Int. Agrophysics, 1996, 10, 77-82

SOIL STRUCTURE AS AN ECOLOGY FORMING FACTOR

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Accepted May 14, 1996

A b s t r a c t. The aim of the investigations consisted in detemination of the optimum ratio of structural components in the sowing layer of the chemozem on cultivation of cereal ear crops and development of a combined tillage machine perfoming the sought for optimization. The method of simplex-lattice planning of experiments has been chosen for establishing the optimum ratio. The investigations have been carried out with structural components in the size from 20 to 5 mm (X1), 5-2 mm(X2), 2-0.25 mm (X3) and less than 0.25 mm (X4).The optimum ratio of structures depends mainly on the level of moistening, mineral nutrition and seed size of crops sown. At favorable conditions crumbles X1, dominate in the optimum texture under the lack of moisture the share of X2 and particularly X3 (X2+X3 attain 80 %) abruptly increases. The ecological value of agronomically most valuable size (5-0.25 mm) consists first of all in the provision of more effective use by field crops of the available soil moisture and in the reduction of the negative effect of drought. A construction of combined (tillage and sowing) machine has been developed for realization of mentioned agronomical demands. This machine has been subjected to the full cycle of successful agronomical and energetic tests.

K e y w o r d s: soil structure, simplex-lattice plan, optimization, combined machine

INTRODUCTION

The role of soil structure in the creation of the favorable water-air regime in soil of medium and heavy granulometric composition is well known.

The more of structural aggregates of the agronomically valuable size from 10.0 (7.0) to 0.25 mm of sufficiently porosity and water stability are in a soil, the more is such a soil able to uptake and store the moisture of atmospheric precipitation and thrifty by evaporate it, - the more it is able to resist erosion, the higher, ultimately is its fertility [2,3,6]. At the same time, the idea of an agronomically valuable structure is developed insufficiently. There are inconsistent data on the optimum size of structural aggregates, their influence on the effectivity of utilization by plants of soil moisture and nutrient elements. Only in the most common form are known the demands of field crops as to the size of structures, or, in other words, to the degree of the seed layer preparation as a result of the presowing cultivation. The method of investigation of the soil structure composition effect on field crops yield is not quite clear. In particular, in the used methods [4] there is not considered the circumstance that in the really cultivated layer there are present not separate aggregates (they are just but the object of comparative investigation in the vast majority of scientific works) but complex combinations (mixtures) of structures of various size. One of the basic aims of this work was to solve the following problems: - to work out methods for the study of soil structure effect on crop yields; - to investigate the effect of a mixture of soil structure components on the effectiveness of the use of nutritive elements and moisture by crops; - to find the optimum ratio between macro-, mezo- and microstructure in the soil sowing layer on the cultivation of cereal ear crops; - to substantiate agrodemands concerning the working tools of tillage machines for crumbling and separation of sowing layer of structural soils.

MATERIALS

Investigation objects. Typical thick heavy-loamy Chernozem soil on loess with the following properties: humus content in cultivated layer - 5.2 %; physical clay - 51 %; silt - 32 %; air-dry aggregates of agronomical size of 10-0.25 mm - 70 %. Agricultural crops: wheat, barley, oat, millet, maize.

METHODS

The methods of the simplex-lattice experiment planning of the type composition - property was used [5], permitting determination of crop yield ('property') depending on the mixture ('composition') of separate soil components. A 4-component mixture was chosen: X1-crumbles in size 20-5 mm, X2- 5-2 mm; X3 - 2-0.5 mm; X4- less than 0.25 mm. Obtained results are presented on the evolvent of a correct tetrahedron. The simplex apexes are pure components, edges -double mixtures, facets - triple mixtures, 4-component mixtures correspond to simplex inner points. 'Properties' (the same is optimization parameters) of arbitrary mixtures are calculated by interpolation on known characteristics of some basic mixtures. Optimization parameters (yield, moisture discharge, N+P+K intake by plants) were calculated on a computer. The following experimental scheme was developed, in which pure components are excluded as not occurring in a real soil (the ratio of structural components is given in relative values -Table 1).

The experiments were carried out in 1982-1990 in vessels and under field conditions on microplots 1x1x0.10 m with 4-fold replication. Separate aggregates of sizes indicated in the table were isolated from soil during optimum crumbling on a special device. Mixing of structures was performed according to the experiment scheme.

Table 1. Scheme of the 4-component plan

Variant cipher	Extent of immersion into the simplex body			
	X1	X2	X3	X4
1	0.7	0.1	0.1	0.1
2	0.1	0.7	0.1	0.1
3	0.1	0.1	0.7	0.1
4	0.1	0.1	0.1	0.7
0	0.25	0.25	0.25	0.25
12	0.4	0.4	0.1	0.1
13	0.4	0.1	0.4	0.1
14	0.4	0.1	0.1	0.4
23	0.1	0.4	0.4	0.1
24	0.1	0.4	0.1	0.4
34	0.1	0.1	0.4	0.4
10	0.475	0.175	0.175	0.175
20	0.175	0.475	0.175	0.175
30	0.175	0.175	0.475	0.175
40	0.175	0.175	0.175	0.475
K1	0.1375	0.2875	0.2875	0.2875
K2	0.2875	0.1375	0.2875	0.2875
K3	0.2875	0.2875	0.1375	0.2875
K4	0.2875	0.2875	0.2875	0.1375

Accompanying observations of plants (phenological measurements) and soils (moisture content, bulk density, structural composition) were carried out by conventional methods [5]. At the end of plant vegetation the weight of aboveground mass and its content of N+P+K were considered.

RESULTS

Experiment 1. Barley, green mass. Moisture 1.0 of field capacity (FC), level of mineral nutrition: (NPK) 50. Results are shown in Fig. 1. Coordinates of the optimum zone: X1=75-80 %, X2=X3=10 %; X4= 5%.

Experiment 2. (after end of Experiment 1). Barley, green mass. Moisture 0.65 FC, (NPK) 50. Results are shown in Fig. 2. Coordinates of the optimum zone: X1=10 %, X2=20 %; X3= 45 %; X4=25 %.

Experiment 2. Barley, green mass. Moisture 0.65 (FC), (NPK) 50. Results are shown in Fig. 3. Coordinates of the optimum zone: X1=10 %, X2=20 %; X3=45 %; X4=25 %.

Experiment 3. Millet, green mass. Moisture 1.0 FC, (NPK) 50. Results are shown in Fig. 4.

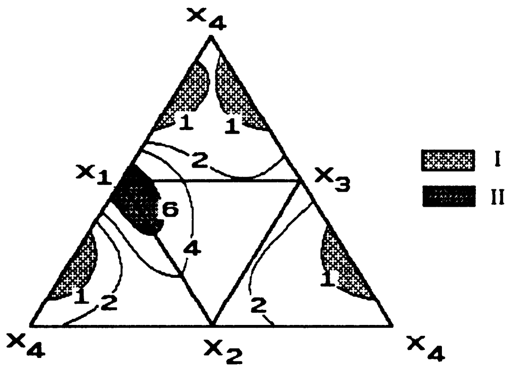

Fig. 1. Isoquants of the green mass of barley: 2-7.2; 4-8.9; 6-10.6; 8-12.3 (g/vessel). I-zone of minimum, II-zone of maximum yield.

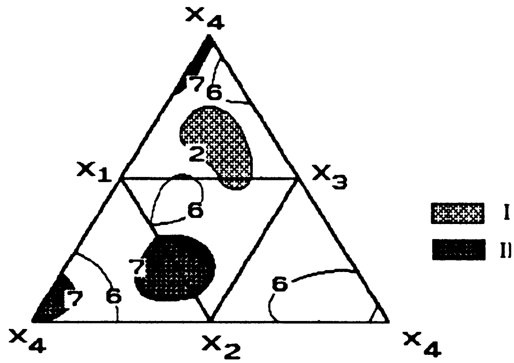

Fig. 3. Isoquants of (NPK) uptake into green mass of barley: 2-122.6; 4-141.2; 6-159.8; 8-178.4 (g/vessel).

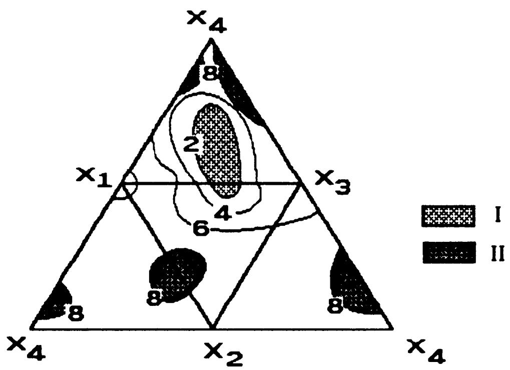

Fig. 2. Isoquants of the green mass of barley: 2-7.8; 4-8.9; 6-10; 8-11.1 (g/vessel).

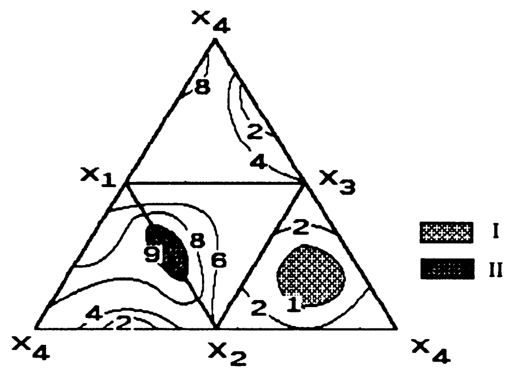

Fig. 4. Isoquants of the green mass of barley: 2-23.6; 4-30.0; 6-36.4; 8-42.8 (g/vessel).

Coordinates of the optimum zone: X1=10 %, X2=20 %; X3=45 %; X4=25 %.

Experiment 4. Barley, different outputs. Moisture 1.0 FC, (NPK) 50. Results are shown in Fig. 5. Mean coordinates of the optimum zone: X1=22 %, X2=X3=32 %; X4=14 %.

Experiment 4. The same conditions. Results are shown in Fig. 6. Mean coordinates of the optimum zone: X1=22 %, X2=X3=32 %; X4=14 %.

Experiment 5. Oat, green mass. Moisture 1.0 FC, (NPK) 150. Coordinates of the optimum zone: X1=20-25 %, X2+X3=60-65 %; X4=15 %; Results are shown in Fig. 7. Results of the most characteristic experiments are cited above. Other experiments, with corn and wheat, including microfield conditions, gave similar results.

DISCUSSION

Results of the vessel and microfield experiments have shown that growth, development and yield of investigated grain crops, efficiency of use by them of moisture and nutrition elements largely depend on the structural composition of the soil arable (sowing) layer. Hence, the control of plant development, use of fertilizers and precipitation moisture is possible with creation of the optimum ratio (mixture) of various aggregates in the soil arable layer.

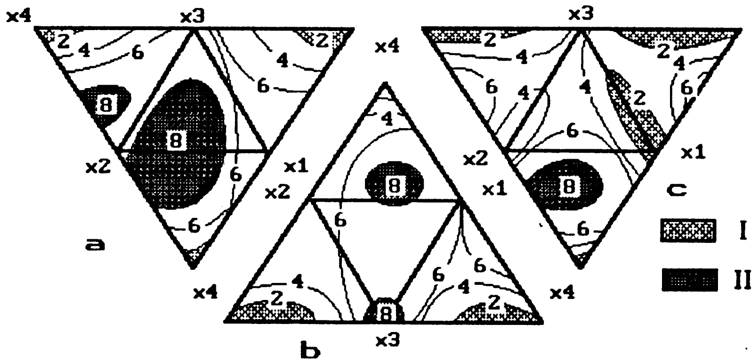

Fig. 5. Isoquants of the different outputs of barley: a) yield of aboveground mass: 2-15.3; 4-17.6; 6-19.9; 8-22.2 (g/vessel), b) grain: 2-5.6; 4-7.3; 6-9.0; 8-10.7 (g/vessel), c) plant uptake (N+P+K): 2-112; 4-122; 6-132; 8-142 (mg/vessel).

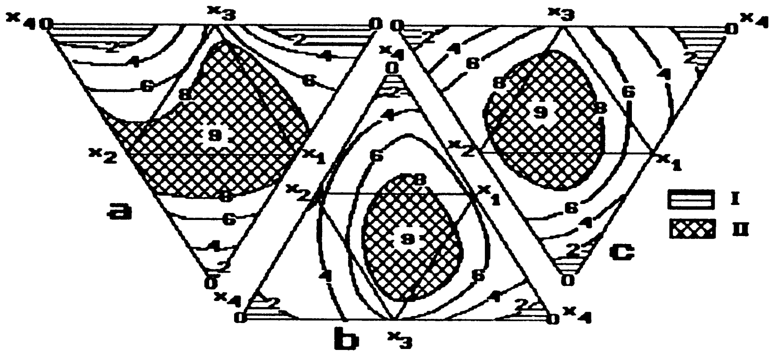

Fig. 6. Isoquants of the summary soil moisture discharge (l/vessel) in the period 7.05.-23.07.86: a) 7.05-1.06 : 2-3.8, further with the interval of 1.0 (l), b) 2.06-26.06: 2-16.9 further with the interval of 1.6 (l), c) 7.05-23.07: 2-33.0 further with the interval of 2.3 (l).

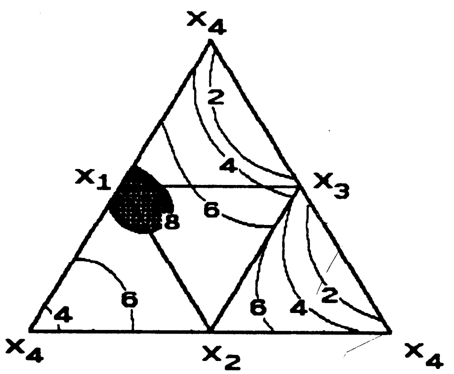

Fig. 7. Isoquants of the green mass of oats: 2-8,8; 4-9,4; 6-10,0; 8-10,6 (g/vessel).

For investigated crops, particularly at the vegetation start, under conditions of moisture and mineral nutrition optimum supply, an obvious advantage has the sowing layer with the coarse crumbled structure containing aggregates from 20 to 5 mm 75-80 %, 5-0.25 mm - 20 %, less than 0.25 mm - no more than 5 %. In the following vegetation periods and particularly at the forming of grain - the higher productivity of these crops is noted at the increase of the content of aggregates in the size from 5 to 2 mm. Then the optimum mixture composition is as follows: aggregates from 20 to 2 mm - to 80-85 %, less than 2 mm - no more than 15-20 %.

At the observations, the component ratio changes in the optimum mixture depending on soil moistening levels and its supply with nutritive elements are seemingly due to the circumstance that with nutritive elements mainly from larger crumbles and having larger pores conditions, higher assimilability by plants of moisture and nutrition, and the mixture with the predominance of small aggregates more economically spend water for physical evaporation. Thus, in the zone of maximum (microaggregates) yield for forming of 1g of the yield there is needed 1.7 l of moisture, and in the zone of minimum (microaggregates) - 2.4 l (Fig. 6). Gedroitz [1] suggested that the optimum size of structural aggregates is to be changed depending on moistening conditions and by lack of moisture must be smaller than by its abundance.

On the basis of these data one can conclude that: the universal optimum mixture does not exist. The components composition must be ranged depending on specific conditions. Furthermore, it is desirable that it would be changed during crop vegetation, which presents a hardly solvable problem. A reasonable alternative in this case could be the differentiation of arable (or only sowing) layer on structural composition with due regard for positive properties of the both found optimum mixtures. In this connection it would be appropriate to express the assumption that the best for cereal crops would be the layer in the upper part of which predominate coarse (directly contacting with seeds) structural components, and in the lower - smaller ones. This assumption has been verified in a special microfield experiment. Differentiation of sowing layer on structural composition in comparison with a not differentiated one turned out to be useful both for crop (reliable millet yield gain has been obtained) and for soil (after a heavy shower the variant with the coarse crumbled upper layer bloated markedly less) and for effectivity of inogranic fertilizers (the coefficient of N+P+K by millet was higher).

All the previously mentioned served as a basis for the forming of the following agronomical requirements concerning soil structural composition for the combined soil filling and sowing machine. The presowing tillage must bring improvement of the sowing layer structural composition and differentiation on its depth due to separation (redistribution) and accumulation (to 80 %) of the fraction coarser than 5 mm in the upper layer and fraction 5-0.25 mm in the layer directly contacting with seeds - to 60-70 %. In this the share of the fraction less than 0.25 mm must not exceed 25 % in the seed layer.

CONCLUSIONS

1. Application of methods of mathematical experiment planning of the type ‘composition - property’ permits to establish the optimum ratio of structural aggregates in the arable (sowing) layer for the cultivation of agricultural crops.

2. A special experiment scheme is developed, including 19 variants, permitting the study of dependence of crop yield (or any other parameter of optimization) on an arbitrary ratio of the 4 components of the soil structure. In the program for treatment of results on a computer is seen the output of isoquant batch of optimization parameters.

3. The ratio of structure components in a mixture changes depending on the level of moistening and nutrients supply during crop vegetation. Under favorable conditions of moisture nutrition for grain crops cultivation, a relatively more than rough preparation of plowing (sowing) layer ($X1=25\%$, $X2+X3=60\%$, $X4=15\%$) is permitted; under unfavorable conditions a more through crumbling is necessary ($X1=10\text{-}15\%$, $X2=20\%$; $X3=45\text{-}60\%$, $X4=15\%$). At the beginning of vegetation the crops green mass is actively formed when the structure coarser than 5 mm is dominating; in later periods of vegetation, the grain forming, a high productivity is noted on increase of the content of structural components less than 5 mm.

4. On decrease of the seed size of sown crops the fraction share less than 5 mm in the structure mixture must increase.

PROPOSITION FOR EXTENSION

On cultivation of grain ear crops on chernozemic structural soils the crumbling (structure

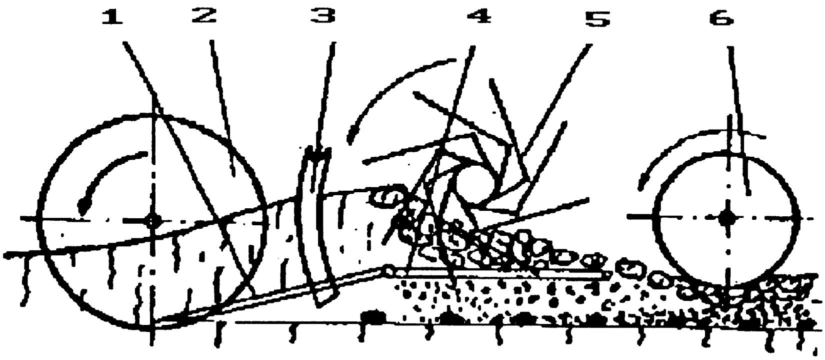

Fig. 8. Scheme of combined machine for optimization of the structural composition of the sowing layer: 1-plowshare, 2-guiding disk, 3-shoe, 4-vibrating grate, 5-rotor loosener, 6-packing roller.

composition) of sowing layer must be improved for sowing. It can be reached by soil elevation, its feeding to separating grate, active loosening and separation into 2 fractions; a coarser one less than 5 mm. The fine fraction falls through the grate and covers sowed seeds. The coarse fraction is concentrated in the upper layer. A scheme of such a machine is proposed, which combines the separation of the structural composition and sowing (Fig. 8).

The machine gave stable and reliable improvement of grain yield in each of the four observation years (1987-1990). The mean yield on the control (standard technology) was 5.22 % t/ha barley grain, and in the variant where was applied developed by us machine instead of presowing cultivation, usual seeder and soil pacing - 6.00 t/ha.

ACKNOWLEDGEMENTS

The author thanks A.S. Yegorshin for his assistance in mathematical processing of experimental results.

REFERENCES

1. **Gedrojtz K.K.**: Soil structure and its agricultural importance (in Russian). Transactions of Institute of Experimental Agronomy. Moscow, 4, N3, 35-50, 1926.
2. **Kachinsky N.A.**: Soil Structure (in Russian). Edit. of Moscow State University, 112, 1966.
3. **Medvedev V.W.**: Optimization of the physical properties in Chernozems (in Russian). Moscow, 'Agropromizdat', 160, 1988.
4. **Modina S.A., Dolgov S.I., Polsky M.N.**: Soil constitution and structure state (in Russian). Agrophysics methods of soil investigation. Moscow, Edit, 'Nauka', 42-71, 1966.
5. **Sheffe H.**: Experiments with mixtures. J. Roy. Statist. Soc. Ser. B, N 2, 344, 1958.
6. **Voronin A.D.**: Structure functional hydrophysics of soils. Moscow, Edit of Moscow State University, 20, 1984.