,72		
Laubhölzer	arm	4	5,5	121,4	19,1	29,9	8,6	38,5	57,6	159,9	0,38	0,77		
	reich	11	5,7	99,9	6,9	77,9	19,3	97,2	104,2	197,2	0,08	0,51		
	durchschnitt- lich	15	5,6	105,6	10,2	65,1	16,5	81,6	91,7	187,2	0,16	0,58		
Mittel für alle Bestände	—	46	5,0	129,7	18,5	44,5	11,6	56,1	74,6	185,8	0,31	0,71		

der organischen Bodensubstanz stehen die Kieferwälder. Der Koeffizient der Ungesättigtheit $\frac{H_{\text{aust.}}}{H_{\text{aust.}} + S}$ illustriert das Gesagte vortrefflich durch entsprechende Zahlen — Laubwald — 0,16, Fichtenwälder — 0,30 und Kieferwälder — 0,44. Doch darf man hieraus noch nicht den Schluss ziehen, dass der Einfluss der Baumarten auf die chemischen Eigenschaften der Waldstreu ein gleicher sein wird. Eine differenzierte Betrachtung der Durchschnittszahlen in Verbindung mit der Art des bodenbildenden Alluviums ergibt andere Resultate. Wie im vorhergehenden Fall zeigen die Laubwälder die günstigsten chemischen Eigenschaften ihrer Streuschicht, bei den an austauschfähigen Basen reichen und den an diesen Basen armen Alluvien (Ungesättigtheitskoeffizient 0,32 — 0,08); Kiefer und Fichte wechseln ihre Stellung. Die Kieferwälder zeigen günstigere chemische Eigenschaften der Waldstreu als die Fichtenwälder, wenn man sie einzeln für die an austauschfähigen Basen armen und reichen Alluvien betrachtet (Ungesättigtheitskoeffizient für Kieferwälder — 0,48 und 0,12 und für Fichtenwälder 0,56 und 0,20). Das Dargelegte berechtigt zum Schluss, dass die Kieferwälder hinsichtlich ihres Einflusses auf die chemischen Eigenschaften der Waldstreu den Laubwäldern nahe sind. Somit kann man die Laubwälder nach Günstigkeit des Einflusses der Baumarten auf die chemischen Eigenschaften der Waldstreu an die erste Stelle setzen, ihnen folgen in dieser Hinsicht die Kieferwälder und an letzter Stelle stehen die Fichtenwälder.

Einige Schlussfolgerungen hinsichtlich des Zusammenhanges zwischen Kiefern-, Fichten- und Laubholzbeständen und den Bodenbedingungen des Standorts

Vorliegende Untersuchung ist interessant nicht nur vom Standpunkte der Abhängigkeit der chemischen Eigenschaften der Waldstreu und des Torfes von der Art der Bodenbildungsprozesse, der bodenbildenden Alluvien oder der Vegetation; es werden hier noch eine ganze Reihe von Momenten aufgedeckt, welche den Zusammenhang zwischen den Baumarten und den Bodenbedingungen des Standorts charakterisieren.

Die erhaltenen Daten bestätigen die von mir früher ausgesprochenen Behauptungen über die Anpassung der Kiefer- und Fichtenwälder auf anmoorigen Böden an Torfarten bestimmter chemischer Eigenschaften — mittlerer Ungesättigtheitskoeffizient der Torfarten der Moorböden unter Kieferwäldern (6 Beobachtungen) — 0,66, unter Fichtenwäldern (8 Beobachtungen) — 0,10. In weniger scharf ausgeprägter Form wird es auch in Böden des gemischten podsolig-moorigen Bodenbildungstypus beobachtet, wo wir folgende Werte des Ungesättigtheitskoeffizienten haben: für Kieferwälder (5 Beobachtungen) — 0,61 und für Fichtenwälder (10 Beobachtungen) — 0,40. In Kiefer- und Fichtenwäldern auf podsoligen Böden finden wir dieselbe Abhängigkeit (Ungesättigtheitskoeffizient 0,44 und 0,30), wobei sie besonders scharf bei Gegenüberstellung typischer Kiefern- und Fichtenrayone in Erscheinung tritt (0,48 und 0,29).

Zugleich geht aus unserer Untersuchung mit ausreichender Deutlichkeit der Zusammenhang hervor, der zwischen Fichten-, Kiefer- und

Laubholzwäldern und der Art der bodenbildenden Alluvien der Podsolböden besteht. Dies erhellt aus den Beobachtungen über die Abhängigkeit von der Art der bodenbildenden Alluvien (Tabelle 3), wo die Anpassung der Kieferwälder an die armen Alluvien (15 aus der Gesamtzahl von 17 Beobachtungen) und der Fichten- und Laubwälder an die reichen Alluvien (21 aus der Zahl von 29 Beobachtungen) der Forscher oft bewusst reine Kieferbestände auf reichen Alluvien und Fichten- und Laubholzbestände auf armen Alluvien zu finden suchte.

Es sei erwähnt, dass auf den an austauschfähigen Basen ärmsten Alluvien sich vorzugsweise Kiefern ansiedeln, die auf armen Alluvien angetroffenen Fichtenwälder sind (ebenso wie die Laubwälder) bereits reicher an austauschfähigen Basen.

Die Anpassung von Fichtenwäldern an die podsoligen Böden auf armen mineralischen Alluvien muss in beträchtlichem Ausmasse durch die Tätigkeit des Menschen erklärt werden. Man wählte früher zum Abtrieb die wertvollste Baumart, die auf solchen Böden wächst, und zwar die Kiefer, wodurch die weniger produktiven Fichtenwälder geschaffen wurden.

Die erhaltenen Versuchsergebnisse decken ausserdem noch den Zusammenhang auf zwischen Produktivität der Kiefer- und Fichtenwälder und den chemischen Eigenschaften der Waldstreu und des Torfs. Die produktivsten Kieferwälder sind mit den reichen Böden verbunden, wo die Waldstreu einen günstigen Charakter aufweist ($\text{pH} = 6,1$, Ungesättigtheitskoeffizient $= 0,12$). Die Abnahme der Produktivität läuft parallel zur Verarmung des mineralischen Substrats, was von einer Verschlechterung der Waldstreueigenschaften ($\text{pH} = 4,8$, Ungesättigtheitskoeffizient $= 0,48$) begleitet wird, andererseits findet diese Produktivitätsabnahme bei Verstärkung der Versumpfungsprozesse statt, was ebenfalls mit einer Verschlechterung der Eigenschaften der organischen Substanz verbunden ist ($\text{pH} = 3,8$, Ungesättigtheitskoeffizient $= 0,61$).

Ein anderes Bild sehen wir bei Fichten: die produktivsten Wälder auf podsoligen Böden haben nach unseren Daten einen pH -Wert $= 5,0$ und einen Ungesättigtheitskoeffizienten von $0,20$; die entsprechenden Werte für die weniger produktiven Fichtenwälder sind $\text{pH} = 4,7$ und Ungesättigtheitskoeffizient $0,56$. Die Anfangstadien der Versumpfung, die die Produktivität der Fichtenwälder niederdrücken, rufen auch eine Verschlechterung der Eigenschaften der organischen Substanz herbei ($\text{pH} = 4,8$, Ungesättigtheitskoeffizient $= 0,40$); stärkere Versumpfangsformen aber verändern die Lage sehr schroff — in diesem Fall kann die Abnahme der Produktivität der Fichtenbestände von einer Besserung der Eigenschaften der organischen Substanz begleitet werden ($\text{pH} = 5,4$, Ungesättigtheitskoeffizient $= 0,10$). So gestaltet sich das allgemeine Schema des Zusammenhanges zwischen Produktivität der Kiefer- und Fichtenwälder und den chemischen Eigenschaften der organischen Bodensubstanz, welches darauf hinweist, dass die Produktivität der Kieferwälder in der Hauptsache mit der Azidität der organischen Substanz der Waldböden im Einklang steht, was in Fichtenbeständen nur teilweise statt hat.

Einige Bemerkungen zur Untersuchungsmethodik und mathematischer Darstellung der chemischen Eigenschaften der Waldstreu und des Torfes.

Einige der angewandten Methoden zur Charakterisierung der chemischen Eigenschaften der Waldstreu und des Torfes fordern genau gleiche Arbeitsbedingungen. In unserem Fall sind wir berechtigt, von einer Vergleichbarkeit der erhaltenen Resultate zu sprechen, nicht nur wegen der gleichen Arbeitsbedingungen, sondern auch, da alle Analysen vorliegender Untersuchung von einem einzigen Arbeitenden — dem Autor des Aufsatzes — ausgeführt wurden.

Die Untersuchungsergebnisse bestätigen zugleich auch den Wert der Charakteristik der Waldstreu und des Torfes der podsoligen Zone auf Grund des Ungesättigtheitskoeffizienten $\frac{H_{\text{aust}}}{H_{\text{aust}} + S}$. Die Bestimmung des Ungesättigtheitskoeffizienten nach hydrolytischer Azidität $\frac{H_{\text{hydr}}}{H_{\text{hydr}} + S}$ liefert einen Wert, der weniger charakteristisch ist für die sauren Waldstreu- und Torfarten, doch wie Präliminaruntersuchungen uns gezeigt haben, ist diese Grösse von unbestreitbarem Interesse für südlicheren Rayone, wo die Austauschazidität oft gänzlich fehlt.

Einige für die Forstwirtschaft wichtigen Schlussfolgerungen

Die durchgeführte Untersuchung der chemischen Eigenschaften der Waldstreu und des Torfes in Verbindung mit den Bodenbildungsprozessen, der Art der bodenbildenden Alluvien und der Vegetation ist zweifelsohne sehr wichtig für die Forstwirtschaft.

Zur Bestätigung des Gesagten führe ich hier in sehr kurzgefasster Form die Schlussfolgerungen an, die aus unserer Arbeit gezogen werden können, und die für die Forstwirtschaft von Interesse sind.

1. Unsere Untersuchungen zeigen, dass die Laubholzwälder sich durch die günstigsten chemischen Eigenschaften ihrer Waldstreu auszeichnen, an zweiter Stelle stehen die Fichtenwälder und am wenigsten günstig sind diese Eigenschaften in der Waldstreu der Kieferwälder. Gleichzeitig sind aber die Kieferwälder hinsichtlich ihres Einflusses auf die chemischen Eigenschaften der Waldstreu den Laubwäldern nahe; Fichtenwälder wirken am wenigsten günstig auf die chemischen Eigenschaften der Waldstreu.

2. Vorliegende Untersuchung bestätigt die Möglichkeit der Besserung der Eigenschaften des Waldpodsols durch Einführung von Laubhölzern, und wahrscheinlich auch von Kiefer.

3. Es wird die besondere Wichtigkeit der Verbesserung der Eigenschaften der organischen Substanz unter Fichtenwäldern festgestellt.

4. Eine ungünstige Prognose wird bezüglich des Existierens der Fichtenwälder auf an austauschfähigen Basen armen Böden gestellt.

5. Es wird festgestellt, dass die Kiefer die günstigste Baumart ist für die an austauschfähigen Basen ärmsten Böden.

6. In einer Reihe von Fällen erweist es sich als zweckmässig gemischte Fichten- Laubholzwälder und Kiefer- Fichtenwälder anzulegen.

7. Anpassung der Fichtenwälder an Böden mit einem an austauschfähigen Basen reichen Profil und der Kieferwälder an Böden mit an diesen Basen armen Profil.

8. Die grosse Bedeutung der Bestimmung des Zustands des absorbierenden Komplexes bei der Bewertung des Bodens als eines Milieu zur Besiedelung mit Pflanzen wird klargestellt. Zugleich wird festgestellt, dass der Ungesättigtheitskoeffizient (nach Gedroiz) die bequemste zahlenmässige Bewertung der Qualität der Waldstreu ist.

9. Der Zusammenhang zwischen Produktivität der Kiefer- und Fichtenbestände und der Azidität der Waldstreu und des Torfes wird aufgeklärt.

10. Es wird der Zusammenhang zwischen den Kiefer-, Fichten- und Laubwäldern und dem Ungesättigtheitskoeffizient der Waldstreu und der Torfe festgesetzt.

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