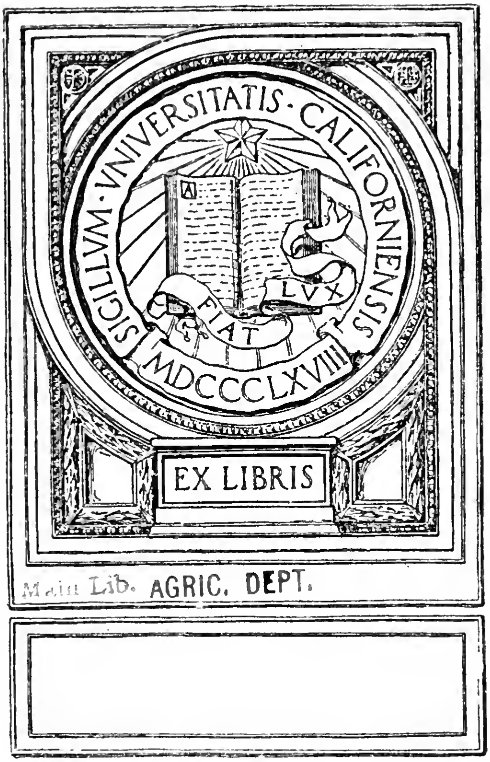

M. of L. and A.

Department of Agriculture

THE NATURE OF DROUGHT

according to the evidence of the Odessa Experiment Field.

With 21 illustrations.

By V. G. ROTMISTROV,
Director of the Odessa Experiment Field.

Translation from russian.

ODESSA.
Printers, Lithographers & Book-binders I. Skalsky, Kolontaevsk. Street, Own House, 18
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Contents.

Detected errata in translation.

For the terms — „black, bare and ploughed fallow“ — is to be understood fields which are ploughed after the harvest in autumn and left unoccupied through the following year until winter plants are sown in the following autumn.

For the terms — „spring and winter corn“ — red „spring and winter growths“.

The frase is left out on page 6, line 38.... of motion „and the liquid water found on the surface of the layer is also transformed into a hard condition and consequently cannot move“.

Pages	Lines	Printed	It must be
1	32	and	i. e.
2	1	so with the „Nature of drought“	so the essential of drought
„	4	of manure	of black mould
„	6	of fibrous	of alluvial
4	1 a. 4	of manure	of black mould
„	31	are proof	can hold out
„	32	Local	District
5	10	forestry	their forestry
„	34	of 1890	of the eighties
6	8	the direct controlling influence played by	a direct controlled determinations of
8	21	comes in early	appear suddenly
„	22	the sub-surface	the surface
9	20	of deep	of various depths
„	39	snow - water	soil - water
10	19	dinimish	lower the level of
„	26	sub - soil	soil
11	18	consideration	condensation
„	34	in	is
„	41	frequent	limited
13	15	90	20
„	18	2 m.m.	2 c.m.
14	22 a. 28	circumference	volume

Pages	Lines	Printed	It must be
15	15	layer under	layer 1 or 2 metr. and more
„	31	unmowed	unsowed
„	37	the decisions of the control departament	subsequent verifications in late years
23	26	1094	1904
26	11	Uoung soots	young roots
29	15	position	position downwards
31	15	irrigation	agriculture
32	10	is	in
„	14	under	above
33	9	sid	rid
„	28	precipitation	fall of atmospheric water
„	38	thick	thin
35	15	gets	acts
36	20	on	including
„	26	moist	deep
37	31	treecourse	three course including
38	11, 27, 31	water	useful water
39	26	10	70
„	42	his	this
40	21	high	light
41	10	of farms	of field culture
„	15	about	above
42	1	The presence of drought	The „nature of drought“
„	2	of spring	of autumn
„	21	in an insoluble condition	undissolved
43	24	the threathing	the thrashing
45	1	every	every pood
„	28	of the form	of the field culture
„	37	from	theirefrom
46	18	the farming thickness	the good thickness

PREFACE.

The present treatise forms a continuation of my previous work intitled „The circulation of water in the soil of the Odessa Experiment Field“ which first appeared in the „Review of experimental Agronomy for 1904 and later in 1907 in the form of a separate pamphlet based upon my report in the Odessa experimental field.

When the material, gathered up to 1904, concerning soil humidity was subjected to analytical investigation, many sides of the question were not then so clear so they are at present. The intimate relation between the phenomena of plant growth and soil humidity, their dependence one upon the other, was so apparent that it was scarcely possible to work upon one question without entering upon the related study of the other. Commencing my investigations into soil humidity in 1895, I found myself obliged in 1897 to take up the study of the morphology of root-systems as applied to our cultivated plants — their dimensions, the tendencies of roots of different orders, and their distribution in the soil. So that it was not until the year 1904 that I felt myself on firm ground and from that time up to 1909 in a position to clear up the most important points of that Section forming the subject of my treatise „The root-system of cultivated plants of one year's growth“ which was published in the same year (1909). In this way both questions — soil humidity and root-system both received parallel investigation from 1895 to 1909, a period, of fifteen years.

It was natural, of course, that certain phenomena concerning the circulation of water in the soil could not become clear to me, until I had grasped the part played by root-systems in that process.

And as drought entirely depends upon certain laws of water distribution in the soil and the lack of water in certain soil-belts, so with the „Nature of drought“ — its characteristics appear when studied in connection with types of soil approaching that of the Odessa experimental field — a chocolate colored clay containing from 3 to 6 per cent of manure.

However, the attention of the reader of my results may be transferred to all blackearth soils resting on beds of fibrous clay such as the Russian steppe belts of the south and the black-earth governements of the East.

During the last two years I have demonstrated the diagrams of the annual course of humidity embodied in this treatise to very many people attending the Odessa experiment field. They all insisted upon the quickest possible publication of my results, but it is only lately that all the details of the desired work have fully developed. Circumstances outside my control have hurried the publication of this work so that certain parts lack somewhat in completeness. I consider it my duty to express my thanks to the former supervisor of the meteorological station on the Odessa field, K. N. Verzilow, who gave me much assistance in investigation soil-humidity of root-systems.

V. Rotmistrow.

I. The state of the drought question.

„Drought and the means of striving against it"—in an ever-active theme as ancient as agriculture itself, and much has been written on this subject: for unbroken drought in some districts and, periodical drought in others, prevents the agriculturalist from working peacefully and always leaves him in a helpless position; for even now the means of prevention are far from decided upon, inasmuch as drought itself, the nature of drought has not been explained. At times it seizes upon great areas—tens of million of acres or again limits itself to a trifling area. They appear on the plains of Russia with singular force and persistence; but here they carry quite an individual character frequently blighting separate districts, separate farms.

The latter case—drought in separate farms—offers peculiar interest inas much as it shows that drought may be a local phenomenon limited to a given farm with its faulty peculiarities in the technical process of farming. Should these faulty peculiarities of technical farming affect whole districts then the droughts becomes not a local, but a general phenomenon. For that reason the means of contention shoued bear a local character only in regard to separate farms; and only certain parts of them should be applied to such as may come under the influence of the governement or district for the attainment of simultaneous and similar treatment.

The most detailed account of drought and the means of contending against it was first give by A. Shishkin about 40 years ago.

He brought down the means of contending against drought to the following points:

1) To establish, if possibls, connection between the bed-water and the soil layer.

2) Deep mellowing (the mellowing of the sub-soil should be repeated approximatively every 5 years) of the soil for the greater accumulation and better storage of water for better developement and deeper penetration of the roots and for the attainment of firmer structure.

3) In the corporation of the soil a structure expedient for regulating the penetration and evaporation of water.

4) Increasing the quantity of manure in the soil to improve the relations betweens soil and water and to obtain more durability of structure.

5) Manuring the soil with dung, artificial manure and salts for the accumulation of manure in the soil: for rich and more complete developmenf of roots and for more productive expenditure of water.

6) Seasonable tillage of fields for a larger accumulation of humidity in the soil.

7) Constructing open ditches and using the mole-plough instead of the ordinary subsoil plough to catch running water more completely.

8) Introducing ploughed fallow for accumulation more humidity in the soil.

9) Using implements for spring tillage which do not turn over the upper layer.

10) Early promotion of spring sowing in order that plants should reap greater benefit from the humidity accumulated during winter and give shade to the soil more quickly.

11) A perfect system of sowing and unremitting attention to plants during growth.

12) Suitable selection of cultivated plants, species and seed and a corresponding suitability of cultures.

13) Improving of productiveness of fallow-land and.

14) Looking out for lands lowly situated where there is a supply of ground water for cultivating lucern, esparcet and rhizocarps.

All the above measures may be arranged in the following main groups :

1) The adoption of mechanical tillage of the soil.

2) Improving the properties of the soil by chemical means.

3) Capillary raising of ground — water to the roots of cultivated plants.

4) Accumulating water in the soil by means of open ditches.

5) Selecting cultivated plants which are proof against drought.

6) Local steppe forestry.

I dwell upon the details of A. Shishkins work because most of the later writers give preference to this method of contending against drought.

Thus, P. I. Kostichew points out as a measure of fighting against drought, that during autumnal ploughing in order to accumulate autumn and winter reserve water in the soil, thus „for the protection of plants against drought it is necessary to bring the soil into such a condition that it is able to preserve better and hold more water out of a usual quantity of rain", to this end the author advises the extirpation of weeds in their initial stage, the destruction of crust on the surface by means of harrowing etc.— identical measures recommended by A. A. Shishkin.

P. F. Barakow also recommends measures very similar to those of A. A. Shishkin.

His views are as follows:

1) The strictest possible preservation of forests and steppe silviculture, especially in the form of protective plantations.

2) Forbidding the tillage of steppe declivities of valleys and forestry.

3) Irrigation of the steppe by the aid of running water and especially by means of the retention of snow and snow-water (the watering of meadow land).

4) Diminishing the area of ploughing and enlarging the meadow and hay fields by means of artificially sowing grass seed.

5) Improving generally agricultural technic, and above all introducing a rational working of black fallow, which is the corner-stone of steppe farming, and depends entirely upon a timely—that is to say as early and at the same time as deep as possible tillage of the soil (black fallow).

6) The introduction of farmyard manure, not only in order to enrich the soil straight away with nourishing matter — azote and phosphoric acid, minute quantities of which undoubtedly exist in the soil, but also in order to save moisture and economise in the expenditure of it by the plants themselves: the dung being previously applied in the form of a pall or covering.

7) Correct rotation of crops requiring the utmost diversity of culture, especially leguminous (beans) and thorough ploughing plants.

8) Improving the sowing seed, by means of carefully selecting, cleaning and sorting them.

Comparing the above with A. A. Shishkins propositions we find the following novelties; prohibiting ploughing on the declivities of valleys and the retention of snow on the fields. As regards the accumulation of snow. this question was raised at the end of 1890.

P. J. Kostichew and P. A. Barakow strongly supported the idea of making use of accumulated snow as a means of fighting against drought and worked up the question very completely.

At that period many authors dealt with this theme. It was suggested, that fields should be enclosed by living hedges being constructed at a distance of 23 yards from one another (Kostichew), the rearing of tall plants the stalks of which should remain standing over winter (Barakow, Batalin), even ploughing over snow, making furrows to hold later snowfalls; and sowing over the winter land spring plants—such as mustard—which would hold the snow between its stalks withered by the winter cold (Batalin).

All these propositions regarding the utility of accumulated snow based themselves on logical considerations without taking into consideration the direct controlling influence played by the moisture in the soil when under a pall of snow at certain periods, commencing in autumn, continuing through winter and finishing in spring

Then the forced, as it were, cultivation of tall-stalked plants not always suitable to given climatic conditions and the problem of organising plans for each farm, did not find acceptance, and the expectations based upon accumulated snow have not been justified up to the present. And if there are still defenders of these old principles, it is only because they are founded on the easily misleading proposition:—that melting snow is almost wholly absorbed in a liquid condition into the soil and raises the quantity of water held there to a considerable extent.

It is out of this supposition — that snow water saturated the soil — that the misunserstanding arises. And I shall dwell on this matter rather fully in order to dissipate any misleading ideas regarding the process of snow thawing in spring and its absorbition into the soil. This comes so much easier for me to do, because the Odessa Experimental Field carry on investigations into the temperature of the soil at the following depths:—o (on the surface), 2, 6, 10, 14, 20, 40 and 80 cm. In the ploughable layer there are therefore five thermometers that is to say there is all the data required for the most accurate explanation both as regards the melting of the snow as well as the thawing of the soil.

It is only possible for snow to lie on the fields in a case where both snow and soil have a temperature below zero. If the soil had a higher temperature its warmth would be transmitted to the snow, which would melt by degrees, the resulting water being absorbed by the soil.

We may observe this in autumn, when snow falls on unfrozen ground. Then the snow thaws quickly. Up to the commencement of spring, the soil layer freezes to the depth of one metre and more, in Central and Nothern Russia, and to 40—50—80 cm. in the South. Throughout the frozen layer the temperature is so low that water finds itself in a hard condition and consequently incapable of motion. Briefly, so long as the frozen layer does not attain a temperature above zero, the water therein remains hard and motionless; and so long as the snow holds out, the temperature of which, of course, is always below zero, the upper surface of the soil-layer is protected against any invasion of warmth from the air; and underneath, the temperature of the whole frozen layer is also below zero, the cold from thence travelling upwards. Therefore the upper surface can only thaw when the snow attains a temperature above 0°, that is, turns into water. Now even if a part of this water penetrates into the minute cracks in the depths of the soil, it will be turned into a solid state and arrest the trickling water from above. At the same time, the water on the surface of the soil gets warm, a part evaporates in the air, and a part warms the lower layer of soil and water, raises the temperature and saturates the thawing belts of land.

The whole question, therefore, comes to this: how quickly does the soil thaw and how much snow-water succeeds in percolating. If the thawing of the soil only proceeded from below upwards, then it might happen that all the snow-water would be absorbed.

But *it not only proceed upwards; but downwards as well from above simultaneously.*

To illustrate this I have traced the course which the process of spring thawing took in 1907 in the soil of Odessa Experiment Field [fig. 1]. In general this process runs just so every year, the only difference being the thickness of the frozen layer and the time the thaw commences: in in the south it sets in earlier; in the North—later.

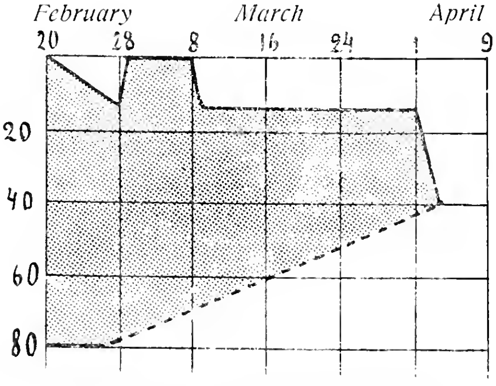

Fig. 1. The proccess of thawing of the soil in spring. (The frozen layer is hatched).

Up to the 20-th February the thermometers showed that the soil had frozen to 80 cm. from the surface [the frozen layer is shaded]. On the 20-th of February the layer thawed to 14 cm. from the surface, and the rest remained frozen. From the 1-st to the 8-th the same layer of 14 cm. was again frozen up. On March the 9-th the layer thawed again to 10 cm. and on the 10-th of March to 14 cm. and remained in that condition until the 1-st of April.

The lower layer commenced to thaw on the 26-th of February, when the thermometer rose above 0^0 at a depth of 80 cm. At a depth of 40 cm. the thermometer remained below zero until the 4-th of April. This temperature evidently extended deeper than 40 cm. until the 4-th of April.

After the 1-st of April the upper part of the frozen layer began to thaw quickly, getting ever thinner, so that by the 3-rd of April it was no thicker than 10 cm. and lay at a depth between 35 and 45 cm. On the 4-th of April both processes of thawing, the upper and the lower, met at a depth of 40 cm. and all the thermometers on that day at all depth rose above zero. And all the water in the soil-layer turned into a liquid condition.

Many years direct investigation of soil moisture at a period of full thaw—this moment always coincides with the commencement of spring field work—has not shown any quick movement of soil water from the upper belts into the lowers ones; and this alone should prove that very little snow-water had found its way into the soil. As far as I know no statistics have been furnished on this matter.

A small accumulation of water, about 3 to 4 per cent, in the upper belts near the surface to a depth of 10 to 20 cm., may be observed in certain years, when spring comes in early. But if the thaw is protracted, owing to a cold spring, the sub-surface gets extremely dry. And by the time spring work begins, we find less water than there was during the course of the winter.

The accumulation of large masses of snow in woods and especially in artificial steppe plantations in the form of narrow strips or belts, give a somewhat different effect. Here the snow holds out one or two weeks longer than on the neighbouring fields; and when the soil of the contiguous fields has already thawed at all depth, it is still in a frozen condition in the woods, under the snow. Water from the melting snow in the woods getting into the soil on the boundary between the frozen and the thawed parts is almost wholly absorbed and serves as a sourse for the accumulation water for the forest.

J. Jukow recommends strewing ashes over the surface of the snow in strips; and affirms that under these strips the snow melts quicker than it does on the neighlouring clean snow strips, and that by this means the snow-water is imbibed into the soil. Of course, if there was no evaporation, the water thus formed would remain on the surface until a certain thickness of the soil layer thawed. But the process of evaporation is a reality and is particularly powerful in spring. Towards the period when spring tillage commences the ash-strewn strips dry up and the others remain damp and we get unequal sprouting. This one circumstance is sufficient to show the impossibility of using these means of watering the soil, for such a motley on the field would exclude every possibility of having the field work done in good time.

I have dwell on this question because much that is improbable and fantastic has gathered round it without having been proved by accurate and reiterated investigation of the moisture in the soil; and also because, up to the present, serious importance has been attached to the accumulating of snow on fields with regard to the question of fighting against drought. In the extreme southern zone, about 100 versts from the Black Sea, this means of fighting against drought has less importance as there is little or no snow there in winter.

Resuming our deliberations on the rest of the proposed measures I shall stop to examine some of A. Shishkin's as he has touched this questinn from very various points of view.

Deep mellowing of the soil which all the writers on this subject unanimously regard as a matter of a great importance with regard to fighting against drought, has also very little real significance. On the Odessa field there have been more than 1000 experiments made on the effect of deep ploughing for winter and spring crops, and no difference in favour of deep [10 1/2 inches] or even mediate ploughing [7 inch.] was obtained in the harvest. Investigations into the humidity of the soil also showed no difference in that respect between deep and shallow [3 1/2 inches] ploughing.

The argument in favour of deep ploughing, that deeply mellowed soil imbiles more atmospheric residue, falls through, because little residue settles on the steppe districts and it all enters the soil whether deeply ploughed or not. On certain types of soil und in more northern regions deep ploughing may have a beneficial effect for other reasons — airing the soil etc.—but not as regard opposing drought.

As for manuring black-carth, which drough attacks very severely, with dung and mineral manures, this question even now, abont 40 years after the appearance of A. Shishkin's work, is not solved decisively. And this is good proof that the effect of manure on black-earth is not so telling as on other soils. Experiece with manuring on southern fields points to a negative answer to this question. A more probable explanation of the reason why dung acts negatively may be thus: — that the higher concentration of liquid in the soil, by introducing manure into it from outside, when there is very little reserve snow-water, brings with it a diseased condition of the plant organisms. And this, instead of raising, may even diminish the crops, as practical observation proves often enough

The choise of hardy, drought- proof [xerophilous] plants or species may undoubtedly weaken the withering effect of drought, but only to a certain extent. At present this measure against drought is mainly theoretical, inasmuch as practical farming has set apart only bearded winter wheat [triticum vulgare, cereale hybernum] and edible 6-rowed barley [Hordeum vulgare genuinum] as being more hardy and at the same time more prolific. At the preseut moment it is difficult to say what a well followed np selection of plants would give us as regards xerophilous forms. One consideration however must be born in mind: — that in moist-years the drought resisting qualities of the plants would be thown away; and if there was a run of 3 or 4 such years then those qualities might be lost entirely. To preserve the xerophilons type in all its purity is would be absolutely necessary to have a reserve of seed, therefore, for several years, and, this is not adaptable to detached practical farming here, with its settled organization.

Steppe arboriculture as a means of fighting against drought, seems to have lost favour within the last decade. Investigation [H. Morosow, N. Adamow, H. Wisotzkii, P. Ototzkii and others] has shown that „woods dry up the sub-soil intensively, diminish the ground-water, thickening it in salt solution, and on the neighbouring fields, especially on those surrounded by woods they not only fail to equalise, but quite noticcably increase the daily variation of temperature [Wisotzkii]. Then again several failures with regard to steppe arboriculture created a certain bias against it. It may be that this came about through the steppe arboriculture itself having been put on a different level to that required by certain considerations. With our dry steppe sub-soil and extremely deep-lying ground water one cannot count upon success in creating forest as thickly wooded as those in northern regions. A few ycars after the trees have been planted, owing to the extreme thickness of the interlaced roots, the reserve soilwater disappears, and as the atmospheric residue of water is insufficient the trees perish through drought in the deep soil layers.

Steppe arboriculture must be understood as tree-planting and the most rational way of undertaking it is to arrange the trees in one or two rows, not more. They are then able to benefit by the moisture from the belts of soil contiguous to both sides of the rows of trees.

Then it is necessary to bear in mind another circumstance: that trees, even if only a scant, single rowed plantation, minimise the injurious effect of wind, which acts so destructively on unprotected steppe growths. If the deep soil layer, which is out of reach of annual cultivated plants, has a paucity of water under tree plantation, all that water evaporates in to the air the humidity of which increases and at the same time increases the chance of rain.

In a word, *tree plantantion, but not in the shape of thick woods* shows itself to be a powerful weapon against drought.

With regard to A. Shishkin's method of accumulating water in the soil by means of open ditches, one must treat it as a theoretical consideration only for it is too expensive and therefore unattainable.

Amongst the others methods of fighting against drought A. Shishkin mentions:—„Establishing if possible connexion between the ground-water and the soil-layer" for the purpose of leading the ground water into the upper soil belts. It is scarcely necessary to speak seriously of raising the ground water on the steppe, where it lies at a derth of 140 feet and more and when the only possible way is by capillary action. Kembell's similar notion of capillarily raising, not the ground water, but the sub-soil water, will also not bear criticism, and is not confirmed by statistics. I shall not stay to analyse the capillary raising of water in the soil here in the introductive port of this work, but shall do it later in a chapter on the movement of soil-water.

Several authors [Golovkinski, Bliznin, Barakow and others] point to the consideration of watery vapour in the soil as a condition favourable to restrain or check drought. They consider that as a conseqnence of the fluctuation of temperature in different depth of the soil and the resulting change in the elasticity of the vapour thereby the latter condenses into liquid drops of water. Golovkinski in his experiments used a glass vessel which he buried in the soil; expecting that the accumulated water in the soil above the vessel would penetrate deeper and would be collected in the vessel. Water was, in fact, found in the vessel but as my experiment have proved this water came from condensation of the glass walls of the vessel and funnel placed above it: for in the soil belt nearest to the upper edge of the funnel there was no humidity, even approching a saturated condition, from which alone liqnid drops of water could trickle down. A. Lebedew brings certain statistics regarding water in the sandy dunes of Anapa [of North Caucasus] bnt whether this water was an atmospheric deposit or condensed from air vapour has not been proved experimentally. Even if vapour condenses into liqnid drops in the soil the process in very insignificant and in reality does not effect the balance of soil water. But it is possible in spring and autumn when on the one hand, the difference between the deeper belts and cooling of a'utumn and heating of spring on the other may be considerable that water may be precipitated and condensed on the boundary between them.

An analysis of these proposed measures of fighting drought has shown that they do not appear reliable and further that they do not clear up the nature of drought, the reasons of its frequent appearances and do not give solidity to the comprehension of the interdependence between the technical methods of agriculture and their effects on the water regime of the soil. The lack of sufficient statistics on the humidity of soil, or various methods of investigating soil-water in the root inhabited soil layers and as a consequence of this the ignorance of the laws regards the circulation of water in the soil made it difficult to gather deductions regarding the latter or which is the same thing regarding the phenomena of drought.

The Odessa Experimental Field has several thousand sets of statistics at its disposal got together in the course of 15 years. And this makes it possible, in my opinion, to get nearer to the truth.

II. The method of investigation *).

In every experimental investigation, method is the deciding factor; and the incontestability of the facts gained hereby, depend entirely upon the directness and the nearest approach to truth, of the method adopted. It is therefore necessary first of all, to consider the adaptatibility of the method, to the work before us.

In studying the humidity of the soil, investigations kept to the method of average quantities, in the first period of their treatment, of this question during the lact two decades of the past century; (A. A. Ismailsky and H. I. Bliznin amongst others.

By this method, evidence as to the state of soil-humidity may be obtained if a sample from a layer of soil of a certain thickness, be obtained in such a manner, that it shall contain a similar quantity of soil from all parts of the layer; which means, that a column should be taken from the soil, of a length equal to the thickness of the layer— from the surface to a depht of 10 cm., from 10 to 90, from 20 to 30, and so on, or from the surface to 35, from 35 to 50 cm. e. t. c.; and as the weight-should not particularly heavy—from 20 to 30 gram the thickness of the column should not exceed 1 or 2 m.m.

If the experimenters in this method. had made use of samples, taken from the vertical walls of open pits, they coold have taken an equal proportion from each layer at all levels and the samples would then, have held a similar quantity of soil from each horizontal depth.

But pit-digging comes expensive and takes up a great deal of time. So that instead of this inconvenient method of selecting samples, a soil-borer is used. Those investigators who adopt the method of average quantities use, for siqnificant thickness of soil-layer borers, wilh a long spoon or trongh, split down its entire lengtn of from 10 to 15 cm. The

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*) Here, thismatter is treated as briefly, as possible, but it i may be found, worked out in detail in my treatise. ,,The circulation of water in the soil of the Odessa experimental field", published in 1904 (the Journal of experimental Agronomy. Book VI), to which I refer all those, who are interested in this branch of my work.

soil borers of Voislava and Bliznina, belong to this type. They have however shown themselves to be utterly unsuitable, for the simple reason that soil enters the spoon in so promiscuous a fashion as to preclude any possibility of making an accurate partition of that which falls into the spoon, through the slit, and from which. the sample is obtained by cutting a certain thickness of the layer, the whole length of the slit. It may happen, that soil particles from only the upper and lower layers of the bored depth — or from only the middle impinge against the slit; in short there is not, and cannot be any assurance that an equal quantity of soil from all depths passed through, by the borer will get into the sample, through the slit. Therefore a sample selected from the spoon cannot be an average for the pierced depth; it may show a much larger or a much smaller proportion of water, than the average for the whole penetrated layer depending upon whether more soil, from the moist or from the dry strata, gets into the slit of the spoon. Another objection to the spoon--borer, is that it collects the soil in a very compact or compressed condition; and if the ground under investigation contains a large quantity of water, the compression of the soil will cause a part of that water to be pressed ont of it. This water will undoubtedly take the line of least resistance; which means, the slit of the spoon-borer. Therefore in a sample collected from the slit may be fomed water pressed ont of the whole circumference of the spoon, in consequence of which, a sample may be obtained containing a lot of water from a moderately moist soil. On the other hand firm ground, containing an insignificant quantity of water, will give a sample with still les water in it; for the friction caused by the spoon-borer in piercing firm ground, is so great, that it may be heated to 60 or 70 degrees, and this entails the loss of water, by evaporation in the whole circumerence of the soil, in, and surrounding, the spoon on every side, and consequcntly heated on every side. These two defects—the impossi bility of getting an average example from the bored depth, on the one hand, and the probability of always getting either an increased or a dimished quantity of water in the sample taken fromthe spoon on the other hand—condemn the use of the spoon-borer in investigating the humidity of the soil with anything approaching accuracy.

Thus the idea itself the method of arriving at average quantities of humidity in more or less significant layers of soil, turned out owing to the adoption of imperfect soil-borers, to be infeasible. Indeed, work carried out be this method has not cleared up the most essential factors of the water processes in the soil. The method of getting the average quantities of water in significantly thick layers of soil could not resolve the main qnestions of the balance of water therein, inasmuch as it could not deal with the limit line between layers having a plentiful and those having a meagre supply of water; and it involuntarily glossed over the characteristies of the distribution of soil water, which only themselves come out in the perceptible deviations of the contents of two, or more contiguous soil layers.

The sharper these deviations are defined, the more they explain the process of water distribution and it's circulation in the soil.

In order to explain these processes — distribution and circulation it is necessary to fix a point of observation frow whence these processes with all their modifications, may be kept in view for a long time.

These point of observation should be fixed at certain depths of strata in the ground in which, during the course of one or more years accurate estimates of the quantity of water are carried out from time to time, and if these layers are disposed as near as possible to each other as regards depth, then every variation in the amount of water they contain may be fixed accurately in the soil layer under investigation of horizons lying as near as possible one to the other these principles 9 have followed in my own work. I may add that in ieach horizons a layer of soil was investigated 1—5 c. m. in thickness. To take a sample from such a thin layer of soil with the spoonborer is not possible; therefore I constructed a soil borer of a special type which rendered it possible to obtain a vertical sample at any depth of the bored hole by means of a ringshapod cut in the walls of the hole. There also in the hole at the same depth, the sample falls at once, into a zinc box which only closes in the open air after having been taken out of the hole *).

The method adopted by me, during a period of one or more years, in investigating soil humidity, was the registration in a soil layer of 1 or 2 metres, of the amount of water contained in layers of 1 - 5 c. m. thickness at every 5 or 10 c. m. That is to say that layers from 5 to 6—5 c. m. 10 to 11,5 c. m. 15 to 16,5 c. m. and so on, were kept under observation. The registration of humidity was carried out on fallow land, both unmowed and under maize, potatoes, flax, pumpkins and castor plants, then, unber winter wheat, barley, oats and other grasses; on unploughed land lying fallow for many years.

The total number of estimates of moisture on the Odessa experimental field, amonut to about 60,000, and should show themselves ample for arriving at more or less precise results which have been confirmed in every case by the decisions of the control department.

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*) A more detailed description of my borer may be fonnd in my work „Circulation of water in the soil" Which also describes the whole technical side of taking a vertical sample and of drying it.

III. The laws of the circulation of water.

In order to explain the phenomena of drought. it is necessary to investigate the processes of water distribution in the soil previous to the droughe, and to keep them under observation during the period of drought. Undoubtedly this will be possible, if the laws of water circulation in the soil be established, both in superficial layers and in deeper ones, but accessible to the roots of plants.

Water circulates in the soil upwards, downwards and sideways.

As regards the circulation in an upwards direction, there exists a wrong impression, which our literature has almost made a household word. It is maintained that water can rise to the surface from the *deep* layers by capillary action. I shall not name the authors who maintain this theory—they are too numerous; but I do not know of a single author who could prove this proposition. Of course, by „deep" soil layers almost any measurements may be understood: 50 or 200 cm., 35 or 70 feet. But it must be admitted that deep layers, from which it is desired to raise water into higher ones, are those, the water of which is inaccessible to the roots of plants unless it be raised; if it were otherwise, there would be no object in drawing the water upwards, inasmuch as the roots would get at this water, if it existed in accessible layers, although perhaps not until they reached a somewhat late development. Consequently by the word ,,deep" must be understood those layers into which the roots of cultured plants do not strike.

The root-system of cnltivated plants and its role in the distribution of water especially its upwards movement bu the roots will be treated more fully below. As regards the mechanical raising of water however by capillary action it may be assured that the limit from which water can make its way upwards, lies much higher than the limit accessible to roots. All laboratorial experiments have shown that the upward movement of water in dry soil due to the mechanical composition of the latter, is comparatively very small for a given space of time—not more than a few centimeters in coarse sand, and from 20 to 30 cm. in very fine soil. In soil from the Odessa Experimental Field, sections of which were kept in glass tubes about 10 sq. cm., water showed a rise of 82 cm. in three months. But a rise of only 30 cm. was observed in sections of 900 sq. cm. (30 30) enclosed, in wooden boxes. Evidently, its circulation upwards by capillary action proceeded very slowly.

But it must be borne in mind that such a slow upward movement of water is observed only when the bottom of the pile of soil is sunk in the water, a condition scarcely ever observed in fields, where the ground-water lies comparatively deep. On the steppe for instance it lies at a depth of several tens of fathoms.

Direct observations of soil humidity, carried out on the Odessa Experimental Field showed, that in the course of 1½ to 2 months drought, a field with a compact surface void of vegetation, loses water in a layer not deeper than 30 cm. But in the deeper lying layers, commencing at 40 to 50 cm. no decrease of moisture was observed. And this period gave ample opportunity of seizing the phenomena accompaning drought, for a rainless couple of months is an actual drought in every sense. If a process of raising soil-water by capillary action from significantly deep layers, really went on in fields, it could, be determined or registered. And this could be done all the more easily if the humid layer diminished in thickness, for then it would be possible to affirm with confidence that the whole of the humid layer had been transferred upwards: and an impoverishment of water would be observed precisely in the lower belts of the humid layer. If such a process of raising or moving soil-water upwards existed in nature generally, it would not only be possible to verify it during a period of drought, but as a result of the action of roots: and in that case the absorption of water by the roots in the upper and middle parts of the humid layer should be reflected in the lower parts in the shape of a diminished ratio of water. But during the course of fifteen years observation on the Odessa Experimental Field no such facts have been brought to light; for when the ratio of water diminished in the lower parts of the humid layer, an impoverishment of the water in the middle and upper parts was simultaneously observed. Therefore the existence of a well ordered, simultaneous circulation of water at all thicknesses of the humid layer cannot be confirmed. It is only those layers into which roots penetrate that lose water, and the thickness of the impoverished and partially dried layer corresponds to the length of the roots in the soil; thus, if winter wheat be sown in a field under black fallow having stored up water in a layer of over two metres, there will be found by harvest time, an impoverished layer of from 120 to 130 cm.; for this depth is the limit required by the roots of winter wheat for their development (table I).

Table I.

Winter wheat on bare fallow ploughed 10½ in deep.

Depth in centimetres	October 5	November 3	December 4	January 5	February 7	March 4	April 4	May 3	June 6	July 1
5	19,2	7.2	20,3	18,8	20,5	20,2	16,3	10,0	9.1	13.8
10	20,4	11,3	20,0	19,2	20,4	19,1	16.6	11,4	10.1	9.8
15	19,9	15,6	16,5	18,4	20.7	19,4	17,7	12,3	10.5	9.7
20	20,1	17,3	19,7	18,0	20,8	19,0	18,3	12,6	10.8	10.6
25	19.4	18,4	17,8	19,3	20,6	19,2	18.6	12,4	10.6	10.5
30	18,8	16,5	17,1	20,1	20,6	18,7	18,1	12,5	10.7	10.5
35	18,0	17,1	17,2	18,7	20,0	18,2	17,6	12,6	10.5	10.4
40	17,5	16.4	16.7	18,3	19,3	18,4	17,3	12,8	10.4	10.4
45	17,3	16,3	15,5	17,6	18,5	17,4	17,4	13,7	10.4	10.2
50	16,8	16,3	16,0	17,2	17,9	16,7	17,1	13.0	10.4	10.4
55	16,8	16,4	15,9	17,3	17,2	16.1	16,8	13,2	10.2	9.9
60	16,9	16,1	16.0	16,7	16,4	16,1	16,7	13,7	10.2	10.0
65	16,7	15,5	15,6	16.5	16,0	16,0	16.3	14,0	10.3	10.1
70	16,7	15,9	15,8	16.0	16,0	16,0	16,9	14,6	10.3	10.3
75	16,1	15,3	16,0	15,6	16,1	16,1	17,1	14,2	10.6	10.6
80	15.8	15,1	15,9	15,4	16.3	15,5	16.6	14,1	11.0	10.8
85	15,1	15,3	15,4	16,0	15,3	15,8	16,6	14,2	11.0	10.8
90	15,9	15,6	15.8	15.8	15,6	15,5	16,1	15,2	11.2	10.9
95	14,8	15,6	15,6	15,6	15,9	15,5	16,7	15.3	11.4	10.8
100	15,3	15.4	15,9	15,6	16,0	16,2	16,4	15,6	11.5	11.1
105	16,0	15,3	15,4	15.6	16,0	15,5	16,1	15,7	12.4	11.4
110	15,8	15,5	15,5	15,2	15,7	—	16,3	15,5	13.0	11.6
115	15,7	14,7	15,6	15,2	15,5	15,9	15,5	15,5	14.0	11.6
120	15,5	15,4	15,3	15,4	15,8	15,5	15,1	15,7	14.8	11.9
125	14,8	15,5	15,0	15,5	15,1	15,4	15,2	15.7	14.8	12.4
130	15,4	15,1	15,0	15,4	14,5	15,1	15,0	15,5	14.5	12.5
135	15,7	15,0	15.1	14,9	15,0	15,0	14,9	14,9	14.1	14.8
140	15,5	15,3	14,9	—	14.8	15,0	14,7	14,6	14.1	13.7
145	15,4	15,2	14,8	15,0	14,8	15.0	14,9	14,0	14.0	14.1
150	15,6	15,0	14,8	14,8	14,8	15,2	14,8	14,5	14.1	14.2
155	14,5	14,9	15,0	14,7	14.8	14,9	14,8	14,0	13.8	13.9
160	14,7	14.7	14.7	14,6	14,8	14,7	14,9	14,3	13.9	13.8
165	15,5	14.6	14,5	14,3	15,3	14,9	14,1	13,9	13.7	13.8
170	15,5	14,3	14,6	14,0	15,0	14,9	14,6	13,7	13.3	14.1
175	15,3	14,2	14,3	13,0	14,6	15,0	14,5	14,2	13.4	13.5
180	15,4	13,9	14,4	13,8	14,6	14,7	14,2	14.9	13.1	14.0
185	15,6	14,4	14.3	13,7	14,3	14,7	14,1	14,1	13.0	13.4
190	15,3	14,5	14,3	13,6	14,4	14,6	14,3	13,9	13.1	13.1
195	15,2	14,3	14,1	13.8	14,1	14.7	14,5	13,8	13,4	13.5
200	15,3	14,1	13,9	13,8	14,3	14,5	14,3	13,9	13.3	13.5

How the process of the upward transference of water in the soil is carried on, under conditions of a non-saturated soil, and in the absence of an available sourse of water in the immediate vicinity that is to say whetber the water gets to the top in a liquid or in a state of vapour-it would be difficult to say with certainty in the present state of this question with its lack of precise evidence founded on fact.

But there is one consideration which tells in favour of the movement taking place in a state of vapour and not in the state of liquid drops. It is the following:—the so called capillaries in dry soil form an extremely irregular network of hollow spaces of various, size and shape. They do not resemble in any way those glass capillaries or tubes which are used for experimental purchases in the laboratory and with which they are usually compared. For the glass walls of these tubes prevent any air from entering from the sides, a condition which does not exist in the soil; and for that reason the condition of water circulation in soil contained in glass tubes will be different from that in the soil of open fields. In a strict sense, capillaries or „tubes“ as some authors call them, no more exist in the soil than they do—to give a familiar example—in a heap of small-shot of various sizes, which, with their interstices, may be compared to the soil.—When the soil is not fully saturated with water—and this is always the case in fields—a certain proportion of the interstices between the particles are filled with air. and the others with water; in consequence of which water is found in these interstices in the form of separate drops cut off one from an other by air. If under any circumstances whatsoever an upward movement appeared in a significant thickness of soil, that movement could only concern the more mobile parts viz: the air, which circulates in the free empty spaces not taken up by water—and the drops of water could remain where they are; or because of their weight sink downwards. All these considerations, and the absence of facts to the contrary, lead to the conclusion that an upward movement of water only goes on in soils saturated with water: whereas those in a non saturated condition suffer a loss of water wherever a drop lies, by evaporation in the air surrounding that drop. For this reason the loss of water in the superficial soil layer goes on very slowley even when the layer is in a compact condition, Campbell's system so much spoken of latterly, will not bear criticism in regard to its main thesis:—increasing the capillary process in deep soil layers and leading water from them up into those layers near the surface.

Compression with the subsoil roller causes the soil particles to adhere closely, expels the air from their interstices, at the same time satiating this compressed layer with water—and nothing more. It cannot be doubted that the conditions for the growth of seeds, sown on such a dense area, are improved thereby; inasmuch, as a certain portion of water can be actually squeezed, into the upper part of the compressed layer by intense pressure, and the seeds can benefit inmediately by this moisture. So that subsoil rolling is beneficial only just before the sowing of winter corn. As regards capillary raising of water from the deep layers, the less said about it the better.

On the other hand the constant movement of water downwards, both in the upper and lower, even in very deep layers, cannot be denied. In my treatise of the circulation of water in the soil *). I gave numerous examples of the downward percolation of water at big depths from 95 to 105 c.m. (3 cases) and an insigneficant depths - from 35 to 45 c. m. (2 cases), at a speed of 15 to 20 c. m. per month **) on old ploughed fields and twice as slowly on unploughed soil.

All the data at my command regarding moisture on the soil of the Odessa Experimental field, point only to one conclusion viz: *that water percolating beyond a depth of 40 to 50 c. m.* does not return to the surface except by *the way of roots; all the water not seized by the roots goes down into the deep layers,* moving at the rate of about 7 feet yearly. In order to verify this theory a pit was dug 1040 c.m. deep on unploughed land; that is on soil covered with vegetation. And as this pit lay in a hollow, where rain water collected but had no outlet, there was a certain surplus of water every year, which not being imbibed by the roots, percolated into deeper layers, as stated above at a speed of about 2 metres per year (table II). At 260 to 330 c.m. remains of the previous years 1903, water were fonnd and at 460 to 530 c.m. the surplus water which had percolated thither in the ccurse of 2 years (from 1902) previously. If it be taken into consideration that the extreme limit of the Superficial humid layer was fonnd to be at a depth of 130 c.m., then the foremost or leading part of the previous years (1903) humid layer should have been abont 330 c.m. deep but was fonnd at 330 c.m. The foremost part of the 1902 layer should have been about 530 c.m. deep and was found at that depth. In both cases the remains of each year's water have a distance of about 2 metres between them.

Therefore there is no doupt about the process of water transference from above downwards and its significant preponderence over the process of the supposed capillary raising of soil water to the surface. The formation of ground water goes on, not only at the expence of water oozing into the depths from ponds. hollows and snow water in planta-

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*) Circulation of water pp. 30 and 81.

**) Ditto page 32.

Table II.

Depth in centimetres	°/o	Depth in centimetres	°/o	Depth in centimetres	°/o	Depth in centimetres	°/o
5	14.0	210	11.4	610	11.9	1010	14,3
10	16.3	220	11.4	620	12.1	1020	14.2
15	17.0	230	11,6	630	12.1	1030	14.3
20	17.7	240	11.6	640	13.6	1040	14.3
25	18.1	250	11.1	650	14.4		
30	17.8	260	11.7	660	14.4		
35	17.5	270	12.4	670	14.0		
40	17.0	280	12.4	680	15.1		
45	16.3	290	11.8	690	14.6		
50	15.7	300	12.6	700	14.9		
55	15.7	310	11.2	710	14.7		
60	15.7	320	10.5	720	14.8		
65	16.0	330	11.5	730	14.4		
70	15.9	340	10.4	740	14.3		
75	15.1	350	10.1	750	15.1		
80	14.7	360	10.1	760	14.9		
85	15.0	370	9.5	770	15.1		
90	15.0	380	9.1	780	15.0		
95	15.0	390	10.1	790	14.5		
100	15.0	400	10.0	800	14.6		
105	14.5	410	10.4	810	14.8		
110	14.4	420	10.6	820	14.0		
115	14.1	430	10.7	830	14.5		
120	12.2	440	10.4	840	—		
125	10,5	450		850	14.4		
130	10.7	460	11.7	860	14.7		
135	10.4	470	11.7	870	14.1		
140	10.5	480	11.9	880	14.0		
145	10.6	490	12.7	890	14.0		
150	10.7	500	12.2	900	14.3		
155	10.7	510	12.4	910	14.3		
160	11.0	520	12.4	920	14.3		
165	10.9	530	12.4	930	14.7		
170	10.8	540	11.9	940	13.9		
175	10.4	550	12.0	950	14.0		
180	11.0	560	11.4	960	14.1		
185	11.1	570	11.9	970	14.0		
190	11.5	580	11.7	980	14.3		
195	11.2	590	11.8	990	14.2		
200	11.1	600	—	1000	14.4		

Table III.

8 pit-holes dug on lay-land at a distance of 35 centimetres one from another.

Depth in centimetres	I pit-hole	II pit-hole	III pit-hole	IV pit-hole	V pit-hole	VI pit-hole	VII pit-hole	VIII pit-hole
5	7.9	8.3	9.8	18.2	14.0	9.4	5.6	6.9
10	8.4	9.7	11.1	18.3	16.3	11.0	9.3	8.5
15	8.8	10.0	12.7	18.2	17.0	11.6	9.9	9.7
20	9.5	9.7	14.6	18.1	17.7	11.1	10.7	10.0
25	10.2	10.3	15.0	17.8	18.1	11.8	10.9	10.9
30	9.9	10.3	15.1	17.8	17.8	11.1	10.8	10.9
35	10.0	10.4	14.7	16.1	17.5	13.1	11.2	10.5
40	9.9	10.0	14.2	17.4	17.0	13.6	10.7	10.4
45	8.0	10.2	14.1	15.7	16.3	12.0	10.4	10.3
50	9.8	9.9	14.8	15.3	15.7	12.1	10.2	10.1
55	9.9	9.8	14.3	15.9	15.7	12.4	10.2	10.0
60	9.6	9.8	14.3	15.2	15.7	11.6	10.0	10.3
65	9.8	9.7	12.8	16.1	16.0	10.6	10.4	10.4
70	9.7	9.7	11.8	16.1	15.9	10.2	10.1	10.5
75	9.7	9.9	11.2	15.5	15.1	10.2	10.3	10.6
80	10.0	10.1	11.2	15.6	14.7	10.6	10.6	10.5
85	9.9	10.0	10.7	15.6	15.0	10.6	10.4	10.7
90	10.4	10.3	10.6	15.5	15.0	10.6	10.3	10.8
95	10.4	10.1	10.5	15.1	15.0	10.8	10.8	10.7
00	10.4	10.4	10.4	15.2	15.0	10.6	10.6	10.4
05	—	10.5	10.2	14.3	14.5	10.7	10.6	
10		10.4	10.4	14.3	14.4	10.6	10.5	—
115		10.5	10.5	13.2	14.1	10.8	10.2	—
120		10.8	10.8	11.0	12.2	10.8	10.4	
125		10.5	10.3	11.4	10.5	10.8	10.5	
130		10.8	10.0	10.7	10.7	10.8	10.1	
135		10.8	10.2	10.8	10.4	10.7	10.2	
140		11.0	10.2	10.8	10.5	10.7	10.0	
145		10.6	10.4	11.0	10.6	10.7	10.2	
150		10.5	10.7	11.0	10.7	10.8	10.3	
155			10.7	10.8	10.7	11.0	—	
160		—	10.1	10.8	11.0	11.0	—	
165			10.7	10.1	10.9	10.9		
170			10.9	10.8	10.8	11.0		
175			11.1	10.8	10.4	10.4		
180				10.8	11.0	—		
185				10.2	11.1	—		
190			—	10.2	11.5			
195				11.1	11.2	—		—
200		—		11.0	11.1			

tions, as A. A. Ismailsky imagines, but as will be seen below, preeminently from surplus water not used up by the vegetation on the surface.

Finally a third process of water circulation side ways, in a horizontal direction undoubtedly goes on. In order to elucidate this process, the following experiment was carried ont on the Odessa experimental field on a piece of waste land in August when the soil for a certain depth was dry. A fine jet of water (about 2 m.m. in diameter) from a wooden cask was by means of a syphon turned on to a certain spot for several days. Then, on a straight line drawn through the point to which the jet of water had been directed eight pit holes were dug at a distance of 35 c.m. from each other, and samples were taken from all the pitholes at every other 5 c.m. of depth. The following picture of water distribution was secured thereby.

At similar distances from the source of the water, in pit holes I and VIII a most layer at 25 to 35 c.m. depth was found. in II and VII from 20 to 45 c.m., in III—from 5 to 80 c.m. But in VI, which occupied an analogous position to III, from 5 to 60 c.m. In IV from 0 to 125 c.m., and in V—from 0 to 120 c.m. (table III).

And as there was a distance of 122,5 c.m. between the source of the water and the edges of pitholes I and VIII, and as the water percolated to a depth of 125 c.m. it is evident that water was imbibed in a horizontal direction on all sides for a distance equal to the depth of its percolation downwards. Consequently, water diffuses itself in the soil horizontally, with the same energy as it does vertically.

In conclusion I must admit that the propositions which I put forward previous (in 1094) regarding the circulation of water. somewhat differ from those conclusions presented by me now, which have been arrived at by subsequent evidence.

The real developement of „the critical horizon“ as I then called it, goes on precisely in that depth (50 to 70 c.m.) where the formation of a very large number of roots takes place; and falls in May or June, when the greatest number of roots are first developed.

Clearly fhe cracking of the humid layer at a depth of about 70 c.m. does not result from any cause of a mechanical character, such as the raising of water by capillary action, but simply from the absorption of water by the roots of plants.

IV. The root-system of plants and their role in the water regime of the soil.

It was stated above that the root-system of plants has an important significence in the water regime of the soil.

But first I shall deal briefly with the root-system of various plants, for without a knowledge of their dimensions and the distribution of small roots it is difficult to explain the water processes in the soil *).

The roots of plants develope very rapidly after the germination of the seed, and already in 7 to 10 days time after the appearance of the sprouts they reach 35 to 40 c.m. in our cereals, going far beyond the limit of the average ploughed depth. At the beginning of the bushing period the roots of spring cereals attain a depth of 50 c.m. (fig. 2) and towards the commencement of flowering the developement of the root-system finishes, or the growth of the roots after that to the attainment of maturity is insignificant. In the case of winter crops, a certain growth of the roots goes on in the interval between the period of flowering and the period of maturity (fig. 2).

This peculiarity the cessation of the root growth after flowering — distinguishes cereal plants from flowers and dictoyledons, whose roots continue to grow after flowering.

Then cereals have a second peculiarity. They have always three or more main roots (fig. 3) from which lateral roots branch off whilst dicotyledons have always one main root (fig. 4). Then the main root of cereals leave the root-head in a lateral direction, almost at right angles one to another, forming a polyhedrous pyramid; whilst the main root of dicotyledons grows vertically.

The limit to which the roots spread downward and sideways (the dimensions of the root system of various plants their length and lateral spread is seen on table IV) is very large towards the end of the vegetating period.—Spring cereals (fig. 5) reach a depth of 110 c. m. and

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*) A more detailed account of root-systems is included in my work „The root-systems of plants of one years growt".

G P L

	Kidney beans.		Trench beans.		Horse beans.		Su v
Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.
					18	18	
	15		15		40	18	
26	25		28		46	24	
30	40	28	35	12	48	28	
64	65	100	62	60	80	84	
64	96	104	85	60	110	84	
	9984		5100		9240		

	Winter plants								SPRING PLANTS											
	Winter wheat.		Winter rye.		Winter barley.		Vicia villosa.		Two-row summer barley.		6-row summer barley.		Summer wheat.		Local oats.		Canary oats.		Summer rye.	
	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.
At the appearance of the germs.											5	2	10							
7 days after.					6	6			35	10	25	22	20	20	20	20	20	16	12	
14 „ „					12	8			40	30	30	22	33	22	35	22	34	18	38	14
21 „ „					20	10	24	8	50	30	46	24	51	32	52	40	50	34	54	30
At the beginning of the budding period of herbaceous plants.	44	30	52	30	50	12			50	30	46	24	51	32	52	44	55	40	54	31
At the beginning of the earing period of herbaceous plants	82	60	84	64	115	100			110	90	98	66	103	74	90	86	107	54	107	60
At the beginning of the flowering period	100	78	90	74	120	110	105	96	120	90	100	72	103	84	107	86	107	54	112	60
At the beginning of the maturation period (milky) of herbaceous plants.	116	126	130	92	120	110	110	110	120	90	110	72	103	104	110	94	107	54	118	60
Root coefficient (the product of the length of the root by its diameter)	14616		11960		13200		12100		10800		7920		10712		10340		5778		7080	

	SPRING PLANTS																			
	Millet.		Setaria italica.		Black sorghum		Yellow sorghum		Maize.		Peas.		Kidney beans.		Trench beans.		Horse beans.		Summer vica.	
	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.
At the appearance of the germs.											—						18	18	10	–
7 days after.	20		10		10		15		10		15		15		15		40	18	22	
14 „ „	32	14	17	4			24		24	8	32	26	25		28		46	24	35	24
21 „ „	40	20	32	14	30	20	30	20	35	30	34	35	40	28	35	12	48	28		
At the beginning of the budding period of herbaceous plants.	45	34	50	24	64	76	63	60												
At the beginning of the earing period of herbaceous plants	95	110	75	82	110	80	106	110												
At the beginning of the flowering period	105	110	80	92	110	80	106	110	112	134	92	64	65	100	62	60	80	84	92	80
At the beginning of the maturation period (milky) of herbaceous plants.	100	110	106	92	110	80	106	110	113	134	92	64	96	104	85	60	110	84	110	90
Root coefficient (the product of the length of the root by its diameter)	11550		9752		8800		11660		15342		9568		9984		5100		9240		9900	

	SPRING PLANTS																			
	Lucerne		White poppy.		Flax.		Camelina sativa.		Sunflower.		Castor.		Cotton.		Potato.		Beet.		Cucumber.	
	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.	Depth.	Diameter.
At the appearance of the germs.									10		15	14	10	4						
7 days after.	—				17	2	10	2	32	18	46	32			20	20	5		12	—
14 „ „	10		20	—	25	6	25	10	38	36	50	36	20	22	25	22	15	12	20	
21 „ „	25		27	12	40	16	38	24	77	62	53	54	44	50	30	28	29	18	25	16
At the beginning of the budding period of herbaceous plants.													—							
At the beginning of the earing period of herbaceous plants																				
At the beginning of the flowering period	92	76	102	80	77	50	84	68	140	120	107	100	72	90	60	100			41	50
At the beginning of the maturation period (milky) of herbaceous plants.	125	76	102	80	105	64	104	96	145	120	120	100	95	104	60	100	146	110	105	84
Root coefficient (the product of the length of the root by its diameter)	9500		8160		6720		9984		17410		12000		9880		6000		16060		8820	

Fig. 2. Barley (Hordeum vulgare genuinum.) at the bushing period.

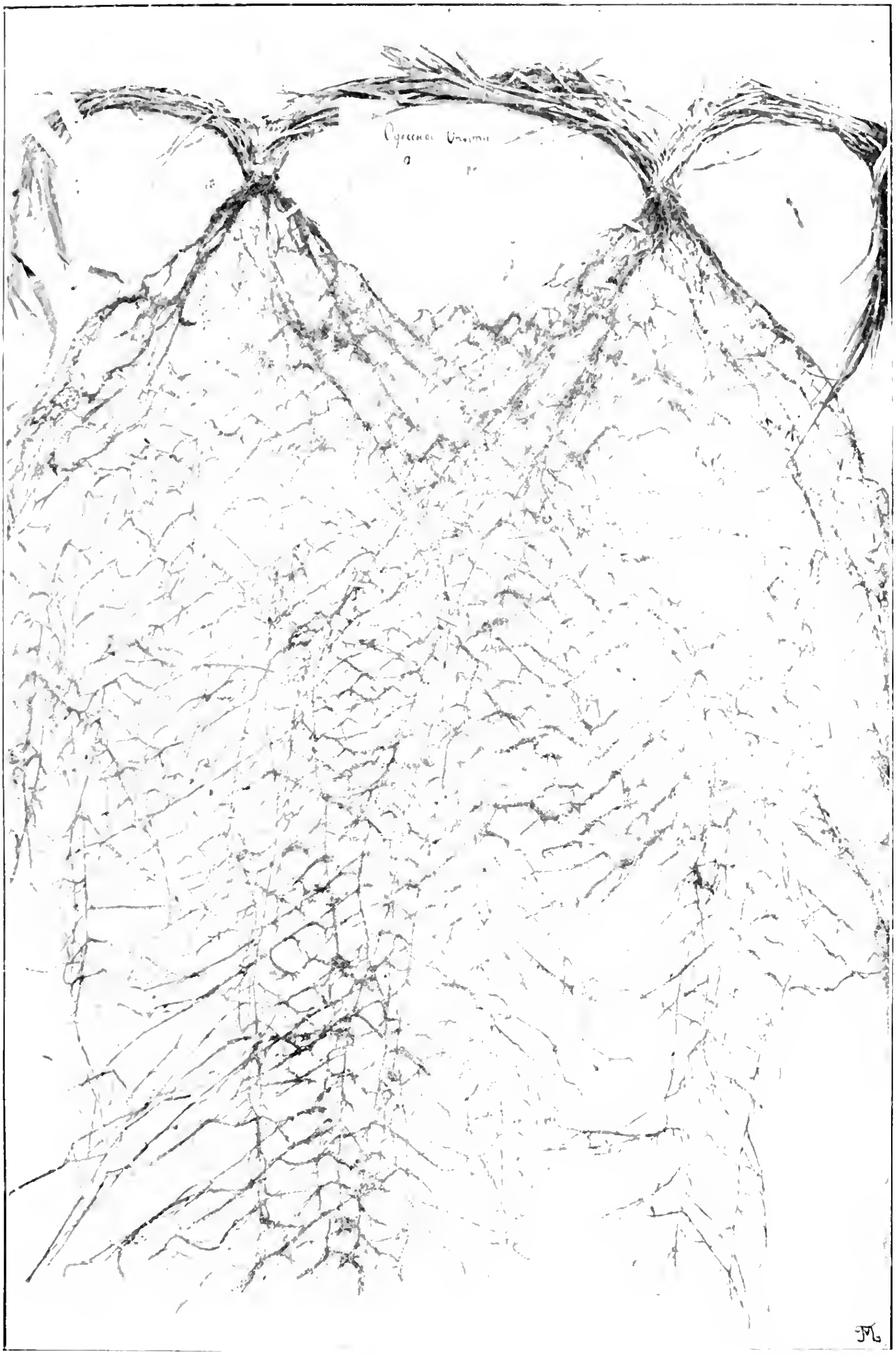


Fig. 2. Barley (Hordeum vulgare genuinum.) at the bushing period.

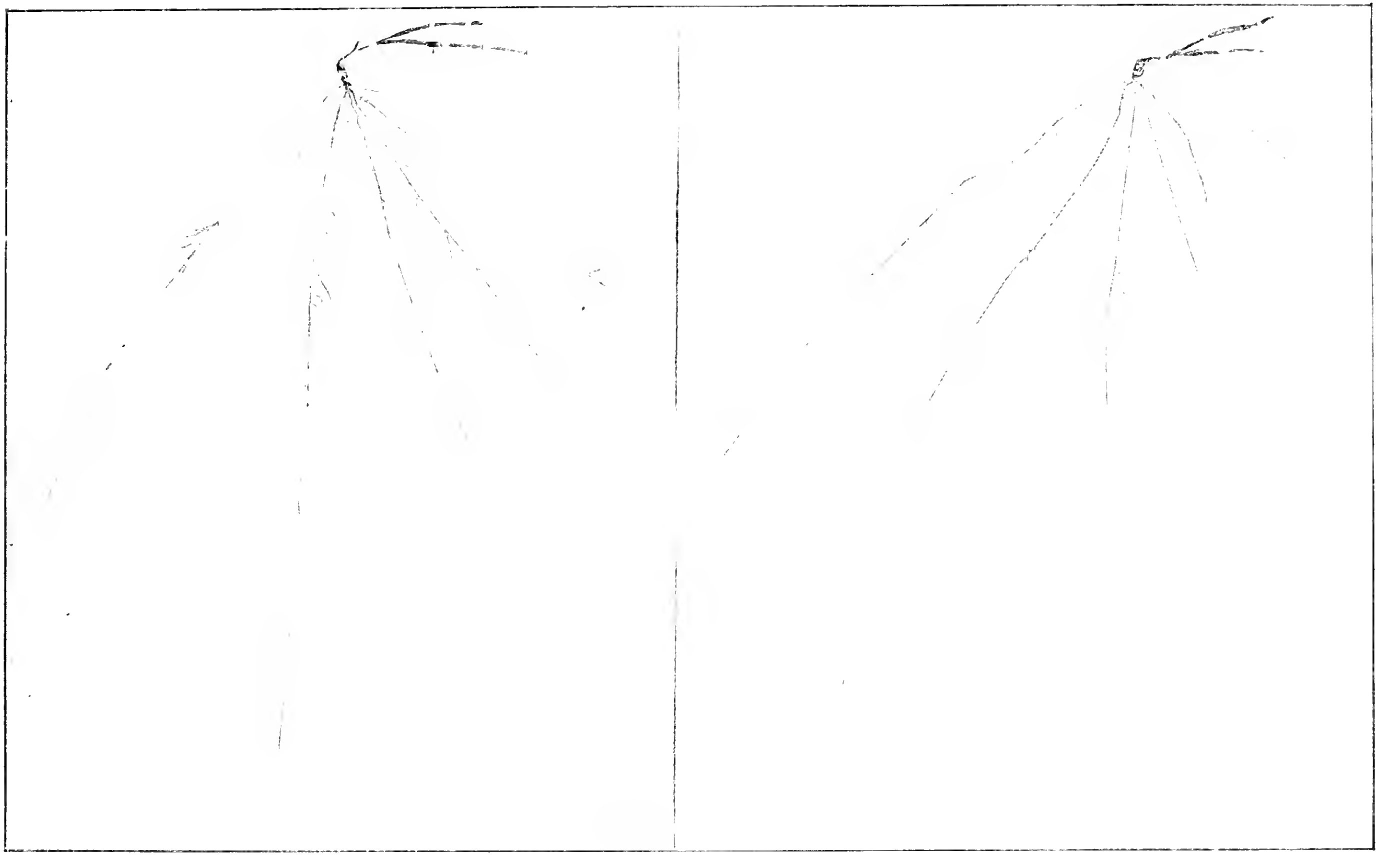
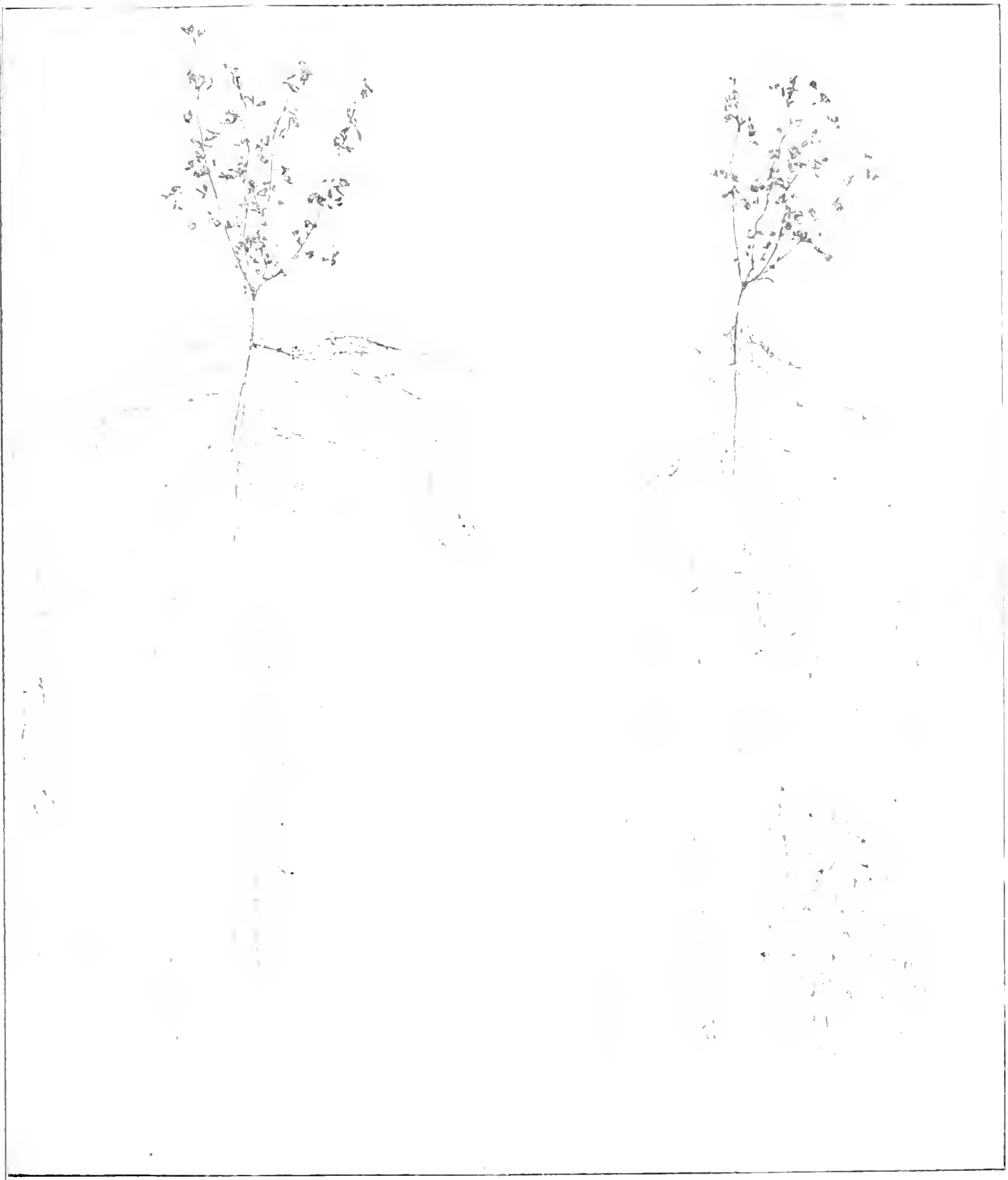


Fig. 3. Barley of 7 days' growth.



On blacksoil. *On sandy.*

Fig. 4. Lucern in the 1-st year before flowering.

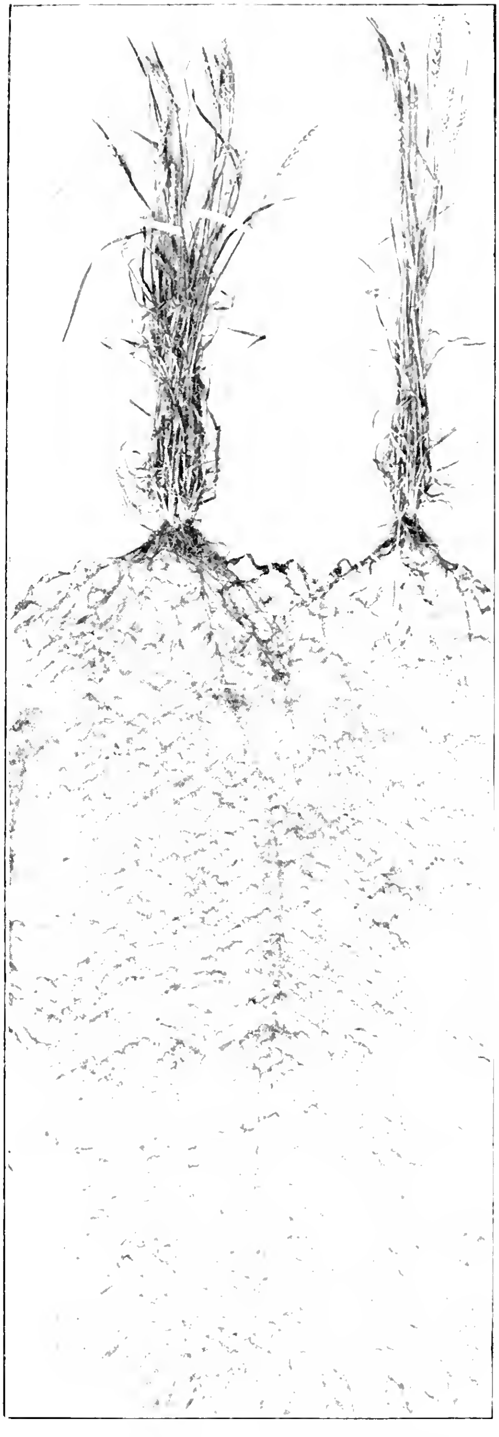


Fig. 5. Summer wheat „Ulka" at the beginning of period of maturity.

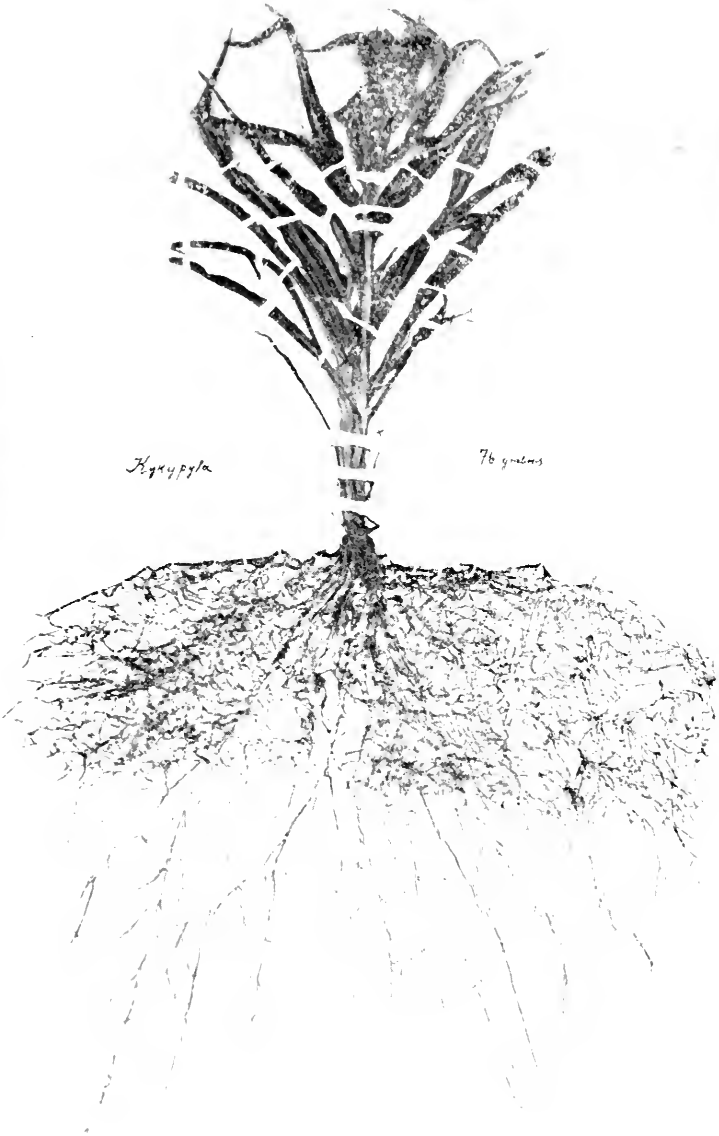


Fig. 6. Maize of 76 days' growth. The upper half of the root-system is reared on very humid soil, the under on somewhat dry. (The hydrotropism of the roots).

On blacksoil. On sandy.

Fig. 7. Peas after the period of flowering.

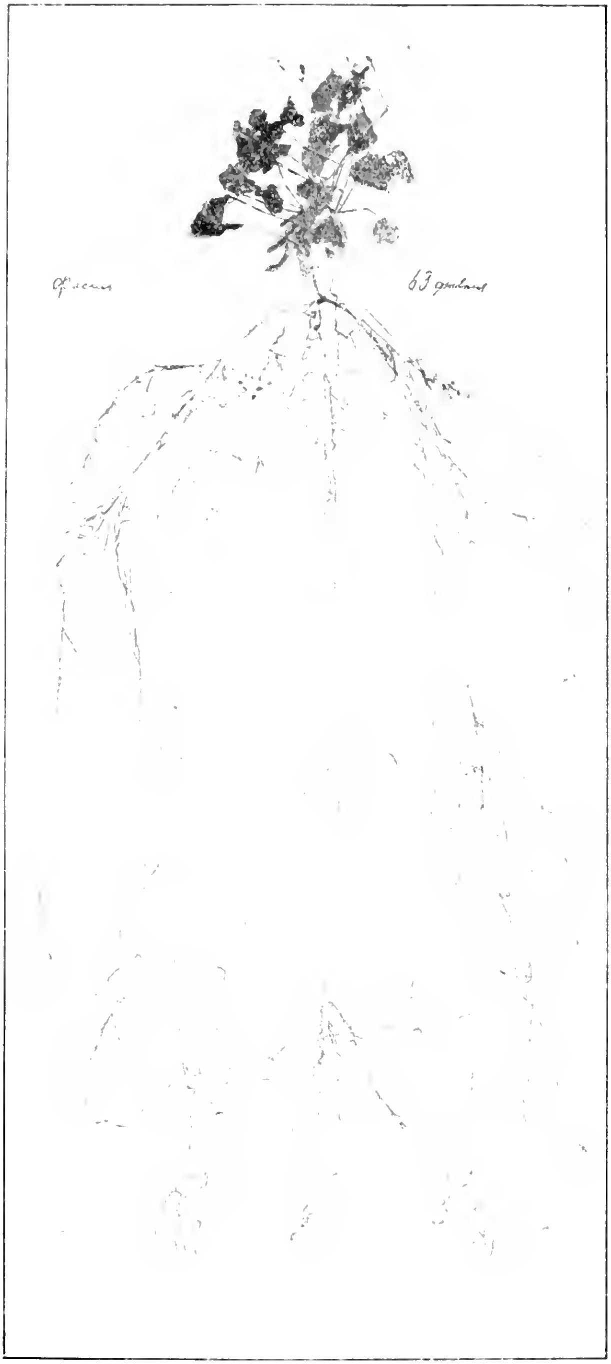
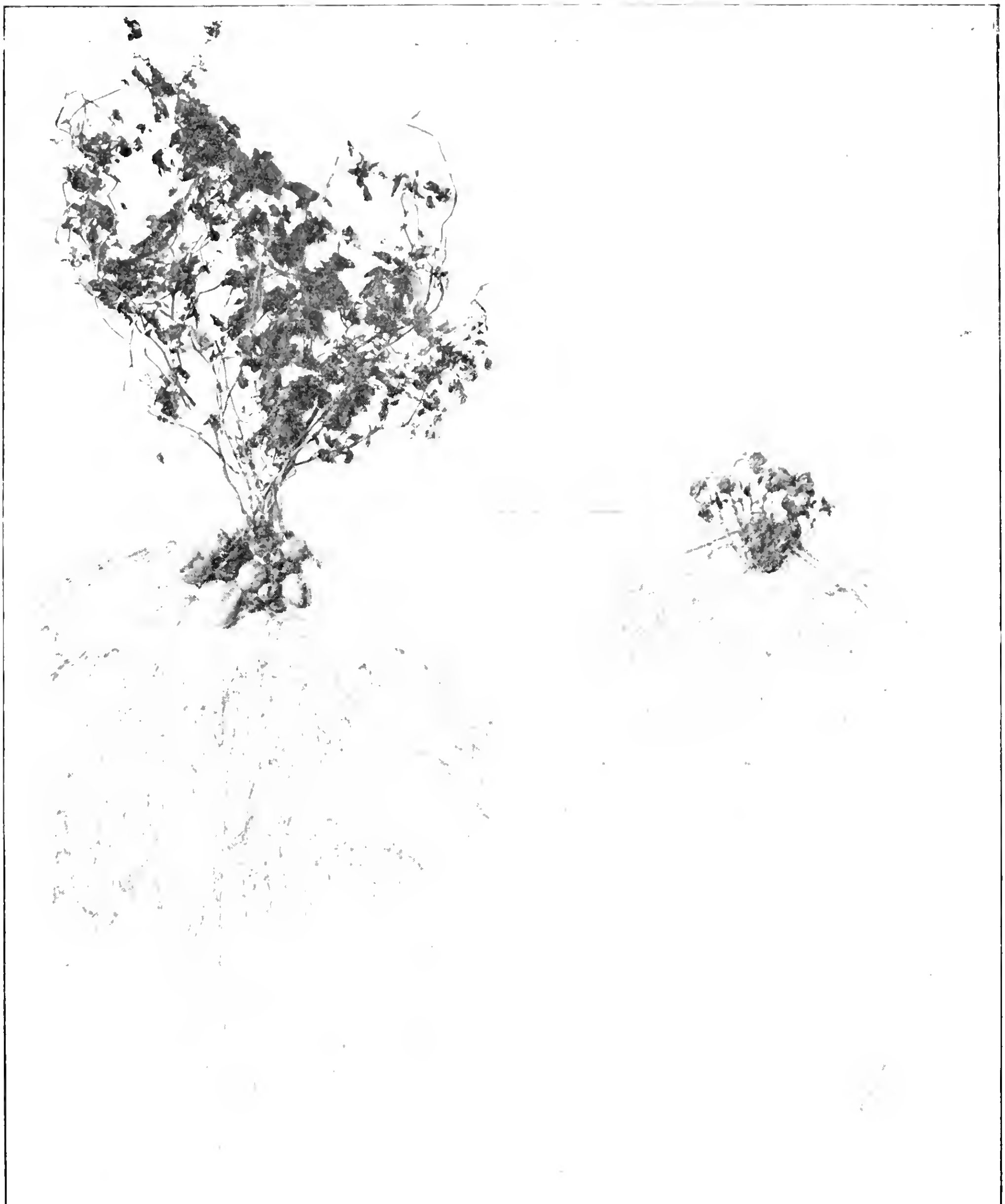


Fig. 8. Beans at the period of fruit-bearing.



At the period of fruit-bearing. *Of 7 days' growth.*

Fig. 9. Potatoes.

spread out to almost the same extent. Maize is an exception, for its root-system is greater in width (up to 150 c.m.) than in length. The root system of winter cereals is longer than that of spring cereals and reaches 130 c. m. (rye). Then in wheat it is flatter from top to bottom, and in rye it is stretched lengthways, Amongst dicotyledons, sunflowers and beetroots haee very long root-systems (over 4½ feet): others like flax, cress, poppies, peas (fig. 7), beans (fig. 8) and cotton have very short-ones (about 100 c.m.); potatoes (fig. 9) very short (about 60 c.m.)

Cereals (fig. 5) have a much denser root network than dicotyledons (fig: 4 and 7) which have a comparatively weakly developed root-system, especially flax with small roots of the 2-d, 3-d and lower orders. It must be noted here that *the thickness of the root network* is almost *equal throughout the soil layer which they occupy*. But small roots are always deuser in that layer which holds the most moisture whether it be the upper, intermedeate or lower part of the root-inhabited layer (fig. 6).

Perennials like green fodder, shrubs and trees extend their roots several fathoms deep, sometimes over 10; green fodder, like lucerne, send their central root down to 8 even 10 fathoms; laterally the side roots do not extend beyond 60 or 80 c.m. The side roots of trees extend from the central one to 5 or 6 fathoms, the white acacia (Robinia pseudacacia) even to ten fathoms.

These morphological properties of the roots of our field plants must be kept in view in order to understand the role played by them in the distribution of water; for the principal, almost the only factor in that distribution, is the root-system (as regards soil layers deeper than 50 c.m. at any rate). The denser the root network of a plant, the easier it will be for that plant to find water of course. But plants with a weakly developed root-system, like flax and cress, must have at their disposal a plentiful supply of water. This apparently explaius the preponderating culture and independent growth of grasses on dry steppe areas, for their denser root network can abtain the requisite quantity of water with greater facility.

The data worked out by me last year concerning the depth penetrated by the root-system of various plants of not less than 110 c.m. (3½ feet) for certain others much deeper—indicates that in order *to obtain an abundant harvest the root-inhabited layer* of soil should be moist throughout and should hold a sufficient quantity of useful water; that is of water which the plants can benefit by. It must not be forgotten that a certain quantity of water is contained in various soils which roots cannot make use of. The finer the soil, the more useless water it contains, and in certain types of soil it exceeds 10%.

The roots of cultivated plants cannot make use of this water, therefore in considering the percentage of water containd in the soil, this factor must always be kept in view, for the figures „12%“ may really mean that in a given soil the useful water amounts to only 10, 8, 4 and even 2%.

The soil on the Odessa experiment field holds about 10% useless water and in the following statements the serviceable water will be principally taken into account; that is, the quantity of water over and above 10%.

In studying the laws of water circulation and the role played therein by the roots the following consideration must not be lost sight of. Uoung soots hold so much water (80% and more) that their growth is only possible where there is liquid water, and the more frequently the tips of the rootlets meet with water drops in the soil, the more normal will be the growth of the root. Therefore the ideal surroundings for roots are those where all the interstices between the hard particles whether of soil, chaircoal or other matter, are replete wixh water. Then the root-covers will meet with no difficulty at any point in obtaining water and the growth of the root will be continuous.

Now suppose that the interstices of the soil are not all filled with water, but that some contain air, as stated above. The more frequently such vacuities are met with the more difficult will be the growth of the root; and it may happen that the distance separating the drops of water is too great for the growing tips of rootlets to traverse, without the aid of the requisite water on the way. Developement in the growth of the root will cease; and if many roots of the same plant happen to be in such a dry vicinity their developement as well as that of the whole plant will cease or the growth may proceed more slowly if the rest of the roots find water. And the oftener any part of the roots of a plant finds water, the better will be the developement. For that reason the whole root-system of a separate plant may show a far from equal developement in all its parts. The hydrotropism of roots (fig. 6) is met with on our dry steppe soils in a very severe form.

All the stages of this process may be found in the same soil: part of the roots may find themselves in an horizon saturated with water; further on, air gaps may be met with at intervals; then, more frequently, but small in extent and interrupted, spaces filled with water drops; then only a few drops of water dispersed simply or several together, in a fairly large area of soil; and lastly we find no drops of water at all in the soil but only that which has adhered to the upper surface of the soil particles in the shape of an extremely thin layer. In the last instance we have useless water; for when the tip of a rootlet comes into contact with it, the rootlet itself is so replete with water, and the area of contact between rootlet and the soil particles is so small, that the water cannot be imbibed. If the air between the soil particles becomes ever dryer the water adhering to them will evaporate and leave the soil bone dry. In arid steppe country, both the soil and the plants grown thereon suffer every year from all the above mentioned stages regarding conditions of moisture. All these inter-relations between humidity of the soil and plants are supported by facts in the following statements; where, out of numerous statistics at my disposal, I shall only cite those observations relating to the yearly soil water regime of fields sown with barley, winter wheat, maize, and potatoes, on waste land, pasture, etc.

V. The yearly water regime in the root-inhabited layers of the soil.

The root-inhabited layer, taking into consideration the depth penetrated by the root-system, is for certain plants like potatoes and flax equal approximately to 2½ feet (70 to 80 c. m.) For others like sunflower and beet-root about 4½ feet (150 c. m.). But for the majority of cereals it is about 3½ feet (100—120 c.m.). On the Odessa experiment field, experiment fixed the soil layer at 7 feet (200 c.m.), that is, the horizon lying deeper than the root-inhabited layer was also investigated.

The observations showed that the root layer became more humid or got dryer according to the time of year and the quantity of atmospheric deposit. I call it *the periodically humid layer.* Under it, to a depth of 160 to 180 c. m. is fonnd a layer which is almost constantly in a dry condition—or only contains useless water—and which I call *the intermediate dry layer.* And finally, under this layer, begining from a depth of 160 to 180 c. m. lies the *permanent humid layer,* containing 2 to 3% in the upper and 7 to 8% in the lower horizon, of useful water and extending to the ground water.

When the intermediate dry layer moistens and the soil becomes moist from the surface to the ground-water we get an *uninterrupted moist layer.*

The diagrams illustrating the yearly course of soil humidity have been drawn up from tables, printed in the reports of the Odessa experiment field*)

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*) In all the following diagrams the unshaded parts denote dry soil without any serviceable water, but with about 10% of useless water. Soil containing 1 to 2% of serviceable water is shaded a light grey colour, and 2 to 7% dark grey. In general the presence of useful water is shown on the diagrams by grey shading of various depths; the more water, the darker the shade. There are also several blended deviations from the normal course, arising out of some accidental feature of the spot from which the soil sample was taken.

The periodically or upper humid layer.

Many years observation of soil humidity on the Obessa Experiment field, permit the following principle deductions to be made.

Every year, at the end of fune or the begineng of july — and with a dry spring season at the end of may—our cereal grasses consume all the reserve water which has accumulated in the whole thickness of the root-inhabited layer (110—150 c. m.) *during autumn, winter and spring;* that is to say, that towards autumn no useful water remains in reserve for the following year or for the subsequent cultivated plants, when grasses have been grown on the soil. The submitted diagrams (10, 11, 12 and 13) show this clearly. Thus diagram 10 shows the early course of soil-moisture sown with barley (in 1905). The accumulation of water in the superficial layer commenced from november of the previous (1904) year. By winter the thickness of the humid layer had attained 35 c. m. and remained so the whole winter because the whole layer froze and the water was in a rigid condition and consequently could not shift its position. After the frost, from the end of march until the end of april the water sunk downwards about 10 c. m. and the layer attained a thickness of 45 c.m. which constituted almost a third of the soil-layer neccessary for the normal developement of the root-system of barley. As we know, from what has been already said about the developement of root-systems, the roots of barley reach a depth of 50 c.m. 31 days after sprouting; and as the barley was sown in 1905 at the begining of march, its roots had already penetrated the whole humid layer by the end of april. Notwithstanding, the growth of the roots ceased at a depth of 45 c. m., or a little deeper, because the root-tips theu reached a dry layer void of serviceable water. To make up for this, the barley increased the developement of its lateral roots in the upper and more humid layer. The increase in the quantity of roots is such an insignificant soil layer as 50 c.m., instead of a normal 110, must have involved an increased expediture of water in the humid layer. In fact, by the middle of may the reserve of useful water was exhausted neither a light nor a dark grey shading is to be seen in the periodically humid layer. The plants must have perished in the absence of rain but during. the period of vegetation (81 days) there were 39 falls of rain giving 68,4 m.m., out of which there were 6 useful ones of from 5 to 10 m.m. With a sufficiently thick humid layer and such a plentiful supply of watery deposit there should have been a good crop; but the thinness of the humid layer produced another effect;—the crop barely ripened by reaping time (2-nd june) and was very poor - about 30 puds (98 s-t). Palpably *the thickness of the humid layer in spring at seed time is of final importance,* if there is not plentiful rain later on. And so by the middle of may

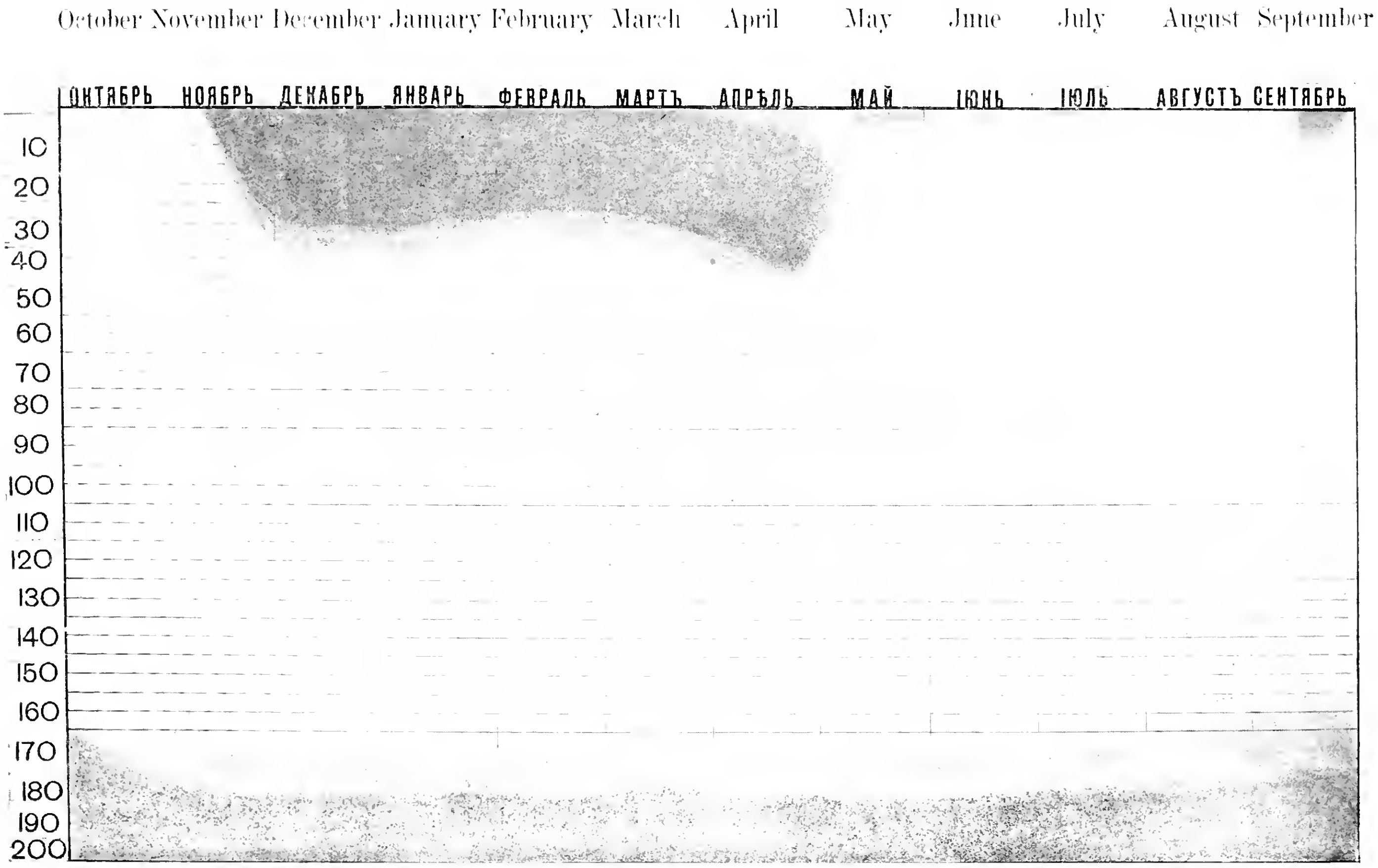

Fig. 10. State of soil humidity on a field of barley, year 1905.

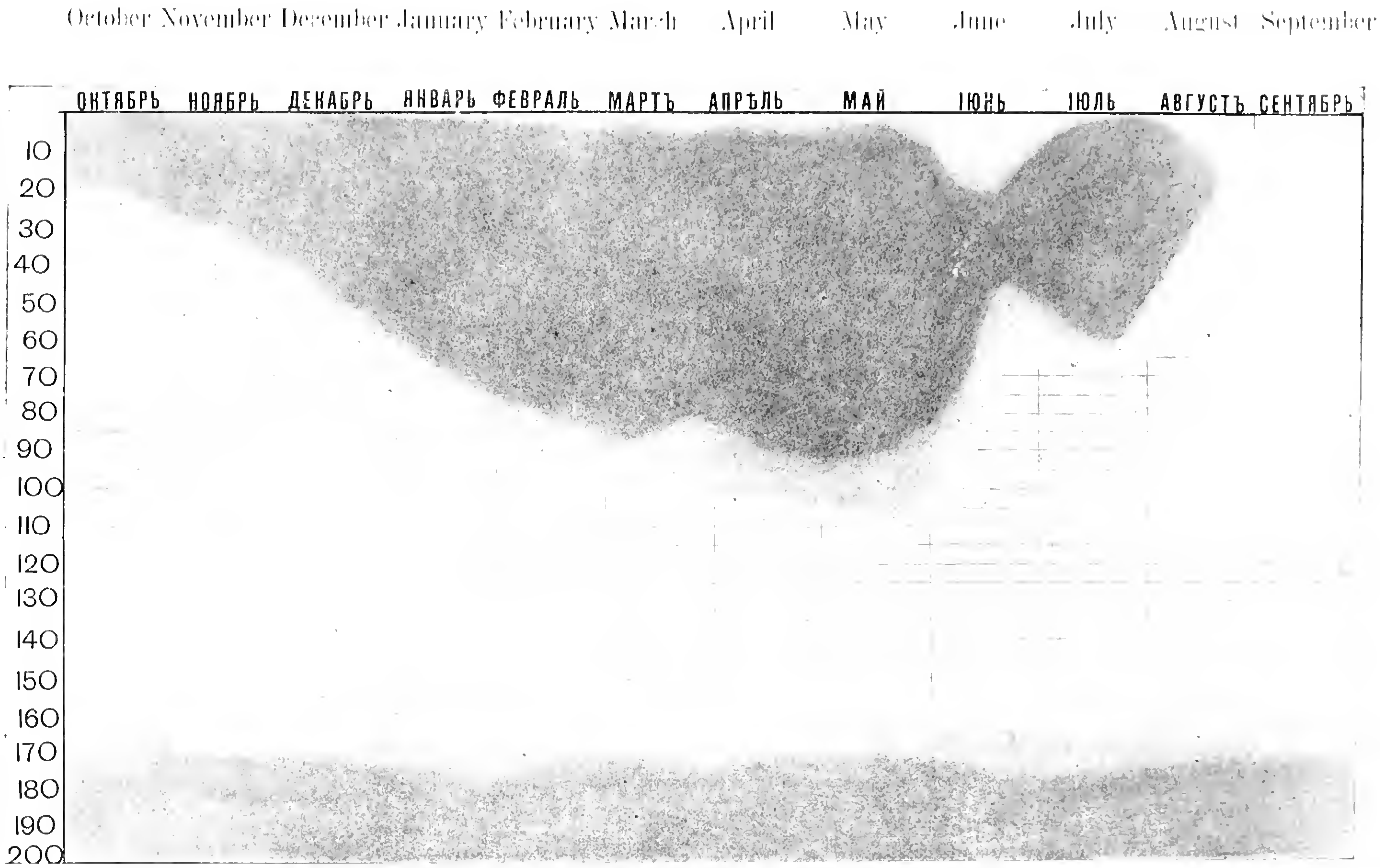

Fig. 11. State of the soil humidity on a field of barley, year 1906.

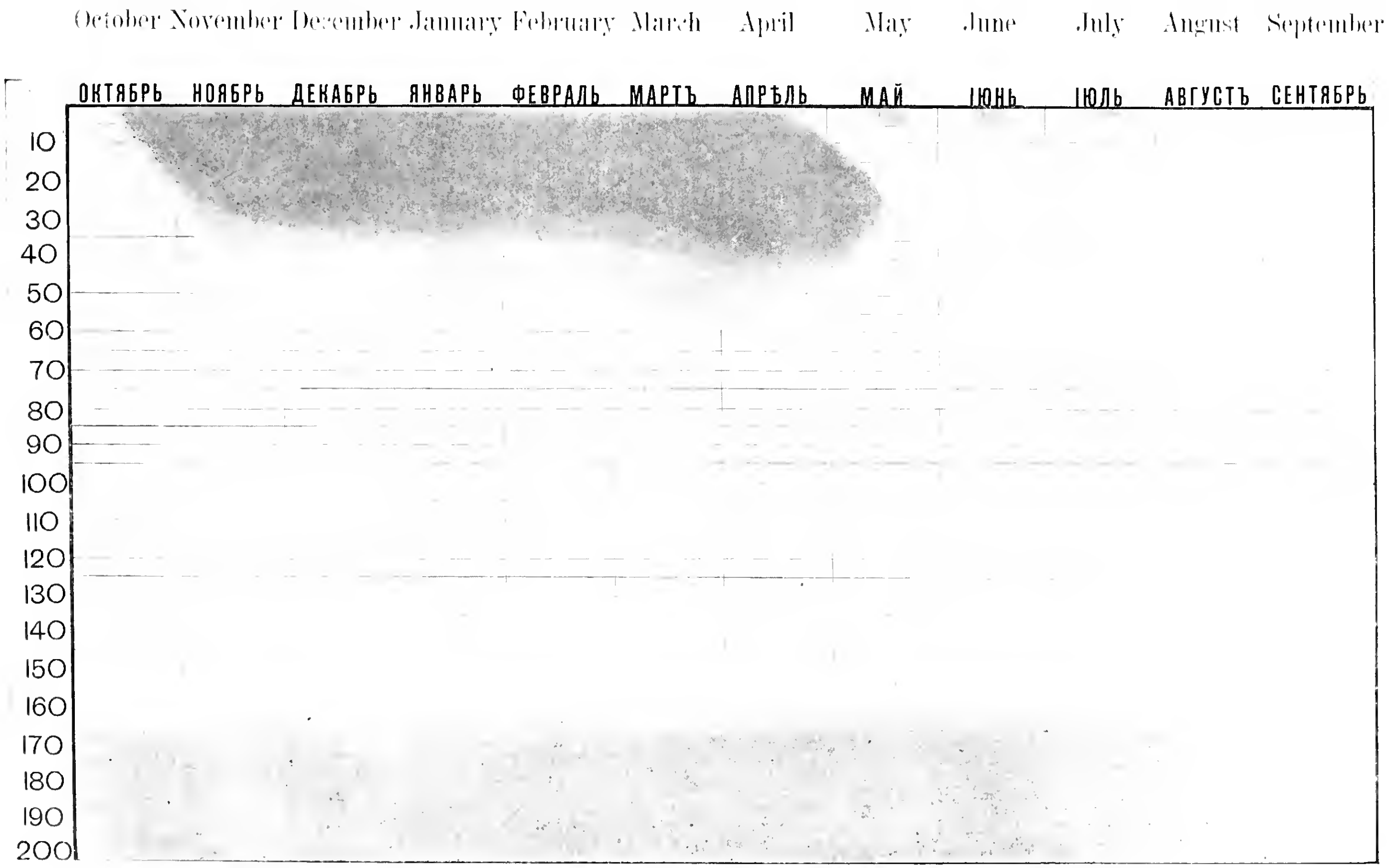

Fig. 12. Midsummer (june) green fallow in 1905.

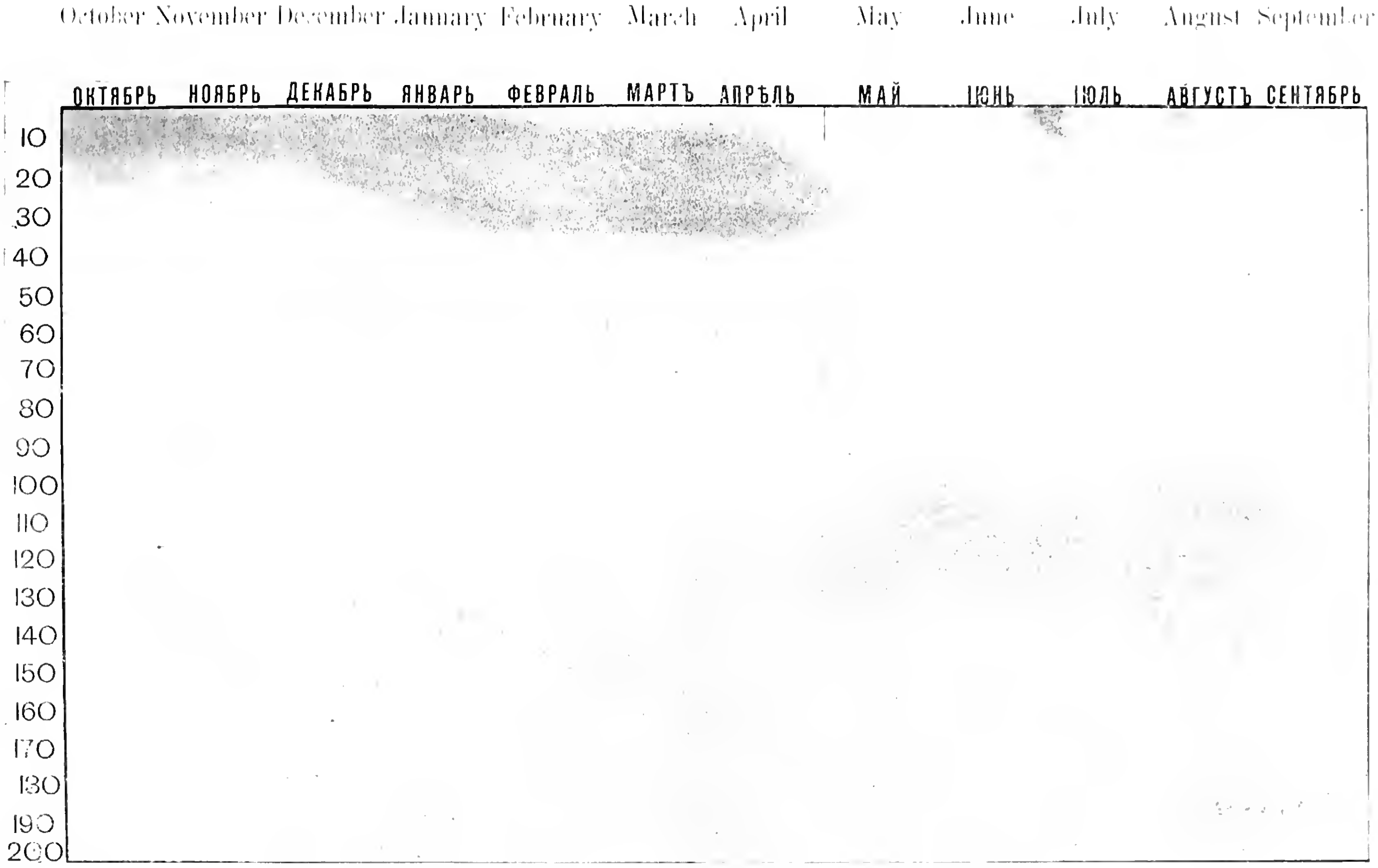

Fig. 13. State of the soil humidity on a field of winter wheat in 1902, sown after barley.

the soil was denuded of all its reserve of water in the root-inhabitable layer.

There were also other cases analogous to the above (see fig. 11, 12, 13). The downward movement of the water (fig. 11) did not cease from october to april, because the soil was not frozen up during winter deeper than 40 c.m., and water contined to percolate into the layers deeper than 40 c.m. up to april. But by that month the roots of the barley sown on the 25-th of february 1906, had already penetrated to such a depth that they took up even the lowest horizon of the humid layer and the percolation of water into deeper layers ceased by the end of june; *and at the period of reaping all the reserve water in the root layer was expeuded.*

In the next instance (fig. 12) we have to deal with wild instead of cultivated plants – intermediate (june) green fallow in 1905. Here also the accumulation of water, or, which is the same thing, the thickness of the humid layer commenced in the previous autumn of 1904. During winter the condition of the humid layer remained unchanged owing to the whole layer freezing up and the water becoming solid and immovable. Although the lowest horizon of the humid layer reached a depth of 100 c.m. in may 1906 (fig. 11) and only reached 45 c.m. in april 1905, nevertheless, in both cases, *no surplus of serviceable water remained,* at the begining of july. In both cases (fig. 11 and 12) the water was consumed by cultivated and wild plants. It is evident therefore that as regards the consumption of water *there is no difference between wild and cultivated plants. By midsummer all the reserve of serviceable water in the root layer is utterly exhausted.*

It is not only spring growths that entirely consume the whole of the useful water by the end of the period of vegetation. The same is observed in the case of winter growths. In fig. 13 the state of humidity is depicted on fields sown with winter wheat following a crop of barley (rotative culture) and after black fallow (fig. 14). In both of these cases the reserve water in the root layer is expended by reaping time.

Maize (fig. 15) impoverishes the reserve useful water somewhat later that grasses—not before august.

Potatoes (fig. 16) and flaxx stand out quite separately from all cultivated annuals at least from those investigated by me. As short-rooted plants, they do not require a deep layer, and from 1 to 2% of useful water remains in the soil after their maturity in august.

On diagram 17 the yearly course of humidity in the soil of waste land in shown as observed from year to year. Usually the humid layer here, in spring, is not thicker that 40 or 50 c.m. and often about 30 cm. Towards midsummer it gives up all its useful water to the roots therein and then remains dry until autumn. But what is particularly inte-

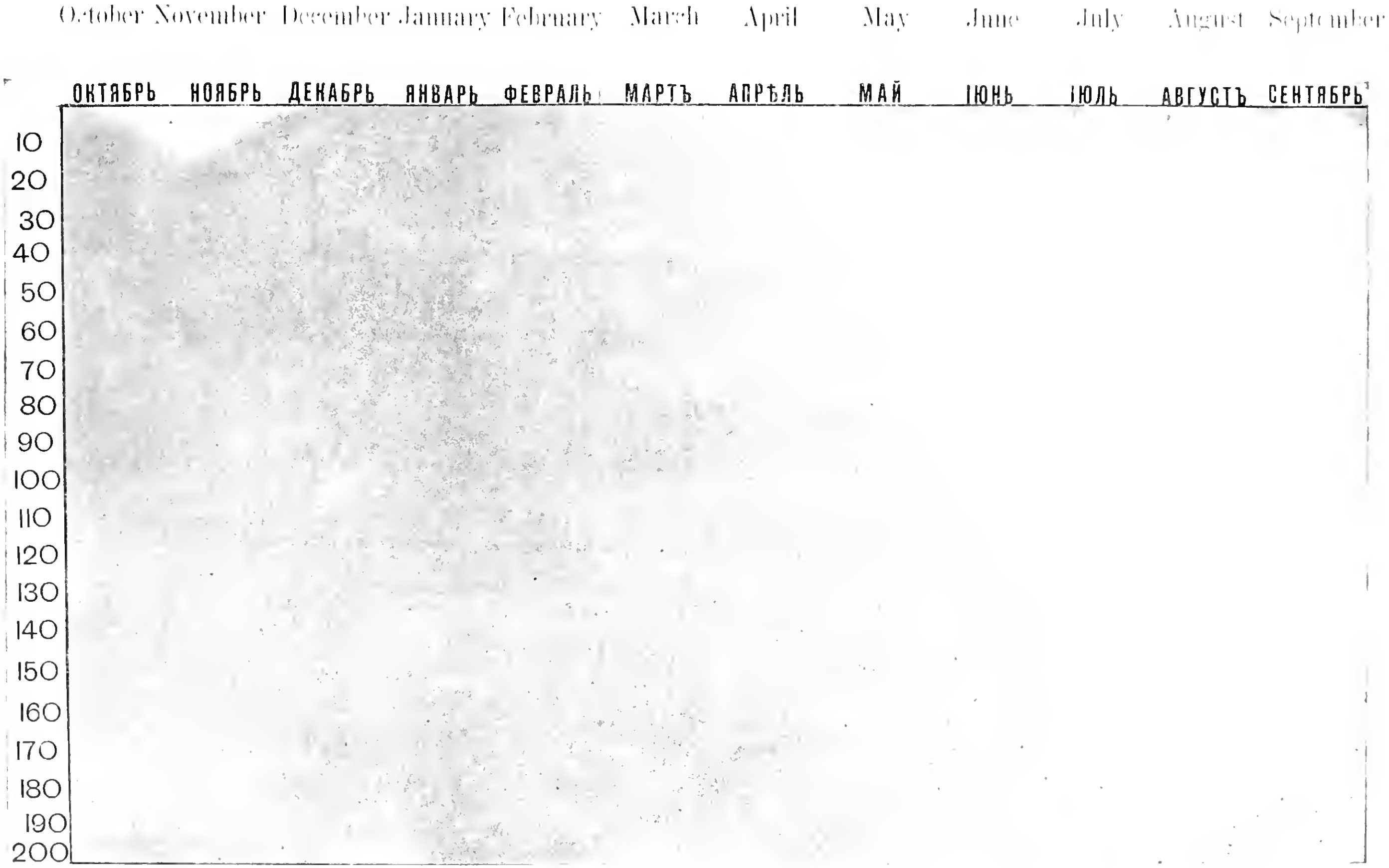

Fig. 14. State of the soil humidity on a field of winter wheat in 1902, sown on black fallow

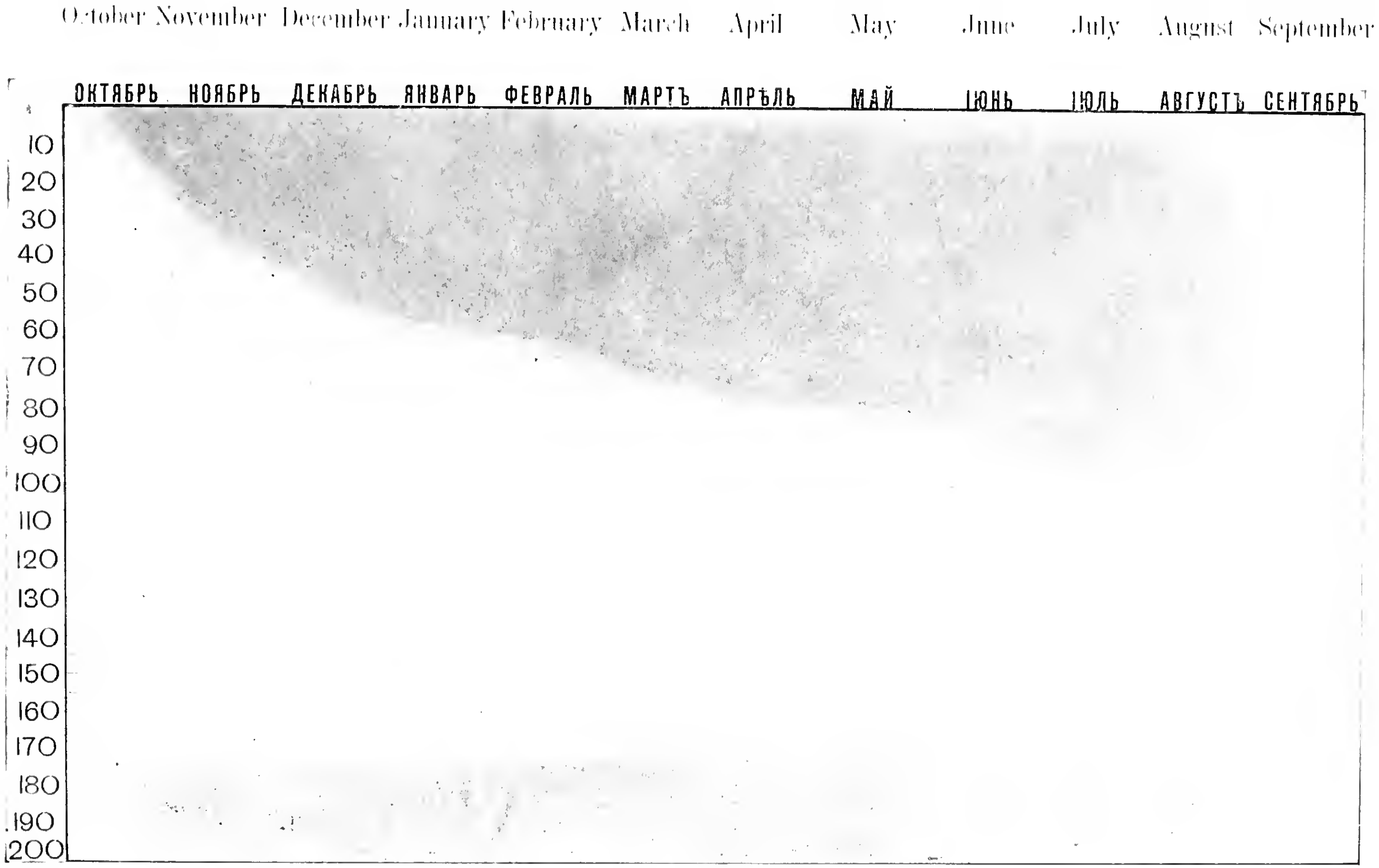

Fig. 15. State of the soil humidity on a field of maize in 1906.

resting is this: that below the humid layer on old ploughed soil lies as we saw before, a dry layer, which however contains about 10% of water (useless). But on waste land this dry layer (shown on the diagrams by vertical lines) has only 6 to 8%, that is to say it is much poorer in water than the old plougled fields. Comparing the two cases the course of humidity on oldploughed and waste land—we see that in the former case the humid layer is thicker and the underlying dry layer holds more water. Consquently, *the yearly balance of water in root-inhabitable layers of waste-land is undoubtedly less than in old ploughed soil*, and that is the defective side of leaving fields to lie fallow, as a remedy against drought. For this old-fashined point of view is diametrically opposed to the truth. The tillage of virgin steppe does not encourage drought, but minimizes it, changing waste land into old ploughed land with its larger yearly balance of water. Therefore *it must be admitted that allowing a field to lie waste for several years is injurious to irrigation.*

The permanent humid soil layer or lower humid layer.

On old ploughed fields (fig. 10 and others) at a depth of 160 to 180 c.m. (4½ to 5½ feet) the permanent humid layer commences, which holds a certain quantity of useful water—about 1,2 or 3%—all the year round. It extends without interruption. to the ground water, on our steppes to 140 or 175 feet. On waste land the permanent humid layer lies far deeper than on old ploughed land about 14 to 30 feet. The permanent humid layer on old ploughed land is shown at the botton of the diagrams by grey shading, but on waste land it is not noticed even at a depth of 240 c.m.—This simple fact—the layer lying at several fathoms on waste land and at a few feet on old ploughed land shows that the depth where the permanent humid layer lies is not constant; and the more the farmer endeavous to accumulate water in the soil, not by letting the land lie idle, but by its culture, the nearer, the permanent humid layer will get to the surface.

The intermediate dry layer *).

Between the upper humid layer of soil, periodically moistened by atmospheric residue on the surface, and the lower permanent humid

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*) H. N. Visotzkii calls this layer „The dead horizon of dryness", but we cannot agree to this title, for, as we shall see later, one year under black fallow would make the soil „alive" and habitable for plant roots. The role of the intermediate dry layer is only mentioned by H. N. Visotskii as iar as it concerns forest growths.

layer, lies the intermediate dry layer, containing only about 10$^0/_0$ of useless water which is not shown on the diagrams. If the upper humid belts have not got into the proper condition required of a normal root-inhabiting layer (110 to 140 c.m.) the roots developing therein always meet with an insurmountable barrier, the intermediate dry layer; for they cannot penetrate into this dry sphere void of useful water.

We saw above that the most essential factor for a good crop of annual plants, whose root-systems do not reach so very deep (100 to 150 c.m.) is the thickness of the humid superficial layer. Perennials—clover, shrubs, trees—differ is that respect. Their root-system must penetrate several fathoms deep in order to enable the plant to develope normally.

If the intermediate dry layer is injurious to cultivated annuals, preventing full developement of the under ground parts when the upper humid layer is less than the root-inhabited layer and the root-system, cannot develope normally, then the effect of the intermediate layer on perennials is to exclude every possibility of their culture. Annuals may develope luxuriously if their root-inhabited soil layer (to 150 c.m.) is moist. Perennials, which develope their root-systems during many years, extending them for several fathoms, must have moist soil in the whole of the depths they penetrate. And if they meet an intermediate dry layer in consequence of which their roots (the upper lateral roots turn downwards after several months and do not differ in size from the main roots) cease their growth, the lateral roots commence to increase their developement. The humid layer gets crowded with a network of side roots which rapidly consume the reserve of useful water and by autumn the whole root-inhabited layer dries up-the plant neverthelless continnes to vegetate weakly far into autumn.

In the following spring the strongly developing lateral roots commence early to exhale large quantities of water and by the end of may or the begining of june all the reserve water is expended. Thus the plant, in the second year of its existence, has to live through the hottest summer period, when useful water is absolutely necessary owing to the heightened process of evaporation, in soil which has become dried up. Usually the plant cannot outlive this period and perishes.

The systematic failures experiences in cultivating perennial edible herbs and trees in dry steppe places can only be explained thus: that these plants are treated under conditions only suitable to annual plants.

A perennial plant cannot satisfy itself with the upper humid layer above; it must be able to stretch out its roots into the lower permanent humid layer which, uninterrupted by dry belts capable of arresting the farther downward progress of roots, extends to a depth sufficient for the roots of

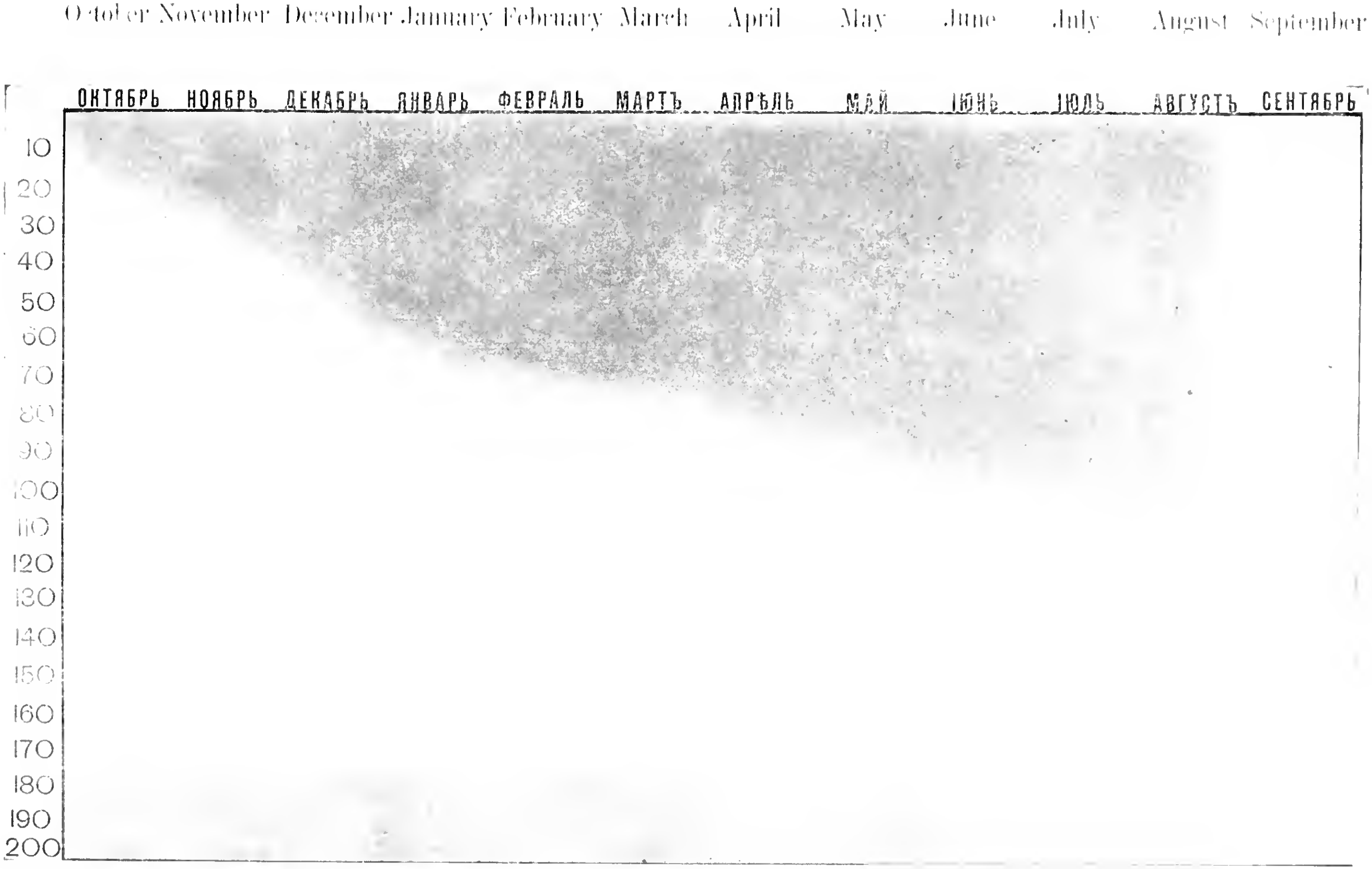

Fig. 16. State of the soil humidity on a field of potatoes in 1906.

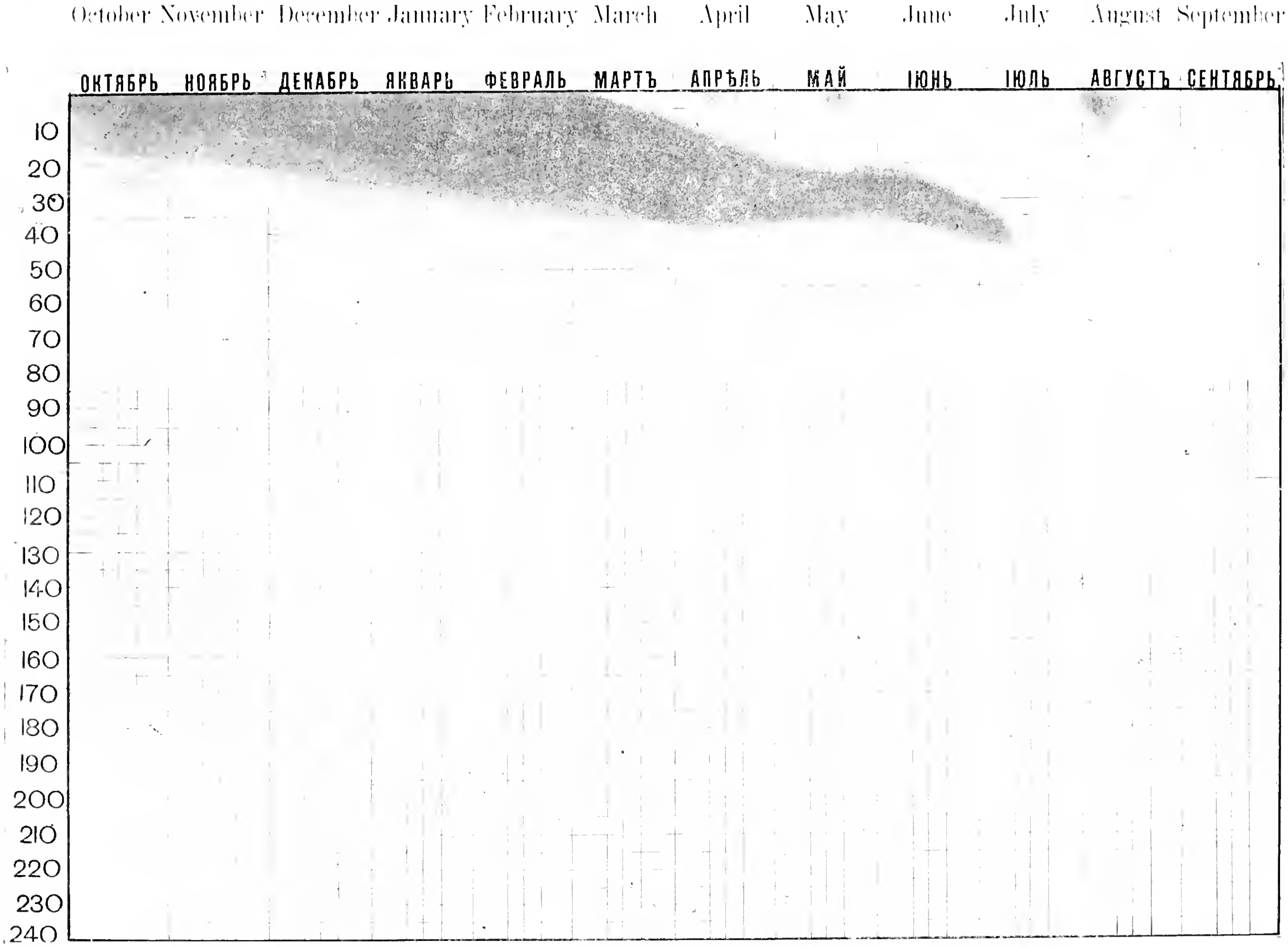

Fig. 17. State of the soil humidity on waste land in 1902.

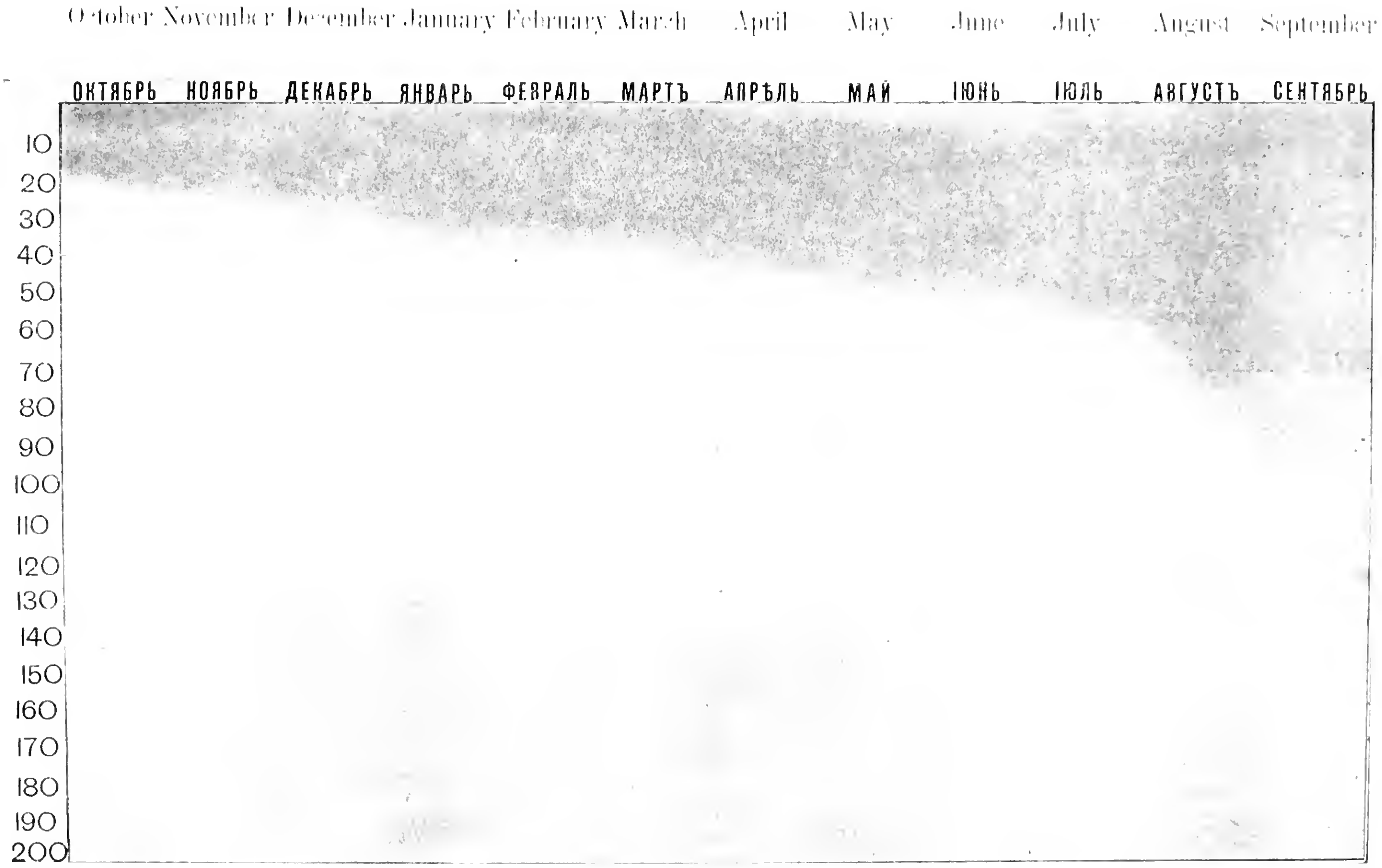

Fig. 18. State of the soil humidity on black fallow in 1902.

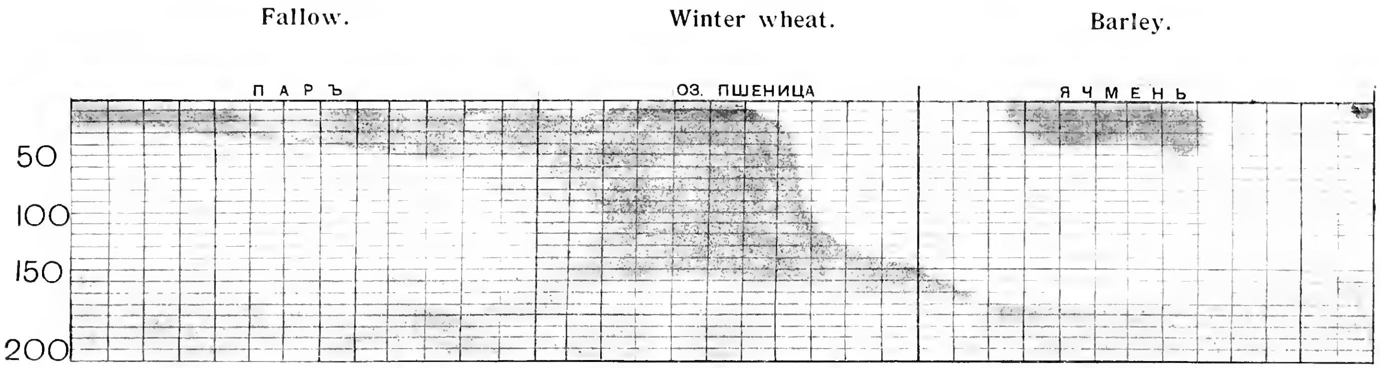

Fig. 19. State of the soil humidity by three-field's alternation of sowing seed: on 1) Black fallow, 2) Winter wheat, 3) Barley.

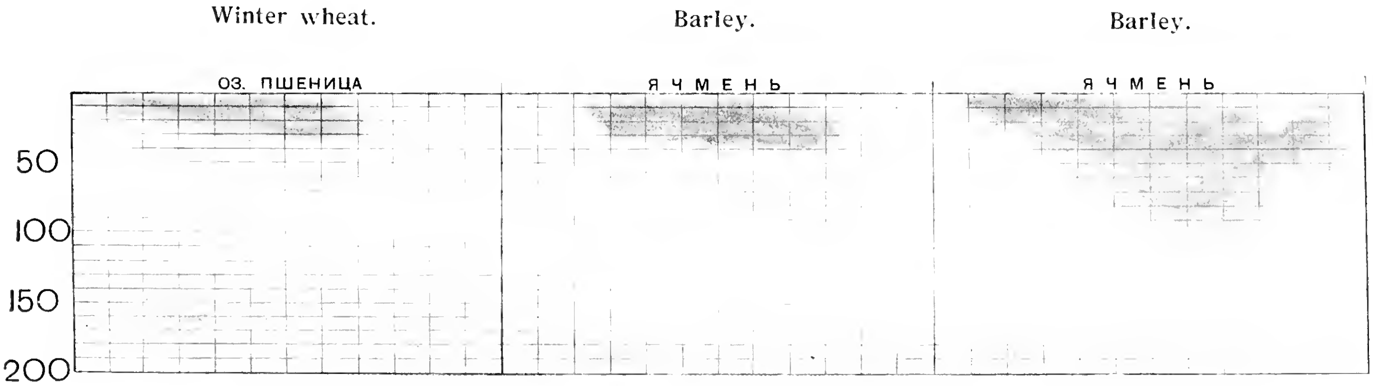

Fig. 21. State of the soil humidity when under uninterrupted culture of cereals.

perennial plants. However between the periodically upper and the permanent lower humid layers, there usually lies the separating intermediate dry layer. And in order that the roots of Perennials may reach the permanent moist layer, the intermediate dry layer should not be there, or it should be also moist. Therefore *the normal condition of existence for perennials require that there should be a humid layer at their disposal as deep as the whole length of their root-system.*

The permanent humid layer.

There is but one way of getting sid of the intermediate dry layer or, which comes to the same thing, of moistening it; and that is by leaving the field in clear black fallow. On fig. 18 the course of humidity on black fallow is shown.

Here the accumulation of water in the upper layer also commences in autumn, as it generally does on all fields under wild or cultured plants. From spring onwards the soil water percolates deeper and deeper until, by auntumn, the period of sowing winter corn, the thickness of the upper humid layer may become so great that the intermediate dry layer gets humid through, upper and lower humid layers meeting and running together. In that case the soil will contain a certain quantity of good water, from the surface to the ground-water, and we get an *uninterrupted humid layer* (fig. 18—in september).

In such a continuous layer, roots of perennial plants will find good trickling water in all its depth, which it will be able to penetrate whether it be 3 or 70 feet.

But it may happen that the water accumulated under black fallow does not sink into the lower permanent humid layer during the first year and that there still remain the intermediate dry layer between the humid ones. With an average years precipitation the upper humid layer will not be less than 100 c.m. ($3^1/_2$ feet) and the lower one will commence from a depth of 160—180 c.m. as we said before. Therefore the dry layer remains towards winter about 60 to 80 c.m. During the winter the water will percolate deeper even in a certain depth of the upper humid layer freezes. If the percolation goes on only at the minimum rate — 10 c.m. per month the upper layer will reach the lower one in the course of the winter and towards the beginning of spring will form a continuous humid layer. In very moist years, which to tell the truth, are comparatively rare here, the atmospheric residue does not accumulate in large quantities in a thick layer of soil, but soaks though a very thick layer of 130 to 150 c.m. In such a year the soil find's itself in the same state of saturation as it does under black fallow.

Therefore the role played by black-fallow in dry steppe localities is of the highest importance, because it is only by its application that deeper soil horizons, even those inaccessible to the roots of perennial plants, can be made moist.

These horizons inaccessible to annuals having received water, hold it and form a permanent humid layer. Than water sinks deeper than the root-inhabitable layer in wet years, whatever plants are under cultivation; and it does the same in average years as regard moisture, when certain plants like potatoes and flax are cultivated. This surplus of useful water percolating beyond the limit of the root-inhabited layer goes towards the formation of a permanent humid layer.

VI. The appearances of drought.

Having become acquainted with the laws of water circulation in soil under various technical modes of culture such as leaving fields in clear black fallow, green june fallow, waste land, and then under culture of various plants, we shall proceed to examine those concrete cases where plants are exposed to drought, and must inevitably face its.

A temporary scarcity of water in the soil, affecting plants and holding back the normal course of their life processes, is what is known as drought. But the scarcity of water in soil does not only depend upon a small quantity of atmospheric residue (rain dew etc).

The farmer way lose many of the advantages of the falling residue principally in the form of rain-through bad management: the adoption of an incorrect mode of tilling the soil when preparing it, for sowing or when attending to plants, an unsuitable rotation of crops, one after another, and finally an irrational organisation of the whole farm.

We have already seen that leaving fields lying waste, gets injuriously upon their state of moistness. By spring, only a small thickness of layer is moistened, and the expediture of water increases from the beginning of the vegetation period. Naturally the extremely compact surface of waste fields prevents water from accumulating therein, for a considerable portion of rain-water runs off the slopes and declivities. And it must be remembered that the same quantity of rain falls on waste fields as on the neighbouring ploughed ones.

It may be seen from the following figures, that insufficient advantage taken of the falling residue, may have a great deal to do with the appearance of drought. There falls in the sonthern governement of Russia from 320 (the western part on the Black Sea) to 400 mm. of residue per year. If we exclude a third of this quantity (about 30%) such as small deposits which evaporate quickly from the soil, and certain fractions which run off the surface without being absorbed we have still remaining not less than 150 mm. which enters the soil and may be used by cultivated plants. Bearing in mind that 1 mm. gives 650 poods*) of water to a dessiatin**)

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*) Pood = 36,11 pounds.

**) Dessiatin = 2,70 acres.

and that the development of one pood of dry mass of the crop in bulk—straw and grain—requires on an average about 400 poods of water (according to Haberlandt about 375) for its growth then from every millimetre of residues we should get 1½ poods of crop, and from 150 mm.—about 225 poods. Spring cereal give twice as much straw as grain (roughly estimated, although barley give about equal quantities ot each) therefore an average crop of 225 poods schould give 75 poods of grain. Such schould be the average fertility of spring cereals in our southern governements if the whole of the water entering the soil is taken advantage of. Nevertheless, the average fertility according to statistics equals about 40 poods. Evidently, the cultured plants do not get the benefit of the whole of the water. As the height of the crop in our southern governements depends exclusively on the quantity of the water in the soil, the deficiency in the harvest must be attributed to the farmers bad use of the soil water which was at his disposal and of which he did not take full advantage.

Let us see how the accumulation and expenditure of water goes on under the various combination of farming—the various alternations or rotations of crops.

We will take the simplest cases: a three-course rotation on bare fallow, a four-course rotation and a free course of cereal cultures exclusively. From these combinations many other rotations may be tormed, arranging them to pit in with the diagram of the yearly course of soil humidity.

With a three-course rotation (fig. 19)—bare fallow, winter and spring corn—the humid layer gets so moist during the fallow course, that when the winter corn is sown its roots, which as we have already seen in rye (130 c.m.) are longer than spring corn, can develope to a full normal length; for they do not meet the intermediate dry layer in the whole of their expanse.

Such a large reserve of water in the soil after clean bare fallow *) assures the winter crop even in a dry season **).

After the bare fallow, the winter corn expends all the useful water in a soil layer of 120 c.m.; but below that horizon there is still a reserve which sinks, by degrees, to the level of the permanent humid lower layer, by the following winter.

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*) For accumulating water, green april fallow stands as high as bare fallow, if ploughed, when possible, at that period when the weeds are just commencing their development and have not touched the reserve water.

**) In 1899, when not a grain was gathered in a distance of 40 versts, the Odessa experimental field produced 85 poods of winter wheat sown on bare fallow.

The moment of this deep exhaustion of the humid layer by the winter corn is the commencement of the formation of the intermediate dry layer. In the approching autumn, after the winter corn has been cleared away, the periodical humid layer commences to form on the surface; and in the winter preceding the sowing of spring corn we already find all our three layers: the upper periodical humid (from the surface to 40 c.m.) the intermediate dry (from 60*) to 180 c.m) and the permanent humid layers (from 180 c.m.**) and deeper to the ground water).

Towards the time for sowing spring corn (barley) on fig. 10 the state of humidity with barley is shown for 1905, a dry year—the thickness of the humid layer was about 40 c. m. We saw that the lenghth of ripe barley roots equal 110 c. m. It is obvious that with a thickness of the humid layer of 40 c. m., the root will only reach that depth and then cease their growth, having met with an obstacle which they cannot pass, in the shape of the intermediate dry layer. The life processes in the growth of barley, suffer from such a shortening of the roots first of all, in this respect: that instead of long main roots the side roots will commence to develop strongly and there is not sufficient water for a fresh quantity of roots. The plants, having formed a root-system shorter than others and proved themselves to be in a horizon of the utmost dryness, perish in various states of development. Others, forcing their roots a little deeper give a weak crop of partly developed grain; and finally those which reach the deep horizons before the others give a more or less normal grain. In 1905 the crop was certainly very poor-about 30 poods, comparatively 1/3 of the normal, and the humid layer of 40 c. m. Was also about 1/3 of the normal thickness of the rootinhabitable layer for barley.

In moister years at the approach of the period for sowing spring corn the thickness of the moistened soil layer fluctuates from 79 to 100 c. m.; nevertheless, the water entering the soil from the autumn, winter and spring deposits, are insufficient to moisten the intermediate dry layer.

Therefore, with threecourse bare fallow rotations, a part of the useful water accumulated durind fallow remains unused by the winter grasses sinks into deeper soil horizons and makes up the loss of water in the permanent humid layer. Obviously, the oftener the field is put under fallow the nearer the permanent humid layer will approach the surface with every years fallow, and the thinner and thinner the intermediate dry layer will become.

*) Between 40 and 60 c.m. lies the changing layer from humid to dry, holding 1% and not more than 2% of useful water-shaded a light grey tone.

**) Above it lies also the changeable layer, holding as much water as the upper one-shaded a light grey tone also.

With four-course rotation (fig. 20)—bare fallow, winter corn, potatoes (thorough ploughed plant) and sprind corn the distribution of water will be different than with the three-course rotation which we have just examined.

In the fallow and the following winter-corn stages the distribution of water, that is its accumulation and expenditure, will be similar to that which we saw in the threecourse rotation. Exactly in the same way, after the reaping of the winter wheat the upper humid layer appears with the intermediate dry layer below it; and still lower—the permanent humid layer. But in four-course rotation potatoes follow the winter corn. not, spring corn. Potatoes (fig. 16) do not use up all the reserve water (5 to 7%). There still remains 1, 2 or 3% in the soil (on fig. 16 shown from august by a lighter grey shade) after the harvest. This remaining unused water forms that fund which guarantees the crop of spring corn following the potatoe crop. Other thorough ploughed peants like melons and flax leave the field in about the same condition of humidity. Maize does not leave any serviceable water in the soil and in this respect is exactly like other cereals.

In this manner thorough ploughed plants give the spring growths which follow them a clean field cleared of weeds, and leave the fields in various conditions as regards soil water, and potatoes leave it in the very best condition. And what is more: popatoes must be reckoned the best predecessors of both winter and spring corns. Almost as good in that respect is flax. Under it the field gets free comparatively early, in june, even earlier than when under potatoes. Then the root-system of flax penetrates to a less depth than grass cereals and leaves a certain water reserve.

After potatoes follow spring corn in a four-course rotation. Having received, besides the remains left from the culture of potatoes, several driblets of useful water from the autumn winter and spring deposits, the spring culture towards harved use up all the reserve water and leave the root layer of the soil in a dry state, with only useless water, until the autumn months when the formation of an upper humid layer commences (on fig. 20 from september).

With tree-course rotations in the fallow stage, and with four-course in the fallow and after potatoes, useful water remains a long time in contact with the particles of soil in deep horizons of 80 c.m. and deeper. During this period processes of a chemical character go on energetically through the whole thickness of the humid layer; and partly, in the superficial layer, of a biological and bacteriological character. Mineral matter is transformed in entering, by assimilation, the roots of plants. After bare fallow and potatoes the process of transforming mineral matter into

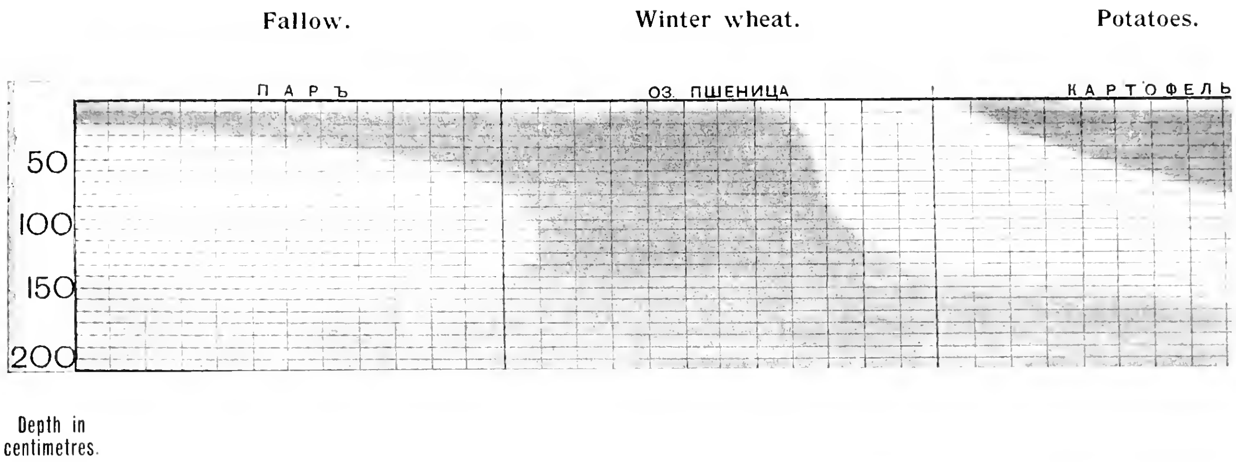

Fig. 20. Jour-field's alternation of sowing seed: 1) black fallow, 2) winter wh

Every year begins from September and ends in August. Each Year is separated one from anather by a

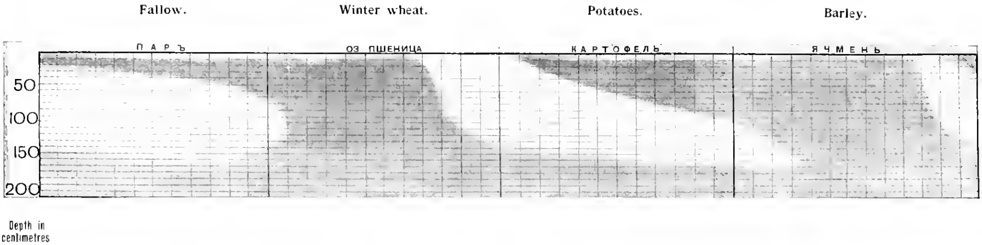

Fig. 20. Jour-field's alternation of sowing seed 1) black fallow, 2) winter wheat, 3) potatooes 4) barley.

Every year begins from September and ends in August. Each Year is separated one from anather by a thick line that goes out of the frame's limit above.

a soluble condition continues throughout the winter. Undoubtedly, besides accumulating water, these methods of culture also enricher the water soil solution with mineral matter, and raises the potential of the crop of that plant which will be sown on such a field.

The distribution of water in the soil assumes an entirely different complexion under a permanent culture of corn (fig. 21).

This farming method — the absense of rotation — is adopted in southern Newrussian governments. On our illustration the series of cereals are — winter wheat, barley, barley. There may be other combination — spring wheat, barley, winter wheat, barley, winter wheat and so on. The order of succession is here indifferent; it is only important that neither fallow nor thorough ploughed plants take any place in such farming, and our local thourough ploughed culture — maize — as we have seen, uses up, by harvest time, all the reserve useful water in the root layer.

Every year the formation of the upper periodically humid layer commences from autumn, generally in october, and by the time the plants sown therein are ready for reaping, it has become dry, only useless water remaining. The distribution of water may be thus depicted. *From the surface to the lower permanent humid layer,* which, under such conditions of culture, often lies deeper than on old ploughed land (160 to 180 c.m.), *the soil layer remains dry for many years,* and only in the superficial parts, from late autumn even from december to july, that is during seven or eight month, moisture appears in a soil layer of 40 to 50 c.m. In very moist years, like that shown on fig. 21, 3-rd year, it reaches 10 c.m. and more. After such an unusually moist year a part of the useful water in the lower parts of the periodically humid layer may not be expended; then it comes in for swelling the reserve useful water in the permanent humid layer, as may be seen on fig. 21, 1-st year, usually upper humid layer is, in spring not thicker than 40 to 50 c.m. It is moist for 7 or 8 months in the year. During that time, the processes of transforming mineral matter into solution, and the preparation of food for the coming sowing, goes on therein. But as regard the soil layer from 40 to 50 c.m. to a depth of 160 to 180 c.m., *it may remain in a dry state for many years with only useless water, and processes of a chemical character will be either absent or proceed on an insignificant scale;* and no transformation of mineral salts into solution may take place.

The soil gets impoverished through lying in dry state for a long time, because more water is required to turn the quantity of mineral salts necessary to the plants into solution than in rich soils, where mineral matter is found in a soluble condition, ready for use. And the longer his dried up layer of soil is without a supply of atmospheric water, the

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In this manner *an uninterrupted culture of cereals brings about,* as an unfailing consequence, *an intense, systematic drying up of the lower half of the soil layer inhabited by the roots of cereal grasses* (the depth of the layer inhabited by them equals 110 to 130 c. m. but only 50 or 70 c. m. moistens yearly at the best of times) *and an almost complete cessation therein of the chemical transformation of mineral salts into a soluble condition,* or, which is the same thing, *a systematic impoverishment there of.*

These chronic absense of useful water in an important part ot the root-inhabited layer, explains the „poorness" of the peasants fields. If these fields sometimes, exclusively in moist years, receive water enough to moisten the whole root layer, that water dissolves but an insignificant unnormally small quantity of mineral salts; and in order to assimilate and use them in building up their tissues, the plant must expend all the water; that is to say, that from a large guantity of water a small quantity of mineral salts is extracted. Obviously the abundance of soil water does not go to the benefit of the plant in this case; it must exhale water energetically, its cells hold too much water, the stalks become spongy, easy to break, and high coloured.

In this way one very moist year amongst a whole row, not of dry, but even of average moist years, guarantees the crop; but that crop will be far lower than it might have been, had the mineral matter been in a higher state of solubility through the presence of water in the root layer during the preceding years.

Have looked into the distribution of water in three-course, on bare fallow, and four-course rotations and then in uninterrupted culture, we see that in a three-course rotation, when spring corn is sown after winter corn, we get a condition favourable to the appearance of drought. On the removal of the winter corn, the whole root layer turns out to be dry, and the whole future of the barley crop depends exclusively on the autumn winter and spring deposits. If they happen to be sufficient we can rely upon an harvest; but if they chould be small the layer only moistens to 30 or 40 c. m. and there can be no hopes of a good harvest even with a decent quantity of deposit like that of 1906 (page 29). Only an uncommonly moist spring. which so rarely happens in southern black-earth districts, can raise the crop above the average.

In a four-course rotation winter corn is followed by potatoes, the root layer for which is not great. Therefore an important thickness of humid layer is not requisite to guarantee the crop. Here, a complete faillure cannot be expected, and even a moderately moist spring guarantees the crop of potatoes. Then, after potatoes, a certain reserve of useful water remains in the soil for the next spring corn, and with a moderately moist spring the crop of barley is guaranteed by a small reserve of water, and a clean soil, after the culture of potatoes. Therefore in a four-course rotation, there is no moment in the culture which could create in the root layer a condition favourable to the appearance of drought.

With an unbroken culture of cereals every year, the reserve of useful water is entirely used up at the period of reaping, and every year the farmer finds himself threatened with drought. Practice confirms the instabilety of farms built up on an uninterrupted culture of cereal grasses solely. There must be a change of culture, but not restricted to changing one cereal grass by another, as barley by wheat. The root-systems of cereal grasses are nearly alike, and so are the limits in which they can make use of serviceable water. In a change of culture one must reckon, not so much with, the varieties of the parts about ground, as with the varieties in the dimensions and structure of their root-systems. Maize and barley differ greatly in their above ground features, but they both dry up the root layer, towards the reaping period, completely.

The chain of seed changes or rotation should be made with the idea of root changes. Song rooted plants should alternate with short-rooted and dence rooted (with a thik network of small roots) with meagre-rooted (with a open network). In our four-course rotation after long rooted (winter wheat or rye) follows short-rooted (potatoes). Then again long-rooted (barley, oats). If after spring corn, we place thorough ploughed short and meagre-rooted (flax) and after that agaitn long-rooted (spring grasses) we get a six-course rotation probably the most perfect for southern steppe black-earth of a lightish type. And so, the cause of drought is not confined only to the fall of a small quant'ty of atmospherie water. The cause of drought is more complex and is rooted pre-eminently in the incorrect technical methods of farming-late turning up of the fallow in spring (june fallow fig. 12), in an incorrect organisation of crop rotation and in the system of letting land l'e untouched. The farmer himself prepare the way for drought in the course of a whole series of years by failing to look after the accumulation of water in the root layer of the soil and by the way the increase in the quantity of soluble matter. Our blackearth soil, on condition that a certain reserve of useful water is left in the root-layer as, often as possible, gives a prolific harvest, in a year with a less than average quantity of falling deposit; for the water which enters the soil finds there a sufficient reserve of dissolved mineral salts; and the plants in order to assimilate it and use it in building up their cells expend less soil water than they would from impoverished soil, in getting the same quantity of mineral salts.

The presence of drought is brought about as follows. Towards the advent of spring the field becomes covered with weeds which appear here after the cultured plants are cleared away. These weeds absorb the whole of the insignificant remainder of useful water, held in the small interstices of the soil particles in the form of small drops, which the more exacting cultured plants could not use. The soil on such a field turns out to be dry to a depth of 4$^1/_2$ feet or more. Autumn, winter and spring (the non-vegetation period) contributes so little water to the soil, that at the period of spring sowing only the superficial soil layer becomes moistered to 40 or 50 c.m. The roots of the cultured plants rapidly penetrate the whole of this layer with a dense network, and, meeting further with an insurmontable barrier in the shape of the intermediate dry layer, cease their downward growth, and give out a much more than normal number of side roots, which expend the reserve useful water in a shorter time than a normal number would. In consequence of the failure of water in the soil the weaker plants commence to perish, and the more hardy become prematurely ripe having reached the deeper horizons of the humid soil layer with their root-systems.

The intermediate dry layer, lying under the upper periodically humid layer, does not contain sufficient useful water, and the mineral salts therein remain in an insoluble condition. When a favourable moist spring arrives and the dry layer moistens, the plants use up in assimilating mineral salts alone, much more useful water than they would on rich soils where the mineral salts are already dissolved.

Consequently drought is preceded by two factors:

1) A part only of the root-inhabited soil layer being in a moist condition at the period of spring sowing, instead of the whole layer of 110 to 130 c.m.

2) A chronic perennial dryness of the intermediate dry soil layer lying under the periodically humid layer; and as a result of their dryness, the absense therein of the chemical processes for transforming insoluble mineral matter into soluble and

3) A deep position of the permanent humid layer owing to which, the intermediate dry layer is of very great thickness.

VII. Measures for contending against drought.

Having become more acquainted with the primary causes of drougt, we can with greater facility decide upon the means of contending with it, because in doing so, quite definite aims must be put forward. The first and most important aim is to increase the upper periodically humid soil layer. This may be attained by the accumulation of water, careful nursing of that already accumulated, and an economical outlay of it.

The only water that can accumulate in the soil is that which enters it from the atmosphere. Consequently the farmer should see to it that all the water falling on the field is absorbed by the soil and that none of it from any reason whatever, runs off the surface; and that it percolates into the superficial layer as quickly as possible. A spongy ploughed surface on the field fully favours these conditions, and the furrows should run across the declivities, if there are any.

Attention to the accumulate of water should be given immediately after the crop in got in. The thing is that in july after reaping finishes there is heavy rain for a more or less short time all over the southern steppe governments in certain years the most copious of all the spring and summer rainfalls. If the field is scaled after reaping, even to the small depth of 3 or 5 inches, all the water will be absorbed by the soil and will serve as a pledge for the futur crop.

On unploughed fields a considerable part runs off the slopes, and is lost. Our farmers treat this summer rain with criminal carelessness. It appears to them neither beneficial nor welcome, as it interferies with the threathing of the corn.

Nevertheless there falls (on the Odessa experiment field), on an average for twelve years, about 45 m. m. If about 30% of this is lost through evaporation, as we mentioned above, still, for all that, about 30 m. m. may be held by the soil for the future crop, or, reckoning 1½ poods to each millimetre, an addition of 45 poods will be guaranteed to the crop, giving about 15 poods of grain. This calculation must however be regarded as underestimated because the water which enters in the soil, will increase the change of mineral matter into a dissolved condition during the 2 or 3 summer months. It is only necessary to harrow the scaled field after the rain.

In the Newrussian governments it is the custom to sow winter corn, without previously preparing the field, after the first rain at the end of august or during september. It is the custom also for that corn to give a weak crop, because the roots of the growing plant quickly reaches the limit of the humid layer, under which lies the dry layer, and their growth is arrested until the next horizon moistens, which may not happen until autumn is well advanced. Winter corn may be sown on scaled ground without any great risk, if the humid layer equals 50 or 60 c. m.; but, as we saw before, such a humid layer is absolutely necessary in order that the winter corn may bush by the advent of winter*).

The field having been scaled soon after clearing up the cereal grasses, requiring looking after; that is, harrowing after rain and repeated scaling or turning over whilst weeds are growing. But *whoever wishes to have a cultured field must concern himself with the renewal of the reserve water therein, immediately it has been spent; and the sole means of doing this is to scale off the stubble immediately after reaping, between the unbourd heaps of corn.* In preserving water in the soil, by scaling stubble off the field, and by subsequent tillage far into the autumu, the farmer rids his field of large quantities of weeds and destroys their seeds. The autumn weeds, which develope so riotously in certain years, exhaust the whole of the atmospheric water whish enters the soil after the reaping of the crop.

By the term „economical expenditure“ of soil water should be understood a condition preventing a simple drop of water from being wasted on the growths of weeds, which the farmer must, by all means, destroy. But of course it is more profitable to destroy them while they have not yet used up the priceless water which cultured plants must have without fail, and before they have run to seed. This is the ideal to which the farmer should constantly strive to attain. Therefore the field, having been scaled after the harvest, must receive the same attention as it wauld do under culture; then the sown field should be occupied exclysively by cultured plants, and all the processes of their cultivation thourough ploughing, hoeind etc) should facilitate the destruction of weeds. For that reason fallow land should be ploughed in autumn or as early as possible in spring, before the weeds have yet touched the reserve of useful water.

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*) Cereal grasses bush when their root system reaches a depth of 50 c. m. (25 inches).

The farmer should always remember, that every of dry weeds take away 400 to 500 poods of water from his fields— that the root-systems of wild plants develope more rapidly than those of cultured plants; and therefore with simultaneous sprouting, the moister soil horizons will be seized upon the roots of wild plants — and finally that wild plants can absorb from the soil those minute drops left from the reserve useful water, which cultured plants cannot make use of. He should not forget *that the bitterest enemy of his field culture and the best friend of drought* are the weeds on his field, which by attracting the reserve water left after cultivated plants and by using all the atmospheric water entering the soil in summer and autumn, prepare the way for drought. By neglecting his cleaned up field right away to winter and by giving it over to the disposal of weeds, the farmer himself takes a part in creating conditions favourable to drought. In fixing the greatest loss to the farmer. through weeds, at an extent equal to the crop, I do not exaggerate; the loss is undoubtedly far greater.

The second aim for successfully contending against drought should be the transformation of the greatest possible quantity of insoluble mineral constituents of the soil into a dissolved condition and that is only possible when the root-inhabited soil layer holds permanently, as far as possible, a certain, even a small reserve of water which will aid the chemical processes.

We know that cereal grasses expend all the reserve water in the root-inhabited soil layer, even if that reserve be as large as it is on the field after bare fallow (fig. 18). On the other hand, we know that certain thourough ploughed plants like potatoes, flax and pumpkins do not use up all the reserve water in their root layer. Therefore the organization of the form or in other words the roration of crops, should not de confined exclusively to grain or cereal grasses. It is necessary that one crop should succeed another in the rotation in such a manner that one year of intense expenditure of useful water should be succeded by an year when water, even if only a small quantity, is accumulated. From this is derived the main principle of rotation for our black soil steppe districts- *after grass a thourough ploughed plant must be sown, but on no account a grass*. The simplest of such rotations will be two-coursed: 1) a cereal grass, 2) a thourough ploughed plant. But a combination such as 2, 3, 4, and so on, may be taken, and we get from six and eight course rotations.

If we add to our four-course rotation (fig. 30) another thourough ploughed growth and a grass we shall probably get the very best rotation for steppe black soil: 1) bare-fallow 2) winter wheat 3) partly-potatoes and partly beatroot, 4) barley or sprind wheat 5) flax or pumpkins, 6) barley, or oats. Such a rotation besides quaranteeing a fine crop cereal grasses, gives the farm sufficient fodder for his cattle. Here I shall take the opportunity of saying a few words about the sowing of grass. Grass cannot be included in the rotations and for this reason. Perrenial green fodder has a very long root-system even extending to several fathoms. All that thickness of soil must hold useful water, otherwise the roots will not develope. Meanwhile in our soil at a depth of about 3½ to 4½ feet the intermediate dry layer commences, about 2½ to 3½ feet thick which stops the developement of the roots profoundly. And the only way of distinging the immediate dry layer is to moisten it that is to leave the field under bare fallow (fig. 18). Therefore the only method which will guarantee success in cultivating perennial green fodder in places with a small quantity of atmospheric deposit, is to sow it on bare fallow. The most suitable fodder for the extreme south must be reckoned lucerne and for the more northerly esparcet. In culture of green fodder all depends upon the quantity of water held in the deeper soil horizons accessible to roots in the 2-nd, 3-rd and subsequent years, and this circumstance shows, how many years the fodder will keep preserving the farming thickness of grass when standing. In favourable conditions lucerne can remain on one place 5 or 6 years. On the Odessa experiment field there were occasions when it remained 9 years giving in the first four year 1 or 2 mowings of hay and in the last five years-yearly mowings for grain and, if when it was possible also for hay.

In view of all these considerations, perennial grass cannot be included in rotations. It is more practical to sow it on field part outside the rotation, which at any moment when the grass begins to thin out, may be used for rotation and a new area can be put under grass.

An increase of fodder matter in farm is undoubtedly necessary for our south, where cattle breeding has always meet with unsurmountable obstacles in the shape of the lack of fodders.

And so *a correct seed rotation based not only on a seed change but also on root change, is a great remedy for contending against drought, as it averts the perrennial drying up of the root-inhabited soil layer.*

The extirpation of weeds on the whole space of the land possession and a correct rotation of crops with a persistent alternation of cereal grasses and thourough ploughed plants, are measures of fighting against drought which are accessible to every farmer and their accomplishment is not dependent upon the nearest neighbours.

But for all that the quantity of atmospheric deposits in steppe black-soil districts is so small that its increasing is only desirable. If the adoption of the above technical measures and the organization of seed rotations depend only upon the wishes of separate farmers and are under the power of every separate person, a change in the climatic conditions as regard the quantity of atmospheric water may only be taken in hand by the government or some other large administrative unit.

An increase in the qnantity of atmospheric water however improbable it may seem, is quite possible, if the humidity of the air in a given dictrict increases; for we know that the more the air of that district is saturated with water vapour, the more abundant the fall of deposits. An increase in the quantity of water vapour in the air is possible when there is increased evaporation on a more or less wide areas of a given district; and this latter may be possible, by opening up here wide water expanses for the steppe—ponds for instance or by increasing the quantity of plants which exhale a great deal of water, such as trees. The making of ponds in the steppe valleys although not presenting any great difficulties and might be made even profitable by the artificial breeding of fish theirein. does not guarantee a favourable solution to the problem; for two dry years in succession are capable to destroy even well made ponds.

The preservation of the existing waters and the raising of new ones upon the ground surfaces can only be undertaken by government, as it is not a suitable thing for private initiative.

A much greater chance of success is offered in the increase of arborial plants on fields. I do not speak of making forests on the steppe, like our steppe experimental schools of forestry did; but of planting trees rather of a garden than of a forest character, on large steppe areas or even on whole steppe expanses, of planting the boundaries between fields, along paths and generally on all boundary areas not utilized now. At the present time, with developement of our farm culture, tree planting is the most urgent need of these farms. And the preservation of the young saplings is now much facilitated here, in comparison with the peasants fields in settlements. If mulberry trees were used for that purpose, it would raise our silk - worm breeding which has thriven now, thanks to the easier method of dealing with the cocoons, but held back by the absence of mulberry trees, which have not been cultivated by our foresties in proportion to the demands. Such single or double rowed tree planting, drawing up water from deep soil horizons not accessible to field plants, could screen off the wind, which blows with double force, on our bare steppes, compared with western Europe throughout the whole year, bringing up the speed to 14 metres per second sometimes for whole weeks.

The again tree planting on the steppe will serve as the strongest barrier against injurious insects, as the greatest mass of them do not rise in their flight highe. .han the average height of trees. From injurious insects especially the hessian and sweedish flies, then the sawer, and the winter corn worm, millions of poods are absolutely lost every year. It is impossible on the steppe to adopte any remedy against them, and the constructon of tree barriers, even single rowed, but sufficiently thick, appear to be the only means of contending against injurious insects.

Reckoning the total of all that has been written, we come to the conclusion that the measures against drought which may be adapted by each farmer individually are: the unsparing destruction of weeds on fields throughout the whole year and crop rotations based on the principle not only of a seed change but also of a root change. We saw a proof of the incontestability of these measures in the laws governing the circulation of water in the soil, and if we do not reckon with them, it means being always under the threat of drought. The reader is perhaps not satisfied with such a simple solution of the question: but then the truth is always simple.

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