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THE PROBLEM OF SOIL STRUCTURE

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PREFACE

The widening and deepening of our knowledge of the chemical, physical, physico-chemical and biochemical properties of soil raises the need to review once more some of the scientific problems in the domain of soil science, which seemed firmly established; especially those closely connected with practical enquiries relating to agriculture.

Among such problems should be mentioned that of soil structure listed by the Soviet Section of the International Society of Soil Science for special discussion at the All Union Conference of the 1st Commission, which met in May 1931.

At the suggestion of the Soviet Section this problem was also included in the program of the work of the 1st Commission of the International Society of Soil Science and was to have been discussed at the International Conference of the VIth Commission of the International Society of Soil Science in Groningen in 1932.

It is to be regretted that the delegates of the USSR were not all to attend this Conference, so the discussion of the 1st Commission did not take place there.

However, with the aim of bringing the problem of the structure of soil before the III International Congress to be held in 1935 in England, the Soviet Section considers it necessary to publish now a summary of the work done at its suggestion by the members of the 1st Commission, thus giving an idea of the state of investigation and the progress of researches in the USSR into the questions of soil structure.

SOIL PHYSICS IN RELATION TO THE FIVE-YEAR PLAN

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Before me lie two manuals of soil science very popular in their time: «Natural-history principles of agricultural soil science for farmers, silviculturists, agro-chemists, phytophysiologists» by V. Detmar, published in 1876, 556 pp., and «Soil science» by Glinka, 577 pp. Ninety pages in the first book deal with soil physics; only 43 in the second are allotted to this subject. The chapters in the second manual carry the following headings: 1. Specific gravity of soil; 2. Absolute and apparent specific gravity of soil; 3. Porosity of soil; 4. Air conductivity of soil; 5. Plasticity, cohesiveness and tenacity of soil; 6. Water properties of soil; 7. Influence of forests on water conditions in soil; 8. Thermal properties of soil. The title of the main section of Detmar's book is «Physical and physico-chemical properties of soil»; «Soil physics» is a subsection consisting of the following chapters: a) General physical properties of soil (absolute, apparent and real specific gravity of soil; volume ratios of soil; adhesion of soil particles). b) Relation of soil to gases: the diffusion of gases, absorption of oxygen, carbonic acid, ammonia and others, ability of soil to condense water vapor; c) Relation of soil to heat, light and electricity (relation of soil to light, importance of soil heat to vegetation, general notes on soil heat, heating of upper layers by sun rays, circulation of heat in the soil, cooling of soils, relation of soils to winter frosts, relation of soils to electricity). d) Relation of soil to moisture (importance of soil moisture for vegetation, water absorbing capacity of soil, water conductivity of soil, loss of soil moisture by evaporation). It is true that Glinka has a special three-page chapter «Soil air», and in the chapter on «Absorptive capacity of soil» there are five pages devoted to the «Absorption of gases and liquids by the soil». Still, the impression is that the soil-scientists of fifty-five years ago paid a great deal more attention than those of the present time to soil physics and had a far broader conception of it, including within its limits the relation of soil to electricity; while the soilscientists of our epoch — an epoch of electrification — are but slightly interested in this field.

Yet, if the contemporary soilscientist is not interested in electrification, still he seems to have taken something else from the older times, which even now keeps him closer to the problems of the past than to those of the present.

Nearly a hundred and twenty years ago Humphrey Davy made a mechanical analysis of soil. After passing the soil mass through a sieve he boiled it in water in the proportion of four parts of water to one part of soil. After cooling and agitating, he let it stand for a few minutes for the large particles to settle, filtered the upper part, and examined separately on the filter both sand and silt. In 400 grains of the sandy soil Davy found 19 g. of water, 53 g. of stones and grit, 14 g. of non-disintegrated vegetable fibre, 212 g. of sand and 81 g. of silt. Fifteen years later Schuebler merely repeated these experiments based on the same principles of mechanical soil analysis already established by Davy. These principles, however, were mentioned in very ancient times by the first soilscientist of the sixth century B.C. Eleven years after Schuebler, Schultze classified seven more distinct mechanical fractions of the soil mass, establishing exactly the dimensional limits of each of them. First of all the soil itself was divided into two contrasting parts — the skeleton and the fine earth. The first is sifted for further separation, the second is treated by means of an elutriation apparatus. Investigations of soil made by Thier and Einhoff convinced them that the more fine earth — particularly'clay — the soil possessed, the more fertile it was. Thier's soil consisted of 74 per cent of clay, 1.5 per cent of humus, 10 per cent of sand and 4.5 per cent of lime. If the fine earth is a store of nutritive substances, the skeleton is merely its mechanical receptacle. The agronomist takes into consideration only 20—40 cm. of the upper layer of soil, but the agro-chemist considers only the fine earth. The soil skeleton has no water-holding capacity, no permeability, no nutriment — chemically it is passive (Detmar). But what is fine earth?

It is possible to make the meshes of a sieve of any size; e.g. in coarse soil areas these meshes are made larger, and in regions of well-developed soil formation they are made smaller, and a still greater rôle is played by the investigator's individual taste, the tradition of one or another school, laboratory or experimental station. Thus it happens that the size of the meshes varies from 0.2 to 5.0 mm.: Novatski —5.0 mm.; Feske — 4.0 mm.; Neubauer, Schöne, E. Wolf, Koenig, Siats, Schmidt, the Conference of Experimental Stations in Bremen, 1891,—3.0 mm.; Vogel, Vanschaffe, Laufer, Lüdeke, Woltmann, Gruner, Biedenkopf, the German Experimental Stations, Investigations of Dokoutchaev — are all 2.0 mm; Grandbau, Toms — 1.0 mm.; Riesler and Colomb — 0.7 mm.; Reitmeyer, Klemm, Osbourne — 0.5 mm.; Knop, Fadeyev, Williams, the Soil Science Bureau of the American Department of Agriculture — 0.3 mm.; Lorenz, Sabanin and most of the soil institutes, — 0.25 mm.; Bisler, Atterberg, the International agreement — 2.0 mm.

In 1872 Knop wrote that «the choice of sieves for separating the fine earth from the skeleton is arbitrary, but this difficulty may be overcome by agreement.» «A precise boundary established by nature between the coarse particles and the fine earth does not exist; there should be an agreement about it», said F. Lorenz to Lieburnau ten years later. For half a century the soilscientists, agronomists and agro-chemists preferred to go without it; each was willing to adopt his own sieve provided the others would join him, or he would agree to any sieve provided it were proved to be rational. For this purpose it was not necessary to establish such well-defined distinctions between the fractions of fine earth as between fine earth and the skeleton. It was necessary to endow each fraction of the soil with its own independent and individual existence, equally with the soil itself — which is essential to it. When this should be done for good or ill it would be possible to come to an international agreement, also for good or ill. This was done by the magician Atterberg! It was he who established a peculiar property of the figure «2» in the individual «life» of the fine earth fractions. He established experimentally three boundary signs: first, 0.2 mm. grains, the size of the grains indicating the higher limit of water permeability, for from this size down they retain water to a considerable degree; second, grains of 0.02 mm. as the limit of coagulation in weak salt solution; third, 0.002 mm. for grains showing the limit of Brownian motion. These so-called laws are completed and accompanied by more detailed characteristics of the fine earth sections which they define. Thus, in the «floury sand» (Mo of the Swedes) the grains 0.2 to 0.02 are distinguished by capillary properties (moderate height and rapidity of the rise), good water holding capacity, water conductivity and air conductivity; they are easily penetrated by roots and heat and easily tilled.

From the «dust» (particles 0.02 — 0.002 mm.) a colloidal condition begins. It is the boundary between sand and clay. Roots cannot penetrate into the necessarily small interstices. Capillary action is moderate, the rise is considerable and its duration long. These particles of 0.002 mm. have a higher cohesiveness and plasticity; bacteria cannot move freely in it and capillary conductivity is very slow. Penetration of water, air and plant roots is poor; absorption of heat is also poor; it is difficult to till; water-holding power is great; in most cases the amount of nutriment for plants is satisfactory.

The mythical «2» applies also to the skeleton; the sand particles coarser than 2 mm. possess a low capillarity and cannot retain water. Thus was the intricate problem of a rational boundary solved by the agro-chemists, or rather it would have been solved, had it not been, as Glinka says, that Atterberg f o u n d i t m o r e c o n v e n i e n t t o u s e t h e v a l u e 0.3, 0.03 a n d 0.003 i n s t e a d o f 0.2, 0.02 a n d 0.002. Such is the inevitable fate of all metaphysical magicians!

This example, concrete as it is, illustrates marvellously an old habit common to naturalists «of examining the peculiarities of the phenomena of nature apart from their inter-relations. He sees them in a state of rest but not motion, fixed, rather than constantly changing in their essence, not in the processes of their life but in a state of death» (Engels). From this all the consequences are derived.

Schultz (1849) thought it possible for chemical investigation to include not the whole of the soil, but only the last three out of seven fractions, i. e., the fine earth. It was a conclusion drawn from the above-mentioned experiment of Thier and Einhoff according to which «the fertility of the soil is equal in proportion to the amount of fine earth it contains». Did not the Nile silt which was the most fertile and well-known soil in ancient times, consist of nothing but fine earth? Have we not been told now, at the Conference on Soil Structure, that the medium — that is the cloddy part of the soil — embracing structural units of from 0.25 to 10.0 mm. in diameter is agronomically the most valuable?

Thus, if each separate fraction of soil powder, torn away from its living whole, can be estimated by itself, if the agronomical magnitude of different fractions varies, it is obvious that the agronomist should first take into account the most important of these fractions and from this make an estimate of the whole organism. It appears that some of these fractions are not to be considered because they are agronomically useless, but they might be taken into account if they were rationally and adequately estimated.

What does an agronomist, or agro-chemist or an agriculturist study? The soil or one or another derivative of it? Fragments of the soil, soil rubbish varying in different degrees as regards size, looseness and deterioration? Is it not soil that he studies even when taking only the upper 15-20 cm. layer in all its fractions, puts it into the vegetation pot and dilutes it with sand, just as milk sellers, who after they have diluted their milk by halves with water, are still convinced that they are selling not water but milk? Has he the right to do this? Of course the agronomist has a right to substitute sand and water entirely for his soil. We all of us know what an important part the pot culture experiment, with the application of nutritive solutions, has played in the physiology of plant nutrition. But then it must be stated that this experiment does not deal with actual soil; this non-soil cannot be adapted to sovkhoz (Soviet farm) or kolkhoz collective farm fields.

M. B. Novorusski, in both his books «Life of soil», and «Soil», demonstrates that soil is unnecessary, not only for scientific experiment but also for agricultural industry. «The chief strength of soil is not in the earth but in the water». «It is the water which nourishes, not the earth». «We might, in case of need, do without earth when sowing». One of the paragraphs of Novorusski's second book is entitled «Ploughing water only»; in it we read: «if we had no land whatever, we might substitute a concrete vessel measuring one dessiatin [1], and we should only need to fill it with water and during the summer add some 15 — 20 pouds [2] of fertilizer in order to get a normal yield.» The author is carried away by this possibility. «Who knows: perhaps in the not distant future concrete tanks will be installed on the roofs of houses in towns, the town water supply will fill them, and the chemical factories will easily supply the few pouds of fertilizer, or rather, ashy elements needed for plant nutrition. Then such fabulous crops will be reaped as have never been dreamed of by the farmer! The hard labour of the peasant which used to be expressed in the already obsolete sentence, «the farmer ploughs the land» will then seem strange to us. The future farmer will plough water only, with the utmost ease — and in the city!»

But as yet we have not come to the realization of Novorusski's vision; we still plough «land» though we no longer employ the peasant's «convict» labour. Is there any doubt, however, that were it necessary, in the process of Socialist construction, to put such a fantasy into practice, we would do it and would substitute water for soil? Then all our aims, all our measures in the field of labour processes, such as the construction of agricultural machinery, production of fertilizers, research work in the institutes, course of study at the colleges — all these would be brought into harmony with this technical link in the chain of Socialist construction. Still, for the present, we must plough the same land, the same soil, and we should know this soil as thorougly as we can, in order, to put into practice in the shortest possible time, Stalin's slogan that we must «overtake and surpass the leading cultural countries».

We cannot agree with another point of view of the same author. In 1922 he said «The soils all over Russia have already been overworked, but there is little harm in this. The soluble part is so negligible that it can be introduced entirely as fertilizer. As soon as the farmer understands that this is the sole normal way to take care of his soil, then only will he be sure of securing a good harvest». In other words, the author suggests obtaining nutriment for plants not from the soil, but from the mineral-fertilizer factories. And again we may say with full confidence that were it

[1] One dessiatin = 1.09254 ha.
[2] One poud = 16.380496 kg.

necessary we could and would carry out such a procedure. But it would require a complete change in our research work and production with regard to soil. The soil, as a reservoir of nutrients for plants and a producer of plants, would be devoid of interest for us. Then we would have to agree with Novorusski that «soil, be it deep or shallow, sand or clay, chernozem or any other, is nothing to the plant but a support for the roots which are firmly held against wind and storm like a post driven into the ground».

But in fact it would be nonsense to think that the soils all over Russia have been overworked and that, therefore, they can only serve as support to the plant. In 1907 Lenin wrote: «in Russia a bourgeois democratic revolution is taking place under such conditions that all progress in farming technique and in the development of the freedom of the population will create not alone a possibility of investing capital and labor in the old lands, but also of using the unlimited amounts of contiguous new lands».

In fact we are not thinking of substituting for the natural fertility of the soil, chemical products; for us, the latter is only, in general, a means to restore the former. This is why it is absolutely necessary for us to master the technique of restoration itself, for technique, in the period of restoration, is a decisive factor. A good Soviet soil should possess all those physical, chemical and biological properties which will facilitate and promote the growth of plants, and at the same time reduce the cost of agriculture. A good Soviet soil should possess the property of changing its nutritive substances into a form available to the plant, demanding from outside sources as little fertilizer as possible, as this always involves additional expense in labour and material. A good Soviet soil should possess all the necessary conditions for creating within itself a healthy biological life, from which must spring an army for the destruction of the forces of death and the creation of fields for the higher forms of life. All these properties of a good Soviet soil should be persistent, steady and self-perpetuating. But a good Soviet soil requires not a knowledge of its fractions, but a synthetic knowledge of its dynamics.

Up to the present time agronomists and agro-chemists have been interested in the dynamics of soil more for the purpose of curing a sick soil than for establishing laws for a normal, healthy one. But pathology must be based on physiology. Our neglect in this respect has cost us dear when carrying out soil reclamation. We have gigantic problems, not only in this latter field, but also in the complete reconstruction of the cultivation of the soil, and the planned fertilization of many million hectares on a prodigious scale.

These gigantic problems and prospects are not devoid of great dangers which the capitalist countries have already experienced though in a different form. A dialectic conception is required in order to get thoroughly acquainted with the soil of one's own sovkhoz or kolkhoz with the calculation of its dynamics and, on that basis, a continual interference with the soil in the interest of the plants to be cultivated is necessary. It is far easier, in case of trouble in the production of plants, to have one universally adopted remedy which can be applied mechanically. When at the close of the last century, mineral fertilizers began to be produced in large amounts by the factories, fertilization became such a universal remedy. «One has got so far in the theory and practice of agriculture that fertilizers prove to be the only means for remedying trouble». (Wollny, 1897). This is similar to what the American, Hilgard, wrote: «Fertilizers are always recommended whenever the normal growth of sugar-beets is disturbed, be it from lack of moisture or bad treatment of the soil or unfavorable weather conditions. Very often, together with the fertilizer, portions of saltpetre and sulfates are introduced into a soil already cotaining over 500 kg. per hectare of both. If you try, however, to tell the farmer that he is mistaken, you will hear him say that learned men should mind their own business and not interfere with practical things about which they know nothing». In order to avoid similar replies our agronomists and agro-chemists should endeavour to establish the closest possible contacts with local agronomists and kolkhozniks (collective farm workers), and work with them in taking charge of the propaganda of technical knowledge of soil science, agro-chemistry and agro-technique. They ought now to join forces in a planned way with scientific institutions and other scientists, and, together with them, start with the aim of a systematic agronomic study of the soil as a whole. The idea that the soil is merely of the nature of a mechanical mixture must be done away with once for all.

«Suppose we take some cleanly-washed sands of various kinds, says Novorussky (1932), some well-rotted manure, dried and reduced to powder, add some water, mix it into a paste, and we shall find that we have a good soil». Thus we can select the various constituents of soil, and by combining them form an artificial soil — not one soil but different kinds of soils — suitable for any purpose. At this point we are reminded of Liebig's fertilizing mixture, his patent fertilizers, Polychresta and Panchresta (Mulder), which he put together in this way for various soils and groups of plants. Due to these fertilizers, fallow, three-field, crop-rotation and other methods still existing for lack of adequate fertilizers, could be entirely abandoned. If our knowledge of soil science is to remain only at its contemporary level, we shall not be able to avoid, in the near future, serious expense, waste of time and loss of authority in the teaching of soil fertilization. We have already come close to this in soil physics and chemistry. It must be remembered, in the domain of soil physics that the past teaches us that such excesses as those noted above in chemistry are quite possible. Hilgard himself wrote (1897) about a school which taught that if fertilizers affect the yield it is only as the result of their influence upon the physical properties of the soil. He considered this teaching to be the counterbalance of that school whose hobby was fertilizing. Some scientific workers have a metaphysical tendency to force the various factors of fertility of yield into opposition, instead of subjecting them to a common study of dynamic processes as a whole, and watching how these logically built polarities are resolved into a dialectical unity. Have these tendencies entirely come to an end at the present time?

The subject of soil structure seems to be the most developed, the most thoroughly treated and the one upon which there is the most general agreement. Only a subject which has reached this stage can be referred to so directly and convincingly as is now done by modern authorities in soil science, agronomists and agro-chemists.

«A cloddy structure as a main factor of normal soilphysics» is the heading of a chapter of a recently published German textbook on soil science. The author says: «Only a cloddy structure is able to give the soil physical properties in all respects favorable. It is indispensable for the normal growth of vegetation as well as for the self-renewal of the soil». Other authorities say that the fertility of soil depends upon its structure, and also that only elementary farming can exist on structureless soil; and that a marked lack of stability of yield and a low average yield will be the result of such farming. This is the opinion of W. Williams, who says that he is an enemy of the harrow, roller and disc, for they are always harmful implements, since they convert more than half of the soil to a powdery, structureless state.

The fact that large areas are converted into deserts as the result of the systematic breaking-down of the soil structure, is enough, according to Williams, to convince one of the great importance of soil structure. He says, finally, all the civilisations — Ninevah, Assyria, India, China, etc. — perished from the deterioration and absence of cloddy structure of the soil. Legends, ruined city, and nomad cattle rearing are the only traces left of a once flourishing agriculture; the people themselves have become parasites of the cattle.

At the beginning of the vogue of chemistry applied to agriculture, Liebig made a similar statement. «In all countries and parts of the world where the hand of man did not return to the fields material for keeping up the yield, we notice a gradual decline from a state of maximum population to that of devastation and barrenness». «The temple of Paestum is surrounded by a desolate waste overgrown with meagre grass and thistle instead of the rose gardens and rich corn fields which once flourished there».

Should it not be considered «dizziness from success» if, as N. Tulaikov says, one were to disregard in the near future the very notion of rural economy as such, simply because sometime in the future we shall have neither villages nor farming, but agro-industrial combinats which, by their nature, have nothing in common with primitive farming? «Comrades», says N. Tulaikov, «in view of the possibilities which are not looming in the distance but are immediately facing us, can we refer to the natural forces of nature or call them to our help or hope in them? Far be it from me to lessen their importance! But they must be made to obey us. There is no doubt that our scientists could, within two years, create a soil structure, if that were the sole requisite for restoring the fertility of the land. If, as we say, structure is formed by the coagulation of soil particles, it would only be necessary to use an electric current to produce this coagulation, and then we shall have exactly what we need». «Indeed, the new factor of mechanisation which has been introduced into our agricultural life, upsets all our former conceptions. I am an old farmer working in a semi-arid region since 1903, but I had never dreamed ot the wonaerful achievements in technique which I saw when visiting the grain sovkhozes this year... Nowadays when our husbandry is so far behind, can we, at such a responsible moment of our socialist construction, rely upon such elemental factors in the restoration of fertility as nature and the natural forces of the soil?»

Not only with regard to the present and future but also to the past, N. Tulaikov, like Liebig and Williams, refuses to estimate the magnitude of elemental factors in the restoration of soil fertility. «I should like to be shown», Tulaikov continues, «how soil loses its fertility. I think it may be assumed that a declining yield of any crop is not due to loss of soil fertility, and this question need be discussed no further. World history seems to indicate that we are not losing soil fertility but gradually increasing it... Hence I am not in the least afraid of the so-called rapacious utilization of productive forces... Actually we do not exploit these to the limit». And when Tulaikov is told that he is rapacious, that he squanders the riches of nature, he replies that this question seems of so little importance that he never even considers it. The human mind and its achievements are more decisive for him. (Spacing mine, A. Y.). I take the liberty of reminding N. Tulaikov of the views of Marx upon these questions. «Any progress in capitalist agriculture is a progress not only in the art of robbing the worker, but also in the art of robbing the soil. Any progress in the temporary increase of its fertility is, at the same time a progress in the destruction of the permanent sources of fertility».

We have lingered on the views of N. Tulaikov because he so clearly reflects the impetucus movement of Socialist construction, which in the sphere of science and scientific thought and technique, indicates the great influence of our «existence in consciousness»; and this encourages a phalanx of enthusiasts, builders and inventors and contributes to our constructive advance. At the same time this trend often confuses that which is desired with what actually exists, relying upon the human intellect and upon a science which has not yet come into existence, and rejecting from the present all that seems, in the light of this desired tomorrow, to be useless, obstructive or moribund. Tulaikov says «fertility of soil can be restored in only one way — by getting rid of the shackles of the past and having before us a clear field upon which to build our agriculture according to science and the results of experiment».

One can see quite clearly what are the tendencies of this authoritative representative of science!

It is time to recall the statement of Engels: «Let us not boast of our victories over nature; each victory is avenged. Every such victory has at first the expected consequences, but later and still later, unforeseen consequences wipe out the value of the initial success. The people who, in Greece, Mesopotamia and other places, rooted out forests in order to have arable land, never dreamed that they were starting the process of destroying these countries by depriving them, not only of the forests, but also of the centres of moisture accumulation and storage. When the Italians of the Alps felled all the coniferous trees on the southern slopes, carefully keeping them on the north, they did not foresee that they were cutting the very roots of cattle-breeding in this region. Still less did they foresee that they were depriving their mountain springs of a reservoir of water during the greater part of the year, and that, during the rains, water would stream ruinously down into the valleys.

So step by step we discover that we do not really rule nature as a conqueror rules a foreign people, or like supernatural beings apart from it. On the contrary we can see that, flesh, blood and brains, we belong to it; we are within it; that our lordship over nature is due to the fact that we alone can comprehend and rightly apply its laws.»

Prof. Tulaikov is perfectly right in objecting to the universal application of Williams' grass-rotation system. But he arrives at this conclusion, not as a scientific worker who generalises and synthesises his experiments and theoretical conceptions and scientific ideas with the practical tasks of Socialist construction, but as a mere local worker who says: «I am a country worker and can I, as a practical worker, do thus and so?..

As a worker in a definite region I take no interest in the grass-rotation system... I neither support nor oppose this system, nor do I defend or attack the fallow system. I take each concrete c a s e». (Spacing mine, A. Y.). Also he says: «We cannot look upon rural economy in our Soviet Union as an individed whole».

But if people like Tulaikov refuse to work out theoretical problems of rural economy and technique, of planning the rural economy of the USSR as a whole, who is going to do it? Will science come spontaneously? Lenin said: «The role of a fighting leader can be taken only by a party with a progressive theory». «Theoretical work should not only keep pace with practice, but precede it, thus arming our practical workers for their struggle for the victory of Socialism» (Stalin). «The tendency of our practical workers to get rid of theory contradicts the very spirit of Leninism, and may be pregnant with dangerous consequences to the work» (Stalin).

An antagonistic attitude toward the science and experimentation of the past, if carried to excess, may it not result in too great a confidence in the human intellect?

And was not Comrade Krzhyzhanowski right, when he replied to the statement of the followers of Tulaikov: «I am not an admirer of general economics, since we ourselves create them»? He answered that we cannot escape from ourselves and our past.

These, then, are the two basic trends of our agricultural thought: one builds the new on the foundation of all that is useful and valuable in our past and present science and experience, while the other assumes a t a b u l a r a s a and starts entirely afresh.

These two divergent points of view from which problems of soil and soil fertility have recently been approached have inevitably destroyed the single and generally accepted conception of the structure of the soil which hitherto existed.

But the principal exponents of these two opposing theories at the USSR Conference, in May 1931, of the Soviet Section on Soil Structure were not the followers of Williams and of Tulaikov, but representatives of the University group of soilscientists, on the one hand, for whom Com. Kachinski reported, and the agrochemists of the Moscow and Kharkov groups, on the other hand.

All the participants in the Conference joined either the «structurists» as defined by Kachinski, or the «anti-structurists»; but these latter included some who refused to be so classified, and still others who, although they claimed to be structurists, might perhaps be called not so much «macro-» as «micro»-structurists.

One of the participants in the Conference wrote that he was afraid that the Conference might have no results whatever, but this fear proved to be unfounded. The Conference had more results than could have been expected. Did it not testify to a rapprochement between the pedologists in the universities and the agrologists of the Timiryasev Academy?

If you look into the soil science courses given by Glinka or even by Kossovich, you will find very little about this main property of the soil. There is, however, more in Sabanin's course. Sibirtsev considered that the phenomenon of artificial structure belonged to agrology. At the Conference held on the 3rd and 4th of May the pedologist appeared for the first time in the role of leader of the agrologists.

And how does it stand with the subjects of investigation involved in the problems actually discussed? The results of the Conference speak for themselves. We have reports «On Structure of Soil» by Akhromeiko, on «The Agricultural Importance of Soil structure», by Pronin, on «Soil Structure as a Factor of Abundant Crop Yield» by Kvasnikov, and a number of others. But do any of these authorities really cover the subject adequately? Not in the least; none of their monographs can be considered as a profound or comprehensive discussion of the the questions before us: What is soil structure? What is its importance in agricultural industry, and what are the measures to be taken by the agronomist and the kolkhoznik in relation to it?

Do any of the authors give any answer applicable to any of these problems? No. None of their works can be considered as a th rough or deep treatise answering the question, what is soil structure, its importance in agriculture and industry, and what are the measures to be taken by the agronomist and the kolkhoznik with regard to it?

At the Conference the work of A. Akhromeiko, and the discussion of it, seeme to be the centre of attention. Did the Conference go beyond this? Very little. When Pronin touched the question of micro-organisms in structured and structureless soil, it appeared that not one among the 200 soilscientists, agronomists and agro-chemists present, could support or contradict him.

But the question ought to have been raised at the Conference not only how far structure may be useful or harmful, but also how the structure itself should be effected. The words «ripeness of soil» were never mentioned at the Conference. Nevertheless the latter means quite clearly «a completely expressed form of the highest stage of soil structure» (Lang). Have the Soviet soilscientists, agronomists and agro-chemists ever studied the phenomenon of soil-ripeness? Have they any opinion of their own about it? Can anything about soil-ripeness be learned from the soil science manuals?

Virgil wrote of this soil-ripeness in his poems: «The earth heaves and swells in spring» ... Such was the great importance attached 2,000 years ago by agricultural thought to the phenomena of soil-ripeness. From this idea Virgil created the picture of the famous pit which could or could not hold the earth taken out of it, and this idea continued through antiquity and the Middle Ages, and was expressed by Florenus, Turbelli, Home, and has lasted almost to our own times. The pit has always been the chief feature of soil evaluation, representing not only soil fertility in general, but also the approach of the time of soil maturity, that is, sowing. In Russia this method of soil amelioration by means of a pit was advocated by Samborski (1681), Komov (1788), Levshin (1799) and Vetchinin (1845), and even by Skvortsov (1865).

A theoretical explanation of the swelling of the soil due to the presence of colloids, bacteria and geobionts has been added at the present time to the practical deductions arrived at by these long-continued researches. They began from the following incident. A hundred and seventy-five years ago an experienced Swedish farmer drew the attention of his learned contemporaries to the fact that when walking in a field, if the earth in the footprints rose like dough, it was a sign that the time of sowing for that particular field had come. The secretary of the Stockholm Academy, Peter Adlerheim, was greatly interested by this information and resolved to ascertain the truth of it for himself. He came to the conclusion that this property of elasticity and heaving is found only in chernozem, and in other soils only so far as they are mixed with it. The more elasticity there is in the soil, other conditions being equal, the more fertile it is. From this originated a new method for determining soil fertility by observing its swelling capacity. Soils previously desiccated in an oven were mixed with an equal amount of water, and the one which swelled most was considered the most fertile.

If you read a description of the spring soil swelling by Rosenberg-Lipinski (1871), or by the modern investigator, Mitscherlich, you will be surprised to find that it is similar to that made by the above-mentioned Swede in 1740. And is not Rodewald's and Mitscherlich's method of determining soil fertility by determining its hygroscopicity similar to the eighteenth century swelling method, merely improved and modernised? This phenomenon of swelling of ripe soil suggested a comparison with the fermentation of dough. At the beginning of the eighteenth century Home recognised pure black soil as the best, because of its capacity to ferment. Warmth, light and air encourage fermentation. Without air there can be no inner fermentation. Therefore Home thoroughly approved the custom of raising the earth from the fields into ridges (or walls) so as to enable the air to affect the increased surface of the soil layer. Home tried to explain the phenomenon of fermentation. He assumed that fermentation is due to soil particles being constantly inclined to separate one from another. According to Somerville (1798), plant roots affect soil in the same way as burrowing animals — moles or earthworms — and also contribute to fermentation. Humus carries into the soil the process of fermentation (Kukolnik, 1810). But, like all soil substances, even the richest, it must previously be subjected to oxidation (Livanov, 1797).

A practical deduction from the teaching about fertilization was the corresponding view of the nature of fertilizers. A fertilizer according to Dekkerman (1807) is anything in any way capable of fermenting. Fertilization, according to Krells' Annals (1785), is nothing else but a substitution for the too-costly yeast by that uncomprehended substance which produces fermentation. It is not so long ago that van Bemmelen reported that the barley sprouts used for the production of malt, were applied as fertilizer at the Deli (Sumatra) tobacco plantations.

Kette in 1862, dissatisfied with all endeavors to explain the phenomena of soil ripeness, formulated his own theory of soil fermentation, which, incidentally, includes a study of geo-absorption to which is due, in his opinion, the absorptive capacity of the soil. Kette seems inclined to attribute the greatest importance to gelatine-like substances — that is, salts of humus acids and hydrates of silicic acids. Furthermore, Kette formulated his ideas which made him the forerunner of the much talked of American theory of soil fatigue. Like the latter he asserts, first, that the soil never lacks anything essential, and, secondly, he attaches a great importance to plantroot secretions.

It would be out of place here to go into further discussion of Kette's fermentation theory; I have done it elsewhere. It is important to us to establish the character and extènt of the hypotheses explaining the different aspects of the phenomena of soil ripeness and its connection with soil structure, fertilizing, etc. Can all these hypotheses be related to those discussed at the Conference?

Furthermore let us ask ourselves: can they be related to the propositions developed at the Conference itself?

What has been done in a century and a half by agronomists, agrochemists and soilscientists in order to approach, on the basis of the immense achievements in physics, chemistry, physiology, biology and micro-biology, a conception for explaining and utilizing in production this mysterious phenomenon of soil-ripeness — or the «awakening of the spring» — which is the supreme form of soil structure so intimately connected with the farmer's practice since the earliest days of sowing, fertilizing and harvesting? «Much attention has been paid to the practical importance of soil ripeness», says Ramann, «and yet until now, 1911, we have no satisfactory explanation of this phenomenon». We see in the recently published work of the Munich Professor P. Lange: «up to now it has not been defined what is the origin of soil maturity in the field...». «It is true», he says, «that Mitscherlich, for the first time (!? A.Y.) has observed when setting foot on a structural soil that the latter possessed elasticity and sank down very perceptibly. This must have been observed by anyone who has walked on ripe soil». Mitscherlich supports the opinion of Rosenberg, Lepinski and others that gases arise from the soil, as well as from dough. Wollny rejected this theory, denying the increase of interstices in the soil when in a state of ripeness, and presumed that the latter was due exclusively to particularly favorable moisture conditions of the soil in connection with its structure. Based on the catalytic action of soil manifested by the decomposition of hydrogen peroxide (known to Saussure and Liebig; Scharrer has lately shown that iodine salts also are affected by it) an attempt has been made to attribute a great role to this catalysis in the formation of soil ripeness. But the experiments of Waksman and others do not justify this point of view. According to Rümker «Soil ripeness may result from the activity of atmospheric agents, soil colloids and the activity of soil microorganisms; this can be obtained only if the soil micro-flora can be given sufficient time to work». The agronomist and bacteriologist Löhnis considers soil maturity as a physical and microbiological condition of the soil during which it is most fit for sowing (! A.Y.). Löhnis, as well as Rümker, both emphasize the necessity for giving the soil a rest, i. e., a certain length of time for the development of the useful activity of soil organisms. (The necessity of fallow is based upon this principle). According to Müntz and Godeshon, soil ripeness is due exclusively to bacteria, and according to Mitscherlich, mainly to bacteria and yeast fungus. According to France and his collaborators, it is due to all the organisms constituting the population of the soil — to the edaphon in general.

Evidently, we have here only generalisations without any concrete knowledge of the phenomena which alone would lead the practical worker to action.

Thirty years ago Rümker indicated «that the further study of these unseen stimuli of ripeness and their life conditions is the most important problem to be taken up next». Has this problem been solved yet? Ten years ago Kantz described a very interesting microorganism which he called Actinomyces oligocarbophylus which had the property of coagulating into small clods even pure quartz clay. Does this organism play any part in the formation of structure, ripeness, fertility of soil? We have as yet no answer to this very concrete question. By what, then, can we explain the slow tempo and low efficiency of the research work in the agronomical disciplines which are so interesting to us?

Obviously this can be explained, first, by the fact that agriculture has always been the most backward and conservative branch of the people's economy, always dependent upon the elemental powers of nature; production was always based on routine culture and survivals; it expected less assistance from science and technique than, for instance, from industry and transport. Here, especially in countries with the so-called «Prussian» (Lenin) tendencies to develop capitalism in farming, the remains of serfdom delayed the transition to capitalism. This gave rise to a prolonged state of agrarian over-population. There originated instead of a proletariat a series of semi-proletarian, semi-independent poor farmers where work-power was not completely separated from the «means of production». The poorest peasants combined the sale of their labour-force (seasonal town work), with a minimum of sowing, which put them in the position of farm hands and day labourers who possess small plots of land (Lenin).

Under such conditions the large landowners were not interested in the development of capitalism, encouragement of technique or science. They had always at their disposal a constant supply of cheap, surplus labour which they could exploit.

Peasants, in their turn, who in the time of serfdom had been given plots of land, often inadequate for even bare support, were compelled to work for the landowners and were certainly unable to improve in the technique of their farming or call science to their aid.

There naturally originated on the survivals of serfdom the ideology of the neo-narodniki [1], an ideology which justified the advantages of small farming, sanctifying a further evolution of the people's economy on the basis of small ownership and petit bourgeois elements (Chayanov), although the introduction of technique and modern implements only intensifies the lack of work among the farmers. This gives a seasonal character to labour, resulting in free time in winter, an idea that Lenin severely criticised (The Development of Capitalism in Russia).

Naturalists, learned men, theorists and specialists are too often entirely indifferent to any kind of general philosophy. They are absorbed in opening up ever-new avenues of purely objective science, and have therefore no time to look into their own minds and develop an adequate philosophy (I am, of course, referring only to a certain type of narrow specialists), but accept uncritically the false philosophy which prevails — the philosophy of the stewards of feudalism and serfdom — which has permeated and corrupted their scientific work. K. Dudin, for instance (I do not know him personally; he may be a great specialist) has evolved a doctrine of the harmfulness of tractors in peasant farming (see his book: The Use of Tractors in Peasant Farming). But the method of soil appraisal of the grain sovkhozes was based on the false postulates of these neo-narodniks. They taught that the tractor forces the human workmen out of production, and so help to ins-

[1] A Russian political party the members of which went among the peasants to educate them.

crease surplus labour, and if the tractor lengthens the period of seasonal unemployment, then of course no neo-narodnik government could ever introduce a tractor in peasant farming, but must prefer the system of intensification of labour — that is, the systematic predatory exploitation of the living, working forces.

A wide, varied application of science and technique, undreamed of in the past, and even at present by countries most advanced in technique, may exist only under the conditions of the large, industrialised, collectivised economics of the USSR where unemployment is unknown.

In those cases where the old agronomy was set a task by life or industry, it was in the guise of a demand for first aid. The old agronomy and agricultural economy directed its scientific activities toward an immediate response. It did this the more gladly because sincere, serious work on complicated and difficult problems connected with agricultural production was beyond its strength under former conditions and resources.

Now only in the light of our Soviet vast scale and tempo, in the light of our technical and scientific achievements, are we able to evaluate the inheritance received from the old agronomy and realise how negligible was its tempo and efficiency, and how much of it was what we might now designate as money-making, crawling empiricism and the throwing of dust in the eyes.

The realisation of all this should not in any case prevent us from acquainting ourselves with the scientific and practical experience of other countries in the domain of agriculture, nor from selecting everything useful for our Socialist construction. Agro-soil science, or agrology (Fallon) being one of the basic disciplines in agronomy, while it remained within the limits of agronomy and agricultural chemistry could not become an independent science for the the above-mentioned reasons. In addition it lacked a theoretical and natural-history basis, which Dokuchaev gave to it. «Dokuchaev, says Williams, was the first to detect in soil something more than an object used by man for securing material prosperity. Dokuchaev was the first to view the soil as a body, having a right to exist upon the earth's surface, as do rocks, minerals, plants, animals; a natural body having its history and age which developed and is developing under the combined influence of its progenitors — rock, atmosphere, climate, topography and the organisms inhabiting it».

For the half century of its existence pedology — that is, Dokuchaev's soil science, the natural, the genetic, the geographic, the geographic-genetic and the «profilic» soil science has had a great influence upon the development of many natural sciences — geology, geography, botany, micro-biology, geo-morphology, hydrology, archeology, etc., and the practical disciplines (that is agronomy, silviculture, land reclamation, draining, highway-building, etc.). Gradually it has been acknowledged, in all civilised countries, including China, even beyond the boundaries of the «sixth part of the world», that scientists are familiar with pedology and take advantage of its achievements for use in their own scientific domain. In the USSR Dokuchaev's soil science can be divided into three branches — geographical (territorial), agro-chemical and agricultural. The first is connected with the name of the great Academician, K. Glinka, the second with that of K. Gedroiz and the third with W. Williams.

The primary branch is geographical soil science, directly connected with the work of Dokuchaev, and the period of the creation of this new science. Glinka was the pupil of Dokuchaev and succeeded Sibirtzev to the chair of soil science which was first occupied by Dokuchaev. This new natural science was created before the very eyes of that generation, and they witnessed its first successes at home and abroad. During this period they had to stand the attacks of practical people who disputed its right to existence. Let us recall on the one hand the struggle with the Zemski (local) statisticians, the pamphlet of Firsov — «However great may be the merit of Dokuchaev's soil researches, they are perfectly out of place and useless in such a purely practical business as appraising the land for taxation. They would be just as appropriate here as a careful chemical analysis of each piece of food which we should give to a hungry man».

On the other hand we may recall the assaults of the agronomists and agro-chemists on soil science. One of the greatest authorities, K. A. Timiriasev, wrote: «Who has not heard of our school of soil science at the head of which is Prof. Dokuchaev? It has absorbed a tremendous amount of state and local money without giving any answer to the question how can two ears be reaped where only one sprouted?»

If we say that Dokuchaev's followers of Glinka's generation over-estimated their achievements in soil science and were «dizzied by their success», we may say too that their adversaries underestimated the new discipline, partly because it was theirs and they did not know how to use it in the interests of research work in their own field of knowledge.

At the time when the building of Socialism began it could in no way be regarded as normal to withdraw from life and plunge into pure academical science, as doubtless the soilscientists of Glinka's generation did. Nearly five years ago the author of this article raised the question before the soilscientists — Glinka's adherents — of their participating in practical Socialist construction. «If the soilscientists have come to the conclusion at present, that this science should be only a pure science, strictly theoretical, that none of the soil charts is drawn for the agronomist, economist or farmer; that the researches of Dokuchaev, Sibirtzev and others in methods of soil bonification have to be regarded as completed and as having negative results, then they should honestly acknowledge this and logically deduce the following: first they should transfer all the soilscience research work to the Academy of Science, and secondly refuse the appropriations assigned for the purpose of making charts fitted for agronomists and farmers. These appropriations should be transferred to agronomists, economists or whoever will undertake with competence the work the soilscientists have rejected».

I think that at present we have the right to say that the soilscientist geographer has turned his face towards agronomy and is carrying out its tasks, spending less time and attention on theoretical work than is necessary to keep ahead of practice.

The greater part of the blame belongs to the agronomists and agro-chemists, if they fail to co-operate with the soilscientists.

In 1914 the agronomist Kurochkin mentioned that no connection existed between the work of regional agronomists and that of soilscientists. «Although questions of soil science play a great part in the work of the regional agronomist, the results of their work remain buried». The agronomist looks at the soil simply, as something final and obvious; he is quite content with the terminology of utilitarian classification — loam, podzol, etc. On the whole the agronomists are not sufficiently prepared to connect their work with the colleges and laboratories of soil science.

Thus before the World War and the Revolution the regional agronomists had a perfectly simple attitude toward the soil, and had no connections with the soilscientists; but now, what do the agronomists and agro-chemists advise? «Researches for the purpose of elucidating the subject of soil fertility must be based on agrochemical investigations; the study of soil adapted to the cultivation of technical plants by means of Mitscherlich's vegetation tests and Neubauer's physiological experiments, Lemmermann's citric extracts and acid extracts in general, and micro-biological reactions» (E. Bobko).

This means that, as a basis for the study of the problem of soil fertility, not soil but powder is taken, because the methods of contemporary soil science cannot give us the characteristic qualities of the fertile soil. What has our Conference shown us? Once that the agronomist and agro-chemist is quite willing to work in close contact with the German agro-chemist who still has the aims of the «good old times» — less philosophy, the law of decreasing fertility, a mechanical following of statistical methods, knowledge of powder, the universal application of the pot-vegetation method, etc. But he is unwilling to do any real co-operative work with soil science and his own soilscientist.

At the same time it is quite obvious that it is only by the combined efforts of the agronomists or agro-chemists and their own soilscientists that it will be possible to solve these problems which the agro-chemists and agronomists are now trying to solve by the help of those agricultural chemists who take their stand on what they consider to be the «unchangeable laws of nature, such, for example, as the so-called law of the decreasing fertility of soil», and those agronomists who recommend the use of the tractor as merely supplementary to horse power.

Under their own conditions these agronomists and agro-chemists can teach nothing else. But do we need this? Of what use to us is this eternal and universal «law of nature» and all that is built upon it? What do we want with this «empty abstraction which neglects the most important item — the level of technique, the state of productive forces?» (Lenin). The laws according to which we are building up our Socialism, reconstructing our people's economy and culture, do not lead us to a descending curve but to curves impetuously rising at an ever-growing tempo.

It is true that four years ago N. M. Tulaikov had a different point of view. A farmer was ignorant and did not know how to consider soil as something constantly varying in its chemical composition and physical properties, and in the nature of its macro- and micro-inhabitants; and only now that we, the farmers, have won the opportunity of working in close contact with soilscientists, do we understand quite clearly how essential for the progress of our work is that joint study of the soil and of the plants growing upon it from which we derive a knowledge of the productive capacity of soil at any given moment. We believe that by carefully analysing the processes of plant growth at different times and simultaneously studying and estimating the changes taking place in the soil in which these plants grow, we shall be able to ascertain the main features characterizing the correlation of the soil and the plant. We shall in this way be able to make out the intricate dependence of different soil states and the influence of man on the soil; and as the effect of man upon soil is entirely in his own hands, we can imagine the possibility of controlling the processes going on in the soil. If we establish an interrelation between the conditions of the soil and the plant at any given moment, we can imagine, although at present only as an ideal, a simple and not so very different art of utilising the natural forces of the soil for the welfare of the farming population. Further, N. Tulaikov advises using an agronomical appraisal to make soil charts of more practical use. «An agronomical appraisal will permit us to take stock of the natural resources used in farming; we shall more clearly see our resources for the future, and know how to use them for the development of the productive forces of the state and for increasing the people's welfare. The taking of an inventory of our soil resources is just as much an immediate problem in the building up of a Socialist country, as is the taking of an inventory of the means of production in industry. We are not yet used to this. Time and tide wait for no man. We must at once start a campaign for the working out of methods for the agronomic appraisal of the soil in order to be ready when the course of events brings this question in all its fullness before us.»

The picture drawn by Tulaikov of this intimate and prolonged inter-relationship of the agronomists and soilscientists corresponds much more accurately to the requirements of Socialist construction than his present position does. It corresponds exactly with the views of P. A. Kostychev who is considered by agronomists to be the founder of Russian agro-soil science. According to him, «the depth of tillage, the degree and character of soil loosening and the time and method of application of various fertilizers, can strengthen or weaken the chemical processes in the soil, can increase or decrease its capacity for drying or for retaining moisture, can help to equalise the temperature in different parts of the field — all this can be determined with the hope of obtaining the desired results, only with the precise information about soils and their properties under various conditions, and this information can be given only by soil science.»

E. V. Bobko wants to oppose to Soviet soil science the fact that in many of the older European countries, in the course of the cultural development of the soil, all traces of its natural history have been obliterated, and soil no longer exists there in our understanding of the word. It might appear that there is no basis for our soil science there, and that it can be of no practical interest in those countries. But in reality its basis becomes stronger and the interest grows. This is what we read in Prof. Stebutts course of soil science (1931). The potential fertility of soil is in immediate relationship to the trend of soil farming processes — that is, to the approximation of the soil to the soil type. Therefore we can discern directly the normal character of a cultivated soil by means of the trend of soil formation. However, as the trend of soil formation is expressed in the formation of soil type, the latter itself is an expression of soil fertility. This is a great achievement of modern soil science, and this also justifies the leading role of general theoretical soil science with relation to the practical, and the importance of this role increases.

What conclusions can we draw about what has been said concerning the conditions due to which the theoretical front of agroscience lags — the slowing of tempo and irregularity, due to bad management of the joint work of soilscientists, agronomists and agro-chemists with relation to collectivisation?

Above all things it is necessary not to arrive at a negative result by the process of a mere piling up of learned conclusions. From the standpoint of Prof. R. Heinrich writing in 1882, and agreed to by Wiliams, the factors of the agricultural production of plants are all of equal value. It follows that all those factors should be carefully, seriously and scientifically studied by a group of appropriate specialists on the basis of planned tasks, division of labour and co-ordination and synthetisation of the separate stages of progress. Since the problem of mastering science and technique is the problem of the masses at present and of the whole army of the builders of Socialism, we can no longer tolerate the lagging of the theoretical front, and the slowness in working out of such important problems as that of fertility connected with the most essential question of soil structure.

The classification of various kinds of structure by R. Lange was not touched upon at the Conference on Soil Structure («True and Untrue Structure and Ripeness» in the «Forstwissenschaftliches Centralblatt» 1931, No. 9—11). Lange, as we shall see, connects the question of structure and soil ripeness. In his opinion the term «structure» is applied to two or three entirely different phenomena, the classification of the nature and properties of which have, for the last two decades, differed more and more. A real structure, according to Lange, is a microstructure, a union of the most minute grains into small clods, measuring 0.01—0.03 mm., and corresponding to the size of fine sand. Formation of structure is followed by the formation of structural pores which increase the volume of the soil. A structural soil has the properties favourable to vegetation of both sand and clay, particularly with respect to water; the absorbing capacity of a structural soil is far greater than that of a structureless. Soil structure is a typical property of chernozems and of the dryer parts of south, middle and northeastern Germany, and of «rendzina» soils. Frost contributes to the formation of structure in soils. Lange calls it a frost structure; but such a structure lasts only until the following spring.

Besides this real structure, formed under the influence of electrolites, especially calcium, we have also a mechanical weathering of the soil.

The kinds of mechanical weathering are thermic, frost weathering, mechanical root weathering, all of which produce a simila loosening of the soil. This latter may also be produced artificially by means of a hoe, a plough, a harrow, a grubber, etc. Lange goes into the details of two kinds of mechanical loosening of the soil: loosening with a plough and root loosening. In many cases mechanical loosening by means of a plough is in absolute opposition to structure; by its nature it is contrary to the latter. Lange dwells on three factors of this difference and the opposed character of the different kinds of loosening:

1) Structure formation is based upon the aggregation of the finest particles into coarser complexes, whereas mechanical loosening is based on the decomposition of coarser particles into

finer ones. Structure is «self-structure» and mechanical loosening is a compulsory structure («real structure» and «pseudo-structure» of Tiulin).

2) A chemically structural soil is penetrated with fine, structural pores similar to the pores of a fine, sandy soil, while mechanical loosening produces interstices of different sizes, much larger than in the former — block pores.

3) A structural soil remains long in the same condition, including the structural pores, while mechanical loosening lasts for a few months only — the maximum is one to two years.

What has been said with regard to the mechanical treatment of soil applies also to root loosening.

Lange insists that the further conception of structure should apply only to real, inner self-structure which is formed by the coagulation of the clay particles of the soil by the action of salts.

Passing to soil ripeness, Lange deems it necessary to specially differentiate this kind of structure from the other two. As a well-treated field soil always has structure, soil ripeness may be considered the highest form of a structural soil. Ripeness means a condition of the utmost looseness, very great structural capacity and a state of easy decomposition of soil. A decided increase in the secretion of carbon dioxide in the ripe soil, shows the important part played by micro-organisms in the production of soil ripeness, and especially by nitrogen bacteria. This is confirmed by the researches of Suringar who has shown on the soils of Dutch East India that the poisoning of the soil by carbolic acid hinders the process of soil ripening. Ripening is followed by the formation of «ripeness pores», the dynamics of which has been studied by Nitsch. Soil aggregates of ripe soil are considerably larger than structure aggregates (0.02 mm.), thus with soil ripeness originate larger complexes of the second order ripeness complexes. Being familiar with natural phenomena in field and forest, Lange maintains that soil structure and soil ripeness differ so much that they should never be considered together. The lowest limit of formation of soil ripeness is at the $pH = 6.0$. At a greater depth the soil is no longer affected by Azotobacter which is the most important representative of the bacteria which disintegrate cellulose and which inhabit chernozem soils rich in lime. Lange differentiates the ripeness of field soils from that of forest soils, distinguishing the ripeness of the bedding layer from leguminous ripening.

It may be seen by this short reference to Lange's work that he has a conception of his own of the phenomen of the structure-capacity of soil which he unites with the problem of ripeness. His opinions should be given consideration, though there are points which require discussion.

The above-mentioned narrow conception of soil physics, even more than that of Detmer, exposes the modern West European soil science.

Soil science in America divides soil physics into at least seven sections: 1. Mechanical analysis of soil; 2. Soil structure; 3. Soil texture (constitution of soil); 4. Electro-conductivity of soil; 5. Heat conductivity of soil; 6. Radio-activity of soil; 7. Osmotic phenomena in soils.

How can our Russian backwardness be explained? By the general conditions of agriculture in retarded countries similar to ours. On the other hand, the American way led to the rapid development of capitalism and the division of the country into proletarian and capitalistic parts. The demand for technique and science started early and grew rapidly.

We may say that we have just come to a specialised soil science, as a department of soil physics. At the Conference for Planning Sciences the Academician Joffe counted only two physicists in the USSR. He meant, of course, specialists working at the problems of soil physics. In a late article in «Technique» Joffe writes «Agronomy sets vast problems before physics». In order to control the thermal behaviour of soil, the exchange of moisture and air within it, the exchange of radiant energy, heat radiation and the absorption of different substances, must all be thoroughly studied. When all this data has been mastered, it will be possible to regulate intelligently the soil, change its properties as well as its composition. It will further be possible to influence the colloid properties of soil, to create a soil. One must study radiation and absorption at ordinary temperatures, freezing and thawing and also other processes little known to the physicists.

The Conference has shown that soilscientists, agronomists and agro-chemists are studying agro-physics by means of obsolete methods similar to those which they apply to agro-chemistry. We see in Bobko's article how rich an armamentarium for research the agro-chemists possess and use; but a rich armamentarium is not always a proof of the qualities and efficiency which should be attained with its help. If finally an agro-physicist takes from this armamentarium what was proposed by Wollny 35 to 50 years ago, he severs his first constituent «agro» from the second, «physic». Is there any physicist working at present by the methods which his predecessors used a half century ago? K. Foytt stated «Whoever wished to utilize chemitry for studying living phenomena must be not only a chemist but a physiologist as well». Putting it in other words one might say that whoever wishes to be an agrophysicist should be not only an agronomist but likewise a physicist, and, since he studies the soil, a soilscientist.

And this agro-physicist-soilscientist should take his stand firmly on the achievements and the new methods of contemporary physics and soil science, reconstructed dialectically.

Is it advisable to attempt to solve such a complicated problem as that of soil structure by field experiments without any or with only inadequate control, on contiguous plots of 4 sq. m.? These plots may suffer severely from the experimenters themselves, and the results may easily be affected by moles, hares, neighbouring roots and the slightest carelessness on the part of the research worker, as Vincent indicated 75 years ago.

The dimensions of the plots and their arrangement side by side without being separated by a protective strip, was planned according to the method of field experiment devised by Mitscherlich. The closer the plots are located around a centre, the more uniform will the soil be, writes Mitscherlich. «Therefore the plots that are to be compared must be as small as possible, square, and arranged close to one another around one point.» Mitscherlich reckons that the minimum for fertilization experiments with cereals is 5 sq. m., and for those under general tillage, 20 sq. m. Four to six parallel experiments are indispensable.

Is it admissible that attempts should be made to solve such complicated problems as those of soil structure by means of pot culture experiments, by archaic methods? The above was the method employed in the time of Ochakov and the conquest of the Crimea (about 1780).

Mitscherlich, who is a great authority among agronomists and agrophysicists, says, that, since the time that Liebig's «Law of Minimum» has been superceded,—Mitscherlich had been an adherent of this law — the old method of pot culture experiment has lost its importance. At present the pot-method needs a complete alteration in order to meet the demands of our science. Can we not assume with S. P. Kravkov that «soil lives another life in pots than under natural conditions»?

Do not the words of V. L. Omelianski refer, from another point of view, to the investigator who studies soil structure and soil fertility in pots? «To study micro-organisms in a state of artificial isolation from other species, instead of under natural conditions and environment, is quite as mistaken and unnatural as to study man and his conduct apart from human society and without the social conditions which are inseparably connected with life itself, and which to a considerable extent determine personal and social relations». And furthermore, would it not be reasonable to take into account the warning of another great microbiologist, Vinogradski: «if we keep to the contemporary research methods of soil micro-biology (We say, study of soil structure. A. Y.) we shall never have a true notion of the role of microbes (add physical, chemical agents, plants, animals, climate, etc.) in soil processes, though experiments be carried on for whole centuries». These words were confirmed by the fact that for nearly a hundred years we have made no progress. If an agro-physicist or an agro-chemist tried not only to imitate their remote predecessors Schuler (1838), Shumacher and Wollny, but to familiarize themselves with the history of this science, he would easily see the necessity of searching for new ways, new subjects, new methods, and first of all new methodology which would revolutionize all their former conceptions.

The new methodology is not imposed upon science from without, but is given by the entirety of our present condition, by the qualitative as well as quantitative aspects of our Socialist construction, by the heroic efforts of the proletariat embodying in life the plan dialectically established by the founders of scientific Socialism. A new methodology cannot tolerate an old formulation of these questions. We must have either the pot culture method or field experiements; the school of structurists or anti-structurists, etc. It does not permit a purely mechanical following of its teachers, and this must never be forgotten in scientific research. The Conference has shown that there are no longer any anti-structurists pure and simple; they could not exist because all the stock of arguments and experiments that they accumulated is too unimportant, qualitatively as well as quantitatively, to oppose to the old, deeply-rooted point of view of the structurists. Both should acknowledge themselves structurists. But, as the resolution passed at the Conference has shown, such a general basis is not enough to solve the concrete problems put by the large-scale Socialist agriculture of the Soviet Union. It is necessary to develop quickly the general aims in a new form, discarding all the old mistakes of method; and work out new ones, attaching them concretely to each of the physical, geographic, economic or other realms.

It is not enough, however, to stand, or not stand, for structure; one must know exactly what is understood by structure. The Conference has shown that even with respect to this question there is no positive agreement among agronomists, geo-chemists and soilscientists. It is therefore useless to discuss other basic ideas dependent on this primary idea.

The Conference has shown likewise that some of the authors were not sufficiently critical in fixing the terminology, methods of work, etc., and also that there existed subjective difficulties in agreeing about joint researches, and in verifying each others work.

More than ten years ago A. N. Sabanin wrote: «In my opinion it is time to use measures and weights in deciding the question of soil structure». Have we got very far in this direction? Not very! The methods of Barakov, Puchner, Tiulin and others are the first steps which are by no means perfect. This can only be achieved by the co-operation of the Commission of the whole International Society of Soilscientists.

In order to expand the field of soil physics and make it the guiding principle in deciding on the practical measures connected with the reconstruction of agriculture which are ahead of us in the USSR during the second Five-Year Plan, there is needed a careful dialectic weighing of all the experience of world science on this subject, the fullest use of our own specialists and a thorough checking over and working up of the accumulated and accumulating facts and experience of our sovkhoz and kolkhoz farms and experimental and regional stations.

We should not only make extensive use of world science, but at the same time we must contribute our experience and share the achievements attained in our quite different rural economy which has such different methods and technique.

The Second Five-Year Plan makes great economic demands on Science, and Soviet Science must be able to satisfy them.

THE PROBLEM OF SOIL STRUCTURE

(A brief review of the study of soil structure in the USSR)

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In connection with the problem of the agricultural characteristic of soils, it becomes necessary to emphasize the moments to which a special attention is to be paid, when determining the agricultural properties of a soil. The supply of nutritive elements the soils require and, especially, of nitrogen is connected with biological processes, with the activity of microorganisms, which either help the plant by means of converting the nutritive elements into an assimilable form, or, on the contrary, hamper its life, consuming these elements themselves: it is of a special importance in case of biogenetic elements, particularly in the case of nitrogen and phosphorus. But the life of microbes depends on the above main groups of factors, whereas the needs of the aerobic organisms— the most interesting from an agricultural point of view — as to the outward conditions are analogous to those displayed by our common cultured plants. Thus, the influence of soil conditions upon the crop-yield expresses itself not only in a simple and immediate manner, but besides and in no lesser degree, through the life of the soil's micropopulation. Not indulging into details, I shall confine myself to reminding that, according to the most interesting data of Rothamsted investigations, soil microbiology gives an extremely complex aspect of changes in the composition and quantity of microorganisms in soil, of competition between particular groups of microorganisms (bacteria and protozoa) and of the yearly, seasonal and even daily fluctuations in the number of organisms. According to these, varies the supply of nutritive matters for higher plants. Besides the store of assimilable nutritive elements, both plants and micropopulation are essentially affected by the reaction of a soil, for it changes the properties of «the body» of soil, of its colloidal part, as well as the saturation of soil with Ca (compare: the importance the English authors ascribe to calcium carbonate in soil. A. S.), and by the properties of humus, the latter being the source of nitrogen, and in a certain degree — by the quantity of humus.

The supply of nitrogen matters required by vegetation is closely connected with general physical conditions — water and air-supply, and mechanical properties of soil. It is here that the question arises, which long since — since the times of Liebig — has been the subject of discussion in agricultural science. Is it true, that physical factors are of so great an importance in the problem of crop-yield? This question was once put in an ironical way by one of the representatives of an extreme conception of the theory of mineral nutrition, who considered nutrition to be a process of increase of mass and weight, due to the assimilating capacity of nutritive elements; however, as an agrochemist should say, if a bit of meat were put on the belly, it would give no result whatever be its physical properties; therefore, he says, the physical properties of soil are of no use whatever.

Similar opinions may be heard nowadays (especially from agrochemists), and certain investigations are carried out to support these opinions.

It is obvious that this theoretical opinion contradicts both the common practical considerations of the farmers, and the main conceptions of agricultural science in other countries. We believe such ideas to be nothing else than a misunderstanding due, on one hand — to the fact of some cardinal questions not being cleared enough [1] and some principles not being thoroughly defined [2], and on the other hand — to a methodological bias, owing to which one sees but one side of the phenomenon, instead of the many-sided complex. It seems that this misunderstanding is connected with the attempt of basing the conclusions of universal practical importance mostly on the pot-culture experiments, carried out under artificial conditions, having nothing in common with those natural.

Both the data of chemical analyses, and the results of these artificial investigations are but seldom to be connected with the phenomena of life of plants under natural conditions. Climate plays such an important part, that a direct relation between such analyses and investigations and crop-yield is not to be spoken of, unless at least the same climatic conditions be given. This may be understood, for instance, from the fact, that the effect of manure varies according to climatic conditions; furthermore, the limits of the influence of manure change in different years, now shifting southward, now retreating northward, again according to changes of meteorological conditions.

Climate affects all sides of the life of vegetation and crop-yield through the hydrothermal regime, characteristic of this or that region.

[1] I mean the cardinal questions of, so to say, agricultural physiology of plants.

[2] For instance, the problem of soil structure.

But the water regime of a soil, as well as its antagonist — the aeration of soil, and the closely connected with them thermal regime, under natural conditions are quite different from those artificially created in a pot-culture experiment, where plants are put into the most favourable conditions of water and air regime, while in nature, depending on the peculiarities of the climate, crop-yield is often threatened by the whims of the climate, by the unsteadiness of meteorological conditions, owing to which the «minima» in nature have often a different meaning and value than those of a greenhouse.

All the above said might be illustrated by a great many examples.

Of course, the influence of climate on the plants is not immediate—it is refracted through the soil and its properties, and at the same time spreads to the allies of agriculture — microorganisms.

It is no wonder that, under natural conditions of agriculture, natural soil properties often influence our operations in a decisive way and impart different values and different signs to their results. Here Russell's aphorism is to be remembered that, where crop-yield is concerned, plant cannot be separated from climate and soil [1]. When speaking about the physical properties of soil, we mean the following: mechanical composition (texture), the structure of profile, structure, cohesion, adhesiveness and porosity. The importance we attribute to these moments, consists in their influencing the absorption, store, loss and conservation of water in soils, the movement of water in them, their freezing and thawing, as well as the aeration of soils, their fitness for being tilled, the greater or lesser possibility for roots to force their way through the soil and subsoil, in search of water and nutrients.

As to mechanical composition, the particles of the soil, which mostly form the bulk of the soil, are of a size ranging from several millimeters (the sand particles between 0.25—3 mm.), down to several microns, even millimicrons; better to say, there are in soil macroscopic, microscopic and ultra-microscopic particles. On the size (diameter) of particles depends the diameter of the pores in soil and the surface of the content of particles, and, therefore, in a considerable degree, the cohesion of the soil. Special importance presents the quantity of colloidal particles — those of them, which owing to their small size and high degree of hydration strongly affect the water properties of the soil, as well as its mechanical properties. Thus, the properties of sand are: permeability, low capillary capacity, low water-holding capacity; silt exhibits considerable capillary capacity which then begins to drop, again according to the decrease of the size of particles (with a

[1] Let the reader not resent my indulging into such, one should say, elementary details, which is necessary, for even nowadays there are tendencies to maintain quite a contrary opinion.

diameter of about 20 microns), so that the minute particles of silt do not raise water as high as the coarser cnes. In highly dispersed, still finer particles of clay we observe the same features, but more distinctly displayed. Hence, good aeration, heat conductivity, early drying and easy tilling of sandy soils, — and the opposite properties of silty and, especially, clayey soils. But under different natural conditions, i. e. in different climate and different soil zones — and, therefore, in different genetic types of soil — the influence of these variations of mechanical composition is not the same: in the North the representatives of opposite types are characterized by bad agricultural properties; thus, we find sandy soils very poor with nutrients, and clayey soils — cold, heavy, mostly boggy on the surface. Owing to this, the agricultural value even of rather rich clayey soils is low all over the North. Passing to the South, to the chernozem zone we find quite different an aspect: first of all, here even sandy soils are much richer, their fertility is much higher, the behaviour of clayey soils changes in the same direction: the normal clayey chernozems contain 5-10 times as many fine particles (clay, according to Williams,— 0.001 mm.) as clayey podzolised soils do; they must be appraised quite differently, and no one should dare call clayey chernozems bad soils.

Structure. What is the cause of this difference? The cause is the structure, of which podzols are devoid and which is well developed in normal chernozems. Now, it should be agreed as to the structure we exactly mean here. We mean the so-called granular structure, the capacity of clodding spontaneously, without any man's action of breaking these clods to fine pieces, without distinctly shaped surfaces and edges: these «grains» are of various sizes; if a clod of soil is dug with a spade, out of a virgin cherouzem and is sufficiently tossed, we may see all the clod break into grains, which hang on small roots, like a bunch of grapes. So good a structure is not to be found in old arable soils, yet we find here both structural and quite structureless parts.

Just now I have, lying before me, two samples of arable soils, which I took in the whereabouts of Kharkov at the beginning of summer: one — near the Saltovo highway, from a somewhat degraded chernozem, and the other — from one of the plots of the Kharkov Experimental Station (normal chernozem); both spots, from which the samples were taken, are situated not far from each other, and yet the difference of their properties is striking at first sight. One of them presents a whole, compact, strong clod, which does not break off by itself, and a considerable effort is necessary to break a piece off it; the other, on the contrary, consists of a number of small grains, more or less round in shape, and falls to pieces, as soon as it is taken into hands. The former is a sample of a structureless soil, the latter — a sample of a granular structural soil. It is this granular structure, the only one of all types of structure known in morphology, that possesses agricultural value, wherefore it may be called «agronomical structure» of soil, and it is but of this structure that it will be further spoken about.

As to the sizes of structure in structural soils, no definite size is to be fixed; larger pieces are easily seen to successively separate into smaller ones, even when some quantity of both, structural and structureless soils, is rubbed up in a mortar. The difference between them is not swept away, the visible grains disappear. But if we put both soils into test tubes containing some distilled water, stir them and let them stand still, we shall soon see, for instance, in the test-tube, containing the sample of soil of the Kharkov Experimental Station, the earth precipitate and the water above it become quite translucent and clean, while during the same period of time, the soil from the Saltovo highway will not have precipitated and the water will be still muddy. The difference will prove still greater, if we take some chernozem and some alkali soil. The difference in the behaviour of both soils is due to the chernozem having a better structure than the degraded chernozem and especially the alkali soil. Owing to this, the precipitation of chernozem is not that of separate particles (for sand, which precipitates very quickly, is present in a very insignificant quantity in the Kharkov chernozem), but that of minute grains in which particles are united into groups; if the particles be disintegrated, the chernozem loses its properties and the precipitation of its particles in the test-tube proceeds still worse, than in the case of the degraded chernozem. The presence of small grains even in a rubbed up soil, which was structural before, may be ascertained by the microscope. One more feature is to be paid attention to, which discriminates good structure from bad in an agricultural sense — it is the behaviour of structural elements — in a dry or wet state: if a piece of structural soil is put into water or the water is filtered through it, separate grains do not get soaked through, nor disintegrate for a long time and keep letting water through, thus displaying a considerable stability, while in a dry state such a structural piece readily crumbles and yields to treatment falling to separate grains— structural aggregates. Such is the behaviour of a piece of good structural chernozem. It is quite different in the case of a soil of bad structure — alkali soil, for instance. If we examine separate columnar alkali soils, we see that these are lumps of earth extremely hard and strong; when dry they cannot be broken by ordinary means, but when put into water, they gradually swell to such a dimension that they cease to let water through and even finally slacken under the action of water. Therefore, we require the structural soils to be friable, to readily disperse when dry, and to be firm, not to slacken, not to get sticky, to pass water through — when wet. Such a combination of opposite properties in a dry or wet state, is characteristic when this or that type of structure is to be appraised.

Thus, taking into consideration this contrast of properties of structural and structureless soils in a dry state to those in a wet state, we must acknowledge, that a good structural soil is that, which readily crumbles, is easy to plough when dry, and does not get sticky when wet.

There are not only the formal morphological signs (features) of structure (though we pay due attention to the fact that necessary properties are to be found in soils, having granular structure), nor the size of structural aggregates (though it is of a certain importance too), which is of special interest to us, but those functional peculiarities of a soil, which are connected with the essential of a structure formation and are associated with a certain type of structure, while absent in other types of it.

Generally speaking, soils good for cultivation present quite opposite properties, when dry, to those, they possess when wet: when dry they readily disintegrate falling to pieces, which facilitates ploughing, and when wet they do not get sticky, are not adhesive. And in both cases the cause is the same: in structureless soils one has to deal with numberless ultramicroscopic and microscopic particles (elementary or compound) which lie separately, each acting upon the others with great strength (this strength stands in an inverse proportion to the distance between the centres of particles raised to a certain power), then, owing to the great number of particles, we have numberless points of contact too, and, therefore, a very large surface, on which the forces of reciprocal adhesion of particles act [1].

The phenomenon of the structure formation considerably diminishes these forces of reciprocal cohesion between the particles of soil, firstly—by means of gathering separate particles, secondly—reducing accordingly the number of points of contact by many times [2]. It is obvious that thereat the general cohesion of the bulk of the soil diminishes too, as well as the force that is to be applied to disintegrate this bulk, for instance, when tilling the soil. In nature we have, so to say, the whole scale of differences between soils, due to differences of their cohesion, and to each of them corresponds a different amount of expenses and force required for cultivation; each of them requires a different implement for this purpose.

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[1] Ramann, Williams, Loukashevich and Sokolovsky supply figures enough to illustrate the above observations.

[2] This is to be seen from Ramann's estimate: «if in a certain volume we have 4 sphere-shaped particles of the same size with the radius=2, there will be 3 points of contact; with a radius=1, there will already be 24, and with the radius=$^1/_2$, 192 points, and so on».

Microstructure. To avoid any misunderstanding it is necessary to say that structural aggregates, as well as separate elementary particles—mechanical elements, may be both macroscopic, i. e., seen with an unaided eye, microscopic—i. e., seen only through a microscope, and ultramicroscopic—i. e., of such small size that they cannot be seen even through a microscope, wherefore their presence may be found out only by means of an ultramechanical analysis. The investigations of structure show that, firstly, no type of structure is formed accidentally; secondly, that a certain complex of conditions — factors of structure — is necessary for this; thirdly, that every type, subtype, and even every variety of the same soil, possesses its own structure which is characteristic of it; fourthly, that under the influence of new factors this structure changes, deteriorates, vanishes and regenerates.

Observations and experiment show, that the properties of structure, that is the capacity of soil particles to form aggregates of some type or other, are, perhaps, as characteristic of a soil, of its colloidal part, as the capacity of taking some crystalline form or other—is of crystalloids.

Just as, when successively breaking a large crystal into smaller pieces, we see that they all always keep their typical crystalline properties: so successively breaking structural aggregates of a soil, we get the fragments progressively diminishing, but their type always remains the same, that is — granular macrostructure will change into granular microstructure, and so on.

Let us now examine the conditions under which a granular structure is formed, what are the factors which play the principal part in this process, how it changes in nature, that is—what is its dynamics, what makes it vanish, and how can it be restored, how does it influence the other properties of soil and, finally, what are the properties of structural and structureless soils from the standpoint of cultivation.

Structure and soil type. First of all, we have to try and find out in what soils and under what conditions we may expect to discover a good (granular) structure.

By the way, when we have to deal with some natural body, it is best to study its properties on such samples that have not changed under the influence of man's operations, in order to be able to explain the processes that created the cultural varieties of soils. So is it in the case of structure: when comparing the soils from this point of view, we must turn to soils not yet affected by cultivation, that is to virgin soils or laylands[1]. Then, following from North to South, we shall find the following aspect:

In the northern, podzolised zone granular structure is not to be met with even in virgin soils that have never been tilled:

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[1] Field with permanent grasses.

if anything of the kind occurs, it is nothing but worms' excretions: these readily crumble and have no practical importance. In clayey varieties a fine laminar structure occurs. It is obvious, that such soils hold water and become boggy on the surface: then air scarsely penetrates into this soil, owing to which the conditions become unfavourable for the processes, which require oxigen for the respiration of roots and for aerobic microorganisms; on these soils the effect of tilling vanishes very quickly, for the soil subsides soon after tilling; such soils are difficult to plough; owing to their water holding capacity their tilling is retarded in spring and after rains; in spring they are sticky, and in dry weather they form dry, hard clods (and this takes place though the content of clay[1] is rather insignificant — maximum 3—5 per cent). In the chernozem zone, on typical, normal (not degraded, nor alkaline) chernozems on virgin soils (for instance, in the steppes of the Poltava region—Karlovka, Strukovo steppes) we find a very good granular or pealike structure. In ploughed soils structure is not good, though much better here, than in podzols, even such as have never been ploughed.

In the confines of the chernozem zone, spots of soils are met with, having a structure much worse than in normal chernozems; it always occurs in regions, where the chernozems are either degraded or alkaline. Then on a ploughed field, slices do not fall to pieces — grains, but are rather compact and hard. To the South and South-East of ordinary chernozems, where on the map of soils «southern», «chestnut» and «chocolate» chernozems are shown, and still more on «brown» soils, we find bad structure again, which is nearly as bad, as that of podzolised soils; here granular structure is not to be met with, neither on ploughed, nor on virgin soils: a shistose and laminar structure is most characteristic of the upper layer in these spots. Especially bad structure, as well as bad physical properties, are to be found on alkali and salinized soils. Structureless, as well, are the gray soils of Turkestan.

Thus does the structure change according to the main natural soil zones; as everything in nature, this is due to definite causes, to alterations in the structure factors.

It must be remembered, that the structure and physical properties of a soil also change under the influence of certain methods of cultivation, in particular of a nitrate of sodium, potassium salts and ashes manuring. To this many a hint has been made by writers in former times.

It is evident, that owing to natural peculiarities of soil and to some agricultural expedients, the conditions necessary for the structure formation vary considerably.

F a c t o r s o f s t r u c t u r e. What then are these conditons? What is necessary to cause the slices of ploughed soil to break

[1] Particles < 1 mm.

into small pieces — grains? The cause of this may be partly found out by comparing the above mentioned three main types of soils: podzol, chernozem and alkali soils. The first observation that catches one's eye is that podzols were formed on deposits very poor in lime — glacial deposits; chernozems — on deposits rich in lime, carbonate — on loesses and similar deposits; alkali soils and salinized soils in their subsoils always contain, besides lime, carbonate, dissolved salts of sodium; they were formed from salty rocks.

In connection with this, the three types of soils we have just taken as example, contain different quantities of lime and of absorbed calcium too. To ascertain this, the following simple experiment is to be performed. Take three small funnels, put some glass beads into them, then a round bit of filter paper; upon it — a tea-spoonful of soil (under examination), cover it with another piece of paper, and then press with a fragment of glass. The funnels thus arranged, put a test glass under each, and then pour in some solution of ammonium chloride or of common salt. When approximately equal quantities of the solution have percolated through, slightly heat all the three test glasses, add some ammonium oxalate; then the test glass under the chernozem will first become very turbid and then will give considerable precipitation of lime oxalate: the podzol and alkali soil will give almost translucent solutions; only after some time the precipitation will set.

Some instances are given here as to the quantity of Ca as a result of this experiment. The Stroukov chernozem gave 0.986 per cent of calcium, washed out of the soil with ammonium chloride; the Moscow podzol — between 0.07 and 0.211 per cent; the alkali soils from the Ascania Nova (Chaply) — 0.083 per cent.

Thus, a soil possessing the best structure, shows the greatest calcium content, which may be removed out of soil by means of washing it with ammonium chloride; this is the absorbed calcium connected with the colloids of soil.

But may it not be a simple accident, there being no connection between this absorbed calcium and the structural character of soil? If so, let us continue our experiment. We take the funnel containing the chernozem, which has now been deprived of a part of its calcium, and wash it with pure water, but not with a salt solution; we watch the water pass through the soil. At the beginning the drops fall rather fast, but then, the further, the slower, until they finally stop; we see, at the same time, flowing out of the funnel, no more pure translucent water, but a dark, black solution — that is humus, flowing out of the soil. What does this mean? What has occurred? It means that no sooner had we removed the calcium of the soil that was connected with its colloids, the latter began to swell, to slacken, owing to the peptisation of humus; the structure also began to disappear, to decompose to smaller aggregates and elementary particles it consisted of; the pores between the structure grains began to fill up with fine particles, thus destroying the soil's permeability [1]. The same phenomena in their most typical form were described by Sokolovsky so far as in the year 1916 («Vestnik selskogo khosjajstva», 1916, №46), and in 1919, when they were conceived in connection with natural and economical processes, and when the explanation was found of the part that colloids and lime play in soil («Liming of soils», 1919). Furthermore, these phenomena could not remain unnoticed by the founder of the new period of studying the soil colloids—the Member of Academy K. K. Gedroiz (see «Journ. of Exper. Agr.» 1912, 1916, 1918). He mentions this himself in one of his works («Journ. of Exper. Agr.», 1921—1923). Thus, it is long since that this phenomenon has been known and quite clear to soilscientists.

Now let us carry out a contrary experiment: i. e. give back to the soil, what had been taken away from it. For this purpose we have to add some lime-water to the funnel, where the soil had been put. You will then see the water begin to filter little by little through the soil, which means that the minute particles, which had disintegrated, now begin to aggregate into pieces — namely, that the structure, which had vanished, is now being renewed.

There is one more means of verifying the possible conclusions. Let us take the black solution which had flown out of our chernozem, and add some lime-water to it. Then, examining it, we shall soon see flakes appear in this solution (pseudo-solution) which up to this moment had been clear, and see these flakes take in all the humus which precipitates on the bottom of the test-tube; above it clear water remains instead of the black liquid.

We can make experiments as well not only with a moist soil, but with one dry — with that which is being ploughed; therefore we let our chernozem dry up. Let us see the way it changes, during the process of drying up. Firstly, it gets adhesive (sticky) as a cart grease; then, when drying up, it gets hard as a stone, — it does not remind in the least the mellow crumbled lump, which we had taken for our experiment. Nevertheless, even now it can be returned to its former state — we have only to moisten it with lime-water and let it dry up, after which instead of a hard mass impossible to break, we get again a crumbled body. Thus, we can state now with certitude that the colloidal matter, with which are stuck together the separate particles of soil, this, so to say, cement which binds together the structural aggregates, without which they would fall to pieces as the sand does, serves, as a factor of structure, on the one hand; on the other hand — this matter fulfills its func-

[1] These phenomena were described by prof. M. A. Egorov, as «quite unexpected» and never known before in literature («Science in Ukraine», 1922).

tion of cement only when there is enough calcium to hold particles together, so as not to let them separate, be washed out of the soil.

That means that soil, in order to be structural, must contain humus and clay enough (colloidal cement) and that soil colloids have to be sufficiently saturated with calcium. The latter plays here the part of a protector of soil structure.

It is now comprehensible why the chernozem is structural, while the podzolised and alkaline soils are not; the podzolised soil lacked in lime from the very beginning (as there was not enough of it in the soil forming rock, and what was of it, was mostly washed out during the process of soil formation).

M o r p h o l o g y o f s t r u c t u r e. The calcium was swept out by natrium from the alkali soil, owing to the composition of the natrium ion (result of alkalization). V. V. Nikitin, who has compared the results of the mechanical analysis of two chernozems of the Troitzky district in the Ural region, on the one hand—without any chemical treatment, and on the other — after a preceding saturation of the colloidal complex with the ion Na — gives data, showing how the exterior properties (morphology of structure, its form) correlate with its interior properties, particularly with its strength, hardness. The mechanical analysis has given particles < 0.0003 mm:

A clayey granular chernozem non prepared	9.90 per cent
Same, saturated with Na	30.19 »
A clayey cloddy chernozem without treatment	31.38 »
Same, saturated with Na	38.42 »

Consequently, in the granular chernozem the grains are so well bound together by means of the colloidal cement which they possess, that only some 33 per cent of small particles (0.0003 mm.) can be separated by means of the usual method (though for other chernozems — not those Siberian — this per cent would be much too great and correspondingly their structure too would have a more striking granular form); nevertheless, this is of no consequence: we are interested in the relative difference between two structural variations of chernozems of one and the same district; and at the same time the same methods concerning the cloddy soil present quite another proportion: here the simple method of a mechanical analysis gives the possibility of dealing out already 82 per cent of the actual reserve of those small particles.

Thus, the granular aggregates, which are nothing else but natural clods created from the soil colloids under the influence of chemical and physical factors of coagulation, are conserved, notwithstanding the destructive influence of usual methods of preparation for analysis. Yet where, owing to the lack of fundamental factors of structure, this granular structure had not been formed, no stable aggregates exist, but only those artificial—lumps (clods) created under the influence of tillage; they do not stick together and disintegrate very easily under the influence of water. Thus, the only type of structure remained up to now strong and stable, and having a great agronomical value — is the granular structure, created due to the soil containing colloidal cement (humus and clay) which gets «insoluble» (passes to a state of gel) under the influence of an absorbed calcium-ion, and the humus, besides, under the influence of physical factors, as the drying up, and simply of changes occurring in the course of time (the so called process of «growing old» of the colloids).

The strength of structure. But it is not sufficient for the structure to have been created; we should like it to be strong and stable, not to grow poorer during tillage and under the influence of rainfalls. Meanwhile, we know that the calcium carbonate is soon washed out of the soil, as it is not to be found in the upper horizons of the chernozems; likewise the absorbed calcium, together with the colloids which we have just named, the «soil protector», is being washed out; «the protector» having disappeared, the same fate may be awaited by that, which he had guarded; in reality this occurs sometimes to chernozem: this was mentioned in due time by Kostychev.

Happily, therefore, soils have not only factors of soil structure, but also such as protect them from destruction when the «protector» has left, that is in the period when, due to it being washed out, it would not suffice to hold structure together to coagulate the colloids. Such a violation of the equilibrium between the soil colloids and the absorbed calcium occurs from time to time in soils under the influence of rainfalls and certain fertilizers.

Which is then the factor of strength of the structure? Practice and investigations in nature have unanimously shown it to be one of the cements — the humus. We have already seen that, when the absorbed calcium is being washed out of soil, humus passes into a solution together with the soil clay. Meanwhile, there is a certain difference between the clay and the humus. It consists in the following: clay, as well as humus, possesses the capacity of converting either in a state of colloid solution or into sediment, conformably to that whether the soil had been deprived of calcium or, on the contrary, there had been added some lime to the pseudo-solution of humus, or to the suspension of clay. Should this be repeated many times with the same soil, the quantity of the washed out clay and humus would always be the same only under the condition of the soil not to be dried up; otherwise, under the influence of the drying up, part of the humus would become indissoluble and would retain besides part of the clay. At the same time the latter, i. e. clay without humus, does not change its capacity.

Taking up the language of the colloidal chemists, we must say that, at a normal temperature, clay is fully reversible, and humus presents a partly irreversible colloid. This partial irreversibility of humus is the reason why it is possible in soils, where there is enough of it, to get a more or less strong structure. In order to understand this phenomenon, let us remember the capacity of the said clay; it is reversible under ordinary conditions, at ordinary temperature, it can be dried up and peptized again, it does not change its properties, and objects made of ordinary clay fall to pieces or grow soft from water. But, if before using such objects they are baked, they become very hard and the clay loses its natural properties, which means that under the influence of a high temperature after being baked it becomes quite irreversible. The same occurs to clay under a high temperature; an analogous change occurs to humus only from drying. Just as clay after baking hardens in the articles made of it, likewise the dried up humus hardens in the clods of soil it impregnates. The dried up, partly irreversible humus does not «dissolve» (peptise) even when part of the lime (calcium) is being washed out of the soil. Taking into consideration that there are sometimes rather sticky, even adhesive, soils although having but a very little per cent of clay, Schloesing in his time forwarded the question of whether clay alone had the properties of cement, or humus possessed it too. Having added experimentally some clay and humus to sand, he found out that humus bound sand 11 times better than clay. This does not astonish us in the least, for, as we know now, humus has a much higher degree of dispersity than clay, having not only microscopical particles, but also ultramicroscopical ones (Maslova). Consequently humus, as a colloid of a high dispersity, binds the soil particles together even when there is but a small per cent of it. But, as it has been already known to Schloesing, humus is not quite like clay; the fundamental difference is that humus after drying up loses partly its adhesive capacity; yet, when there is a great amount of humus in soil, even after its being dried up, it still plays a great part even then. If the structural aggregates were crushed into powder, moistened with water, and dried up again, the strength of the new lumps, into which the soil would break then, would be much less than that of those former; this occurs because of the decrease of dispersity, i.e. of the tenacity of the colloids of humus.

It is interesting to note that humus does not only alter, but also gives other properties to clay, for the clay-soil containing humus, after b ing dried up, is less hard, becomes mellower. A sort of strong enough combination occurs here between clay and humus. In his time Sokolovsky has discovered this combination to be so strong, that, to deal completely clay or «Schlamm», after Williams, out of a soil sample is not possible until the humus is destroyed with the help of hydrogen peroxide. The quantity of such undispersable clay in a fresh, moist soil (or in its deeper layers) is very small; but it markedly increases after drying up. This complex, consisting of clay and humus, is named a «passive Schlamm». Kostychev has discovered that dried up soil gives much less «black matter» after Grandeau. And even more — that the notion of this «passive» complex had already been found by Saussure, who discovered that one could get from humus a certain quantity of «extractive» organic matter; one can get more of it, if a moist soil is allowed for a certain time to be aerated. Sokolovsky's experiments proved, that the passive humus recovers again its «active» form under the influence of microbiological processes.

K. K. Gedroiz arrived at the same conclusion, which manifested of the existence of a «rather close connection between organic and alumosilicate absorbing complexes: it is possible that in soils both those parts do not make a mechanical (or perhaps not only a mechanical) mixture, but something more intimate».

Thus, the passive humus binding stronger the particles themselves together (owing to its own insolubility) at the same time gives a certain mellowness to the whole of the soil mass; a fresh active humus, whether added to the soil in the form of the products of decomposition of manure, or created owing to the biological «renewing» of the «old» passive humus, by increasing the quantity of the highly dispersed particles, at the same time increases the cohesion of the soil (the more so because, at the same time, a decrease in the saturation of the soil colloids with Ca takes place during the wet periods of the year).

Owing to all this, a small tenacity of the structural aggregates is to be encountered, together with a higher adhesiveness and strength of the soil, as a mass. It does not only grow, according to the washed out Ca rising to the surface in the form of bicarbonates, but the cement itself, that is to say, the fresh humus with which the lumps are saturated, — acquires such a form, that the summer heavy rains are of no danger to the structural grains.

The correctness of what has just been mentioned is proved by observations on nature and by many theoretical experiments. We often observe in nature a different tenacity of the soil structure, in different soils, as well as in the same soil, at different periods of its existence.

Kostychev had paid attention to chernozem upon virgin soils just plowed; the structure of such a soil is extremely favourable and at the moment of plowing falls to fine granular very hard particles, so that rain cannot destroy them. On recently plowed virgin soils, according to the same author, the ploughed layer has a granular structure wholly composed of small aggregates as big as a pea and up to the size of a small nut; it does not contain any dust; yet, after a certain time (on the 3rd and 4th year) dust appears and increases, while granular lumps get fewer and at last, the pores between them get chocked with dust; the former structure of the virgin soil disappears. According to Kostychev, only a virgin soil possesses so good a structure, which it is impossible to make artificially. He has also made some investigations in that respect, on creating and renewing the structure likewise on cultivated for a long time, ploughed soils.

Kostychev presumed that one could not always ascribe even to the chernozem a granular structure, the latter being but one of the forms of the chernozem, which we encounter but under certain conditions. We have already spoken about one of them, the special properties of which appear on the virgin chernozem. Concerning the arable soil, Kostychev gives the following picture. If a dry soil is ploughed, we get large lumps, and clods which it is difficult to crush. But, some time after rain they easily fall to pieces. The reason of such a phenomenon, as suggested by Kostychev, is that the humus under the influence of desiccation loses its cementing property. The soil becomes friable because parallelly with the decrease of the capacity of humus (and at the same time of clay which is bound with it) of cementing soil, the cohesion between the particles disappears. The crumbled state is a temporary phenomenon, disappearing when the humus recovers its capacity of keeping the particles together. After a certain time, if one wets the soil, humus from one dried becomes again fresh, good for cementing. Properly speaking, Williams has expressed the same opinion, considering as a condition of the tenacity of the structure, the converting of a part of the «humic acid» (a soluble part of humus) into «humin», which is indissoluble. Kostychev's conclusion was such: «the chernozems may have themselves the capacity of creating again a strong structure». Thus, the only reason of the changes in the tenacity of the structure lies in the dynamics of the humus.

Let us return to laboratory experiments. Schloesing had still earlier paid attention to the peculiar properties of humus, which has the capacity much higher than clay of sticking together the soil particles (mechanical elements), and changes its properties under the influence of the drying up. Later on this property of the humus was stated by Kostychev, who added that «the organic matter does not only change its properties under the influence of drying up, but transfers its capacity of changing likewise to clay». Our investigations have shown that in the chernozem, as in other soils, there are two main groups of colloidal matters: one part of it is detained in soil under the influence of calcium connected to it; as soon as the equilibrium between this particle and calcium is broken,— which means that the saturation with calcium of the soil colloids has diminished,—the corresponding part of humus and clay breaks off immediately its connection with the soil, and then gets easily washed out of it. Should one extract from soil all the exchangeable calcium, it would be easy to extract from all the humus, all the clay which had remained in soil under the influence of calcium (an absorbed calcium ion) — «aktiver Schlamm». Nevertheless, there remains after this in soil a greater or smaller amount of colloids (as well as of humus and clay) — «passiver Schlamm». A very characteristic phenomenon is the change of structure and of the physical properties of the soil after its losing its absorbed calcium (connected with the colloids). Such a soil, when dried up, gets as hard as a stone and loses its former structure; yet, when sprinkled with some lime-water, it may regain it. This occurs because of there having remained some humus and clay, which under the influence of calcium may possibly be gathered up into aggregates. Just the contrary occurs to a soil deprived not only of the absorbed calcium, but also of the active part of the colloids, which sticks it together. Then the soil, after having dried up, will have no structure whatever, and will not acquire it under any conditions—neither under the influence of liming, nor from drying up and wetting — and this notwithstanding that there remains in it, in a rather considerable quantity, humus and clay (the colour of such a soil is rather dark). This has given me the possibility of calling the first, so to say, «sort» of soil colloids which is usually connected with calcium, — the a c t i v e form of the colloids, for on it depends the process of the creation of the soil structure, as well as because of it being excessively mobile, easily converting into «solution» (peptisation) and, on the contrary, becoming indissolvable, either under the influence of lime, or through physical factors— the drying up of the soil. Another form of the soil colloids is the p a s s i v e form: it is that part of humus and clay which in its properties does not depend on calcium, and remains in the soil even after the exchangeable calcium has disappeared.

There is a close connection between the active and the passive forms: under the influence of the drying up (even at an ordinary temperature) the active humus is converted into a passive form, and thus protects the structure of soil from being destroyed by washing off. But this is not all: if the dried up humus is moistened, decomposition takes place in it under the influence of biological processes, and the dried up indissoluble humus is converted into a «soluble» form.

Together with my collaborators in the Ukrainian Institute for Soil Research, I succeeded in proving that under the influence of desiccation at a rather low temperature, which often occurs in soil in summer (40°—60° C), first of all the quantity of the «active» colloids diminishes considerably, when converting into the «passive» form. It is to be remarked that during this period the structural aggregates—not only those macrostructural but those microstructural too (as this is to be remarked even in a grinded soil) — become much stronger and not dispersable by water. But when the soil is dried up at a higher temperature, for instance, at 100°, then even after long boiling its lumps do not dissolve.

Thus, the question of the soil structure has now become clear enough to us: in order that soil could be able to create structure, it is necessary for it to have a considerable amount of colloidal humus and clay, both of them being sufficiently saturated with calcium. If the soil loses even a small part of its calcium, a corresponding part of colloids gets loose, and the structure is destroyed the more, the more the soil has lost of its calcium.

Thus we have learned to know how the soil structure was formed, why there is none in certain soils, why in one case it is permanent and in others on the contrary, it easily disperses by tillage and is washed off by rains. It is evident, however, that one should consider the soil structure from the point of view of yield, one is able to form or renew it only when there is a corresponding complex of structural factors, mentioned above in soil; when there are none, it is by no means possible to form this structure; the same should be said about the tenacity of the soil structure.

It is evident that a structure might be formed in every soil, where mechanical composition permits of it, where there is sufficient clay and humus, and where the soil is sufficiently saturated with calcium. Therefore, it is not casually that we meet structure in chernozems and in meadow soils (a granular flood-plain, according to prof. Williams). There is no structure in sands and in silty soils for lack of cement; there is none in loams and clays for lack of lime. In loams not containing any humus (on slopes where the upper layer of the soil has been washed out) a good, structure is not to be formed, for lack of that which is provided by humus.

Soil	What was done to it	The quantity of active «Schlamm» (in per cent) which did not settle	
		for 24 hours	for 7 days
Chernozem of Strukowo. Hor. 0—8 cm. Analysed in 1916	From 1916 to 1922 kept in the laboratory	18.7	7
The same analysed in 1922	—	12.5	—
The same profile. Hor. 42—50 cm.	Unchanged	26.2	—
»	After drying (40°-60°C)	23.2	—
The Kharkov chernozem	Unaltered	24.2	15.2
» »	After being dried at a norm temp.	19.3	—
» »	Dried over $CaCl_2$	14.5	—
» »	Dried during a week in a thermostat (50°)	12.0	6.1

The last of the analyses of the Kharkov chernozems belongs to Miss N. B. Vernander, our collaborator in the Ukrainian Institute of Soil Science, who studied the changes of the structural phenomena in different soils under the influence of the drying up. As a feature of those changes, in her investigations, were the changes of the permeability of soil under the influence of its desiccation.

Structure of virgin soils. What is the reason of the virgin soil having a good structure, of a plowed soil losing it, after a certain time, or, at least, of a plowed soil not having such a macrostructure as that of a virgin soil? The fact is that a structure is present here also, as we see in the example of the Kharkov chernozems which are the object of our study: besides, our experiments, as well as those of Gedroiz and Bouyoucos certify that in a case, when the macrostructure of a soil is scarcely visible, nevertheless it is present, and it is impossible to destroy it by ordinary means. Thus, out of two ground soil samples, when it is not possible to distinguish visible structure, and they seem to be alike, one can be really non-structural, and the other can be (if there be any factors of structure) of a microstructure. Therefore, the essential feature of the structure capacity of a soil is not its macrostructure, but its microstructure.

The reason of the structure capacity of a virgin soil lies in a particular property of the soil cement and in its greater saturation by calcium.

A virgin soil[1] in its natural state is much more dense than one plowed; water does not penetrate into it, as it does into a plowed soil; its surface exposed to the influence of atmospheric factors and, first of all, to that of rains, is considerably smaller; owing to this its drying up is also much more rapid than that of a plowed soil.

The grains of structure, formed under the influence of alternate moistenings and dryings up, are not destroyed as in plowed soils. Besides, the saturation with lime of the upper layer of a virgin soil (and even in laylands) is higher than that in old plowed soils[2]. Therefore we have here the conditions necessary for the formation of a hard strong structure.

[1] To avoid any possible misunderstandings, I beg to note that the plowed soil is being compared here to a likewise plowed virgin soil.

[2] The saturation with lime of the Kharkov Experiment Station's chernozem, depending on the cultural state of the field, changed in the following order: permanent fallow—78 per cent of the total capacity, permanent plant-culture—36 per cent, and the layland—88 per cent. Thus, in a layland we have most of the saturation, the permanent fallow and culture have considerably lowered the degree of saturation; this confirms the correctness of the supposition concerning the cause of the structure, for in permanent laylands it is the best, and in a permanent fallow—the worst.

There are many data concerning the improvement of the soil's physical properties, the increase of its looseness after a burning out (at a forest-fire culture of the forest zone); there are, besides, farming data, concerning the influence on the properties of a soil (chernozem) of the burning out of the stumps.

After that the soil takes an extraordinary aspect: it becomes very loose (as seen from some reports).

This is quite comprehensible, if we take into consideration all that was already said concerning the principal factors of structure.

There are indications that even plowed alkali soils, after having lain through summer, become more friable (O. M. Mozhejko's experiments on Chongar); and here it is a comprehensible result of the change of the properties of humus, as we have mentioned above. The structural character of a soil improves to a certain degree after manuring; here the cause lies in the influence of the fresh organic matter, which farm manure provides. This happens in different soils. The influence of sown grass (clover, according to investigations of the Nossovka Experiment Station) is to a great extent explained by the influence of the additional organic matter provided by grass on the soil's physical properties.

Yet, both the virgin soil and the layland have not the same influence on every soil.

Therefore, it is not everywhere that one may equally rely upon them from the point of view of improving the physical properties of soil and, mostly, its structure.

Even in a virgin soil we cannot much improve the bad properties of a podzol, which owing to the conditions of its origin, has lost both its cement and exchangeable calcium.

This takes place in the forest zone. But in the steppes, as well as in virgin soils and laylands, we have not got everywhere a good granular structure. The late prof. Kostychev observed it in the middle part of the chernozem zone in the Kharkov and Voronezh gov., etc.; it is there that he came to his conclusions, concerning the agricultural value of soil structure. Actually here, in virgin soils the wonderful structure had been formed we have spoken about. And the analysis of those chernozems clearly explains the reason of this: everything needed for it is to be found here; there are factors of structure, — a sufficient quantity both of humus and clay, besides it is well saturated with lime. We do not find the same picture further down to the South of the ordinary chernozem — to the South and the South-East of the Union, where the soil cover presents an original complex, where the typical normal chernozem presents an exception, where the further to the South, the oftener one meets with alkali soils and sometimes salines, and where other soils too are more or less salinized. On laylands, and even on virgin soils, no granular structure is to be found.

Thus, wild vegetation by itself cannot form any granular structure; (though it may be, that virgin soils have better properties than cultivated lands); and the extra-humus which it supplies, as well as the mechanical influence it has on soil, provided through roots, is not enough to form a structure. And here too the data secured by nature, conform excellently with the theoretical data: here also the question lies in the want of principal factors of structure—the soils of those regions are not sufficiently saturated with calcium (a result of alkalinity or salinization) and contain little humus.

Consequently, all efforts used for improving the structure of those soils only by means of a grass rotation or permanent grass are, as we think, not well grounded, and further study is still required. Likewise, practice gives us no right to try to find any panacea for those extensive regions in the system of grass rotation which would guarantee the fertility of their soils; for, whereas a layland really yields better crops on normal and even slightly degraded chernozems, crops on the so-called chestnut (which means faintly salinized) soils are, after layland has been disturbed, not better than on a long cultivated land. Likewise, there is no structure in the chernozem soils, where their texture should be sufficient for securing the «cement» needed for structure. Mostly amongst such are to be ranged the soils of the ancient river terraces (the 3rd Dnieper terrace, the Donetz terrace, etc.);likewise, the structural properties of chernozem differ, depending on the mechanical composition of those deposits which were left as a result of the action of the complex of factors connected with glaciation: in silty, scarcely clayey strata, structural conditions are not to be found even in virgin soils.

Thus, the mechanical composition (texture) and the properties of the soil colloids (depending on the rate of saturation with calcium and on both the quantity and quality of humus) influence the structure of soil; vegetation, by means of the pressure of its roots, partly strengthens the structure mechanically, and partly increases the reserve of the organic cement in it.

Unfortunately, the problem once suggested by prof. Kostychev was scarcely studied after his death, both by pedologists and agriculturists, and, therefore, we have not got arguments enough to say with certitude, whether a virgin soil or a layland can really appear as a factor for improving the structure and the fertility of soil. Up to now, direct definitions of the changes in structure under the influence of tillage are very scarce and not systematized; they have not embraced as yet even the main soil types, and have not classified the changes in structure as to their types and seasons.

The way of determining structure. The following methods have been applied for determining soil structure:

1) Determination of the filtering capacity of a soil — Kuzmin, Vernander, Barakov.

2) Determination of the porosity of a soil— Dojarenko, Kvasnikov, Tretiakov.

3) Determination of the dispersity of a soil — Gedroiz, Bouyoucos, Egorov, Shoshin, Konakov, Maslova, Kharchikov, Tretiakov, Kuzmin, Denisievsky.

4) Direct determinations of structure — Mankovsky, Barakov, Vinokurov, Tiulin, Kuzmin.

Part of those methods had in view only the constitution of the structure for the time being, without paying any attention to its tenacity; others tried to elucidate the latter question.

Having neither the intention nor any need to examine here the method itself for investigating structure, we shall only offer the results of the determination for different types of soils and, accordingly, for their different ways of culture.

Barakov used to take from 300 to 500 g. of soil at a time (chernozem from Bogodukhov), and having dried it upon sieves he distributed it into fractions, according to the size of the clods; then he filtrated water through every fraction, determining thus the strength of the lumps when softened by water.

In consequence of such an experiment he found that the per cent of the clods of different diameters was different, according to the soil treatment, which we se from the following table:

Size of clods in mm.	Cultivated land IV		Forest soil		Cultivated land V		Virgin soil
	Plowed 0—20 cm.	Subplowed 20—25 cm.	Plowed 0—20 cm.	Subplowed 20—25 cm.	Plowed 0—20 cm.	Subplowed 20—25cm.	0—20cm.
	in per cent						
> 7	0.8	2.7	0.6	3.2	6.1	1.1	12.5
7—5	3.8	7.4	12.2	9 8	8.0	3.6	15.7
5—3	5.7	18.8	38.3	25.6	7.8	13.3	19.7
3—1	16.6	33.6	40.6	41 6	22.6	40.8	14.4
1—0.5	21.9	16.3	5.7	10.0	26.3	22.7	24.6
< 0.5	48.2	21.2	2.4	9.8	29.0	18.5	13.1
Roots %	3.0	—	0.2	—	—	—	1.5

The pulverescent character of the plowed layers strikes us at the comparison both with the virgin soils and subplowed layer, Mankovsky's investigations on forest loams of the Poltava Experimental Station gave analoguous results, friability of soil under the influence of cultivation appearing there clearly.

Comparing the number of the small particles (dust) of the Poltava samples, we clearly see that the difference between the layland and the fallow consists in that on the layland the per cent

Size of clods in mm.	Layland in per cent	3 inch. plowing green fallow without manure	Bare fallow	Layer
10—2	53.4	34.1	36.5	0—13.5 cm.
2—0.5	37.2	34.9	33.6	
< 0.5	9.4	30.9	30.0	
10—2	52.6	55.3	63.6	13.5—27 cm.
2—0.5	29.6	28.1	24.9	
< 0.5	17.8	16.6	11.5	

of those or other structural fractions (mostly of the larger ones) is almost alike, both in the upper and in the lower layer; whereas on fallows we have a difference between both layers, and the greater, the more intensively has the land been cultivated. That is the phenomenon to which Tiulin has later on given the name of «structural deficit».

Vinokurov takes, as a criteri n for the soil pulverescence under the influence of cultivation, the proportion between the structural parts (>0.5 mm.) and those non-structural (<0.5 mm.).

His figures show the following proportions in a layer 0—15 cm. the most affected by cultivation:

Chernozem of a virgin soil № 14	1.0 : 1.03
» cultivated soil № 14	1.0 : 2.30
» natural layland soil № 14	1.0 : 1.47
» layland covered with *Bromus inermis* № 13	1.0 : 1.05

Here there outstands likewise a by far better structure of the upper layer of a layland, either artificial (sown grass) or natural: the difference between the plowed and the subplowed layer on a layland is much smaller than on that of a cultivated land, where under the influence of tillage the structure of the upper plowed layer has to some extent been destroyed. Same results were obtained by Kuzmin for chestnut soils. The structural deficit on laylands after perennials, as well as after tillage, was less than in a long cultivated land; on brown salinized soils the influence of the layland was already much less to be noticed (the «structural deficit» was no more than 10).

But unfortunately, we have as yet no such method that would enable us to correctly determine the structural character of a soil. Methods applied for it up to now have shown, at the best, the quantitative side of the question, i. e. the quantity of clods of this or that diameter, unsufficiently characterizing the quality of those structural units, i. e. their tenacity, not only against those quite artificial and conditional factors that are applied at laboratory tests, but against the whole complex of natural and agrotechnical factors, under the influence of which the structure is formed, altered, disturbed and restored.

Prof. Tiulin's effort to give a «structural deficit» can be but of little consequence, due to his being ignorant of the changes in the structural properties in a soil profile: different horizons not only of different types of soils, but even of the same profile, have different structural properties; their correlation to different soil types is not the same. Let us take, for instance, the podzol, in which the structural properties of the subplowed layer (level E) are worse than those of that plowed (level EH [1]), or else — the chernozem presenting a different picture. Thus, different matters as to their principal properties have been up to now compared, in order to find the «structural deficit». We may see that this is so, from Savvinov's data; he has studied the changes of the structure (the method applied is a combination of Tiulin's and Pavlov's methods with corresponding changes made by Savvinov) formed under the influence of culture in three subtypes of the chernozem of the Sal district.

Quantity (per weight) of particles in the plowed and sub-plowed layers in virgin soils, layland and in long cultivated lands:

Soils	Per cent of strong particles >0.25 mm.	Structural deficit in the plowed layer
I. Thick carbonatic chernozem		
Virgin soil. Horizon 0—15 cm.	74.8	2.7
» » » 15—30 »	72.1	
Layland plowed layer	67.8	8.9
» sub-plowed	76.2	
Long cultivated land, plowed layer	57.6	12.7
» sub-plowed	70.3	
II. Ordinary carbonatic chernozem		
Virgin soil. Horizon 0—15 cm.	60.0	7.4
» » » 15—30 »	67.4	
Layland: plowed layer	54.4	13.2
» sub-plowed	67.6	
Long cultivated land: plowed layer	39.2	20.1
» subplowed	59.3	
III. Southern carbonatic chernozem		
Virgin soil. Horizon 0 15 cm.	52.5	7.2
» » » 15—30 »	59.7	
Long cultivated land, plowed layer	29.4	25.1
» sub-plowed	54.5	

[1] According to my designation of genetic soil horizons.

Those data show a great difference between the three members of the same soil complex — between three variations of the chernozem of the big State Farm «Guigant». Even the virgin soil of different types of soil has not a similar structure, because in its natural state, under the influence of a wild vegetation (perennial grass), the thick chernozems have produced a rather strong (if we use the conditional methods we have spoken about) structure, but those «southern» have shown a much lesser capacity concerning this point; and it could not be otherwise, if we take into consideration that the presence of the factors of structure, their quantity and quality are different in different types and variations of soils.

Nevertheless, this table shows something else too. We have already stated that one may object to Tiulin's method of determining the «structural deficit» by saying that even in a natural state the correlation of the structure of layers of the same soil profile for different types of soils would be different. Yet, we see at the same time that the methods, applied by Savvinov in his work, do not show the different qualities of the structural aggregates. However, they are surely different. We can see this, if we compare the percentage of particles $>$ 0.25 mm. of each soil, only in the upper, plowed layer of a virgin soil and in a long cultivated land.

We should have in that case, for the thick carbonatic chernozem 74.8 : 57.6 = 1.3; for the ordinary chernozem 60.0 : 39.2 = = 1.53; and for that «southern» 52.5 : 29.4 = 1.78.

These data show that the virgin soil of these variations of chernozem has not got the same quality (strength) of structure; that its capacity of being disturbed is at the strongest in the «southern» variation, and at the least in the thick, that not all the particles which have remained intact after dealing out the «structural» part (aggregates $>$ 0.25 mm.) have the same properties; that their capacity of protecting themselves during the tilling and the manuring is not equal.

There is nothing strange about this, for only those properties of the particles serve as basis for determining the structure capacity, which appear when particles are sieved, shaken up, and percolated through a sieve.

Therefore, different aggregates in respect to their quality pertain in different soils to the category of the «structural» part of soil ($>$0.25 mm.). Under natural conditions, as it is seen from the last account, «the structural» aggregates of the thick black soil (chernozem) showed by 37 per cent more strength and stability than did the southern chernozems during all the cultural treatment. And that is the quality that solves the problem in the given case. All the above said warns us not to commit the error of determining the soil structure by stating only the presence of some aggregates, but to discern their quality, adding to the methods of sieving and «bathing» samples, that of determining the presence of the factors on which structure depends.

The principles concerning the formation of structure, as well as of its factors, have been discussed above.

Dojarenko, and after him his disciples (Kvasnikov and others), have taken the correlation of the capillary and non-capillary porosity of soil as a criterium of its structure. The formation of aggregates, a decrease in the pulverescence of soil, means also a decrease in the capillary porosity and an increase in that non-capillary.

Thus, we have a determination not of structure itself, but of moments that present functions of structure. This method makes it possible to prove, for inst nce, that in podzol soils the correlation between the two types of porosity gets improved under the influence of manure or of a better tillage.

Kvasnikov's following experiment serves as an illustration of the dependence of porosity on structure. A sample of podzol soil was taken and divided upon sieves, according to structural fractions; the porosity was determined of the whole, as well as of separate fractions. Results were such:

Diameter of particles in mm.	General porosity	Capillary porosity	Non-capillary porosity
0.0—2.0	49.7	44.0	5.7
1.0—2.0	59.0	30.3	28.7
0.5—1.0	57.5	33.5	24.0
< 0.5	49.1	48.3	0.8

The following figures were obtained by Kvasnikov for an «ordinary» loamy chernozem from the field of the Samara Agricultural Institute.

Diameter of particles in mm.	Capillary porosity	Non-capillary porosity
2.0—3.0	36.5	25.2
1.0—2.0	39.3	22.2
0.5—1.0	39.2	25.3
< 0.25	51.7	3.5
0.0—3.0	50.4	5.2

It strikes us in both of the samples — podzol and chernozem, that with a different general porosity of those soils not only the «unstructural» (better to say — the microstructural) fractions of the soil have the least, both general and non-capillary, porosity (important from the author's point of view), but also the soil in its whole, for its pores between the larger particles are partly choked with smaller ones.

It is interesting to note the difference between the porosity of both soils: not only the whole of the soil (its sample), but likewise the separate structural fractions of the chernozem have all a much higher porosity than the same fractions of the podzol. This geometrical paradox (as the porosity depends on the diameter of the particles) is explained by the difference of the properties of chernozem and of podzol: chernozem is strong, stable, tenacious, while podzol is friable, easy to be destroyed, and disperses in water when being tested.

Dojarenko has proved that different methods of tillage and manuring extremely alter porosity, as being one of the soil cultural constants.

Fallow	Porosity	
	General (in per cent of the soil volume)	Non-capillary (in per cent of total porosity)
Late	43.8	18.0
Early	53.8	47.0
Manured	48.6	29.9
Non manured	45.8	18.4
Permanent fallow	41.7	11.7
Flax field in rotation without grass	40.6	12.7
Same in rotation with grass	51.2	38.4

Tretiakov has, likewise, made use of the soil porosity, and of the correlation between its different forms, for the characteristics of the changes in the soil's physical state at the Saratov Experiment Station.

We have Mrs. A. L. Maslova's experiments for the soils of the Kharkov Experiment Station (the southern subvariety of the thick chernozem). It is interesting to note that alterations in the porosity of soil depending on tillage, both in the dark chestnut soil of Saratov and in the Kharkov chernozem, were very insignificant, or there were none at all, as it happened at the Kharkov Station where neither the rolling of the fallow, nor the loosening of it, changed the porosity of the soil — the black soil. Contrary to the great influence of manure on podzol soils, changing very markedly their porosity, its effect on chernozems from that point of view is scarcely to be remarked.

The degree of porosity of the three soils — the podzol at the Timiriazev Agricultural Academy in Moscow, and those at the Saratov and at the Kharkov Stations — is very different; thus, for the podzols (early fallow), it is 53.8 per cent; for the dark chestnut soil, 52—57 per cent; for the chernozem, 74—88 per cent.

Though those data may excite doubt, because of the method of estimation applied at the investigations (in the investigations of the Saratov Station the obtained figures are almost the same for such different soils as to their properties, as the southern chernozem, the dark chestnut soil and the alkali soil) — the corresponding porosities are: 58, 53, 54 per cent. They show a substantial difference between the three soil types.

It is of interest to note that in Mrs. Maslova's investigations, even the rolling of the fallow did not diminish (but on the contrary, increased) the porosity of soil in the fallow.

This confirms at any rate the extreme tenacity of the structural aggregates of the chernozem, especially so in comparison to other soil types: the chernozem structural aggregates, as already mentioned, cannot get poorer from ordinary methods of tillage. On the contrary, artificial clods formed on the podzol through tillage can be easily destroyed even by harrowing.

Hence, W. R. Williams' aphorism on the harrow as being «a barbarian implement»; hence, the name given by people to podzols, as «sinking down soils».

As proved by Bouyoucos' accurate investigations, soils really possess «elementary» structural aggregates, the stability of which allows them to be, no less than are the mechanical elements, a characteristic factorinfluencing the physical properties of soil.

The filtering capacity of soil, when investigated during a certain period of time, permits not only to state the influence of the mechanical composition upon its permeability, but likewise to precise the quality of structure, i. e. the relative tenacity, and stability of the structural aggregates.

We find in Williams' «Pedology» (1902) an apparatus for this purpose, by means of which Williams has discovered the basis for emphasizing the extreme difference between the stability of clods on virgin soils and meadows — on the one hand, and of those upon long cultivated lands — on the other: 7 — 14 — 20 days are necessary for washing off aggregates from virgin soils, while 15—30 minutes are sufficient for clods upon cultivated lands.

Barakov had found out in the course of his investigations, that the relative water-tight capacity in the Bogodukhov chernozem, depending on the soil treatment, changes thus, if the filtering capacity of a soil under winter crop=1, under spring crop=17, under bare fallow=23, virgin soil=32, layland=61.

Kuzmin supplies data as to the permeability of the samples of several «structural» soils of the South-East (see p. 61).

Thus, the structural elements of different soils of the Trans-Volga region possess a different stability, and the hardest of them (if in a dry state) most readily slacken under the influence of water.

Horizons	Water filtered for 2 hours, in cm.				
	Southern chern.	Dark chestnut	Chestnut	Alkaline brown	Columnar alkali soil of the chernoz. zone
A	620	490	210	330	160
B	1,795	1,370	1030	390	90
B	1,260	840	—	—	185
C	575	—	—	—	—

To the above said we add a scheme of the curves of water filtration through the samples of a chernozem, according to the data of investigations on the soil structure carried out at the Ukrainian Institute for Soil Research.

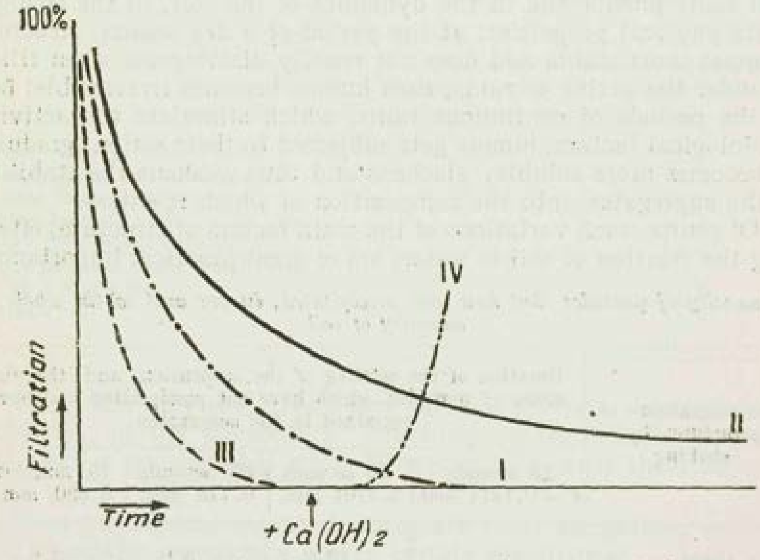

Fig. 1. Influence on the filtrating power of chernozem soil: I curve—natural sample; II curve—dried at 50° C; III curve—detrived of absorbed Ca; IV curve—same, but after adding lime solution.

Investigations on the same chernozem variety (the Kharkov Experimental Station), carried out by Miss Vernander, demonstrated both the part of the individual factors in the soil forming process, and the way in which the increase of the stability of structure occurs. The results of these investigations show in how far the permeability of chernozem varies under the influence of some chemical and physical factors, which were spoken of above when we were examining the factors of structure.

After the absorbed Ca (connected with colloids) has been removed from soil, permeability rapidly decreases, the curve of filtration abruptly drops and finally filtration ceases altogether; then Ca proves to be the main factor of structure. But in a chernozem where some Ca has remained, the structure is rather unstable and disintegrates rather quickly; yet, if we dry the particles — the structural aggregates — the aspect rapidly changes: first filtration drops, obviously, owing to the decomposition of larger aggregates and to the larger pores being choked with finer aggregates; then the filtration curve becomes horizontal, and a further disintegration of aggregates ceases. The «drying» proves to be a factor of the stability of structure.

The essential part of this phenomenon has been explained above in the section treating of the factors of structure. It is evident, that the described investigations have enabled us to explain as well some phenomena in the dynamics of the soil, in the changes of its physical properties: at the period of a dry season, structure becomes most stable and does not readily disintegrate when tilled or under the action of rains; then humus becomes irreversible; but at the periods of continuous rains, which stimulate the activity of biological factors, humus gets subjected to their action, gradually becomes more soluble, slackens and thus weakens the stability of the aggregates, into the composition of which it enters.

Of course, such variations of the main factors of structure, effecting the relation of soil to water, are of great practical importance.

Quantity of particles that have not precipitated, in per cent to the whole quantity of soil

Disintegration of structure: by shaking	Duration of the settling of the suspension and the diameter of particles, which have not precipitated and have remained in the suspension			
	10 seconds $d = 0.1914$ mm.	30 seconds 0.1101 mm.	60 seconds 0.778 mm.	15 minutes 0.020 mm.
6 times	25	12.0	8.0	3.0
12 »	25	12.5	9.0	3.1
18 »	26	13.8	9.4	3.4
24 »	26	14.0	10.0	3.4
30 »	26	14.0	11.0	3.5
Complete disintegration of structure (10,000 rotations per minute)	88.5	86.3	84.8	83.6

Finally, passing to the dispersity of soil, as a method of studying its structural state, it is most expedient to begin with the experiments of the American scientist Bouyoucos, who intended to find out whether there really exist some primary structural elements in the soil — elementary «structure».

According to Bouyoucos, the structural fragments may be made artificially under the influence of humidity, pressure, etc., but such fragments are not stable and readily disintegrate; it is quite different in case of natural structural (microstructural) particles: they are rather stable, do not disintegrate under ordinary conditions, and much strength is needed to destroy them.

Here follow some figures, supplied by Bouyoucos' investigations.

Different soils show different stability of the elementary structural aggregates; namely, there remained in the suspension, after it had been allowed to stand for 15 minutes:

Soils	Particles with $d = 0.0201$ mm. in per cent	
	After the shaking up	After complete dispersion
Fine sandy soil from Fresno	5.6	11.1
Sandy loam from Portsmouth	3.0	8.4
Loam from Hagestown	2.3	48.5
Silty loam from Michigan	14.0	17.4
Clay from Saskatchewan	4.5	58.0
Clay-product of the weathering of a limestone	3.3	83.0
Alkali soil	7.5	18.5

Thus, one may say, that every soil has its own «coefficient of stability», of the elementary structural aggregates. As we have just seen, a considerable effort is needed to destroy them completely.

Does mechanical action disintegrate them altogether, or they may, perhaps, regenerate under certain conditions?

It is to be remembered that 50 years ago Kostychev gave an affirmative answer to this question, based on his observations on nature (see above). Now Bouyoucos' investigations present us such figures, as once more support the former prognosis of Kostychev.

Bouyoucos repeatedly (twice or thrice) moistened and dried a soil, in which elementary structure (microstructure) had been altogether mechanically disintegrated. Results were as follows:

Particles	The percentage of particles with a diameter = =0.0201 mm. that had remained in the suspension		
	After a simple shaking up	After a mechanical dispersion (10,000 rotations per minute)	After a mechanical dispersing the samples were twice moistened and dried
Clay from a limestone	3.3	83.0	5.5
Clay from Saskatchewan	4.5	58.0	22.0
Loam from Hagerstone	2.3	48.5	17.5
Loam from Michigan	14.0	17.4	8.9
Colloids separated from the Saskatchewan clay	—	100.0	3.5

Thus, microstructure can regenerate under the action of physical factors (desiccation).

Therefore, as we stated in due place, it is not the visible structure of soils (macrostructure) that is to be taken as the main feature of the physical properties of cultural soils, but more minute aggregates (microstructure), which appear in soil when the factors of structure are present, and from which macrostructure may develop under certain conditions. These factors being insufficient, macrostructure by itself is of little value, as we have proved it when examining the investigations of V. V. Kvasnikov.

Macrostructure can be disintegrated by means of some mechanical operations while the soil is being tilled, but it is impossible to destroy microstructure under ordinary conditions of the treatment. It may be destroyed by quite different means — by means of the action of chemical and biological factors: those fertilizers, which contain sodium, potassium and ammonium, remove calcium —this protector of structure — out of soil, and thus produce the destruction of the microstructure. To discern microstructure, the rate of which is, of course, as variable as that of the mechanical elements of soil, the best is to apply the same method of sedimentation, as that used for the mechanical analysis of soils: having diluted a sample of soil in water we then let it subside, and observe, in case of a structureless soil (sand and silty soils, for instance) the gradual subsidence of elementary mechanical particles, according to their size, while in the case of a structural soil, where all the particles are gathered into aggregates, these aggregates will subside in the same order, that is — according to their size.

The presence of fragments — aggregates of various size in soil may be discerned by this same method, and alterations in the microstructural state of the soil—may be followed as well. Thus, Germanov and Taranovsky discovered the influence of clover, grown on the soil of the Nossovka Experimental Station, for in a case, when the residue of clover fallow was taken from the bottom of a cylinder, where the sedimentation of a sample diluted in water had taken place, more aggregates were found to have subsided, than in the case of the May fallow. Thus, the growing clover favoured in some measure the formation of microstructure.

The same method was used by various investigators to compare the properties of different soils, as well as alterations in them according to seasons. Modifications in the microstructure in the course of time were observed for the chernozems of the Kharkov Experimental Station by Egorov and, later on, in our laboratory by Konakov. The former suggested to designate the quantity percentage of those particles of a soil which do not subside for 24 hours, as «the coefficient of dispersity» (others call it «the rate of dispersity»). It was found out that the degree of dispersity varies, depending on temperature, moisture, biological activity in soil. The highest activity is to be observed in autumn and in spring, when an increased moisture and sufficient temperature favour the development of biological processes, which result in the decomposition of the organic cement of structural aggregates: besides, in these seasons calcium is washed out somewhat deeper, thus lessening the degree of saturation of the soil.

The latter drops to the lowest degree in the driest part of summer, when humus becomes most insoluble, and the aggregates cemented together by it — the most stable.

Then follow changes in the quantity of the active «Schlamm» in the layland of the Kharkov Experimental Station (Konakov's observations) from the beginning of March, 1927, till December, 1927; 19.76—22.26—24.40 (May), 18.44 (July), 27.72 (the end of August), and so on.

According to the observations of Kharchikov, the sandy chernozem of the Besentchouk Experimental Station changed its dispersity during the vegetative season (layer 0—25 cm.) as follows:

Date of observations	Humidity of soils		Percentage of particles that did not precipitate					
			for 1 day		for 7 days		for 21 day	
	0—25 cm.	25—50 cm.	0—25 cm.	25—50 cm.	0—25 cm.	25—50 cm.	0—25 cm.	25—50 cm.
23/V	20.96	18.0	2.6	0.069	0.545	0.067	0.147	0.122
22/VI	16.99	17.09	1.47	0.065	0.183	0.048	0 092	0.054
22/VII	14.81	17.0	1.00	0.144	0.182	0.061	0.082	0.057
22/VIII	18.68	16.21	3.29	2.379	1.114	0.091	0.084	0.065
23/IX	25.95	18.64	6.57	2.496	2.379	0.074	0.055	0.066

In a columnar alkali soil dispersity was higher for the same periods, namely (in the layer 0—25 cm.): 9.712—4.848—2.255; 4.163—2.072—1.323; 4.991—1.741—1.627; 10.857—7.52—4.83; 14.36—3.55—6.64.

Thus, we may join Kostychev in his statement that not only structure in its whole, but even some degree of the structure development of the same soil is something inconstant, and ceaselessly changing under the influence of alterations in the factors of structure, such as absorbed calcium (connected with colloids — humus and clay) and humus with its peculiar properties; increased saturation of colloids with calcium and the increase, due to drying of that part of humus which becomes insoluble and does not slacken even after it has lost its calcium, — all this makes the structure more stable; on the contrary, in seasons, when due to the washing out of a part of calcium the aggregates di integrate, and sufficient humidity and temperature favour the converting into one more dispersed, more «soluble» form, of that part of humus which not only did not depend upon exchangeable calcium, but itself bound the mineral mechanical elements of the soil, in such periods structure disintegrates and vanishes, which is manifested by many features, observed both in laboratory and in field experiments—the latter being of a special interest to us.

Other methods for the determination of the soil dispersion afford us data, varying according to different soils in a very characteristic way.

Here are some data, extracted from the work of Kharchikov concerning the dispersity (average for a season) of three types of soil: chernozem, alkali soil and carbonatic saline soil.

Fractions		Rate of dispersity	Relative values
1st Fraction	Chernozem	2.830	100
	Alkali soil	8.814	311.4
	Carb.-sal. soil	0.123	4.3
2nd Fraction	Chernozem	0.881	100
	Alkali soil	4.943	520
	Carb.-sal. soil	0.070	7.9
3-rd Fraction	Chernozem	0.292	100
	Alkali soil	3.332	1141.0
	Carb.-sal. soil	0.101	27.7

Here the dependence of dispersity upon natural properties, upon the type of soil is manifested very clearly, which could not be otherwise, as the factors of structure are not equally expressed in different soils.

Different methods of tilling, of manuring and so on — everything that changes the correlation of the factors of structure, invariably entails some changes of microstructure, which are displayed at the study of the rate of dispersity.

The influence of tilling, that is of loosening the soil, always expresses itself by the increase of soil dispersity.

This was demcnstrated in a pure form by Denisievsky, who observed the influence of the ramming and of the loosening of soil upon its dispersity in a podzolised soil (three years fallow).

Rate of dispersity

On plots	Manured		Unmanured	
	absolute	relative	absolute	relative
Rammed	0.364	214	0.172	100
Loosened	0.417	242	0.348	202

Thus, the loosening, while increasing the rate of microbiological processes, also results in a decrease of structureness (microstructureness) of the soil, which expresses itself by the increase of finer aggregates in the suspension of soil, — a result of the disintegration of larger aggregates.

As to the influence of stable manure, it was observed on the podsolized loam of the Kiev Experimental Station that at times it increased, at others—decreased the dispersity (Denisivsky), while on a degraded chernozem (Egorov) its effect was always the same, its tendency being towards the decrease of the dispersity of soils; truly, no decisive conclusion is to be made, for the two experiments were performed in periods of different length: the former, from 26/IV to 4/X; the latter, from 12/VIII to 30/XI.

The influence of stable manure on dispersity and structure is a very complex phenomenon: on the one hand, it increases dispersity by means of adding some new colloids, fresh and, therefore, highly dispersed, to the store of those already present in soil; besides, acting as a protective colloid, it increases the dispersity of mineral colloids too; it yields some ammoniac to the process of decomposition, thus furthering the decrease of the rate of saturation of soil with calcium (Gedroiz) and, consequently, the destruction of structural aggregates.

On the other hand, stable manure behaves like a factor of structure formation and thus, like one of the decrease of dispersion, as it brings fresh humus which, impregnating the clods of soil, binds them together under the influence of calcium present in the soil (provided it be sufficient), as well as in another way — by changing its own properties, its own dispersity (when it becomes insoluble) when drying up (colloids «growing old»). Besides this immediate influence, stable manure is of some importance, as a source of soluble salts and CO_2, which coagulate the colloids, thus preventing them from being peptised.

Thus, it is obvious that the effect of stable manure must vary in the course of the year, now towards increase, now towards decrease of dispersity.

And yet the principal effect of manure, noticed by Kostychev, Williams and Dojarenko, as a rule, is most important: stable manure improves the qualities of the soil, its structure, decreasing dispersity just at the critical period in the life of a plant — in summer; according to Egorov and Denisivsky, the dispersity of manured plots in summer presented 71—80 per cent of those unmanured.

According to the data of G. J. Pavlov, even in gray soils of the Turkestan, stable manure decreases likewise dispersity, while increasing the quantity of coarser aggregates in the structural composition of soil.

Interesting data were obtained by V. P. Tretiakov as to the influence of cultivation upon the state of dispersity in dark chestnut soils (average values for a vegetative period).

Cultivation	Percentage of particles which did not precipitate			
	for 1 day		for 21 day	
	0—20 cm.	20—40 cm.	0—20 cm.	20—40 cm.
Permanent fallow	1.19	2.75	0.22	0.42
Autumn tillage	0.91	2.95	0.16	0.38
Spring tillage	0.88	3.06	0.16	0.29
Spring wheat	0.97	2.46	0.18	0.31
Natural layland	0.46	0.98	0.04	0.13

Thus, the immediate estimation of structure («structure deficiency», according to Kuzmin), as well as the determination of the rate of dispersity, show well enough the influence of different methods of cultivation of the dark chestnut soil upon the peculiarities of its microstructure.

With regard to chernozem we have important data concerning its dynamics, obtained by A. L. Maslova who demonstrated that under the influence of intensive cultivation the dispersity of the chernozem considerably increases.

For this experiment (10/VI, 1926) several samples were taken out, both from early and permanent fallow, to determine the rate of dispersity. The results of the determination were as follows:

Relative quantity of particles, which had not subsided for 21 day (< 0.22 micron)

	April-fallow		Permanent fallow	
	0—18 cm.	18—36 cm.	0—18 cm.	18—36 cm.
Rate of dispersity	100	0	210	525
Absorbing capacity accord. to Gedroiz (regarding Ca)	0.842	0.812	0.704	0.780
Exchangeable Ca	0.655	0.684	0.589	0.659

Thus, owing to the investigations of A. L. Maslova, we now not only see what changes microstructure may undergo, when chernozem is left under fallow for 12 years only, but we also find direct explanations to the causes of these changes: on a plot under permanent fallow, under the influence of increased moistening the colloidal complex («absorbing complex»), which serves as a cement for the microstructure and the structure of soil (humus included)—drops, as well as there diminishes both the absolute and relative quantity of absorbed calcium, which is another important factor of structure.

For the grey soils of the Turkestan, the changes in the structural properties of soils under the action of certain physical factors and in connection with the methods of cultivation, were demonstrated by G. J. Pavlov on the Ak-Kavak Irrigational Experimental Station. When studying the microstructure of soil by the method of an «aggregate analysis», suggested by himself, Pavlov obtained the following very interesting data. First, taking samples of soils for analysis: I — in an air-dry state, II — dried at the temperature of 60°—80° C, III — saturated with capillary water, IV — sample, which had been soaked in water for 24 hours, he observed the following changes in the «aggregate composition» of soil.

Percentage of aggregates

	Diameter in mm.			
	> 3	0.25—3	> 0.1	< 0.25
Sample I	—	11.46	43.63	88.54
Sample II	—	45.68	75.98	54.32
Sample III	32.49	25.06	73.37	42.45
Sample IV	—	11.23	31.33	88.77

Not only the well known action of moistening and drying upon the microstructure of the soil was displayed at that test, but a new moment was detected, particularly actual for the practice of irrigation: one, which Pavlov was lucky enough to find out — that was a strong positive action of a preliminary capillary moistening upon the stability of structural aggregates in water. This phenomenon, as yet unknown, adds one more feature to our knowledge of the factors of the structure dynamics. Pavlov, by applying this method of his own, happened to find out the influence of some plants upon microstructure: it was observed that clover and alfalfa greatly improved not only the micro-, but also the macrostructure of soil: this improvement has been still better manifested, after a peculiar layland had been left along the irrigation channel.

The following figures, taken from his data, may serve as an illustration:

Cultivated plants	Aggregates > 0.25 mm.
3 years' clover	34.69%
3 years' cotton plant	8.92%
One year clover after 2 years' cotton plant	22.79%
One year cotton plant after 2 years' clover	17.47%

Comparing the data of an «aggregate» analysis with those of one mechanical, one may understand the great influence plants exert upon the macrostructure of these, generally structureless, soils in the case of irrigation (comp. Williams).

	Diameter of aggregates in mm.				
	1—3	0.25—1	0.05—0.25	0.01—0.05	<0.01
Cultivated plant, alfalfa					
Mechanical composition	0.37	0.67	2.07	48.30	48.59
Aggregate composition	10.27	20.07	5.63	13.74	2.29
Irrigated layland					
Mechanical composition	0.70	3.02	6.98	45.50	43.80
Aggregate composition	67.98	11.08	15.53	4.41	1.00

Now we have come to comprehend that tilling and manuring highly affect the microstructural state of soil. One more moment is to be studied — it is that of the influence of plants upon the rate of dispersity of soil. This question becomes of special interest, owing to the discrepancies that arose about the problem of the grass-rotation system. Some assert that perennial grasses secure good crop-yield, by improving the structural conditions of soil; others deny any influence whatever of these grasses upon the agricultural properties of soil. Putting aside for the present the part the properties of the soil itself (of its genetic type) play in this case (we have already found out that, when studying the structureness of soils by different methods, we always remarked considerable variations of the structure, according also to the type of the soil), we will dwell upon the action of plants upon the dispersity of soil.

The examination of the data, unfortunately not numerous as yet, which are supplied by Egorov's, Kharchikov's and Denisievsky's investigations, shows that though the dispersity of soil changes, if one plant is substituted by another [1] (as it was, for instance, in the observations of Kharchikov), yet, it is but a matter of average values — for it happens that during the season the curves of the variations of dispersity under different plants do not run parallelly at all; we see the same in Egorov's observations, according to which, while in summer the amplitude of the changes of dispersity under different crops is very wide, in September the differences become in some measure smoothed and, as Denisievsky rightly states, the succession, which the plots under different grasses exhibit at certain moments, may soon reverse. Similarly in Egorov's observations different crops sometimes increase dispersity, in comparison with the fallow plot, at other times, on the contrary, they decrease it.

Thus, if one may speak of a certain improvement of the microstructure of soil after some grasses have been cultivated (for instance, clover at Nossovka), yet there is no sufficient reason to consider perennial grasses to be an absolute factor of improvement of the micro- and even macro-structure of soil: a different action of the same grass is to be observed. Obviously, the influence of perennial grasses upon the structure and microstructure of a soil is not to be spoken of in such a categorical form — it does not so much depend upon the plant, as upon the type of soil where this plant is cultivated, as well as upon the methods of cultivation applied, under the influence of which the conditions of moisture, decomposition and weathering grow now better, now worse, and which either favour the formation of better physical properties of plowed land, imparting to it what is called the «good

[1] As to the connection between dispersity and a cultivated plant, Kharchikov gives such a succession: *Bromus inermis* — 0.321; *Festuca* — 0.421; alfalfa — 0.515; *Triticum cristatum* — 0.623; natural layland — 0.851. According to B. A. Kabanov's data, alfalfa improves the structural properties of the soil of the Annenkovo Experimental Station (faintly degraded chernozem) on the third year, but his own data suggest that, perhaps, the action of vetch, and even that of maize, are not inferior.

tilth» («Bodengare») of the soil, on or the contrary, contribute to the deterioration of these properties.

It seems, now, that we have already sufficient data, enabling us to solve the question as to the influence exerted upon the structure of the soil by a layland, as a form of «recreation» of the soil, according to a former conception.

Examining the above data, we see that, according to different criterions of soil structure, we sometimes come across the best features of structure in a layland, and at other times, we find just the reverse.

On a closer investigation we realize, that a favourable action of layland upon structure is to be found only there, where all is well with the factors of structure: on normal, and in some measure, on degraded chernozems. As to the chestnut soils, there are considerable discrepancies between the statements of different authors and between the results of different methods: Kuzmin found out that the influence of laylands was favourable for chestnut soils, and similar to the influence they exert on chernozems (as to the values of structural deficiency); whereas, according to Kharchikov, a natural layland presents a worse structure (increased dispersity) than a soil under cultivated grasses. As to salinized brown soils, the influence of a layland upon their structure is quite insignificant, according to Kuzmin's statement.

Thus, a good influence of layland upon the formation of structure is to be expected in that zone in those soil types, where it was first found by Kostychev — in normal chernozems; but as soon as other soilforming processes begin to affect it — such as those podzoline or alkaline (see further), parallelly to the deterioration of the factors of soil structure (the decrease of the cement, especially of that organic — humus; the dropping of saturation with calcium, due to the loss, the washing out of a part of it) — the natural structure of the soil deteriorates, and the improvement of the structure on an artificial layland becomes less probable.[1]

A g r i c u l t u r a l v a l u e o f s t r u c t u r e. Now let us examine the part that structure plays among the factors of a crop-yield. Concerning this question some disagreements are to be noted between the representatives of different parts of our territory: while northern agronomy highly appreciates soil structure, as an important factor of soil fertility (Williams, Dojarenko), southern agronomists, on the contrary, mostly presume that structure is of no consequence for this purpose. This difference of opinions was noticed at some congresses, for instance, at the Moscow

[1] Compare — T u m i n, On the structure of soils. «Selskoje Khosjajstvo i Lessovodstvo», 1909, 9; S o k o l o v s k y, S a v v i n o v and F r a n c e s s o n, Trudy naukovo-doslidnoi katedry gruntoznavstva, «Transactions of the Scientifical Institute for Soil Research», v. I, 1930.

Agronomical Conference in 1920; it found its expression in published articles of our most eminent agronomists; lately it has been particularly emphasized in connection with the problem of the field grass-rotation, which W. R. Williams has recently put forward in so impressive a form. Being one of the elements of the physical state of soil, the problem of soil structure is, at the present moment, at the same stage that we had already remarked in the history of the agricultural science, when many agronomists, impressed by the perspectives developed through the theory and practice of German agriculture and by the propaganda of mineral fertilizers, began to neglect the physical properties of soil. Now, in their struggle for a good crop-yield when, together with the mechanisation of farming, mineral fertilizers have taken the first place as a decisive factor of success, when, likewise, we see in Western Europe the renewal of attempts for securing a high crop-yield by means of agrochemical methods, only now, I should say, there is likewise a tendency to neglect the physical properties of soil in our country, when planning the methods of increasing crop-yields, adopting the chemification of our agriculture, independently from the whole complex of natural, social, economical and agrotechnical conditions.

We must remember that such a point of view as to the physical properties, as well as to the whole complex of factors of fertility, not included in the short list of elements necessary for the life of a plant, was once dearly paid for by the German and partly by our Northern farming. As a result of the triumph of a chemical line of approach to the problem of fertility, it happened that agronomy itself became, to a certain extent, a part of chemistry, as Russell justly remarks, and all the attention of the agronomists was concentrated on the question of a mineral nutrition of soil and plant. They lie, first of all, in that fundamental change of opinion as to the methods and ways by which the process of synthesis is produced, concerning the new organic matter in plants; they lie, likewise, in the great achievements that the progress of the chemical science brings about, both in theoretical and in applied chemistry, as well as in the obviously striking results which gives manuring; and lastly, inasmuch as chemical products are generally considered to be products of large-scale industry, the chemisation of life in all its branches is also an object of interest for powerful capitalistic groups.

On the other hand, everything is not quite right, as yet, with the physics of soil. It is true that, according to the above mentioned Russell's scheme, the period, when the whole interest of the scientific agr nomy was concentrated exclusively around the question of plant nutrition, is now finished, since it has been discovered that, however important the nutrition of the plant by itself might be, it is no more a mechanical process; at the same time the investigations of agrochemical problems have notably widened the field of their interests, having embraced, likewise, the study of the plant itself in all its complexness, and the study of the whole surrounding medium in which the life of the plant takes place and on which it depends.

Then numerous investigations began — mostly in the United States — on the mechanical, physical, and physico-chemical properties of soil, to which a particular importance was attributed at the study of the soil covering of the United States.

Nevertheless, the study of the soil physics did not make any considerable progress — it mostly presented preliminary or methodological investigations. Physicists were not at all interested in agronomy, while agronomists displayed very little interest in physics, as quotes prof. Mikhelson. Thus, there is nothing astonishing in that the problem of the soil physics stands very low: «it reminds us of how the question stood in 1830» (Russell). But a plant under natural conditions and the crops, as a result of the interaction of the plant and the soil under normal climatic conditions, do not only depend upon physics of the atmosphere, but, likewise, on the soil physics, and still more — the people that cultivate land have always to do with the soil physics we have spoken about.

We have to note that farmers, who have had much practice, pay attention to the physical properties of soil, giving them different names (light and heavy soils, those «thin» or «dense», etc.); agricultural engineers are also interested in them as the question of constructing implements for soil cultivation and traction engines necessary during tillage, depends, first of all, on the physical properties of soil; on these depend as well the results of land cultivation.

Thus, it would be expedient to see what opinions prevail among the representatives of foreign and Soviet agronomists, as to the rôle of the physical factors and, particularly, that of soil structure.

Let us examine works of the American soilscientists, prof. Hilgard and prof. Lyon. The former, in his classical book on soils, says: «While it is true, that plants cannot form their substance or develop healthy growth in the absence or scarcity of the chemical ingredients they are in need of, it is also true that they cannot use these unless the physical conditions of normal vegetation are first secured. Both these conditions are equally important and require to be fulfilled. Hence, however important be the natural richness of a soil for plant-nutrition, *the first care should always be given to the ascertainment of proper physical conditions in soil, subsoil and substrata*». (p. 319).

Without this, all methods of tillage, manuring or irrigation very often fail to secure good results (p. 319). Lyon, when offering his formula of soil fertility, includes in it, as one of the factors, soil structure too (p. 327).

E. Mitscherlich supposes that «soils deprived of structure are generally of a very small value for our cultivated plants».

E. J. Russell writes in his famous book: «The components of soil do not form a mere casual mixture: their particles are closely intermixed, which amounts almost to a loose physical combination».

«The most suitable structure for plant growth is the crumbled structure, and numerous devices have been empirically worked out by practical agriculturists and horticulturists for converting other structures into this form» (p. 243).

In another place he writes: «The fine friable soil texture, known as good tilth, is the best suitable for plants; it is associated with good water- and air-supply and easy growth for roots. A sticky lumpy condition is unfit for vegetation in all the above mentioned relations» (p. 468).

One remarks upon a cultivated land a close connection between the first stages of plant growth and the drawbar pull needed for plowing, all the same whether you determine the character of growth by the quantity of plants having lived through the winter, or by the number of tillers in early spring [1].

We find, likewise, a few lines about the rôle of structure in another skilfully written small volume by the same author, in which he speaks about the connection between the level of fertility, i.e. the soil productivity, and the system of farming. The author suggests that the fertility of every soil fluctuated now and again between two limits, the highest being the power of a virgin soil recently broken, that of a soil that had always been covered with natural vegetation, and the lowest is that, which is contained in soil constantly plowed: in the latter case fertility remains almost unchanged during a long period of cultivation, when, being at a low limit of fertility, the soil has no more tendency of diminishing crop-yield; it is the natural, inherent fertility of a soil.

The farmer in his work approaches either one or the other level. What does this highest fertility of a virgin soil depend upon? The difference between the higher and lower level of fertility is not wholly a question of percentages of nitrogen, of carbon, etc. The soil possesses at its highest level a good physical texture owing to the adhesion of clay and the disposition of particles: it can be readily got into fine tilth needed for a seed bed: «yet, when it has run down, the texture becomes very unsatisfactory». (Russell, «The fertility of soil», 1913). Of course the fertility of a soil (when speaking about the effective fertility) does not only depend on the natural properties of soil, but no less on the social influences

[1] Similar observations were made by S. M. Bogdanov in Kiev in 1890.

exerted on it, for «the fertility of soil, though being its objective property, nevertheless economically implies a certain development of agricultural chemistry and mechanics, and alters too, when these are changed» (Marx, Capital, Vol. III, p. 2). And further: «the fertility of soil is generally not so natural a property of soil, as it might seem; it is closely connected with the present social relations» (Marx).

Russell writes in his manual for students that «The first object of cultivation is to bring the soil into good «tilth», i.e. to make it assume the nice crumbled constitution, which long experience has shown to be best suited for the growth of plants. The important fact here is that clay may be of two kinds: of a sticky and of a crumbled constitution, and its prevailing feature is that it confers these properties to soil. Consequently, the soil itself forms either a good granular structure or becomes sometimes adhesive after rain, or, when dry, gets very hard, turns into big, hard clods». Ramann thus characterizes granular («Krümel») structure: «a sufficiently developed granular structure of a soil is the most important physical condition for the normal development of a plant». «The spread of roots sideways and downwards in soil always proceeds in connection with the granular structure of soil».

Such references as these could be endlessly quoted; but it might have been useless, for we find the same opinion everywhere expressed, as we may remark, almost identically.

Let us refer now to what our scientists have written about structure, let us try to demonstrate their different opinions concerning this question and analyse, in so far as it is possible, the reasons of some discrepancies we have already spoken about.

Doubtless, the first place should be alloted to the late Prof. P. A. Kostychev. After his observations of the Kharkov and Voronezh steppes, Kostychev stated, that the best crops are to be got on recently plowed virgin soils and laylands. Comparing the chemical and physical properties of an old and new arable land, he had come to the conclusion that the only cause for such a phenomenon was the good structure, formed in consequence of a long period of a virgin or layland condition of soil; the structural fragments get strong, and the soil does not get soaked after a rainfall; no dust is formed during the soil treatment. Such a structural soil guarantees entirely the microbiological processes of the soil, particularly as to the nitrate formation in it. But after 3-4 years have elapsed, the structure gradually gets worse, and at the same time «a decrease of the crops proceeds parallelly to the change in the structure of the virgin soil, and stops when there are no more changes in structure».

Another author of the same epoch, P. Chefranov, suggests that 5 or 10 good crops are to be got first on a virgin soil, after which they begin to fail: at the beginning the crops yield from 15 to 20 times as much as was sown, yet, when approaching the state of old corn fields, the late virgin soil yields no more than the latter do, i.e. only from 8 to 12. The reason of this phenomenon is, according to Kostychev, in that «the character of a plowed virgin soil wholly answers to the ideal requirements for a mechanical soil treatment to bring good results».

As may be seen, Kostychev's diagnosis corresponds to what the English agronomists came to under quite different soil and climate conditions.

«The best for soil is», writes Kostychev in another place, «to have a fine granular structure». Then water does not stop at the surface, but passes deeper, penetrates into the ground to a greater depth. The drying up of soil, in that case, proceeds slowly, so that plants do not suffer from drought for a long period; at the same time «in fine-granular soils there is always a sufficient air-supply for the roots to breathe and for seeds to germinate, there are no voids between them, so that grains and roots are contiguous».

«The recently plowed chernozem (virgin soils) possess such a structure, which to a certain degree explains their fertility».

W. R. Williams, as sharing Kostychev's opinions, gave them an extremely brilliant and persuasive form. As a pedologist-biologist, who attributes a great value to the life processes taking place in soil, Williams puts the question about the soil structure, the fine-granular structure, about which Kostychev had spoken before him, and makes it the central figure of the whole study of the rational use of soil.

Williams supposes that «the fundamental problems of tillage consist in the formation and preservation during the whole vegetation period of a granular soil structure, securing thereby the restoration of the stability and strength of the structure, as it is possible in a structural soil only to properly provide plants with food and water- and air-supply: it is but in a structural soil that no ant gonism exists between air and water, and one finds only in a structural soil conditions for a simultaneous existence of the aerobic and anaerobic processes. Soil may not be used expediently if we take each of the latter apart, but proceeding together they give all conditions for a normal plant nutrition, and, at the same time, preserve the soil from unnecessary non-productive losses of nutrients. It is only upon structural soils that farming can be protected from violent excesses of weather; an accidental success is but possible upon non-structural soils and good crops occur there only as a result of casual conditions — frequent, but not heavy rains».

We find the following in another article by the same author: «the capacity of soil to get and preserve a granular structure, its stability, is in practice its most important property, which warants the stability of the crops and their independence from casualties; only a stable (as to its structure) soil can be in good tilth».

Notwithstanding the statements of some people, the structure of soil even under irrigation plays an important part: without it the soil would not be able to store water, and, besides, salines occur inevitably upon such an unstructural soil, and it gets deteriorated.

A. G. Dojarenko has given an extensive experimental material concerning the study of the part played by structure; he speaks about the decisive rôle of soil structure, on which depends «the water and air conditions and, likewise, the nutritive regime of soil». This occurs because of the soil's porosity, better to say — its type of porosity, its division per capillary and non-capillary porosity being dependent on soil structure. A certain correlation between those two types is necessary, in order that all those processes should take place normally in soil. On this depends, likewise, the movement of water in soil and the loss of it through evaporation: the more non-capillary is the porosity, the less—the height of the water level, and the less — the evaporation of water from soil. The correlation of the types of porosity depends on the structural condition of soil, and on the size of the particles of which it consists, as we see from the following data:

	Size of particles in mm.				
	< 0.5	0.5—1.0	1—2	2—3	3—5
Non-capillary porosity — in per cent of the general porosity	8	49	54	59	63
Capillary rise of water in mm.	117.5	20	9	6	2.5
Evaporation in mm. of water per day	1.58	1.26	1.15	0.96	0.6
Air in soil in per cent per 1 kg. of soil	2.7	24.5	29.6	35.1	38 7
Nitrates in mg.	9	19	—	34	46

This shows that «the starting point for the influence of tillage upon the total factors of the life of plant and soil is the structure of the soil itself, the formation and preservation of which presents the main problem of tillage».

In V. V. Kvasnikov's investigations we see an attempt to determine the dependence of cereals (millet and spring wheat) from the structural condition of soil. A test had been run with a normal chernozem of the Experimental Field of the Agricultural Institute of Samara (17 years' layland); soil was passed through sieves so as to divide it into different fractions, according to the size of the structural particles; part of the experiments was carried out in a glass-house, and part of them — under field conditions (in pots without bottom, dug into the ground on a level with it). The best result was obtained, when plants had to deal with clods from 1 to 3 mm. in diam. Every pulverizing lowered the yield, sometimes quite catastrophically. Thus, in 1926 during an experiment, the crops were such in different structures (crops taken on 2—3 mm. clods to 100 per cent):

Plants	Structure of soil in mm.	Total yield	Grain yield
Millet	1.0—2.0	99.0	93.7
	2.0—3.0	100.0	100.0
	< 0.5	48.0	25.5
Wheat	1.0—2.0	100.0	100.0
	2.0—3.0	93.7	95.2
	0.5	33.3	23.6

It is characteristic, that even the introduction of complete manure into the vegetative pots did not decrease the difference between the different degrees of structure: at the same time millet and wheat have given the highest yield at 1—3 mm. structure (100 per cent), while an unsieved soil, which had not been divided into fractions used to give 74—79 per cent.

Tests of A. L. Maslova, who compared the influence of permanent fallow on the Kharkov chernozem, present an analogous picture. We have already seen some results of these experiments: during 12 years of uninterrupted fallow the physical properties of the chernozem, mainly its structure (microstructure) and the saturation of the colloidal part with Ca had changed markedly. As to the physical properties, especially the quantity of water soluble nitrates and P_2O_5, the difference between an April and a permanent fallow on the II/VIII 1925 was not great in a layer 1 m. thick (in kg.):

	N of nitrates	Mg. P_2O_5 per 1 kg. of soil
Permanent fallow	38.4	1.64
April fallow	41.6	1.35

Permanent fallow has shown a much more pronounced acid reaction of soil in the layers 18—36 cm. and 36—72 cm., pH, 5.9 and 5.8 against 6.2 and 8.0 on the April fallow land.

On the contrary, the yield of millet, during the pot-culture experiment on soils from both fallow plots, has given a rather unexpected picture, as we may see from the table presented by A. L. Maslova:

The yield of millet in g. per pot (the average of both)

Manure	Layland		April fallow		Permanent fallow	
	Total	Grain	Total	Grain	Total	Grain
O	13.9	7.2	9.9	5.3	5.9	2.6
PKN	28.5	13.5	25.4	11.9	13.8	6.3
PK	19.2	9.2	12.6	5.5	6.2	2.8
NK	26.1	12.6	16.7	8.8	18.1	9.0
		21.8			8.4	3.6
PN	30.2	14.6	23.1	10.5	14.8	6.7

The difference between the three series of pots will be still more striking, if we express it in per cent, supposing the crops of the layland soil to be 100 per cent: (12 years' fallow):

	Total	Grain
Layland	100	100
	205	188
April fallow	71	74
	183	165
Permanent fallow	42	36
	100	90

We obtain the same picture when comparing the crops on soils of permanent fallow plots, and on those with permanent sugar beet cultivation. It is of some interest that during the first 3 years of experiments, a 3 years' fall w gave at the pot-culture experiment a greater yield than the soil from other plots; consequently, the fallow does not influence the soil so much at present, as it did at the beginning.

Here we meet with a paradox: we have the picture of an exhausted soil (of course, one conventional in as much as the test has not been carried out in field) just there, where there had not been any plants, wherefrom no nutrients had been taken away by crops, more over, where it seems the best conditions had been created, that is, conditions for the best possible transformation of the reserves contained by soil into an assimilable form for plants.

That this is so, that there had been a sufficient quantity both of nitrates and of phosphates in both fallows, that the reason does not lie in the lack of P and N — is to be seen from their above values. Thus, the question here is not in nutrients.

Evidently, if we want t give back to a soil, which had been under fallow for a long time, its previous fertility, it would not be of so great a necessity to return the matter it had been deprived of (for nothing important had been taken from it); one can but speak of losses produced by the washing out of some fractions into deeper layers, but, nevertheless, not being too deep and accessible for roots — and of a partial loss of the N, owing to denitrification [1], — one should not care so much about nutrients as about other factors needed for the life of a plant. It is true that even complete manuring could not make the «exhausted» soil overtake the unmanured soil of the layland.

Evidently, we have to join the author in his standpoint that «the decrease of soil fertility on a permanent fallow may be explained by the fact that chernozem under permanent fallow undergoes very great changes, which consist, mainly, in the deterioration of its physico-chemical properties, in the destruction of its absorbing complex, in connection with the lowering in the soil of a permanent fallow of the exchangeable Ca content. Anyhow, the deterioration of the structure (and in the first place of the microstructure), as a result of the breaking of the equilibrium of its factors (the decomposition of humus and the washing out of Ca), brings about with it such changes in the general conditions of the life of a plant, that they cannot be improved any more even by complete manuring; it produces the deterioration of the water- and air-properties of soil, a change in its reaction, and at the same time the change of the trend of microbiological processes that take place in the soil; at the same time, it modifies the properties of the products of the chemico-biological processes — and may form some substances having a toxic influence on plants. It is to be regretted, that this conception has not led to further conclusions and to attempts of improving the conditions of a permanent fallow by means of improving its structure, its properties and its reaction.

The influence of the changes of the physical (structural) soil properties upon the growth of plants can be proved otherwise than by means of such practically unreal instances as permanent fallow.

The experiments of the Poltava Experimental Station demonstrate that the same results are obtained, though, naturally, in a somewhat smaller degree, in the case of an ordinary fallow cultivation. It becomes obvious when comparing the crops on the bare and May-fallow. The fact is that, during the first 8 years of the work of the Poltava Experimental Station, the crops grown on the autumn bare fallow were richer, and the next 8 years — poorer than those on the May-fallow. The average yield of wheat-winter crops on both kinds of fallow during the period of 1886-1893 was 119 and 103 puds, during that of 1893-1901 the corresponding data were 106 and 112 puds per hectare. Yields of

[1] That this occurs even when good aeration is secured, is certified by the Rothamsted data (82).

winter rye were for the same period 142, and 124 for the first period, while for the second one we have a quite different relation between yields: on the black (autumn) fallow 114, and on the May one—121 puds. The author, who summarizes the results of the above experiments comes to the following general conclusions: we may consider, as the principal cause of these crops, the reduction and the deterioration of the physical properties of soil in the sense of a higher degree of pulverization and a more readily puddling of the arable layer, which produced a harmful effect on the moisture conditions and the life of soil generally, as well as on the development of plants. This opinion is corroborated by the data of the analysis of soil structure on the above fallow areas.

As to the West Siberian farming, which now undergoes the same critical period of transition from the layland system to that of crop-rotation, which was to be observed in the Voronezh and Kharkov gov. at Kostychev's time, the question of structure presents there also a great interest. In this region, as well as in other countries of conservative farming, not only during the period of the last century but for the last decades too, a considerable decrease of crop-yields was to be observed. According to the data presented by E. V. Bobko, the yield in the Jenissey gov. has thus changed:

Years	Winter crops	Spring crops	For West Siberia		
	Yielded more than was sown		Periods	Winter rye	Spring wheat
1870	by 10-12 times	by 12-20 times	—	—	—
1870-1880	» 6.0 »	» 4.1 »	1905—1914	48 puds	50 puds[1]
1901-1910	» 4.7 »	» 3.4 »	1914—1924	41 puds	40 puds

Vakar, who characterizes the crisis of the layland farming, points out to the sharp decrease of crops in the steppes and forest steppes of the Omsk region. At the beginning of the XX-th century spring wheat yielded 50—60 puds; whereas before the war, only 30 puds. These lands present those very Siberian chernozems, which, according to Dokuchaev, are very soon exhausted. The main cause of this lies in the bad physical qualities of the West Siberian soil, the lack of stability, of structure and a too easy pulverizing during tillage; the latter is due to the influence of salinization.

[1] 1 pud per desjatina =14.5 kg. pro hectare.

The chernozem soils which, in connection with alkalinity, have to some extent lost the absorbed Ca, change their structure and their physical character according to the degree of the losses.

Some soilscientists undertake the estimation of soils in accordance with their structure — as a good feature of physical properties. K. P. Gorshenin, for instance, in his description of soils of the Kalachinsky region, Omsk district, has placed, first in turn, the «granular» chernozem «its value being explained by its rich favourable physical qualities (as result of a granular structure) and the conditions of its location». The cloddy chernozem is less valuable.

Thus, we can clearly see the connection between the general physico-chemical conditions of soilformation, the presence of structural factors and the agricultural qualities of soil as being a function of structure [1].

An interesting characteristic of alkaline soils has also been given by Gorshenin. He classifies them as being the least valuable. «It must be said that the salinized chernozem soils can be generally characterized as being inconstant in their yields: during years of more or less abundant atmospheric precipitations, the alkaline soils are equal to, or even excel, the friable chernozems as to their yield; but under conditions of drought they are not to be trusted». It must be noted that salinization does not mean physiological salinity, as the upper layers of those soils do not contain a great concentration of soluble salts; this concentration is often no greater here, than in chernozems. In this case the point in question is the «physical» salinization, to use the expression of B. A. Keller. This physical alkalinity may be explained as follows: the soil during its life and under the influence of the salts of Na, chiefly in the form of sodium chloride, was gradually deprived of its Ca, and having accordingly lost its structure-protector, it lost its structure as well.

Deferring the examination of further details of a salinized soil-formation process, we will only note that their existence is, as a rule, connected with salty geological deposits; features of soil

[1] As to the denominations «granular» and «cloddy» structures, the soil morphology discriminates them distinctly enough to be able, on the basis of structure, to come to conclusions concerning further details of the soil properties. For instance, the granular structure is inherent to the soils characterized by their capacity to disintegrate into aggregates 1 - 3 mm. in size without any interference of man. It must be added that the granular structure possesses no definite sides, edges or sharp angles. The aggregates of the granular structure are stable under conditions of humidity and easily disintegrate under dry conditions. Under the influence of cultivation, even the non-structural, silty soils acquire an artificial cloddy structure; the aggregates become more solid, not so crumbled and larger in size than the granular aggregates (as a rule larger than 1—10 cm. in size).

salinization [1] may appear provided there be present in the soil-forming rock or, at any rate, not too deep under the surface, salt enough which, reaching the surface by some means or other, causes the replacing of Na by Ca in the colloidal complex [2]. When the soil in this way becomes deficient in absorbed Ca, and the salts of Na are also washed down, it comes to two moments of a great importance not only as regards the morphology, but also the dynamics of soil: this is the fundamental change of colloids which are no more tightly bound together, get swollen and puddle; structure gets damaged, the microstructural aggregates vanish; the pores between the clods get filled with these colloids. The colloids (organic first and then mineral) free from their coagulator are peptised, become movable, convert into a pseudo-solution, and are washed from the upper layer of soil somewhat deeper in; they stop at a certain rather small depth, blocking all the pores between the structural units and the mechanical elements.

It comes to such a redistribution of colloids and to such a change of their properties, that the aspect of soil is thoroughly altered: the structureless, pulverized top layer (sometimes with a laminar, platy or squamose structure), is followed by a more compact, dense layer not only very solid in a dry state, but very adhesive when moistened. These features, naturally, are not always equally manifest; there may be great changes in their sharpness and intensity within the confines of a small area (even at a distance of a f w steps).

A cover of more or less salinized soils appears as the main ground chiefly in the arid regions of the USSR. These are the so-called chestnut brown soils, gray soils and, mostly, the southern chernozems.

Those are the soils which finally, under the influence of salinization (no matter how the details of the very process be explained) have lost their granular structure (or were in no favourable conditions for its formation).

A characteristic feature of these regions is a great complexity of soils which vary, it may be said, with every step; these variations depend, in a different degree,on their salinization. Kostychev was the first to pay attention to this fact; he suggested that «soils of the South-East were motley, that in these regions you might meet every 5 m. stripes and spots of chernozems 4—6 m. wide, sometimes still narrower, crossed by the same kind of stripes and spots

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[1] These are: loss of granular structure, sometimes laminar structure in horizon A (HE), redistribution of colloids and, as a result, formation of the illuvial horizon B (HI, I, IP) not far from the surface.

[2] These salts are not always derived from sea-water, but often are of a continental origin; their accumulation is to be ascribed to the dry (desert or half-desert) times of the quaternary period (W a l t e r, Gesetz der Wüstenbildung, also S o k o l o v s k y).

of gray soil of different degrees of salinization. This variability of soil is equally manifest, be it a simply plowed but not sown land, a virgin steppe, or a wheat field». The non-plowed chernozems represent the feather-grass steppe and salinized soils — the «gray steppe» grown with wormwood, etc. In respect to wheat crops, these different kinds of soil differ in such a way that one of them secures a powerful growth of crops (more than 1 m. high) and is richly developed in every sense, while on the other kind of soil wheat does not grow higher than 18—27 cm., and its leaves are yellowish, with withered points. These soil spots are markedly delimited. Putting asunder the stalks of the crop, you immediately see that under the rich crop of wheat we have chernozems and, under that, a poor gray salinized soil. The same picture may be seen in the South of Ukraine, especially in the Melitopol region, where the surface of the crop forms a peculiar wavy relief. Here the best crops grow on the less salinized, more typical chernozem soils; the areas of the poor crops are surely those with the most salinized soil.

As to the physical properties of the latter and their fitness for tillage — a very good characteristic of them has been given by Bogdan and, later on, by Ostriakov. The upper layer of this soil is thin, structureless, or has a laminar, platy or squamose structure; the next layer, according to Bogdan, «has extremely unfavourable properties»; it is almost entirely impermeable; besides, the clods of this layer very soon disintegrate, even in cases when the water reaches them from underneath, as for instance, when a clod is put upon a plate containing some water.

The same is to be seen in a field: the lumps of such soils on a plowed field readily disappear after a small rain, the field surface becomes slimy, very compact; after a heavy shower stagnant pools are formed on its surface, as dark as muck pools. No use to struggle against those unfavourable properties of the soil by any other means than plowing. No sooner has the plough raised this compact, impermeable and very hard layer, than it is formed again at the same depth, because the finest particles, the colloids of the soil, are very soon washed down to the subplowed layer. According to Ostriakov, this may occur as a result of rain, as well as of irrigation.

An interesting comparative characteristic of the south-western soils, as to their fertility, has been given by the collaborators of the Saratov Experimental Station V. P. Tretiakov and M. S. Kuzmin cite some data concerning the yield on the three types of soil of the station: the southern chernozems, the dark-brown soil and the columnar alkaline soil.

The average yield of the Poltava wheat on the following soils was:

Soil	Yield (quintals per ha.)	
	average	maximum
Southern chernozem	15.6	26.8
Dark-brown soil	8.6	23.8
Alkaline soil	6.4	15.4

The main point of interest is that the pot-culture experiments showed the same succession; having calculated the data of the pot culture experiments per hectare, Tretiakov obtained the following results (average data per hectare for 4 horizons — A, B_1, B_2, C): the chernozem, 37.5; the dark-brown soil, 20.8; alkaline soil, 23.5.

The soil from the top layer (A) gave for the same soils a range which most closely coincided with the results on the field, that is: 59, 45, 34 quintals per hectare. Thus, even under artificial conditions of a pot-culture experiment, when the best moisture conditions were secured, the first place had to be given to chernozems, just as well as in the field.

Some interesting data as to the fertility of the main soil types of the Volga region have been given by Kuzmin.

Average yields for a several years period (quintals per hectare).

Soils	Winter rye	Spring wheat	Oats	Sun flower	Millet	Alfalfa
Ordinary chernozem (Balashev Experimental Station)	15.7	7.0	13.9	11.8	18.6	23.4
Southern chernozem (Saratov Experimental Station)	19.1	13.6	8.7	9.3	17.7	45.7
Chestnut soil (Krasnokutsk Experimental Station)	13.0	7.8	11.1	8.0	9.0	21.6
Salinized brown soil without irrigation (Kostychev Experimental Station)	12.3	4.0	—	—	—	—
Same, but on irrigated soils	21.3	16.3	22.9	—	—	106.0

How might such a sharp difference between these kinds of soil be explained? At first sight, one would presume a different supply with nutrients. But the author's data do not confirm this surmise in the least. Even alkaline soils with regard to the humus content (5.0 and 6.6%), P_2O_5 (0.195 and 0.243), N (0.285 and 0.451) are not much poorer than the chernozems. But the dynamics of nutrients show even more clearly the riches of the alkali soil; it possesses almost the same quantity of soluble P_2O_5 as the chernozems (10.8 mg. per 1 kg, against 13.0 in the chernozems). As to the NO_3, its production in the alkali soil is much greater, than that in the chernozems (182 mg. in the alkali soil, against 40.9 in the chernozems). The same may be said in respect to the other nutrients. The principal distinction between the above soils consists in their physical properties. This fact is also manifested by means of comparing the quantity of nutrients in the main types of soils, the productivity of which is discussed by Kuzmin.

All of them are rich enough in all kinds of nutrients. According to Kuzmin, the difference in the productivity of various soils may be explained by their physical properties. Their physical character, as it was formerly proved (Gedroiz, Sokolovsky), depends on the kind of the exchangeable cations and, first of all, on the rate of saturation with the absorbed Ca (Sokolovsky). Three different soils of the Saratov Experimental Station give the following successive range as to the quantity of absorbed Ca: southern chernozem (0.471%), dark chestnut soil (0.355 and 0.255%), and alkali soil (0.174%). As seen before, a different quantity of this Ca is followed by a great difference in the physical properties of these soils. It could not be otherwise, inasmuch as we mean the difference in the manifestation of the principal factors of structure in those soils. «The character of the absorbed bases is closely connected with the productivity of these three kinds of soil, independently on their relative abundance in nutrients».

As is to be seen from the above data concerning yield, the difference between the three mentioned soils in field conditions is rather great. Under the same climatic conditions the southern chernozem, i.e. the least salinized soil, as compared with other kinds of soils of the Saratov Station, proves to be much more productive. The dark chestnut and the alkali soils belong to the lower group, there being a great difference between them. In other words—there is a sharp delimitation between the typical chernozems and the slightly salinized and alkali soils (the two latter soils having much in common). The difference between these soils, according to Kuzmin, consists in the different structure of soil profiles and in different properties of horizons which constitute them. The salinization, i.e. the replacing of Ca by Na in soil — these are the causes of this difference.

«The maximal productivity of the southern chernozems under field conditions, as compared with the dark chestnut and alkali soil, results, due to a favourable combination of the physical properties of its horizons, through the whole thickness of the layer containing the roots of the plant». As to the dark chestnut soil — «the factor which makes its fertility lower than that of the southern chernozems — is the compact layer B», which causes «the root system of plants to use a less active sphere for its nutrition».

Tretiakov reports one more fact confirming the special rôle of the physical factors, with regard to the productivity of the soils of the Saratov Experimental Station. It was detected that a sample with an integral natural structure (of a monolith type) proved to be $1^1/_2$ times less productive, than in the case of the pot being filled (as it is generally practised) with the soil mass. These results were obtained in spite of the preservation of the natural chemical properties of soil. This phenomenon was observed on the best soil of the Station.

No wonder that in the pot-culture experiment the difference between the 3 kinds of soils was less noticeable. First of all, the very process of filling the pots destroyed to a certain extent the above-mentioned unfavourable physical properties; further on, the influence of an unfavourable combination of the horizons could be eliminated, and optimal conditions of moisture, air and nutrition created, conditions which, according to Kuzmin, are so closely connected in the field with the peculiar physical properties of each soil.

No wonder that the South-Western region with its highly variable continental climate, and its soils of such unfavourable physical properties very often gives such poor yields, which exert sometimes a catastrophic influence on the whole of the economics of this region.

The climatic factors, the distribution of meteorological elements (especially of precipitations) during the season have, naturally a decisive importance. Nevertheless, we must not forget the above mentioned fact that climate does not only influence plants and yield directly, but also exerts an indirect influence through soil. The latter, owing to its physical properties, sometimes lessens the shock which a plant undergoes, owing to the weather fluctuations, and sometimes, on the contrary, it increases their influence.

Thus, far from underrating the importance of climatic conditions, we cannot agree with the old aphorism, that in these arid regions it is «not earth, but the sky that produces the crop-yield», for, owing to the properties of soil, even under the same meteorological conditions, different soils give different crop-yields.

Unfavourable combinations of natural conditions — those of climate and soil — result in frequent crop-failures, as it is the case with the Volga Region, the part of the Union known to be greatly affected by such a combination. Thus, on the memory of my generation, five great crop-failures took place, which caused considerable damage to the state, and starvation to people, it was in the years: 1891, 1901, 1911, 1920 and 1921. Furthermore, according to R. E. David, in the Volga Region the years of crop-failures, — when the crop-yields were below 20 puds, gave 22 per cent for the Balashov district, 26 per cent for Saratov (southern chernozem), up to 56 per cent for Novoozensk and Chernoyarsk, 61 per cent for Stalingrad (chestnut and red-brown soils) during the period from 1889 till 1915. It means that every fourth year there was a crop-failure for the first group of districts, and for that second — every other year.

But just as the alkali soils of the Kalachinsky district K. P. Gorshenin wrote about, these soils of the Volga Region, salinized to different degre s, bring in good years rather satisfactory crop-yields, sufficient not only for the consumption of the population of the district, but even for export. In more humid years grain crops occupy all free spaces, which are fit for tilling, while in the case of a drought, only negative elements of the relief (depressions) are cultivated, such as «pods» (small depressions), ravines and valleys, where not only the conditions of moistening, but the soils are better too.

V. P. Bushinsky thus characterizes the causes of the crop-failures in the region in question: «If in the northern governments of the vast region, affected by crop-failure, the peculiar distribution of meteorological factors (moisture and temperature) is to be considered as the main cause of crop-failure, in most of the southern and south-eastern governments local properties of soils are to be added to this phenomenon, quite natural for them too». These peculiarities consist, in his opinion, in that the soils have lost the structure proper to chernozems; in that the amount of humus and the thickness of the humous horizons are somewhat decreased, and in that a compact horizon (sometimes one thin) is formed throughout the soils. It is the regions of the South-East of th RSFSR adjoining the arid region, that already possess such features as distinguish them from typical chernozems; the first of these features is the unstability of their structure, which very rapidly vanishes under the influence of grain farming. Hence — an extreme unstability of crop yields: good crops in humid years, which abruptly drop in drought.

Such is the fate of crop-yields all over the vast chernozem area of Western Siberia (its salinized chernozems), and throughout Kazakstan.

In the South of Ukraine a broad strip of soils spreads, of which the same properties and the same fluctuations of their fertility are characteristic.

Thus, in other sub-arid regions, wherever such soils are to be met with as are spread all over the South-East up to the Altaï, everywhere the physical properties of soils are of great importance.

We see the same in the Far West of the United States, in the Great Plains, where on the vast area of 450 000 sq. miles spread soils of the type of southern chernozems, of chestnut and brown soils. The attempts to find in the confines of modern, rather conservative agriculture some reliable methods of «dry farming», suitable for this arid region, gave no results which had been anticipated. During 20 years a great work had been done at the 23 experiment stations of the Federal Bureau of dry farming. Here are the conclusions drawn out of these experiments, according to the statement of Mr. Chilcott, the manager of this work.

Regardless of the fact that annual precipitation is a vital factor in determining crop-yield, it is seldom, if ever, the predominant factor; but the limitation of crop-yield is most frequently due to the operation of one or several inhibiting factors, other than shortage of rainfall. In fact, during this period of time, crop-yields, smaller than 10 bushels per acre, took place 75 times out of 218; only in 3 cases, out of these 75, precipitations were less than 250 mm. In the rest of the cases bad crops were due to other factors.

Among those «other factors» an outstanding position is, certainly, occupied by the physical properties of soils, which are as unsatisfactory, as they are in our arid and sub-arid regions. The said is supported by the characteristics of soils as being the basis of American agriculture, which had been offered by Mr. Baker at the 1-st International Congress of Soil Science; he stated that after having started on bad soils of the East (podzols) and then having flourished on good dark and black soils of the middle zone of the United States (chernozem group), agriculture must now find its ways for again utilizing the worse — soils of the West. The same is implied by Hilgard concerning the rôle and importance of physical properties of soils, above referred to.

In British Colonies, under conditions of cotton farming, especially so where water, so precious in a dry climate, is to be used, the importance of the physical properties of the soil is so fully recognized, that cotton growing companies assign considerable grants to the Rothamsted Experiment Station for organizing studies of soil physics.

S t r u c t u r e a n d i r r i g a t i o n. However strange it may seem, one happens to hear now and then the opinion that soil structure has no importance whatever in the case of irrigated lands. We have to prove, further on, that it is not true, while now we but remind to the readers that it is not W. R. Williams alone, who attributes so great an importance to soil structure, even under conditions of irrigation, justly considering that it is but on structural soils that a normal water- and air-regime may be secured, and the salinization of irrigated soils be avoided.

At present, people, who carry out practical work under conditions of irrigated farming, also begin to take interest in soil structure, expecting it to be of use not only in that sense, but also because of the struggle with the surface crust, formed owing to irrigations; the struggle with unfavourable alterations in the physical properties of soils, and the struggle for the most rational utilization of water — give no positive results on structureless soils.

One cannot but agree with Pavlov's opinion, that the study of the dynamics of soil acquires a particular importance under conditions of irrigated farming, in connection with the peculiarities of soil moistening, for under these conditions a series of physico-mechanical phenomena in soil get manifest on a far wider scale than without irrigation. Besides, «from an agricultural point of view, all the said physico-mechanical phenomena in the whole have a completely negative value», as far as the tendency of the arable layer to puddle and become compact brings to nought all the work that had been applied to their treatment, and reduces the soil to its former state, to that in which it had been before methods of cultivation began being applied.

The truth of the above said is illustrated by many instances of the value of lands in arid countries having dropped owing to irrigation. One should think that, where soils are rich (and the soils of arid countries are rather rich, according to Hilgard, — far richer than those of countries with a humid climate), but rains are scanty, the crop-yield is nothing but a question of irrigation: water supplied at the right moment will enable one to utilize the nutrients which the soil contains; hence, when watersupply is secured, crop-yield is secured too.

However, the history of irrigation in countries, where it had been practised for a long time, shows this theory to be wrong. Thus, before the war in Egypt the public opinion was alarmed, for during 11 years (1895-1906) yields of the cotton plant on irrigated soils decreased by 25 per cent; the Government Commission, appointed for the purpose of finding some means against this calamity, did not succeed; yet now, as I have already mentioned, the Cotton-Growing-Corporation has paid special attention to the physical properties of the soil. It is but natural, for the methods of tilling soil have an actual importance under conditions of irrigation— more even, than without irrigation.

The United States present another instance where, according to Hilgard, very good results are to be observed for several years after irrigation; yet on the eighth year, crop-yields very often drop so low that lands are to be abandoned altogether.

In so far as the cultivation of such irrigated lands is organized with the assistance of banks, guaranteed by the State, it is obvious that the latter has to suffer enormous damage.

There are many other authorities concerning problems of irrigated farming, whose statements throw light upon the importance of physical properties of soils and their structural peculiarities, closely connected with the said properties. Thus, N. M. Studenov states that in the Turkestan virgin soils completely change after some years of cultivation. Natural structure disappears, the soil becomes hard, compact, subsides soon after having been tilled, forms after irrigation a strong crust, which no means are effective enough to remove; when discussing the different value of different soils for growing cotton, and speaking of the large stores of nutrients in clayey soils, he, however, observes that, anyhow, heavy soils are not suitable for it. «The heavier is loam, the less favourable are its physical properties for the cultivation of agricultural plants, especially in so far as artificial irrigation is concerned» (spacing mine. A. S.). This is due «to the solid crust, that appears after rains or irrigation, or very hard tillage». If plowed in a humid state, this soil becomes «a mass, as hard as a stone», after it has dried. If the soil is plowed in a dry state, it gives large, hard lumps. It has to be replowed several times, sometimes as many as eight; this is just what we see in Egypt, where the clay loam is to be replowed 4 times.

Owing to this, the heavy hoe (the so-called «ketmen»), 5—10 pounds in weight, is required, as the only means for managing this soil, which operation considerably enhances the cost of tilling. And, yet, it has to be tilled in such a way «that the surface should remain, as long as possible, in a dry and loosened state, for, when it is moistened and then dries up, as is the case with irrigation», the formation of a crust is not to be avoided. But it is obvious that the keeping up of the soil in such a loosened state is possible only under the condition that the particles, into which the soil falls when tilled, are not destroyed, nor puddled; that is, only when the soil possesses good natural structural properties, when the plowed layer during plowing readily breaks into structural grains, and when these grains are sufficienty stable and do not slacken under the action of water when irrigated, nor get transformed into a crust, as it happens to those artificial fragments, into which the hard, dry lumps of structureless soil may be broken by out of the way means (special heavy rolls, etc.).

The same characteristics of the physical properties of soils under cotton plants is given by V. E. Serapikhsky who asserts that these soils are structureless, adhesive, sticky when in a humid state, extremely hard when dry, during treatment turn into a pulverized dusty mass (which is quite natural, for it is the only result to be obtained by crushing hard lumps with heavy implements). «These are the soils, which slacken and puddle in a humid state, but when dry, are hard and compact». When the soil is irrigated, «water spoils physical properties still worse, owing to the soil becoming compact and sinking». Perhaps, the given examples suffice; I want but to bring to mind the observations made by Bogdan and Ostriakov on the brown and chestnut soils of the Trans-Volga region, which are very much like those of the southern and south-eastern soils that have to be irrigated with water from the Dnieper and the Volga. Here also extremely unfavourable physical properties of the soil draw our attention, properties which make tilling hard and difficult, entail considerable waste of water due to surface drying (the crust): all this heavily affects the plant, for it always experiences a deficit in water; the seeds, when germinating, suffer from lack of air and the seedlings force their way through the crust with difficulty; the crust, when cracking, cuts the delicate stalks as with a knife; water, so precious in these regions, is to be greatly wasted without economy. The same was stated by A. D. Murinov. Bogdan observes that under irrigation on the same plots of the Valuyky Experimental Station the crop-yields varied according to soils regardless of irrigation — they were worse on the alkali and salinized soils than on the chernozems.

According to A. M. Mozheyko, the following means for struggling with the crust, formed after irrigation, are observed in the local practice of the irrigation of kitchen-gardens on salinized soils: either some stable manure is diluted (suspended) in water used for irrigation, or some additional quantity of water is used to soak the dry crust. The latter method being very primitive, it only gives some illusion of a favourable result for a short time, but then it entails waste of water and at the same time increases the danger of raising the level of the ground-water.

The great importance of improving the soil structure even of irrigated soils is quite clear. Mozheyko, when investigating the soil moisture at Chongar (between Ukraine and the Crimea), found that the permeability of the strong salinized soil under its natural conditions was very small here, only 15—20 cm.; and after the structure and physical properties of the soil had been improved by means of gypsum, water penetrated down to 70 cm.

The cited examples are more than sufficient, it seems, to prove that for irrigated farming the problem of the formation and keeping up of good structure and physical properties, closely connected with it, acquires special importance. Moreover, all the above said is sufficient to draw great attention not only to the problem of «the melioration of irrigated lands», which is so fully summarized by B. A. Shumakov in his detailed report, but also to the perspective of the proper exploitation by means of irrigation of those immense spaces in the South and South-East of the Union of SSR, which are to be supplied with water from the Dnieper and the Volga.

Besides, these examples are sufficient to show how erroneous are the opinions of some of our agronomists who confine the whole of the problem of reclamation of alkali soils and salinized soils to watersupply; this theory is a wrong one: water will be of no avail, for the main defects of the soils not only will remain, but, owing to irrigation, will grow worse to such an extent that some new «melioration» of these quasi-meliorated lands will be required: we say «quasi-meliorated», because a mere wetting alone does not improve in any measure (and rather deteriorates) the general conditions of the life of plants on such soils (the water- and air-regime and the processes connected with it), as has just been shown on examples from the classical countries of irrigation. Here, like in every structureless soil, the water- and air-regime will vary between two opposite poles — from complete dryness to complete anaerobiosis.

To control these processes, in order to create more favourable conditions, is a hopeless task, for in structureless soils water and air are antagonists: they force each other out.

Thus, when expedient melioration of such soils is carried out, everything must be considered; the productivity of enormous expenses must be secured, which are involved by the construction of an irrigation system. It is not sufficient formally to remove the defect of the climate — which is the want of water; it is necessary, by means of chemical and mechanical measures, to eliminate the defects of the soil itself, of its structure, which have their share in the bad agricultural properties of the soil. Of course, if we examine from this point of view the list of our soils, it will be found out, in many cases, that the improvement of their agricultural properties, especially as to the defects of water- and air-regime, will involve pure «agricultural melioration». This question has been raised by V. P. Bushinsky for the soils of the arid South-East. And in spots where it has been acknowledged that crop-yields must be given more water, than the meteorological factors can secure, there such an «agricultural melioration» is a premise for the efficiency both of hydrotechnical melioration and of the successful exploitation of meliorated soils.

Unfortunately, little attention has been paid as yet by specialists in melioration to those problems, for the carrying out of which a strong basis has been created by the work of the Soviet pedologists.

Thus, considering the broad perspectives of enlarging the irrigated farming in arid regions of the USSR, which must protect these regions against drought, just for a successful solution of the problem of mastering the natural factors of fertility by means of irrigation, it is necessary that the struggle for a good soil structure, for good physical properties, which is closely connected with the former, — the struggle for the use of all other agrotechnical methods (and, first of all, manuring and new methods of tilling), be put as the basis of that complex of measures, which will enable us, without underrating the importance of irrigation, to bring about that every m³. of water spent on the field should give the greatest effect possible.

Now something is, yet, to be said about the soils of the podzol zone, about the importance which present physical properties, physical moments, for their utilization.

As to the importance of the physical properties of soil, and of soil structure in particular, much has been said by Doyarenko. Some descriptions of the soils of the podzol zone give vivid characteristics of their physical properties. The podzoline soils (loams) of the Vladimir government are described in such expressions: they are slimy and sticky in a wet state, in a dry one they are hard, form lumps (clods), are generally bad for tilling, being powdery, but not «fluffy», they are impossible to be plowed both in dry seasons and under wet conditions.

The improvement of the structure and physical properties of our northern podzoline soils is rather a difficult problem, because the content of clay and humus is very scarce. Nevertheless, liming, together with organic manure, will secure good conditions in these soils.

L a m i n a r s t r u c t u r e. The morphology of soils knows other forms of structure than that granular which is characterized by a rather rounded shape. Unfortunately, the classification of structural elements is mostly based upon purely formal features, without being coordinated with the factor which produced the structure.

It may be said that the dropping of the rate of saturation of soil with Ca results in forming a compact, structureless mass, as the simplest experiments can show. The increase of the quantity of colloids without a parallel increase of the quantity of absorbed Ca imparts to the soil the capacity of falling into pea-like, prismatic and other very compact structural figures after drying. That is due to nothing else; but the lack in saturation with Ca is to be demonstrated by adding some lime, which immediately transforms the heavy, compact and adhesive soil into a crumbled state.

Very interesting is the behaviour of the stratified, platy schistose and laminar structure, which is characteristic of podzoline (clayey), salinized and alkali types of soils, and which begins to display itself as an outcome of the process of degradation and salinization. As well known, in podzolized chernozems, according to D. G. Vilensky, or, according to the old terminology — in degraded chernozems, and in gray forest soils, on a plowed field an obvious tendency to split into horizontal plates may be observed in every soil lump. In podzols and in the podzoline h rizon of clayey podzoline soils we find a fine laminar structure. The same structure is also to be found in alkali soils, in «solody» and in salinized chernozems.

Concerning the causes of the formation of such structure, many hypotheses have been made which, in my opinion, have not fully explained the matter, for they chiefly pay attention to outward facts, without considering the quality of the material itself of which the soil had been formed — I mean the shape and the properties of the finest soil components.

Thus, during the investigations in the Chernigov region, the opinion was uttered that the horizontal structure stands in connection with a mechanical action, — the trampling of the ground by grazing cattle (W. W. Gemmerling).

A. I. Nabokikh maintains that the formation of platy-laminar structure in podzolised horizons is connected with the increase of the quantity of fine particles of silica; the process of the washing out lends some help by removing the excess of cementing substances from the soil mass. K. K. Gedroiz considers the origin of a platy structure to be rather obscure. Here, perhaps, the influence of pressure is displayed upon a soil, poor in colloidal substances, but rich in silty particles. Thus, under the action of moistening and drying and, perhaps, of frost, the schistous structure is formed. Neustruev sees the cause of the schistous structure in a sort of successive subsiding of fine particles into a horizon saturated with water. A. P. Treitz (following Sigmond) explains the formation of the laminar structure in alkali soils by the presence of «soda, which either diminishes or destroys capillarity in them». Owing to this, the surface of alkali soils dries up and is covered with a laminar crust.

N. A. Kachinsky sees the cause of the platy structure in the fact that water freezes in horizontal layers from above, distributing the particles of the soil accordingly.

It is, however, obvious that none of these factors could have exerted any influence upon the structure of soil, if the latter itself did not contain certain conditions which produced horizontal forms of structure. It is known that even in chernozem, on high roads, distinct platy structure occurs. By analogy with metamorphic rocks — shales and gneisses, — the causes of this phenomenon are to be looked for in the shape of soil particles. Williams, in his work, was the first to intimate that through the microscope some particles of «clay» are seen to have a flat shape. The same was stated by Atterberg. Krynin, when studying the capillary movement of water in clay, observed the influence of the flat shape of clay particles upon the character of this movement.

My own investigations have proved that, if not only the absorbed $Ca^{\cdot\cdot}$ were removed from a sample of chernozem, but also «the active colloidal complex», with which part of that $Ca^{\cdot\cdot}$ was connected, were washed out by means of the «subsiding», if what remains was kneaded, and a low broad cylinder made, then, after drying up, the samp ei when broken would show a distinct laminar structure.

Thus, in the clayey part of the soil we see such particles that have the shape of tablets or scales, but at the same time we see amorphous colloidal particles in which the presence of ultra-microscopic and amicroscopic crystalline components may be recognized only by means of roentgenoscopy. While these colloidal particles are present, laminar or platy structure may be imparted to the soil only by dint of a strong mechanical action (such as, for instance, the rolling up of roads by wheels); under ordinary conditions this phenomenon of «dynamometamorphism» in the soil reaches some notable extent only, when those colloidal components have been removed from it during the soil-forming process, when they no longer disguise flat particles.

Soil structure and physical properties of the soil. Besides having a general influence on crop yield, structure, as well as those special factors of the physical properties of the soil which are connected with it, considerably influences separate moments of the agronomical properties of soil, specially the soil permeability, as it has been demonstrated above, — the soil's capacity of soaking water and preserving it from unnecessary losses. Under conditions of mechanized farming a special importance is to be attributed to the mechanical properties of the soil — its adhesiveness, stickiness, its resistance to all the properties, which are in connection with its consistence (Atterberg).

The structureless clayey soils present the most of difficulties. That occurs from the very beginning of tillage — from the soil's first pl wing; the structureless soil is very hard, the plough does not enter it, the soil remains a long time wet through, which keeps back the beginning of all the field operations; it gets cloddy, as soon as water is evaporated it dries up too. Therefore, tillage is possible only under very restricted conditions of soil moisture, for, when wet, such a soil becomes very sticky («as cart-grease»), and when dry, it is as hard as a stone. Owing to this, the soil s resistance to plowing in fields with structureless salinized soils varies considerably, increasing there, where the grade of salinization is greater. After A. S. Lvov's data, the dynamometrical curves of the drawbar pull of the tractor during tillage, in the South of Ukraine, calculated for 50 meters' sections of the way of the complex of implements, present an extremely uneven line with amplitudes of the drawbar pull from 1000 to 3500 kg. This tells upon the expenditure of benzene and on the wear and tear of the machines.

The investigations of A. de Sigmond have demonstrated several very instructive features, proper to Hungarian alkali soils. It is K. K. Gedroiz, who noted a long time ago that under the influence of the substitution of Ca in absorbing complex with Na, the physical properties of the soil change a great deal. I have succeeded in proving the quantitative changes that take place in the physical properties of soil if, for instance, in a chernozem, in its colloidal complex, we should replace Ca by another cation of a different grade of hydratisation. Then, first of all, the cohesiveness of the soil would excessively change, which we see from the following table:

The resistance (in kg.) of chernozem samples saturated with different cations

Samples prepared according to the method of	Cations						
	$Fe^{\cdot\cdot\cdot}$	$Ca^{\cdot\cdot}$	$Mg^{\cdot\cdot}$	NH_4	$H^{\cdot}$	$Na^{\cdot}$	Natural sample[1]
Lucaschevitsch	3.5	10.9	29.9	70.5	4.6	—	16.0
Atterberg	—	—	—	—	—	156	36.0

Thus, here the part of the absorbed cations comes forward very distinctly as to the soil cohesiveness: those tri- and bi valent, as being good coagulators, imparting good structure to soil, reduce its cohesiveness, increase its mellowness, thus facilitating its tillage; those mono-valent, especially Na, on the contrary, influence the mechanical properties of the soil in a negative way. A good structure is inseparably connected with good mechanical properties of the soil.

The same investigations have also proved the influence of the replaceable cations on the consistency of the soil: the samples which were saturated with Na, could be made into very thin, fine, elastic cords, resembling rubber, well pliable without breaking, but when saturated with Fe they made only thick cords, which used to break as soon as one tried to bend them; the rest of the cations occupy an intermediate position, differing but little one from another, as to their influence on the soil consistency. The greatest structureness in that case coincides with the least grade of «colloidity» (i. e. lyophilness) and the least plasticity of soil.

At the same time the influence of the absorbed cations has been demonstrated on the water movement in soil. Investigations concerning the rate of the capillary movement of water in soil (with a stop-watch at hand) showed a complete agreement with the previous data, which means that the rate of the water rising in a column of soil 3 cm. high for soil samples was:

Saturated with H — 2 min.
» » Fe — 2 »
Natural — 3.5 »
Saturated with Ca — 3.4 »
» » Mg — 4.4 »
» » NH_4 — 10 hours
» » Na — 1 month.

[1] Grade of saturation by $Ca^{\cdot\cdot}$ — about 86% of total capacity.

These columns contain experimental confirmations of the importance of the soil structure for agriculture, but expressed in a different form from that previous.

The water-regime of a soil depends on its structure, for the structureless soils let the water through very badly (I mean the soils of silty-clayey and clayey-mechanical texture): the water of precipitations stops at the surface without passing into the depth and forming pools on the surface. Therefore, on structureless soils, mostly those alkali and salinized, clayey of the South and South-East of the USSR,—the formation of water reserves is unsatisfactory. Thus, after O. M. Mozheyko's observations, the clayey salinized (chestnut) soils of Chongar did not penetrate deeper than to 20 cm., hampering the field operations after irrigation or after rainfalls, but without giving the possibility of properly using water. While on plots manured with gypsum, on the contrary, water penetrated down to 70 cm. deep. We encounter the same in de Sigmond's investigations, carried out under artificial conditions. The «good» (non-alkali) different layers of soil were wetted with water for a certain time (8—54 hours) to a depth of 360 cm., whereas alkaline soils only to 22—55 cm. during the same period of time. Thus, as we see, a whole series of phenomena more or less connected with the agronomical character of soil depends on its structural properties.

This review would be incomplete, if I had paid no attention to some misunderstandings, which now exist about the problem of soil structure. These misunderstandings are partly due to an extremely formal conception of the very idea of soil structure, when every clod of soil is considered to be a structural unit, irrespective to the way they were formed, — whether they are the result of natural processes such as are the properties of the soil (original ones, as well as those created by cultivation), and the corresponding dynamic changes of these properties, which in turn depend upon the seasonal fluctuations of meteorological, physico-chemical and biological moments,—or whether created artificially under the rough action of implements, and having no conditions for lingering, soon disappear, being pulverized by the subsequent tilling, or puddled owing to rains and artificial irrigation.

Some years ago, I suggested the principal theses concerning the factors of structure, its formation and stability, following in the main the way, which had been shown by Schloesing and Kostychev. Of the pedologists-morphologists it was A. A. Krassiuk, who stated that in soils, pulverized by tilling no granular structure had been observed, but a cloddy and lumpy form of structure. A. F. Tiulin classified structural forms into two groups, according to their origin: the first—comprising natural structures, and the second — those artificial; the former being a «genuine structure», and the latter — «false aggregates»; whereas N. J. Savvinov observes that all the difference between them consists in the former being stable, not puddling in water, while the latter does not show any stability.

Another cause of misunderstandings is that the problem of structure is often treated independently of the site, of the soil type, of its agricultural variety, texture, of the properties of the colloidal complex (first of all, as to the rate of saturation with Ca).

This is why we observe such discrepancies in the estimation of the value of structure for agriculture, as, for instance, the high appreciation of it by pedologists and practical agriculturists, and the complete ignoring of it by some of the agrochemists; or, the struggle for structure and good physical properties, closely connected with it, on the part of the agriculturists of the North and of the South, who work on soils, structureless by nature (for they lack the principal factors of structure) — on one hand, and on the other hand, a rather careless and sometimes negative attitude of those, who work on chernozems, where there are all the necessary conditions for the formation of structure and for the regeneration of it in the process of the soil dynamics, even during the same season.

Hence, obviously, attempts arise to prove that soil structure plays no part in agriculture, which we have observed for the last three years; some of them having but a quite formal conception of structure and appreciating it by the size of aggregates only, try to find a contradiction in some definitions of the structural unit, which now is defined as a particle of 3 mm. size, and sometimes as one of 5—10 mm. size; then they note, that such structural particles are not to be found just in the well tilled (often too pulverized by tilling) soils of sugar-beet fields of the large estates of the pre-revolution epoch.

The question has even been put forward of whether structure had ever been found in virgin soils. (M. A. Egorov and his follower — M. E. Pronin).

It is quite clear that conceptions, similar to that mentioned above, take their ground upon the artificial conditions of the work of some of our agrochemists only, but not on natural relations of agriculture.

As to the doubts expressed by some workers of experiment stations, not by agrochemists, concerning the importance structure presents for agriculture — W. N. Mortensen's and N. M. Tulaikov's are to be mentioned among these. Mortensen, when criticizing Williams' suggestion, which propagates the grass-rotation system of grain farming, as being the only method to raise fertility by means of improving the soil structure, — simply repels Williams' assertion as to the structural soils being easier to till; instead of the antithesis — structural and structureless soil, Mortensen proposes his own, namely: a field after rye or potato — on one hand, and sod layland, transpierced and tied up with roots of perennial grasses — on the other; obviously, this substitution is wrong.

In his other work Mortensen expresses the opinion that, under conditions of arid regions, soil often utilizes water unsatisfactorily, badly conserving and inexpediently spending it. The cause of this are the bad properties of soil, which may be improved, in his opinion, by proper methods: «by creating stable structural aggregates, by means of proper mechanical operations». We see here a certain contradiction to the propositions of the former polemical work; but to everyone, who has any notion as to the problem of soil structure, it is evident that it is impossible to create structure by means of mechanical operation only; its formation is the result of the combined action of mechanical, physical and chemical moments, the part of biological factors being indispensable, which give such a precious cement of structure, as humus.

Doubts as to the value of structure under conditions of practical farming were shown by Tulaikov too, who maintained, that under the conditions of the new large-scale socialistic agriculture it was necessary to revise all the complex of agrotechnics, and to disencumber it of everything that was of no practical value.

According to his opinion, the struggle with the crust and the cultivation and harrowing (mellowing of soil) did not present the importance, which was ascribed to them by our experiment stations and by Hillgard in the United States.

Referring to the investigations of Veihmeyer in California, N. M. Tulaikov asserts that physical properties of the upper layer of soil on fallows (provided there be no weeds) do not affect the humidity of soil.

As to the soil structure, Tulaikov displays the same neglect of different (naturally) structural properties of different soil types under different conditions of farming (we have already seen that the denial of the value of structure in irrigated farming finds no ground in the facts and opinions of those, who work at this irrigated farming — such as Pavlov, Studenov, Serapikhsky). Very interesting data of the Saratov Experiment Station mentioned above [1] are sufficient to prove that, when comparing soils with really different structural features, we realize a very great influence of the structure upon a series of properties of the soil (such as humidity, physical properties, biological processes, fertility). Other works, especially those of the reclamation of alkali soils, demonstrate, how very important it is to improve bad physical proper-

[1] Experiments of M. S. Kuzmin, Tretiakov, Kharchikov, and others.

ties of soil, and, first of all, the bad soil structure of alkali soils and of soils of various rates of salinization. Here, besides Mozheyko's works, which had been carried on Chongar according to our plan, A. Z. Lambin's and S. M. Antonov's works are to be recalled to memory, which have demonstrated the enormous influence of the improvement of the structural properties of alkali soils upon the crop-yield, though after liming the reaction of soil happened to become rather high; the maximal crop-yield (in pots) was at pH—8.46. Obviously, the total effect of liming, which improved a series of physical, chemical and biological properties of soil, prevailed over the harmful influence of the reaction.

Negative rôle of the structure in some cases. But it would not be right to speak only about the positive importance of soil structure without mentioning cases, where it may have a negative influence. Obviously, one can point out a series of cases, when this mellowness of soil resulting from its good structure is harmful, when one has to get a compact impermeable mass of soil; this is the case in a series of technical constructions, made of earth (walls, roads, ponds, dams, etc.).

The requirements exhibited here to the earth material are quite opposite to those we had seen in agriculture: soil must let water through, and soak it as little as possible. Thus, the structural capacity which increases permeability, i. e. its soaking capacity (as a result of an increased porosity) — this structure, which is so highly appreciated in agriculture, prevents the realization of a series of technical problems: obviously, the structural mass of soil is not good to make dams, to dig ponds, canals and to build roads.

Therefore, in corresponding cases, the question does not lie in the formation of structure, but in its destruction for the sake of technical problems. Obviously, the knowledge of the soil structure factors permits to do so: it suffices to remove as far as possible the replaceable Ca, on which depends, first of all, the structural coagulation of the colloids contained in soil, and, at the same time, — its structure.

The knowledge of the factors of structure formation gives the possibility not only to better adapt or to use local material (clay), that one has on the spot for accomplishing the work, but to entirely change their character.

For instance, one has learned to dig ponds and water reservoirs in places, where in usual practice this was supposed to be impossible, even in sandy soils. One can make dams out of a sandy material; one can do it in the case, when one has to stop the water permeability of the walls and bottom of a silos or of a channel, by means of coating them with clay, with an insignificant quantity of this material, — a much smaller quantity than usually.

All this might be attained by replacing the Ca, which coagulates the soil colloids and forms the structure, — by a more hydratized cation Na, by means of washing out the soil with a solution of common salt.

A short time after this, the soil loses its capacity of letting water through. This occurs because the soil colloids swell, puddle, peptise and stuff with silt the pores of the soil. Therefore, the chernozem's permeability drops violently, but, strange as it may be, the same occurs to sandy-loamy soils, even to some sands. At the investigation, which I have done in collaboration with Ereshenko after rinsing the sandy soil and sandy loam from the island Khortytza and from Shosternya (Krivorozhie) with a solution of common salt, their filtering power dropped in the first case by 400, and in the last — by 270 times. One may judge, by the data of the mechanical analysis, of what kind of soils these were. The former soil (. soil almost deprived of humus) contained 81.2 per cent particles of a diameter 0.05—1 mm., and of one smaller than 0.01 mm. — only 8.5 per cent. The latter soil, a chernozem sandy soil (loss of ignition 0.57 per cent) possessed particles 0.25—1 mm, 94.6 per cent, and less than 0.01 mm. — only 3.9 per cent. Obviously, there was still less «clay» (particles smaller than 0.001 mm) Even with such a texture those soils became, in practice, quite water-tight, after a quarter of an hour. Evidently, if such changes take place in soils, which scarcely have any colloids (or better to say, have a small quantity of them), then in corresponding cases one should take quite an insignificant quantity of clayey material to obtain results which one gets at present by using uncomparably greater amounts of clay. Obviously, by preparing the soil for a dam, as has been recommended above, it would be possible to improve by much its technical qualities; the same is true for ensilage pits, etc. Those phenomena confirm evidently, that the structure too, like other phenomena in nature, should not be appreciated with an absolute measure; there is nothing in nature absolutely good or absolutely bad: the valuation depends on the point of view and the problems set forth by the needs of man. In case of using a soil for technical (hydrotechnical) constructions, I suppose that the corresponding criterions, suggested by the practice of estimating the fitness or unfitness of such or other earthy material for those constructions, should be revised.

Also, when revising the problem of soil structure as a whole, we can see that it must be considered as being one very many-sided.

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CERTAIN CONSIDERATIONS ON THE GENESIS OF SOIL STRUCTURE AND ON METHODS FOR ITS DETERMINATION

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The problem of soil structure may be treated from different points of view, as, for instance:

1) essence of the phenomenon of soil structure itself,
2) genesis of soil structure,
3) main factors of the structure formation,
4) effect of different influences on structure,
5) its alterations in the course of time,
6) methods for the quantitative and qualitative determination of soil structure,
7) its significance for agriculture — and others.

We intend the present article to be concerned but with two problems of soil structure, namely:

1) The main factors of the structure formation.
2) Methods for the quantitative and qualitative determination of soil structure.

We have to start, however, by precisely explaining what it is that we mean by — «soil structure», and by the soil structure capacity. Each soil may separately contain primary mechanical elements of different size, form and chemical composition. But in sandy soils only, containing neither humus, nor clay, mechanical elements remain for a long time in a separate condition. Clay or humus being present, the primary mechanical elements unite into conglomerates or aggregates. Thus, the soil structure capacity is the capacity of the soil's solid phase to produce aggregates from mechanical elements; whilst aggregates that arise from mechanical elements, are called soil structure. One cannot help seeing the great discrepancy of the term soil structure with its content. So much more correct would it be to speak of the soil aggregative composition, or capacity, of its cloddiness, than of the soil structure; much better turned is that term in German: «Krümelstruktur». Yet, in virtue of succession, we shall continue using the old expression «soil structure» in this article, implying by it those clods, aggregates of which soil consists. Having noted the essential moment in the formation of structure, the junction of mechanical elements into aggregates, we have not mentioned as yet the main point, namely: the cause due to which the process of the formation of aggregates out of separate mechanical elements takes place. At the present time we may consider it to be established, that the formation of aggregates from mechanical elements takes place at the expense of the cementing properties of the finest mechanical or ultra-mechanical soil elements or soil colloids. Not entering into a more detailed discussion of the cementing properties of colloids, we may, thus, determine the soil structure.

We understand soil structure to be the aggregates, that arise in soil out of separate mechanical elements at the expense of the cementing properties of ultra-mechanical elements or colloids of the given soil. The given determination, however, is not yet complete. In truth, there may be in soil, on the one hand, separate mechanical elements, which do not cement by themselves; on the other hand there may exist ultra-mechanical elements or colloids, which, due to their cementing properties, bind mechanical elements into aggregates. We do not see, as yet, the way through which this cementation is effectuated, though knowing it to take place, chiefly at the coagulation of colloids. Hence, a more complete determination of structure will run as follows:

We understand soil structure, to be — the aggregates, differing in size, in form, in mechanical and chemical composition, that have arisen out of mechanical elements at the expense of the cementing properties of ultramechanical elements or soil colloids, in the process of coagulation of the latter.

We have now a clearer picture of those items which enter the notion of structure:

1) mechanical elements,
2) cement or colloids,
3) coagulators or factors of coagulation.

The moments indicated clearly show us, on the one hand, the possibility of a more detailed determination of separate kinds of structure or of aggregates:

1) according to the form and size of mechanical elements, entering those aggregates,
2) according to the nature of the cements,
3) according to the type of coagulation;

on the other hand the given moments should enable us to state more systematically the factors of the structure formation, as well as the methods of a qualitative and quantitative determination of the soil structure.

I do not cite here voluminous lists of literature on problems of the soil structure, which may be found in my former works on soil structure (37). Later on a review of literature has been given by other authors: Ehrenberg (13), Katschinsky (18), Sokolovsky (32), and others.

I proceed now to the principal factors of the structure formation; those of them, recorded in literature, are: coagulation, pressure, influence of vegetation, of worms, of desiccation, of congelation of soils, of methods of tillage, etc. Gedroiz (14), in his article on soil structure, suggests coagulation and pressure to be the main factors of structure formation. This does not disclaim the significance of other factors, only recognising the prevailing importance of the two former. The author of the given article adheres to the standpoint of Gedroiz. We find the same in Demolon and Hénin's interesting work (8). The majority of factors marked in literature, finally come to pressure and coagulation. It stands to reason that mechanical treatment, congelation cannot be limited by coagulation. We have here a reverse process, a break, a decomposition of large aggregates into smaller ones instead of a junction of mechanical elements into aggregates.

Let us examine coagulation in detail, as a factor of structure formation. As it is well known, coagulation of soil colloids may be caused by:

1) a certain concentration of electrolytes (electrolytic coagulation),

2) a certain concentration of oppositely charged sols (intersettling of colloids),

3) desiccation,

4) the introduction of superficially-active or dehydrating substances.

The quality of the coagulate will be different in all these cases. Still more, the quality of the coagulate will be different, even if we take different electrolytes. Thus, coagulation of univalent, bivalent and threevalent cations will give different coagulates in respect to their hydrophile capacity, reversive capacity in an excess of water. Up to now this has been the moment most emphasized. Colloids coagulated by univalent cations are said to be reversibly-coagulated colloids, whilst those coagulated by bivalent cations: magnesium, calcium, and so much the more by threevalent cations: aluminium, iron, are said to be irreversibly-coagulated colloids.

The f i r s t s t r u c t u r e, that of reversibly-coagulated colloids, as one that may get soaked, is considered to be less valuable agronomically, whilst the second, being water-tight is of a special value for agronomics. Yet, in spite of the great importance of the said systematization of soil aggregates, according to the valency of cations, it cannot be considered as being exhaustive. The second and third type, obviously, have not been sufficiently valued up to the present time. A great many investigators are perfectly right to assert that a soil, deprived of exchangeable calcium and saturated with sodium, deteriorates in its physical properties and its structure. It does not prove, however, that those only of the coagels have existed in soil, that had arisen by way of an electrolyte coagulation. The presence in soil of coagels, originating through an inter-settling or even through coagulation with three-valent cations, is not quantitatively manifested at the saturation of soil colloids with sodium. The irreversible capacity of gels, arisen by way of inter-settling after their saturation with sodium, has been noted in Sokolovsky and Lukashevich's works (33). The irreversible capacity of gels, arisen at coagulation by aluminium and also after their saturation with sodium, has been noted by the author of the present article. Due to works of Mattson and of other authors, we are cognizant now of the cause of such phenomena. For instance, colloids get overcharged at a certain concentration of iron or aluminium hydrosols, as well as of aluminium salts. Naturally, positively charged coagels in soil cannot be peptised after a treatment with medium salts of the NaCl type.

Thus, the s e c o n d t y p e o f c o a g u l a t i o n, the inter-settling of colloids, is not separately computed at the valuation of the soil structure — neither qualitatively, nor quantitatively[1]. We find indications in the latest works, on the properties of a structure, occurred as result of the inter-settling of colloids and of the coagulation of colloids negatively charged with three-valent cations. Thus, we are acquainted with works of König, Hasenbäumer (19), Hager (16), Demolon and Hénin (8). Hager values negatively the quality of those of the aggregates, which had arisen by way of an inter-settling of colloids. Demolon and Hénin are reserved in their opinion concerning such aggregates. The author of the given article continues special investigations in that domain. I find it difficult, as yet, to give a qualitative estimation to aggregates, produced by the inter-settling of colloids. But I am getting convinced that we have in certain soils a noticeable quantity of aggregates just owing to the inter-settling of colloids. I have advanced some of my considerations in that domain in the article of Tiulin and Bystrova (39).

The t h i r d t y p e o f c o a g u l a t i o n takes place at dessication. The latter circumstance has been of long date marked in literature.

One may find indications in some of the manuals of soil science (Puchner, for instance) that many colloids, especially those organic, coagulate irreversibly after desiccation and loss of elasticity. I am sorry to say that the causes of the latter phenomenon have not been closer studied as yet. Such a phenomenon would be quite comprehensible for hydrôphobe colloids: they do not pept-

[1] The rôle of hydrates of aluminium and iron in the formation of aggregates had been noted by old authors too: for instance, B. Warington (40), Hilgard (17).

ise in water after dehydration. Organic colloids are lyophile, and the causes of their irreversibility after desiccation require special investigations.

The f o u r t h t y p e o f c o a g u l a t i o n, obtained at the introduction of superficially-active substances into soil suspensions, has not been studied at all.

The author of this article, in collaboration with Z. I. Lehn, has succeeded in showing that the ordinary threshold of coagulation for silty suspensions shifts to this or other side frcm the addition of small quantities of superficially active substances — of the type of butyric acid, valerian acid, isoamyl alcohol, etc. Should we admit that superficially-active substances may be met in products of the decomposition of soil organic matters, coagulation then must be taken into account, depending on the presence of superficially-active substances. It is to be noted that Talmud (35) has shown in his works, that superficially-active substances may cement mechanical elements into solid conglomerates under certain conditions. It is difficult to say, as yet, whether this process takes its course immediately in nature and what might be the practical significance of the said laboratory experiments.

Thus, issuing from different kinds of coagulation we may distinguish the three following groups of aggregates:

1) Aggregates that have arisen at an electrolyte coagulation. We find here reversibly- and irreversibly-coagulated aggregates, dependently on the valency of the cation. In the case of a mixture of cations (which is very usual) aggregates can occupy a different intermediate position, according to reversibility.

2) Aggregates, occurring by way of inter-settling of colloids. Here too the properties of aggregates are very different, depending on the sign of the charge, on the electrokinetic potential and on the chemical nature of soil suspensions that had been coagulated by the hydrosol of iron and aluminium.

3) Aggregates occurring at soil desiccation.

As mentioned above, it is difficult to say anything definite about the fourth type of coagulation.

As may be seen, the rôle of the coagulation of soil colloids, as a factor of structure formation, is much more complex than it is usually expounded in certain articles on structure.

We shall not stop at what must be the character of the coagulate, and consequently of aggregates, depending on the chemical nature of the soil suspension. Very interesting, newest data concerning this problem are cited in Demolon and Hénin's work (8). There deserves to be noted, in connection with coagulation, the shape of the mechanical elements, entering the aggregates.

The quantity and quality of colloids taken as cement being the same, the result of coagulation will probably be different, in the sense of the properties of aggregates, occurring at it, depending on the shape of mechanical elements. The cement of globular, cubical mechanical elements will, probably, be utilized with a lesser effect than that of those tableshaped, laminar, squamose. It is to be pitied that we are ignorant of any tests in that domain.

When speaking of the cementing properties of the soil colloids, we did not touch upon the modern theory of that problem. As well known, the glutinous and cementing properties of soil possess, as yet, no current theory. Duclaus emphasizes that fact in his manual «Colloids» (11). We are acquainted with two theories, concerning the glutinous properties of colloids: that of Stern — «Glutinous properties, as aggregates of primary particles» and that of Visslitsenius — «Theory of agglutination» [see «Kolloid-chemische Technologie», edited by Liesegang (24)].

The first, Stern's theory, may be summed up thus: a colloid, when concentrating as sol on the surface of the agglutinated body, increases its glutinous power together with the rise of the ash viscosity. After this the moment arrives, when the glutinous power decreases at a further rise of viscosity. Thus, there exists a comparatively narrow zône, on both sides of which the glutinous capacity of reversible colloids rapidly falls. The whole of the procéss is reversible for glutinous colloids, according to Stern, and may be expressed by the scheme: sol $\rightleftarrows$ gel. The optimal aggregation of the primary particles of sol into gel makes it possible to colloids to display their greatest glutinous capacity.

Visslitsenius' theory briefly comes up to the following: the glutinous properties of colloids are manifest at desiccation only at a definite interval of dispersion, namely, when being in a colloido-disintegrated condition. Truly, in most highly dispersed systems, we observe, at the desiccation of molecular solutions (of crystalloids) an enormous tenacity or cohesion along the planes of the crystals cleavage. Yet, in that case a molecular power only is displayed for the internal tenacity (cohesion); no supplementary or residual power remains for the outer tenacity or attraction (adhesion). Roughly-dispersed systems, as gels, for instance, do not possess either considerable residual power. In intermediate systems only, i. e. in colloidal systems, glutinous properties, are most markedly displayed, when ashes desiccate and form a thin layer — bridge — between the surfaces of those objects, which are subjected to agglutination. In other words, the cohesional power is manifest at the desiccation of sols, in respect to themselves, as well as in respect to extraneous bodies.

It is perfectly obvious that both theories do not contradict each other, only supplementing one another. Two essential features are emphasized in these theories:

1) the degree of viscosity,
2) the degree of dispersion.

And still the given theories cannot suit our case of the cementing properties of soil colloids. It is known, indeed, that the cementing properties of soil colloids get manifest after coagulation too, i. e. in a state of gels. Thus, Demolon and Hénin subjected gels to drying, in order to obtain larger aggregates. I also got convinced, through my tests, that only after drying finely dispersed gels are converted into aggregates, including in themselves cemented mechanical elements. In other words, soil colloids in the state of gels are also fit for cementation, further desiccation being, however, necessary after coagulation. Yet, the way in which cementation takes place at that desiccation of gels, remained disputable and obscure. Mitscherlich writes: «Die Ko- und Adhäsionserscheinungen im Boden bestehen in der Kohäsion (besser Kohärenz) gleichartiger oder ungleichartiger fester Bodenteilchen und in der Adhäsion dieser Teilchen aneinander, wobei das Bodenwasser das Bindemittel bildet».

We find the latest works of Lazarev (23), Wolarovich (42), Deriaguina (9) — to confirm the correctness of the just stated opinion. Tests carried out by Deriaguina in her article «Tense properties of thin layers of water» are particularly convincing. According to her data, the modulus of the water shifting in its thin layers is but 300 times less than that of lead. Thicker water films are of the same elasticity — due to durtying.

Reverting to soil colloids, be they mineral or organic, we find on their surface thin films of water, possessing resilient and cementing properties. But as we know, a series of authors object to the just cited standpoint on the rôle of water films in cementation. Thus, Bouyoucos (5) suggests that water, according to tests, contributes to the decomposition of aggregates, rather than to their formation. To our mind, two different phenomena are spoken of, not contradicting each other. Indeed, thin water films on the surface of colloids play the part of cement at the formation of aggregates. This does not mean the water film to be the one thing acting. Indeed, it is not. The water film itself and its behaviour, in the sense of the reversible and irreversible capacities of aggregates, will depend on other causes. To these may be referred: dispersion, the chemical composition of the granule, the degree of dissociation of those compounds, solvatisators, which are to be found on the surface of colloids in a double electric layer (which is itself inside the water films). The electrokinetic potential of these colloids is, in its turn, dependent on the degree of dissociation of these compounds. In other words, aggregates may not even be soaked in an excess of water, if, for instance, compounds, forming the double electric layer, slightly dissociate (the electric potential of such colloids remains lower than that critical). This is just what we have, in the case, if bi-valent cations occur in the diffuse layer of negatively charged colloids or when coagels are electroneutral. In the latter case the stability of the coagels is growing, as has shown in his works S. Mattson (Soil Sci., v. 34, № 3, 1932). Aggregates will be water-tight in so far, as the reversible capacity of such gels is absent in water. Strongly dissociating compounds being found on the surface, the behaviour of gels will be quite different, which is to be met in a great many compounds of Na, K, NH_4. Swelling, the electrokinetic potential, will be much higher with gels saturated by univalent cations, than with those bi-valent, which makes it easy to understand the reversible capacity of such gels and the unsteadiness in water of aggregates from such gels.

Thus, for thoroughly understanding the cementing properties of soil colloids one should take into consideration the rôle of water films on the surface of colloids and the properties of the colloids themselves, of the granule, as well as of the micelle in its whole, of their charge and potential.

We find it most appropriate to make here the two following remarks: 1) coarsely-dispersed systems undergo coagulation on a line with highly-dispersed suspensions. The former being in excess, which is often to be observed in strongly podzolised soils, they introduce their own peculiarities into the coagel properties. According to my observations, such residues are particularly unsteady in virtue of their coarse dispersity. They are easily soaked in an excess of water, blocking up the pores of the capillaries, producing crusts and clods at desic ation. It is impossible to get rid of the noxious action of such rough suspensions by means of liming. In places where they abound (and this is possible and necessary to be established by special analysis), one should raise the quantity of highly dispersed colloids in soil, especially those organic, which, at coagulation with coarse suspensions, or at desiccation would give more impervious aggregates; 2) molecularly-dispersed organic compounds are present on a line with highly-dispersed organic colloids, which are formed in the process of decomposition of the soil organic matters. The latter may be of quite an opposite importance for the formation of aggregates in soil. It is just they that may peptise the ready soil aggregates. The author of the present article succeeded in showing this in the following way: some water extract was taken from a forest floor (coniferous forest). Two equal weighings of a clayey soil were stirred: one — in pure water, the other — in the water extract from the forest-floor. 24 hours later the quantity of the unsettled particles in the water extract from the forest-floor was found to surpass twelve fold that in the pure water. The same was obtained in a peat extract. This might, perhaps, explain the roughening of the upper soil layers under forest. Peptised material is readily washed in into deeper horizons, where we actually find an accumulation of silt. In this instance Aarnio's explanation about the shifting of fine particles from upper horizons into those lower, would have to be considered as a partial case and quantitatively, perhaps, not one paramount. At any rate, we find it necessary to draw the attention of investigators to the noted circumstance. Theoretical premises to the study of the given phenomenon are given in the work of Wo. Ostwald (27) and his disciples.

Let us return to the second factor of structure formation, p r e s s u r e. This is what Gedroiz writes: «Two factors, seemingly, play a decisive rôle in phenomena of the structure capacity — pressure and coagulation. One might say, relatively to the former factor, that this problem is entirely open to question; we may note here that, seemingly, pressure greatly participates in the creation of structure under the influence of cultivated plants» (14). As it was already mentioned, Demolon and Hénin attach a great importance to pressure in the formation of large aggregates from smaller ones. The two following problems are to be discussed at a further analysis of pressure, as a factor of structure formation:

1) in what way does pressure affect structure,
2) how is the pressure itself formed in soil.

Relatively to the first question, as to the cause of the favourable action of pressure on soilformation, we have to return to the resilient properties of thin water films on the surface of colloids. It is necessary for colloids to come into the closest contact with each other, in order that the cementing action of the water films might be displayed. This refers also to fine soil gels, after their coagulation. Undoubtedly, the excess of water between gels, inside the gel itself, prevents the thin water films from manifesting their cementing properties on the surface of colloids. This is necessary, as a first stage of coagulation: it is at desiccation that contractation, the drawing together of particles begins, due to which the whole mass wrinkles, forms fissures, whilst the cementing action of the elastic thin water layers on the surfaces of colloids is fully displayed by the particles drawn together. Yet, the general surface of the contact of separate gels, microaggregates, is far from being full under the influence of desiccation alone. The surface of the contact of gels and microaggregates will be much larger if we mechanically draw them together at desiccation, in proportion with the removal of free and weakly bound water. In our opinion, this is to what comes the positive significance of pressure, as a factor of structure formation. Indeed, special tests, that the author had formerly carried out with E. V. Biriukova and later on with A. I. Skliar, have shown that moist soils only are effective at pressing. Dry soils give no positive effect.

The rôle of pressure is still not exhausted by all mentioned above. We know from colloidal chemistry that the process itself of coagulation is much facilitated by pressure, caused by the swelling of colloids. Yet, we cannot examine here such phenomena in greater details.

We revert now to the second problem, as to how is pressure created in soil? Many authors ascribe pressure to the root system of plants. Not denying the given moment, I still presume that a much greater importance should be given to another moment, namely that of the swelling of the colloids themselves, especially those organic. The author of the present article has shown in one of his works (38) how undervalued is swelling at the determination of non-capillary porosity, by way of soil saturation with water from below along capillaries. I am inclined to think that pressure, developing in soil at the swelling processes, is underestimated by a great many investigators. It stands to reason that an immediate pressure of the upper layers upon those underlying also takes place. I found out, when investigating by means of my method the quantity of water-tight aggregates in different horizons of the profile of one chernozem, that at the depth of 1m, containing very little humus, the quantity of water-tight aggregates was almost equal to that contained in the uppermost layer. Medium layers contain more water-tight aggregates than upper layers, which may be seen in the annexed table.

Quantity of water-tight aggregates $> 1/4$ m.m. in samples from different depths of the profile of the Voronezh Chernozem (Kamenno-Steppe Experimental Station)

Depth of the sample im cm.	Quantity of water-tight aggregates > 0.25 mm.	Total carbon	Cations exchange capacity in per cent of Ca	Analytics
0—15	38.57	6.03	1.00	V. P. Tiulina and A. N. Slovo-okhotova
20—25	48.63	4.44	1.04	
40—45	53.28	3.67	1.01	
70—75	54.46	1.16	0.69	
100—105	34.92	0.57	0.62	

Presently, we might stop at the examination of the positive importance of pressure, as of a factor of structure formation, were not this phenomenon complicated by other moments. Firstly, the quality of the humus may be markedly different, which induces me to explain, by the way, the deductions of the work of Stephenson and Marquardt (34). The cited authors have noticed the lack of dependency between structure and the quantity of colloids. This is easily explained, if we admit that the cementing action of colloids differs in quality. The other complicating moment, at the comparison of the arable layer with that subarable, is that, which I called in one of my works «structural deficit». This means that the arable layer sometimes brings down its structure due to tillage. The structural deficit may be established by comparison of the arable layer with that subarable. It must be emphasized, that I introduced this conception only in respect to thick chernozems, not finding it possible to expand it on other types of soil.

Yet, on a line with the positive importance of pressure, as a factor of structure formation, negative moments have also to be noted. A. I. Skliar and I have observed in our tests that the quantity of impervious aggregates in finely pulverized soils, rises after pressing even when soil is saturated with sodium. Yet, the same soil, being of a good non-pulverized structure, the quantity of impervious aggregates decreases after pressing, or rather, the aggregates become finer. However, a positive effect of pressing on a pulverized soil, cannot be considered agronomically valuable in all cases. Thus, if pressure resulted in the formation of solid water-tight large clods or blocks, this would not be a positive phenomenon from an agronomical point of view, but one—rather negative [1]. As it is well known, such solid blocks are actually formed upon alkali soils, in places over which often pass heavy implements of tillage. Thus, the second factor of structure formation—pressure, is very complex too and requires a further analytical study. This problem acquires a peculiarly great importance in our Union in connection with the mechanization of the soil treatment in Soviet- and collective farms.

Concluding the first part we may advance the following deductions:

1. The first factor of structure formation — coagulation, has been experimentally studied up to the present time.

2. However, not all kinds of coagulation, being of importance for the formation of soil aggregates, have been closely studied. Hardly any information is given on aggregates, formed at the intersettling of colloids. They have not been studied, neither qualitatively, nor quantitatively. Coagulation taking place at desiccation with the formation of soil aggregates has also not been studied.

3. The cementing properties of soil colloids are manifested in the form of gels, especially at desiccation and pressure.

4. The reversibility (soaking), as well as the irreversibility (water tightness) of aggregates in water, take place due to the resilient properties of thin films of water, as well as to properties of the very colloids, particularly due to the degree of dissocia-

[1] The comparative water-tightness of these blocks may depend on their slow capillary saturation with water. Such conjectures are grounded on tests, which A. I. Skliar and I have carried out.

tion of those compounds which are found on the surface of colloids.

5. Pressure, being under certain conditions a positive factor of the formation of structure, may acquire under other conditions a negative significance, raising cohesion in soil. Under natural conditions pressure is, probably, caused by the swelling of soil and, naturally, is conditioned by the weight of the upper soil layers respectively to those underlying.

We proceed now to methods for determining the aggregates in soil.

All existing methods for the determination of soil structure may be divided into two large groups:

I direct methods, and

II indirect methods.

Direct methods for determining soil structure, referred to the I group, are:

1. Fractioning of soil upon sieves in a dry condition. This method is to be found in Barakov's manual (3) for agriculture (1903).

2. Fractioning of soil upon sieves in water, or an aggregate analysis, i. e. a quantitative calculation of water tight aggregates in soil. As far as I know, Pigulevsky (29) was the first to pay attention to water aggregates in soil, in 1913. He too suggested the method for determining water tight aggregates in soil, calling it «coefficient of structure capacity», i. e. the ratio of the weight of water tight aggregates to that of a taken weighing of soil. Later on the aggregate analysis was elaborated by Pavlov (28), Tiulin (37), Bouyoucos(6), Demolon and Hénin (8), and others.

3. An ultramechanical or microaggregate analysis, i. e. the fractioning of microaggregates after Robinson's method, but, certainly, without any preliminary preparation of the soil for analysis. Gedroiz (15) and Egorov (12) were the authors of this method. The method of the latter is known under the name of «coefficient of dispersion», and has as a basis Krüger's conception.

Indirect methods for determining soil structure, referred to the second group, are:

1. The filtering soil capacity.

This method is to be found in Williams' (41) «Soil science», 1902. The given method was elaborated later on by other investigators: Kuzmin (22), Antipov-Karataev (2). The latter author applied the somewhat modified Ostwald's filtering apparatus for other purposes — for studying the factors of dispersion.

2. Soil porosity. This method had been elaborated comparatively long ago, as Bürger (7) notes it. Doiarenko and a series of other investigators have applied it for an indirect study of structure.

3. Plasticity (its upper and lower limit).

The three indicated methods are far from exhausting the list of indirect methods, which may be seen in Stephenson and Marquardt's (34) work. This is quite comprehensible, all physical properties of soil being connected, in this or other way, with soil structure. Hence, the broad possibilities of indirect methods for determining soil structure.

Before we pass over to the valuation of the existing methods for determining soil structure, let us raise the following question: how ought we to approach the valuation of different methods for the determination of soil structure? The answer to that question greatly depends on the significance which soil structure has for soil fertility under different physico-geographical conditions. There would be no sense in our examining the importance of soil structure without referring it to soil fertility. Whereas, if soil fertility is our initial point in our evaluation of soil structure, we should realize the positive significance of structure for soil fertility. It not being possible to stop in detail on the broached subject, I shall briefly note the following. It is considered to be established, at the present time that such important moments of soil fertility, as the water, air, thermal regimes depend in a great degree on the character of the soil structure. One may say, therefore, that wishing to control such important physical properties as those of water, air or, thermal, we must affect accordingly soil structure. It stands to reason that physical properties are not equally dependent on soil structure in different soil zones, even on separate soil varieties within the limits of one zone. But this dependence is everywhere acknowledged as being extremely essential.

The estimation of methods applied for determining soil structure would be easier, were soil structure to determine only the soil physical properties. It is known, as a matter of fact, that water, air and thermal properties of soil depend on its porosity. If the soil has a lower porosity than a certain limit, its water, air and thermal properties will be unfavourable. In order that soil pores should not be too small, or, otherwise speaking, in order that the relationship between large and fine pores were favourable to the cited physical soil properties, the size of water tight small soil clods should not be smaller than to a certain limit, for inst. 0.25 mm. The presence of finer aggregates, 0.05 for inst., or of those larger, but getting soaked in water, would decrease the volume of non-capillary pores. In that case the physical properties would be deteriorated. All this has been noted by a whole series of authors, whose names I am not going to cite now. It is the final deduction of all the above said, that is of great importance, namely: favourable physical soil properties, determining fertility, are possible but in the presence of water tight aggregates not smaller than 0.25 mm. This means that methods for determining soil structure from the given point of view should be evaluated according to: 1) the size of aggregates, and 2) to their water tightness.

Proceeding further, one may say that, of all modern methods, those direct should be considered the most favourable for the purposes mentioned above, and of them the aggregate analysis, in the modification, for inst., applied by Demolon and Hénin.

It is true, that objections have been made against the aggregate analysis, in the sense of its grounding and preciseness. In particular, critical remarks have been passed by Sobolev and Chapek upon the aggregate analysis, that I had suggested in 1928. Yet, on principle, it has not been rejected by anyone. Therefore, we shall stop at this method further on, whilst now let us continue to discuss the main problem, as to what should be our initial point in the valuation of methods for determining soil structure.

In our opinion, the mechanical tenacity of aggregates should be taken into account, besides the recorded physical properties, determined by the size and water tightness of soil aggregates. We should like, thereat, two moments to be distinguished:

1) the mechanical tenacity of large aggregates, clods > 10 mm.,
2) the mechanical tenacity of aggregates up to 3—5 mm.

The former formations, i. e. large clods, rather represent the soil cohesion, being mechanically tenacious in dry state. There exist certain methods for studying it, which we do not intend touching upon here. We shall only note, that cohesion increases, as have shown Sokolovsky and Lukashevich's works, depending on the composition of exchangeble cations, in the following order:

Cations which saturate soil	Cohesion in kg.
Initial soil.	15.8
Saturated soil	3.5
Same with Ca	10.9
» » Mg	29.9
» » NH_4	70.5
» » Na	156.0

In the given case cohesion was determined by small briquettes made from soil and which were later on subjected to splitting, when in a dry state.

This method is not applicable for determining the mechanical tenacity of aggregates from $^1/_4$ mm. to 3 mm. Perhaps, it is not even of great necessity. Most important would it be to find the quantitative expression of the force of rupture of macro-aggregates into micro-aggregates, which develops when wetting a dry aggregate with water. As Krinin shows it in his works, «pinched» air, i. e. air adsorbed by the soil aggregate, giving its place to water at moistening, is expelled by water under a certain pressure. This pressure is accompanied by the rupture of non-tenacious bonds of aggregates. The quantitative measurement of such tenacity of aggregates is of a considerable interest in the valuation of soil structure. However, direct quantitative methods do not exist. An indirect way might, perhaps be here of use. I, personally, think, that if we apply an aggregate analysis in one case with a preliminary capillary saturation of the soil weighing with water from below, and, in another case — without such preliminary capillary saturation, we shall obtain from these two analyses a difference, which will summarily show the mechanical tenacity of aggregates. In truth, this conception has not been yet confirmed experimentally, and I cannot confidently speak of the fitness of my suggestion.

Returning to the main point one may say, that the mechanical tenacity of aggregates from $^1/_2$ to 3 mm. is the second property, which should be taken into account when evaluating methods for determining soil structure, it being of a particular interest to determine the mechanical tenacity of water tight aggregates. In other words, we have noted two qualities, which it should be desirable to make manifest quantitatively for soil aggregates:

1) their water tightness,

2) the mechanical tenacity of common aggregates, as well as of those water tight.

It is scarcely necessary to explain the importance of the mechanical tenacity of aggregates for soil fertility. It is perfectly evident that just mechanical tenacity, and especially that of impervious aggregates, will show us the stability of the soil structure, when affected by strong vacillations of moisture in soil. A rapid wetting of soil (with rain), at least of its surface, is a usual phenomenon in nature. And it is of the greatest importance to know beforehand how will behave this or another soil under such conditions, in connection with the valuation of the same physical properties, we have already spoken about: water, air and thermal.

When pointing out two qualities of structure: water tightness and mechanical tenacity, we have not yet exhausted all the qualities of aggregates, being of significance for soil fertility. Not only those physical properties of soil, which are determined on the whole by soil structure, are of great importance for soil fertility, but also those which determine its nutritive regime. The latter depends on a whole series of physico-chemical and biochemical properties of soil. We know that nutrients are assimilable to plants in an oxidised form, as common salts. Many of them dissolve well in water; and salts would be leached out, — if there will be no hindrances for this, as it takes place in sandy solls. But in loamy and, still more, in clayey soils the leaching out meets with impediments. A certain part of soluble salts is mechanically or physically kept in soil; this takes place not only in capillaries, amidst aggregates, but also in the pores of the aggregates themselves, chiefly of those water tight. Otherwise, we want to emphasize one more important quality that aggregates possess, especially those water tight; this is — the degree of their porosity. It is hardly necessary to explain that what is meant here is not the exchangeable adsorption of aggregates, but the mechanical and physical absorption of different salts by aggregates from the soil solution. I presume that it would be of interest to study this property closer, in connection with the porosity of aggregates, especially of those water tight. A certain importance of the determination of the cations exchange capacity directly in water tight aggregates is not to be denied; but this moment bears, certainly, no direct relationship to methods of determining soil structure. So far as we know, no ready methods for determining the p rosity of soil aggregates exist at the present time. All we know is L. D. Bayer's very interesting attempt to study the size of the pores of silt, saturated with calcium in one case, and with sodium in another. This author has shown, by way of ultrafiltration, that pores of silt saturated with calcium are by 8.3 times larger than those of silt saturated with sodium. What is the way of determining the size of pores of aggregates and of their general volume, without special investigations — is difficult enough to say.

Thus, I presume, that at least the three following qualities of aggregates, in connection with their size, should be taken into consideration at the valuation of methods for determining soil structure:

1) their watertightness,
2) their mechanical tenacity,
3) their porosity.

The mentioned properties of soil aggregates may seem superfluous for the elaboration of methods for determining soil structure. It might be simpler and, perhaps, sufficient to confine oneself to the size of aggregates and to their watertightness. Without predetermining this question, I still suppose that the properties of soil aggregates have, comparatively, been little investigated, as yet. The study of such properties of aggregates, as their mechanical tenacity, porosity (especially connected with swelling) will possibly discover new moments of soil fertility depending on structure. I am inclined to think, at any rate, that the life of soil, its fertility, for an enormous majority of soils (those loamy and clayey) depend, in a great degree, on the nature of clods or soil aggregates. I do not mean by this that aggregates play a positive part always and everywhere. But it should be emphasized simultaneously that the importance of soil aggregates for soil fertility, depending on their nature, their properties, is far, as yet, from being duly recognized among investigators.

We have now to proceed to the valuation of existing methods for determining soil structure. First of all, how should we value, by themselves, the two groups of methods, i. e. those direct and indirect. We may see from the above mentioned that an immediate and comparatively subtle determination of certain properties of soil aggregates is of great importance for a proper evaluation of soil structure. In that case indirect methnds are cf little value. They may help conjecturing on certain properties of aggregates, and even that very uncertainly.

Therefore, it would scarcely be expedient to study soil structure by indirect methods, those direct being present. The former, such as permeability, porosity, plasticity and others are important even by themselves. And much more expedient would it be, from my point of view, to compare the results of the determination of the said properties (permeability, porosity, plasticity) with the results of a direct determination of soil structure, than to replace the latter by the former.

Consequently, I will no more touch upon indirect methods and am proceeding to those direct.

The following of the direct methods for determining soil structure, have already been pointed out:

1) fractioning of soils on sieves in a dry conditicn;

2) fractioning of small clods $>$ 0.25 mm. in water (macroaggregate analysis);

3) ultramechanical or microaggregate analysis, i. e. an aggregate analysis of small clods $<$ 0.25 mm.

Only two direct methods may be spoken of, on principle: 1) fractioning in a dry condition, and 2) fractioning in liquid. The first method — fractioning on sieves in a dry state, does not give, as a matter of fact, any qualitative characteristics to aggregates. It only fixes the size of aggregates, such, as we find them in dry soil. But a sample, taken immediately in field, is not always dry. It is then preliminarily brought into an air-dry condition, without suspecting, perhaps, that cementation sometimes takes place at the process of drying up and aggregates are formed, that had not existed in field when soil was moist. This shows the given method to be very limited. In order to avoid the altering influence of the drying up of a moist soil, I suggested in one of my former works, to carry out fractioning of a natural structure, such as we find it in field at any moisture in an inert liquid of a kerosene, toluene, benzol or the like type, as no decomposition of aggregates has been observed in such cases. Yet, in spite of it being so very limited, the method spoken of may be of great use in certain cases. Thus, if we want to value in how far perfectly varicus implements of tillage crumble the soil, it would suffice to make a fractioning of soil on sieves in an inert liquid, after the compared implements had done their work. Finally, such a determination may give us valuable indications, if we accompany and supplement it by determining the water tight structure. At the comparison of the two curves, natural structure and that water tight, we shall come to a better understanding of the dependence in the formation of large clods from the quantity of separate fractions of the water tight aggregates.

Certainly, a much greater importance should be attached to the second method of those direct, to the aggregate analysis [1]. Lately it has come to be rather widely recognized. It is true that no sharp limit exists between water tight aggregates and those getting soaked. To say more precisely, the natural aggregates which we find in field (after a preliminary capillary saturation with water from below) when treated on sieves in a water bath, are rapidly subjected to decomposition at the beginning, after which there gradually takes place a continuous isolation of new products of the aggregates decomposition, though in small quantities. There arises a natural question, — when should these «bathings» be stopped? In order to answer this question one must point out, first of all, that in the majority of soils studied by the author there has always been observed a marked leap in the decomposition of natural aggregates when treated upon sieves in baths, if soil had been preliminarily saturated with water from below along capillaries. After this the decomposition of aggregates in soil containing a great many leaching out aggregates, was very intensive at starting (at the first 10—15 baths), then it gave a leap, sharply decreasing further decomposition. We considered this leap to be conditionally the end of reversibility. Parallel definitions gave very equal results, fully admissible for the given method. It was still improved, later on by Bouyoucos (6) and Demolon and Hénin(1). Bouyoucos suggested stirring, after which there remained extremely tenacious ultimate natural aggregates. The introduction of the leaching out alkali is, from our standpoint, a disadvantageous side of Bouyoucos' method. Demolon and Hénin suggested to use a solution of calcium nitrate — instead of distilled water, 1 g. to 1 l. The peptising action of distilled water is thus diminished, and parallel determinations give good results.

However, the very fact of the absence of a marked boundary at the decomposition of natural aggregates, is, more or less, comprehensible. A complete irreversibility in water is possible for gels, fully saturated, with calcium, for inst. A complete reversibility takes place for gels, saturated, e. g., with sodium. Such extreme conditions are seldom to be met in soil [2].

[1] V. Novak in his article on soil structure (Vestnik Ceskoslovenska Akademie Zemedelske, Jhg. VIII, 1932, № 9—10) proposes a new term: «aggregat-mechanische Analyse». I fully agree with him.

[2] For alkaline soils is the aggregate analysis hardly good; for the evaluation of the physical properties of soils of that type a special modification of this method or even quite other methods are to be invented.

It is more often we have to do with a mixed composition of exchangeable cations. Hence, the possibility of a gradual peptisation of gels, having such a composition. Knowing beforehand the composition of exchangeable cations, one may partly foresee the character of the curve of the aggregates decomposition at their treatment in a water bath. There is one more circumstance, which we had formerly noted. We mean the presence of coagulated coarse suspensions (about 2—3 microns). At a gradual bathing they may readily peptise, due to the small degree of dispersion. Finally, soil aggregates, those water tight being of the number, are not simply gels, but gels, containing mechanical elements in the interstices of their inflexions. On the surface, and at the angles of these elements, in particular, there may be so few colloids, as cement, that a small mechanical influence, quite inevitable at a bath-treatment, may suffice for tearing asunder aggregates in places where they are most feebly bound. In other words, an aggregate analysis is, on principle, orientated on the test of the reversibility or irreversibility of gels, whilst, in fact, its result depends too on the mechanical influence of water upon aggregates, as well as on the presence of roughly dispersed suspensions in these aggregates. According to the Bouyoucos' method the mechanical influence is exerted intentionally, due to which reversibility alone cannot be spoken of, as such.

The last difficulty we meet in an aggregate analysis consists in the presence of non-decomposed root residues, which often give artificial aggregates. This happens, when a great quantity of microaggregates, similar to a bunch of grapes, present outwardly one whole, one large aggregate. One has not succeeded yet in distinguishing them from c.mmon aggregates. However, by Bouyoucos' method, they will convert into microaggregates and sooner take their own place.

Let us proceed now to the second variety of the aggregate analysis to the «coefficient of dispersion», as well as to the ultra-mechanical analysis. In what do the given methods radically differ from the aggregate analysis? In that only that they take into account the part of the curve of the aggregate analysis, having fine fractions, starting, for inst., from 1. Without denying the importance of a microaggregate analysis, we still presume it to be much more expedient to obtain the whole of the curve of water tight aggregates, macro and micro, than only a part of this curve. This is true, so much the more, that it is difficult to obtain the curve of water tight microaggregates, it being comparatively much easier to get the curve of macroaggregates.

Thus putting an end to the examination of the existing direct methods for determining soil structure, we shall briefly stop at those definitions, which are expedient to be made, as a supplement to direct methods, and not for replacing them. We have to remind that any study of separate soil properties is considered from a definite point of view, namely, to expose separate moments (or their totality) of the soil fertility.

From the standpoint just mentioned, we consider soil porosity under different conditions of moisture, to be a valuable supplement for the determination of soil structure. It is to be pitied that we do not know as yet, how to determine non-capillary porosity, which is of special importance for understanding soil fertility. One should work hard at that problem, successful results being very promising for the estimation of soil fertility. The swelling of soil should occupy the second place. We have outlined in the first part of our article of how great an importance swelling is for creating structure itself, however it is not the latter that comprises the whole significance of swelling: it is very possible that the motion of water along horizons mainly depends on swelling in certain soils.

Finally, the nature of the soil absorbing complex, usually represented in soil by gels (coagels) is considered to be the essential criterion of the soil fertility, after Gedroiz's works. We know that, up to the present time, it was the composition of exchangeable cations that was studied in soil gels. This made it possible to understand a great many soil properties, valuable for their fertility. Such determinations are to be broadly applied henceforth, which should be of great assistance for understanding the character of the soil structure. Yet our understanding of it will be still more endeepened, when we are able to determine the cementing properties of soil colloids and likewise to distinguish gels by the method of their coagulation. This will elucidate too the mechanical tenacity of aggregates and their porosity. Whilst, on the ground of a thorough understanding of structure, yet supplemented by the characteristics of such soil properties as porosity, swelling and nature of the soil absorbing complex we shall penetrate still deeper into the essence of soil fertility.

Summing up the second part of our article on methods, we may conclude it as follows:

1. Preference should be given to direct methods, as compared to those indirect in the determination of soil structure.

2. Fractioning on sieves in a dry condition is an imperfect method of those direct, as a moist soil has to be dried, which alters its aggregative capacity.

3. In cases when natural structure is still to be determined, the author of this article suggests the test to be carried out in an inert liquid.

4. A complete aggregate analysis, i. e. a macro and micro analysis gives valuable results, noting so important a quality of soil structure, as water tightness. Its best modification is, in our opinion, the Demolon and Hénin's method.

5. The «coefficient of dispersion», an ultramechanical analysis, is but a part of a full aggregate analysis. It is expedient to carry out a full aggregate analysis supplementing it sometimes by a determination of the natural structure.

6. No methods exist as yet for evaluating the mechanical tenacity of aggregates, their porosity, but they are most desirable.

7. On a line with the aggregate analysis it is most expedient to determine porosity in soil, not only the one total, but also that non-capillary (and, consequently, the one capillary), next the swelling and, finally, the main properties of the absorbing complex.

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