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MICROMORPHOLOGICAL DIAGNOSIS OF THE STABILITY OF CHERNOZEMS UNDER IRRIGATION

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Chernozems used under irrigation for a long period of time have been studied by micromorphological methods. The soil porosity, the amount of microaggregates, biogeneity, humus microforms and the presence or formation of optically oriented clay were taken as the basic indices for estimating the stability of chernozems to irrigation during 30–50 years. The different ionic composition of the irrigation water served as evidence of varying anthropogenic evolution of chernozems.

Keywords: fabric, humus forms, optically oriented clay, solodization, compactness.

INTRODUCTION

The changes in the fabric and properties of chernozems caused by massive human interventions (plowing, fertilization, heavy machinery, chemical amelioration and irrigation) attracted special attention of many researchers. The study of irrigation-induced changes in chernozems started in the 1930s of the XX century (in Valuy irrigation system). The intensive development of irrigation taking place in the 1960–70s has being accompanied by studies aimed at assessing its effects on chernozems. Examples are studies carried out in Krasnodar and Rostov regions [10, 14, 1], in Ukraine [3, 9, 2], in Moldavia [7] and in the Trans-Volga region [12, 4, 13].

The micromorphological investigations allowed studying the irrigation-induced changes in the microfabric of chernozems. What is the advantage of micromorphological methods? First, the soil is studying in the undisturbed state; second, the initial stages of changes in the soil mass organization are easy fixing what cannot be determined by the other methods. Third, there is a possibility for observing the effect of definite amendments on the structure of the peptized fine-dispersed soil mass and for forecasting the further changes in the structural organization, redistribution of some fabric components and formation of pedofeatures.

The microfabric of chernozems and processes taking place in them were first investigated by Yarilova (1981) and Polyakov (1981). The fabric and its transformation, the fate of pedofeatures, the porosity and aggregation, the mineralogical composition and fabric changes in chernozems were also the subject to more thorough studies [18, 15, 23].

The numerous field experiments and analytical data were essential for understanding the irrigation-induced changes in chernozems and showed that in the major cases (over 90%) the irrigation has an adverse influence on the state of chernozems. Having generalized original and literature data, Shein (1995) came to the conclusion that the chernozems are adversely affected by irrigation causing changes in these soils, which are the following:

1) The hydrogeological and geochemical processes reveal changes (the rise of the groundwater level, increase in the water amount within the aeration zone);
2) The structural-hydrophysical status of soils is changed (the structure destruction, decrease in the porosity, soil compaction and crust formation, deterioration of water and air regimes in soil);
3) The ground water and soils become secondary salinized: solonetzisation, compaction and secondary carbonate formation due to the rise of the groundwater level and irrigation with water of hydrocarbonate-and chloride-sodium-magnesium composition;
4) The calcium regime is transformed (the ionic exchange processes, $CaCO_2$ dissolution – precipitation, specific humus formation);
5) The natural humus formation is destructed indicating the dehumification due to increasing the humus mineralization and illuviation as well as increasing the humus content and organic detritus);
6) The initial fabric is changed being accompanied by the loss of the microaggregate amount owing to decline of the iron content in the humus-clayey plasma especially during the development of the gley formation;
7) The solodization process is developed in case of chernozem irrigation with alkaline water including the peptization of the aggregated

humus-clayey plasma, removal of humus films from mineral grains and lateral leaching of the dispersed mass.

The above changes in irrigated chernozems are adverse by nature. In literature sources there is only one example of positive changes taken place in Karagash irrigation system (Moldavia), where ordinary and calcareous chernozems have been irrigated with water of the Dnestr river [7]. In view of this, we made an attempt to specify such conclusions by using the micromorphological methods to study the samples of chernozems irrigated by waters of different composition for a long period of time.

OBJECTS OF RESEARCH

The objective of the present study is to show changes in the fabric of chernozems resulted from plowing and irrigation with water of different composition. Under study were ordinary chernozems in Kursk and Samara regions, southern chernozems in Ukraine, calcareous chernozems in Rostov region, compact chernozems in Stavropol region. The composition of irrigated water was varying from hydrocarbonate-calcium (the Volga and Dnestr water) to slightly alkaline (water of small rivers in Krasnodar and Rostov regions) and strongly alkaline water in Sasyk Lake.

Three following indices were used to study the stability of chernozems to anthropogenic effects and irrigation-induced changes in the natural environment:

1) aggregation of the soil mass and the porosity pattern;
2) humus content and composition (humus microforms) as well as the biogenic transformation of the soil mass;
3) drainability in the soil profile and the movement degree of soil mass components laterally or downwards the profile.

Just these indices should be considered as the basic characteristics in studying the soil degradation and cultivation. It is necessary to take into consideration definite indices of the fabric so vital for the stable soil status. To our mind, the aggregation degree may be diagnozed by the form and size of structure elements (peds), by the aggregation degree of the soil mass, the porosity and forms of voids.

The humus content and its nature depend on the ratio between the humus microforms, the amount of organic residues (detritus) and the quantity of excrements. The profile drainability is micromorphologically characterized by (a) the gleying degree (the amount of iron nodules and zones without iron), (b) the presence of traces of the fine-dispersed material transport (clay cutans) (Table 1).

Table 1 Indices of the microfabric in chernozems according to their cultivation degree.

Index	Cultivation degree		
	low	middle	high
Aggregation			
Macrostructure (>0.25 mm) form	Blocky	Crumbly	Crumbly
(% of structured zones)	<20	20–70	>70
Microaggregation (% of aggregated material)	<10	10–50	>50
Total area of voids (S) (% from the thin section)	<10	10–20	>20
Form of voids	Fissures	Vagi, fissures	Vagi, channels, canals
Broken voids	<4	4–6	>6
Ratio between the void perimeter and the perimeter of the thin section common factor of the form	>6	4–6	<4
Content of humus	Single	Few	Many
Amount of organogenic	1–5	5–10	>10
resides	Small	Average	High
Biogeneity (amount of	1–2	2–5	>5
excrements)	Charred, pointed, clot-like	Pointed, clot-like, charred	Clot-like, pointed, charred
Humus microforms			
Migration and segregation of components	>10	2–10	<2
Gleying degree	Many	Little	No
Pedofeatures from the optically oriented clay	Heterogenous (many)	Slightly heterogene	Homogeneous
Composition homogeneity			

Let us consider the characteristics of the studied chernozems and their irrigation-induced changes. To prepare the thin sections, the soil samples were taken by the author (together with the other researchers whose names are given in brackets).

1. Ordinary chernozem in Bezenchuk experimental station, Samara region; irrigation water from the Volga river, its mineralization is 0.4–0.5 g/l of HCO_3–Ca. The soil has being irrigated for 50 years (Baranovskaya V.A.).

2. Southern chernozem under irrigation for 25 years in Odessa region (Gogolev I.N.).

a) the irrigation water from Danube and Dnestr rivers, mineralization is 0.3–0.5 g/l of HCO_3–Ca–Mg; the soil was used under irrigation for 20 years (Bilanchin Ya.M.);

b) the irrigation water from Sasyk Lake, its mineralization is 1.4–1.8 g/l of CO_3–HCO_3–Cl–SO_4–Na–Mg, the soil was irrigated for 10 years (Poznyak P.S.);

c) the wastewater with mineralization of 0.7–1.2 g/l, HCO_3–Cl–Na–Mg. The soil was irrigated for 15 years (Turus B.M.).

3. Calcaresous chernozem in Rostov region; the irrigated water from Manych river with mineralization of 0.8–1.3 g/l, HCO_3–Ca–Mg–Na. 12 years of irrigation (Andreev G.I.).

4. Compact chernozem in Stavropol region, the irrigated water from local small rivers; its mineralization is 0.6–0.8 g/l, HCO_3–Mg–Ca. 10 years of irrigation (Khadzhinov N.I.).

RESULTS AND DISCUSSION

1. Ordinary chernozems in the Trans-Volga region. Bezenchuk experimental station. 50 years of irrigation. As compared to chernozems in the other regions these soils display a rather stable structure at all the levels of the material organization (from macro-to micro). Plowing, fertilization, heavy machinery decreased the soil porosity and aggregation but the crumb-spongy microfabric remained due to a higher amount of excrements and coprolites. The dry chernozems (without irrigation) in the Trans-Volga region reveal the increased content of different-decomposed organic residues, the humus is predominantly dark-brown and sometimes brown. The humus microforms are clot-like and dispersed ones. There are dense humus-clayey coatings around the

mineral grains. The fabric of upper horizons is heterogenous: compacted layers enriched with voids-fissures are alternated with loose crumb-spongy layers. The porosity is rather high (about 2%) and diverse predominating by voids of packed aggregates and void-vagi. The pedofeatures have biogenic forms. At a depth of 40–60 cm the pedotubule AB horizon with the increased content of humus and clot-like microforms is well diagnosed. It remains in irrigated chernozems as well (Fig. 1).

Thus, the dry ordinary chernozems in the Trans-Volga region are characterized by (a) a higher aggregation and clearly expressed inter- and intraaggregate porosity; (b) a high content of clot-like humus and organic detritus, the biogenic soil mass; (c) the profile drainability at a depth of 70 cm resulting in the increased content of coarse silt (20%) and fine sand (10%) as well as feldspars and the primary carbonates.

The irrigation for a long period of time changed the main structural parameters of chernozems. The aggregation of the soil mass and humus microforms remained the same, but the topsoil became compacted due to decreasing the inter-aggregate porosity and appearance of new void kinds – void-fissures. The clot-like humus microforms remained being added by dark humus that is mobile and capable to illuviation. The positive irrigation-induced change in the microfabric is the increase of the biogeneity, the amount and diversity of excrements becomes increased in the topsoil, new kinds of fine-silted biogenic pedotubules occur in voids-channels (Fig. 2).

2. Southern chernozems in Odessa region. As distinct from chernozems of the Trans-Volga region they were initially characterized by the structure capable to be compacted (the dispersion coefficient is 10–15), the lower porosity and a great amount of fissures; the content of clot-like humus is rather low, a higher percentage of dispersed humus. The profile at a depth of 40–50 cm is heterogenous: the humus horizon reveals the clearly expressed biogenic retreatment, the pedotubule structure and a higher aggregation (probably, it is a buried horizon of atlantic maximum Holocene). At the same depth of the profile the soil texture is also changed revealing the increased amount of the sandy fraction in admixture with the loess-like material.

The irrigation of these chernozems with the water of hydrocarbonate-calcium-magnesium composition didn’t cause adverse changes in their microfabric. They are similar to those described in chernozems of the Trans-Volga region. It is worth emphasizing that the thickness of the humus horizon increased to 0.67 cm/year due to intensive biogeneity and illuviation of humus; the depth of carbonate effervescence decreased to 1.33 cm/year during the first 15 years of irrigation.

3. Irrigation of southern chernozems with alkaline water from Sasyk Lake had an adverse influence on the macro-and microfabric of these soils. Due to mixing this water with that from the Dnestr river its mineralization became somewhat decreased to 1.3 g/l but the alkalinity of the irrigation water remained (pH 8.2–8.7 frequently higher than 9.0). In the first 3 years of irrigation the soil surface proved to be covered by a compact crust of different color in dependence on the elements of micro-and nanorelief being whitish on elevated elements and black in depressions. The crust was varying from 0.5 to 2–3 cm in thickness. After 5 years of irrigation a very compacted structureless (blocky) solodized horizon was diagnosed under the whitish crust. When comparing the total content of clay equaled to 28.0% in initial chernozem it was possible to observe its decrease to 12.2% in the topsoil and increase to 15.0% in the solodized part of the plough horizon under the crust. The amount of exchangeable sodium and magnesium changed in top-and subsoil as well, showing an increase of sodium from 0.4 to 5.1% and magnesium from 15.6 to 28.5% of the sum of exchangeable bases. The bulk density seemed increased from 1.19 to 1.62 g/cm^3; the water permeability was declined from 1.56 to 0.33 mm/min [3]. The changes in the microfabric of chernozems under irrigation with alkaline water are the following. The crust formation resulted in peptization and separation of the humus-clayey plasma and the development of zones composed of sandy-clay grains of the primary minerals and those enriched with the humus and humus-clayey plasma within the 2–3 cm of the topsoil. The crust proper revealed the zones of porous fabric with numerous closed rounded voids, the zones of the layered fabric with subhorizontal porosity and the structureless zones with a slightly expressed aggregation and a lower porosity (Fig. 3).

1. The humus became not uniform due to mobility of the humus-clayey plasma, on the one hand, and, on the other hand, due to changes in humus microforms, where the clot-like microforms were disappeared being replaced by the increased amount of dispersed ones. It

was possible to see an alternation of light-colored zones without the humus-clayey plasma and dark zones enriched with illuviated mobile humus or the humus-clayey plasma.

2. As a result of changes in the humus state the microfabric of the fine-dispersed material seemed to be changed as well: the aggregated isotropic state of the plasma became anisotropic, thus indicating the zones of optically oriented fine cutans – coatings around the voids.

3. The crust displayed a new structural organization of the fine-dispersed material – the porous-layered structure as identical to that described in crusty solonetzes [17, 8]. In general, the microfabric of the topsoil became heterogenous being slightly aggregated up to strongly compacted with numerous fine fissures and porosity that is lower 10–15% (coarse voids of 0.05 mm and more) (Fig. 4).

One should conclude that under the effect of irrigation with alkaline waters several processes take place. (1) Dispersion of the aggregated humus-clayey plasma and its removal (vertical and lateral) with the formation of a shallow solodized-crusty horizon. (2) Replacement of calcium by magnesium and sodium in the absorbing complex and changes in the soil water-physical properties resulted from the development of the solonetz processes in the top-and subsoil. As a result, it was possible to observe a transformation model of southern chernozem into the agrogenic solodized-crusty solonetz affected by irrigation with alkaline water.

4. The irrigation of southern chernozems with the waste water showed that the changes in the structural state seemed insignificant. The structure formation in the topsoil was somewhat decreased (Fig. 5) being rather high in the subsoil at a depth of 25–35 cm [21]. The spongy microfabric of the plough horizon was changed into the compacted one due to the formation of ooidseptic fabric with a higher concentration of the optically oriented clay particles (Fig. 6).

The initial aggregates are becoming close to each other thus decreasing the interaggregate porosity. The surface of microaggregates reveals dark-colored humus cutans, the zones of coarse-dispersed material can be also observed. The subsoil horizon becomes heterogeneous and displays the zones of a higher biogenic retreatment – coprogenic-pedotubule ones and those characterized by the structure absence and a very low porosity. It is advisable to remember the history of the cher

Table 2. Evolution of conditions for the soil formation in Holocene (Ivanov, Chendev, 2010)

Period	Age, thou.years.	Climate	Increase of the. A1 horizon
ДР – ancient	12–8	Changeable cold	35–50 см
AT – atlantic	8–4.8	Thermic maximum of Holocene	50–60 см
SB – subboreal	4.8–2.8	Temperature and precipitation fluctuations	50–100 см (3 мм/год)
SA – subatlantic	2.8 up to the present time	Changeable climate	No increase, but the profile is increased due to increasing the depth of the BC horizon

nozem development in Holocene. The total sum of pedofeatures in the middle part of the soil profile at a depth of 40–60 cm including a higher stability of specific pedotubule microstructure, the high biogenic retreatment of the soil material, charred humus microforms due to the increased humidity and maybe temperature permits to speak about the specific conditions for the soil formation in the middle Holocene what is well agreed with data obtained by Ivanov and Chendev [5].

5. The calcareous chernozems in Rostov region differ from ordinary and southern chernozems by a low microaggregation, the increased content of carbonates, the absence of the biogenic-pedotubule horizon in the middle part of the soil profile, the brown humus with a small share of clot-like humus; the compact carbonate horizons which complicate the drainability of the soil profile. In the middle part of the profile the vertical long void are met as associated with the formation of slickensides. All the properties of compact chernozems are inherent from the parent materials – diluvium of maikop clays.

Under the influence of irrigation all these unfavorable properties of compact chernozems are changed towards the worse: the porosity is decreasing due to increasing the optical orientation of the clayey plasma in the upper soil horizons and its reorientation from anisotropic into the fine-crystalline; the soil compactness is increased, the crust formation. The higher swelling, ability to the crust formation and the low

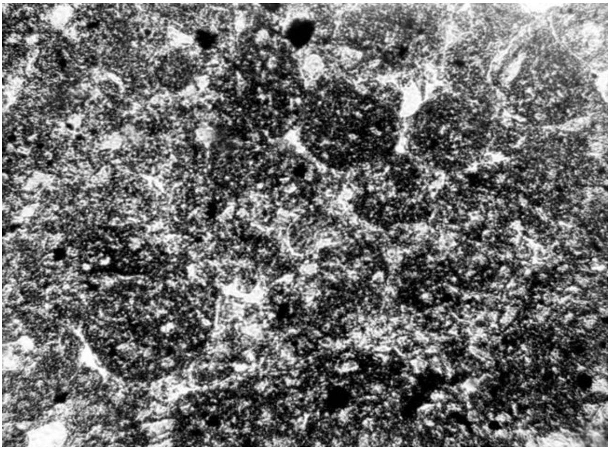


Fig.1 Clot-like microforms of humus in the pedotubule horizon of southern chernozem under irrigation. The AB horizon, 60–70 cm. N‖.

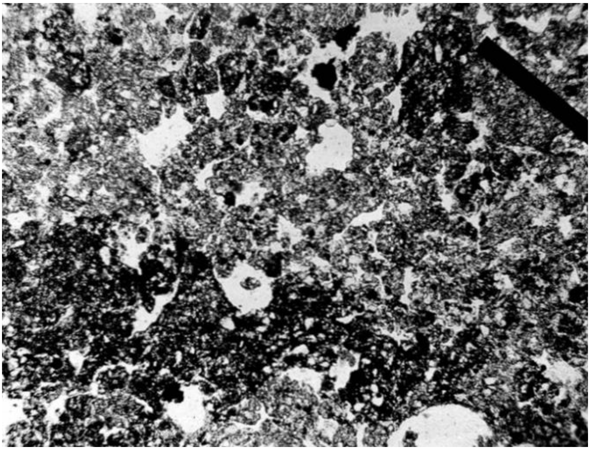


Fig. 2. Different content of humus in the soil mass associated with the biogenic retreatment N‖.

porosity due to irrigation serve as evidence that these soils should not be irrigated in Stavropol region.

The study of the mineralogical composition of the fine-dispersed material in many irrigation systems within the chernozem zone including the objects described above [22] showed that it is significantly changed as affected by irrigation:

1. The firmly combined components are lost;
2. Desmectization of the fine-dispersed material takes place in the plough horizon;
3. The quartz content becomes increased (crushing in the silty fractions).

RESULTS AND DISCUSSION

When irrigating the chernozems, it is necessary to take into account their initial properties (macro-and microaggregates, biogeneity and humus microforms as well as the features of the profile drainability) and the quality of irrigation water. This is clearly demonstrated by irrigation of ordinary chernozems in the Trans-Volga region that have been irrigated by waters of hydrocarbonate-calcium composition for 50 years. One could observe only compacted packing of aggregates, increasing the biogeneity and illuviation of humus with the formation of dark-colored humus zones in the lower part of the topsoil.

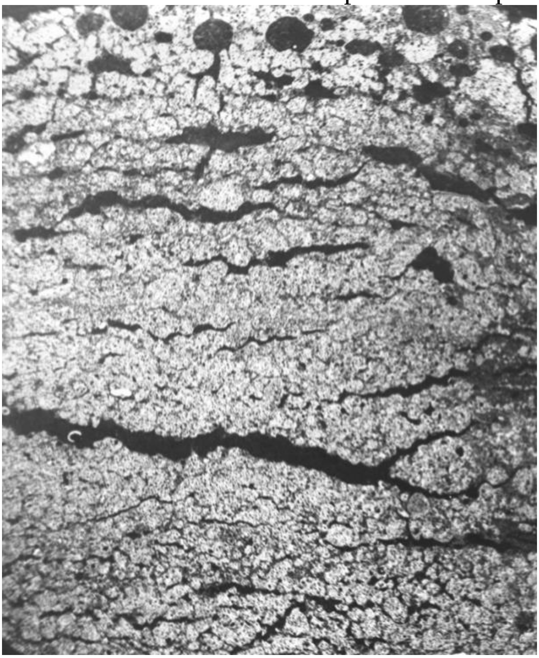
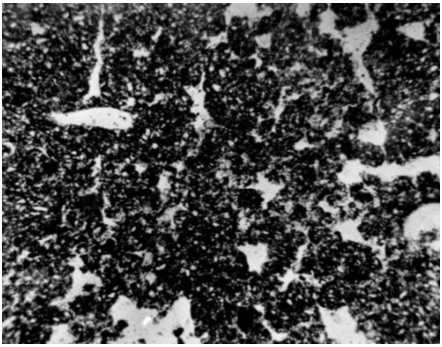


Fig. 3. Microfabric of the crusty horizon in chernozems irrigated by wastewater from Sasyk Lake.



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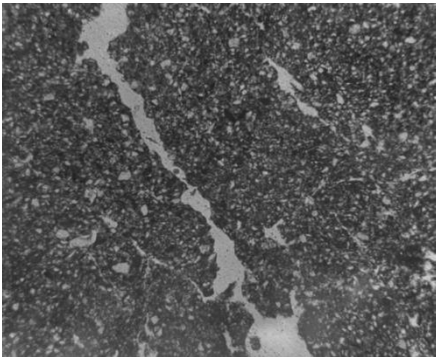

Fig.4 Aggregated (А) and massive (Б) microzones in the plough horizon of irrigated chernozem.

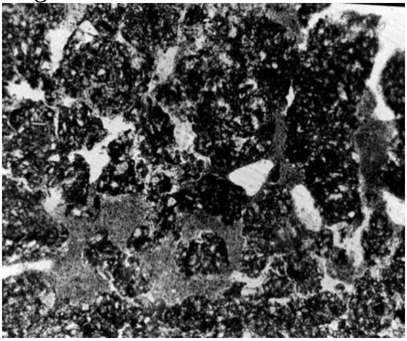

Fig.5 Irrigated chernozem, the Ap Horizon, 0–10 cm

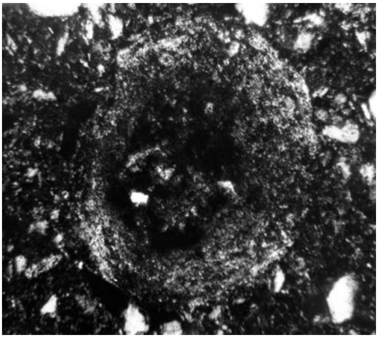

Fig.6 Irrigated chernozem, the Ap horizon, 0–10 cm. Ooides bordered by the optically oriented clay N X.

The southern chernozems in the Odessa region being irrigated with more or less favorable waters for 25 years partially remained the stability of the structural and humus status. However, the aggregation and compaction of the soil mass became heterogeneous being alternated by zones with well structure and those lost their porosity. The reason of such instability is the increased dispersion of the soil material, decline of the depth for calcium effervescense and a higher content of magnesium in irrigation water from Dunabe and Dnestr rivers.

The greatest changes in the macro-and microfabric of chernozems are associated with the use of alkaline waters from Sasyk Lake. In the first 2 years of irrigation it was possible to observe the peptization of the aggregated humus-clayey plasma and its lateral removal and the formation of the layered-spongy crust at the soil surface. Later on the lateral process of the plasma illuviation was added by vertical one resulted in solodization of the upper part in topsoil, accumulation of the illuviated clay enriched with sodium in the subsoil, i.e. its solonetzisation. The initial favorable combination of structural properties of this chernozem seemed to be adversely affected by irrigation with alkaline waters.

The irrigation of southern chernozems with wastewater proved to be somewhat favorable. For 20 years of irrigation although the content of exchangeable sodium became increased to 5% and the aggregation was decreased but due to a higher content of active surface substances in water the microaggegation of chernozems remained rather high.

The irrigation of southern and carbonate chernozems with water rich in magnesium for a long period of time caused adverse effects due to increasing the amount of calcium and magnesium carbonates in the topsoil causing the transformation of the isotropic-aggregated state of the plasma into fine-crystalline one. Such a change in the plasma led to decreasing the meso-and microporosity and increasing the macroporosity. Simultaneously the soil mass in topsoil became cemented by magnesium carbonate, the crumbly structure was changed into blocky one.

In the compacted chernozems of Stavropol region a number of negative features (a higher swelling and a low porosity, optical oriented plasma and cutans, capability to crust formation and compaction by carbonates) proved to be increased as affected by irrigation, i.e. these soils cannot be recommended for irrigation.

CONCLUSIONS

The data mentioned above permit to make the following conclusions:

1. The profile microfabric of ordinary and southern chernozems serves as evidence of the idea proposed by many researchers about the polygeneity and varying age of this soil profile [26, 19, 24, 5]. The pedotubul highly porous and well aggregated horizon at a depth of 40–50 cm enriched and pigment humus is a relic of atlantic maximum Holocene and its microfabric differs from that in over-and underlying horizons to a significant extent. The high and stable aggegation of the pedotubul horizon provides the clearly expressed profile drainability in ordinary and southern chernozems.

2. The mutual dependence between the processes of solodization (in the first 2–3 years of irrigation) and solonetzisation (in subsequent years) shows that the above processes should be changed in their place. According to Gedroits the solodization is a consequence of solonetzisation but not a reason as it has been established in chernozems irrigated by alkaline water.

3. Among the properties of chernozems and the soil formation factors the composition of irrigation water plays a leading role in the evolution of irrigated chernozems. The irrigation water with mineralization of 0.5–0.7 g/l should be favorable for irrigation. Its mineralization in the amount of 0.7–1.5 g/l is unfavorable because serves as cause for the higher alkalinity in irrigated chernozems and the development of such processes as solodization, crust formation and solonetzisation. In the water with mineralization higher than 1.5 g/l the magnesium content is appreciably increased as compared to sodium; during the irrigation the amount of carbonates becomes higher in the topsoil and leads to carbonate cementation (dolomitization). The high content of magnesium in irrigation water can be a reason of chernozem compaction.

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