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THE USING OF OVER DEEP PLOWING FOR RECLAMATION OF SALT-AFFECTED SOILS

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Abstract

The life on Earth depends on the health of soils. Ukraine joined to the implementation of the European Green Deal for the ensure climate neutrality, protect soils, ecologization and improve human well-being. Soil salinity influences on the soil quality, ecosystem services, productivity and food security. The results of studying the effectiveness of over deep plowing (on 75 cm) with the manure (100t/ha) for reclamation of salt-affected chernozem ordinary are given. Such processing ensures the extraction of reserves of calcium salts from deep layers to the soil surface. This technique is called self-amelioration of saline soils. In this variant soil decompaction, improvement of water-physical properties and an increase of the humus horizon were established. The soil buffer capacity against alkalinization increased as a result of an increase of the calcium content (up to 8.3-8.7%) and the saturation of the soil absorbing complex with calcium. The content of absorbed sodium and potassium cations decreased from 6.6-7.0 to 4.3-5.2% of the total absorbed cations. The yield of crops on this variant increased on 21-38%. This agromeliorative technique had a longer effect than ameliorants.

Key words*: alkalinisation, over deep plowing, reclamation, salt-affected soil, soil absorbing complex.*

INTRODUCTION

The life on Earth depends on the health of soils. Ukraine joined to the implementation of the European Green Deal for the ensure climate neutrality, protect soils, ecologization and improve human well-being, ensuring sustainable development of Ukraine. Soils play a central role in achieving the goals of the European Green Deal. Human health and wellbeing are closely connected with soil health and sustainable soil management (Montanarella, 2020).

Soil salinity is one of the main global environmental problems in arid and semi-arid regions (Justo, 2021; Tedeschi, 2020; Zhang, H. 2020). It presents a serious challenge that requires co-ordination between countries that share common water and land resources (Handbook, 2018). Salt-affected soils are a global issue. It needs special attention during agriculture.

Therefore the issues of classification of salt-affected soils, their influence on soil properties and fertility, elaboration of measures to improve the productivity and quality of these soils are very actual for many countries (Pankova et al., 2018; Justo et al., 2021; Dhima, 2021; Vorotyntseva, 2016; Baliuk, 2020).

As an answer to all these threats, the Global Soil Partnership (GSP) has launched the International Network of Salt-Affected Soils (INSAS) to deal with these crucial issues.

FAO held the Global Symposium on Salt-affected Soils (GSAS21) «Halt soil salinization, boost soil productivity» in October 2021. A recent FAO estimate reported that a large portion of total global soil resources are degraded and this problem is persistently expanding (The state, 2011; Kramer, 2020; Baliuk et al., 2017; Baliuk et al., 2021).

Salt-affected soils are subdivided into two groups:

1) Saline soils without Natric/Solonetzic/Sodic horizon;

2) Alkaline soils with a well-developed Natric/Solonetzic/Sodic horizon, which is the diagnostic horizon of this group (Figure 1).

The former group includes Solonchaks and other saline soils without the solonetzic horizon, the latter – Solonetz and solonetzized soils (Handbook, 2018).

Figure 1. Salt-affected soils in Steppe zone of Ukraine

Salinization has a serious impact on soil functions such as its ability to act as a buffer and filter against pollutants, its participation in the water and nitrogen cycles and its ecosystem services in supporting the health of the environment and biodiversity (Handbook, 2018). Soil salinity influence on the soil quality, ecosystem services, soil health, productivity and food security of a country (Abrol et al., 1988; Novikova, 1984). The effects of salinity on plants include ion toxicity, osmotic stress, impaired growth, mineral deficiencies, photosynthetic imbalance, and combinations of these effects (Tedeschi, 2020).

Saline soils in Ukraine constitute a relatively small area (7%) - 1.92 million hectares. 1.71 million hectares of them are used in agriculture. There are about 350 thousand hectares of salt-affected soils on irrigated lands (Baliuk et al., 2020; Handbook, 2018). 70-100 thousand hectares of them are secondary salt-affected soils. Without proper management this expansion can result in environmental problems of irrigation induced soil salinization.

Alkaline soils contain a certain amount of sodium and potassium cations in the absorbing complex. It gives soils unfavourable chemical, physicochemical and water-physical properties. The area of alkaline soils in Ukraine is 2.8 million hectares. Solonetzes do not form continuous massifs, but occur as individual spots of various sizes and configurations among zonal soils, forming complexes.

Soil salinity and alkalinization are the most prevalent and widespread problem limiting crop productivity in irrigated agriculture (Tomaz et al., 2020; Kramer et al., 2020; Baliuk et al., 2009; Handbook, 2018).

Management of salt-affected soils is imperative for achieving most of the Sustainable Development Goals (SDGs) of the United Nations. It is necessary for achieving the «Zero Hunger» (SDG2) and «Life on Land» (SDG15) among other SDGs (Singh, 2021).

A complex of reclamation measures should be applied for increase the fertility of salt-affected soils, The Concept of sustainable management of soil resources of ameliorative lands has been developed in Ukraine (Concept, 2020). The system of sustainable management of irrigated lands was described in it. It ensures a balanced and controlled use of ameliorative lands, preventing of degradation processes in the soil and achieving their neutral level.

Applications for irrigation of limited and unsuitable water leads to the salinization and alkalinization process (Vorotyntseva, 2021). The study of the salt regime and the composition of the soil absorbing complex are especially relevant for reducing the negative impact of salts and absorbing sodium on soil properties and developing a complex of reclamation measures to improve their fertility.

The purpose of is to develop practices for and their sustainable management.

The purpose of our researches is to develop practices for reclamation fertility and rehabilitation of secondary salt-affected soils and their sustainable management on diagnostics and monitoring to improve the ecological land state, reduce soil degradation and rationally use them.

In this article we will consider the effectiveness of over deep plowing (self-reclamation method), its effect on the physical and physico-chemical properties of irrigated chernozem ordinary secondary medium salt-affected (Chernozems Chernic, WRB). This measure has not been studied on irrigated secondary salt-affected soils.

MATERIALS AND METHODS

The researches were conducted in field experiment in the Northern Steppe zone of secondary medium-saline Ukraine (in Yasinovatsky District of Donetsk Region). The researches were carried during eight years. Repetition of experiment variants was sixfold. In this article we present the results of the three

variants of the field experiment: 1 - Control, 2 - Rotted manure (100 t/ha) into 0-25 cm plow horizon; 3 - Over deep plowing (on 75cm) + the rotted manure (100 t/ha) into 0-25 cm plow horizon (Figure 2).

Figure 2. Over deep plowing

Over deep plowing was done when laying an experiment and then its aftereffects were studied. Rotted Manure in the soil (0-25 cm) was applied once on laying the experiment.

The experimental field soil is chernozem ordinary low-humus light clay on loess (Chernozem Chernic, WRB).

The soil on layer 0-25 cm was characterized by such properties and chemical parameters. Groundwater was located at a depth more 10 m. The content of physical clay (< 0.01mm) in layer 0-25 cm of chernozem ordinary was 65%. The soil was characterized by light clay granulometric composition. Humus content was 4.4%, pH_{water} - 8.0, total calcium carbonate ($CaCO_3$) - 1.6%. Total content of water-soluble salts was 0.10%. Content of toxic salts was 0.06%. The content of water-soluble local pond calcium in the water extract was 0.46 mmol (equiv.) /100 g of soil, water-soluble sodium was 0.59 mmol (equiv.) /100 g of soil. The Ca:Na ratio was 0.8. Content of mineral nitrogen was 18.5 mg/kg of soil, P_2O_5 - 240 mg/kg of soil, K_2O - 198 mg/kg of soil (the Machigin method, State standard of Ukraine DSTU 4729:2007). Content of exchangeable cations Ca was 38.8 mg/kg of soil, exchangeable cations Na - 2.9 mg/kg of soil.

Irrigation in the field experiment was carried water from a local pond. On national classification (State standard of Ukraine 2730:2015) the irrigation water is classified as unsuitable for irrigation on the dangers of soil alkalinization and limited suitable on the dangers of soil salinization.

In the experiment winter wheat - buckwheat - corn for grain - barley with sowing of alfalfa - alfalfa 1 year - alfalfa 2 year. Irrigation rates ranged from 800 to 1200 m^3/ha depending on the crops grown and climatic conditions.

On the field experiment the influence of irrigation and over deep plowing on soil processes, properties and morphology of chernozems was studied.

Pits were laid to a depth of 1.5 m. We study morphological profile of chernozem ordinary. We took soil samples on the genetic horizon.

In the field every year before sowing crops (in spring) and after harvesting (in autumn) soil samples were taken in layers 0-25, 25-50, 50-75, 75-100 cm.

The soluble salt content in water extracts and pH of water suspensions (with the soil-to-solution ratio of 1:5) were determined. The composition of exchangeable bases was determined after extraction from the soil with 1 mol/dm^3 ammonium acetate solution (pH 7.0).

The humus content was determined by the Tyurin method. Humus carbon was oxidized with a solution of potassium bichromate and sulfuric acid to obtain CO_2. The excess carbon was titrated with Mohr's salt.

$CaCO_3$ in the soil carbonates were determined by the Sokolovich method using sodium fluoride.

RESULTS AND DISCUSSIONS

The differentiated complex of measures for amelioration of salt-affected soils was developed in Ukraine. It includes the following groups: 1) hydrotechnical - drainage systems and soil leaching to remove salts, 2) agricultural - crop rotation systems, fertilization systems and soil tillage systems including ameliorative deep plowing and 3) chemical - chemical amelioration treatments of irrigation waters and soils (Chemical, 2012).

High efficiency of ameliorative plantage plowing on natural saline dark chestnut and chestnut soils was established (Gavrilivich, 2006; Drozd, 2009; Drozd, 2015; Novikova, 1984). Deep plowing carried out in compliance with the requirements can provide a positive

impact on soil properties and crop productivity for 50 years (Baliuk, 2014).

In this article we will consider the effectiveness of over deep plowing, its effect on the physical and physico-chemical properties of irrigated chernozem ordinary. This measure has not been studied on irrigated secondary salt-affected soils. Over deep plowing is a special tillage with a plantation plow to a depth greater than the boiling depth of 10% hydrochloric acid by 10-15 cm. During such system the soil reserves of calcium salts contained in the transition horizon are removed to the surface. It are the ameliorants of salt-affected soils (self-reclamation method). The upper humus layer moves to the depth of the transition horizon. As result in the first years after plowing the humus content in the arable layer decreases, while in the deeper layers it accumulates. This measure has a long effect because there is a gradual dissolution of calcium compounds (Chemical, 2012).

The chemical composition of irrigation water is one of the main factors determined the degree of soil properties changes. The chemical composition of irrigation water is presented in Table 1.

Table 1. Chemical composition of irrigation water (averaged datas)

Mineralization of water, g/dm^3	pH	Ion content, meq/dm^3					
		HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$
3.0	8.1	7.6	13.0	25.2	7.9	10.5	27.4

The mineralization of the irrigation water was 3.0 g/dm^3; pH - 8.1; type of salt - magnesium and sodium chlorides and sulphates. On national classification (State standard of Ukraine 2730:2015) the irrigation water was classified as unsuitable for irrigation on the dangers of soil alkalinization and limited suitable on the dangers of soil salinization.

During the over deep plowing soil layers and horizons were moved. This led to a change in the natural structure of the profile of common chernozem ordinary and its morphological indicators. The soil section on the variant with over deep plowing was laid 8 years later. Morphological characteristics of horizon of the soil profile is given in Figure 3.

Genetic horizon/ depth, cm	Morphological characteristics
Phkpl 0-25	the upper arable layer of the over deep plowing soil, dark fawn, heterogeneous in color, loose, lumpy-powdery, carbonate, violently boils from 10% HCl, permeated with plant roots, there are shrews; the transition is gradual in color and density
Hpkpl 25-50	transitional horizon, heterogeneous in color, darker than the upper horizon, dark gray spots alternate with dark brown, lumpy-mountainous, moist, loose, permeated with plant roots, weakly boils from 10% HCl, there are shrews; the transition is gradual in color
HP(k)pl 50-75	lower transitional plantation horizon, darker than the upper, loose, moist, lumpy-nutty, densely permeated with plant roots, weakly boiling from 10% HCl; the transition is sharp in color and density
P(h)k 75-115 and deeper	loess, yellow-pale, moist, dense, hints of humus, variegated from white stars, violently boils from 10% HCl

Figure 3. Chernozem ordinary morfological profile after over deep plowing

In variant 3 soil decompaction, improvement of water-physical properties and an increase of the humus horizon were established.

In the practice of salt-affected soils fertility improvement content and depth of $CaCO_3$ accumulation play an important role. This is confirmed by studies other researches (Boaghe, 2021; Novikova, 1984; Drozd, 2015). The distribution of calcium carbonates $CaCO_3$ in the soil of different variants is shown in Figure 4.

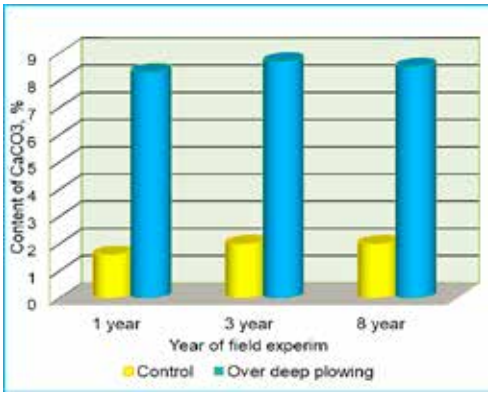

Figure 4. Content of calcium carbonates in the soil of field experiment (0-50 sm)

On the control its content was insignificant in the topsoil. $CaCO_3$ was 1.6-2.0%. In the subsoil their content increases. As a result of the extraction of calcium carbonates during over deep plowing from the horizon of their accumulation to the surface their concentration sharply increased to 8.3-8.7% in the 0-50 cm layer. Natural calcium compounds gradually dissolve in irrigated soil. Therefore they have a long-term ameliorative effect. $CaCO_3$ indicator determines the high potential buffer capacity of chernozem ordinary to irrigation alkalinization. The anti-salt capacity of irrigated ordinary chernozem by mineralized unsuitable water was increased.

The increase calcium carbonates in the soil of 3th variant had a positive effect on the physical and physico-chemical properties of irrigated soil.

The quality of irrigation water is one of the main factors determined the direction of soil processes and regimes, physical, physico-chemical, biological properties of irrigated soil and its ecology-agromeliorative state. In the control variant on irrigation by saline water the accumulation of salts in the soil profile occurred. The concentration of toxic salts in the 0-50 cm layer was rises to 0.11%. The soil was classified as slightly saline.

The reclamation effect of over deep plowing in the direction of soil desalinization was established. The content of toxic salts during this period reached an equilibrium concentration at the level of the control variant (Vorotyntseva, 2015). Seasonal and annual fluctuations in salt content and their distribution in the soil profile were observed. Type of salts was sulfate-soda calcium-sodium.

The pH of the soil variant 3 ranged from 7.9 to 8.1 (layer 0-50 cm). The reaction of water extract of chernozem ordinary was alkaline.

Organic matter content is an important indicator of soil fertility. In the control soil the content of organic matter gradually decreases from the upper horizon to the parent rock. Distribution of organic matter in soil profile of control is characteristic for given subtype of soil. Its content decreases from the upper to deeper horizon.

In 3th variant compared the 2th variant and control, the profile distribution of humus changed due to the movement of the upper humus layers in the lower ones. As a result the thickness of the humus horizon increased. This has a positive effect on plant growth.

Therefore in the first years of researches there was a decrease in the values of this indicator in the arable layer. In the variant with plowing 100 t/ha of the rotted manure was added to the stock so that the humus content in the soil did not decrease.

For the 6th year of the aftereffect of over deep plowing the content of total humus in 0-25 cm layer has not yet reached the level of the control. It was 3.3% (in control - 4.6%). In the lower layers of the planted soil its content increased to 4.9 %.

On irrigated by saline water alkalinization develop in the soil. Especially in the upper layer (0-50 cm) in the soil complex the content of absorbed sodium and potassium cations increases, adsorbed calcium vice versa decreases. On the content of alkaline sodium and potassium cations the soil of control variant was characterized by middle level of alkalinization. Prior the field experiment soil was used in the intensive irrigated crop rotation long time.

Significant qualitative and quantitative changes in the soil absorbing complex took place in the plantage plowing soil. This affected on the soil processes and the fertility of chernozem ordinary. In 1 year after over deep plowing, the saturation of the soil absorbing complex with calcium increased, and the saturation of sodium on the contrary decreased (layer 0-50 cm).
The dynamics of the content of absorbed sodium and calcium in the soil of the variants of the field experiment is shown in the Figures 5 and 6.

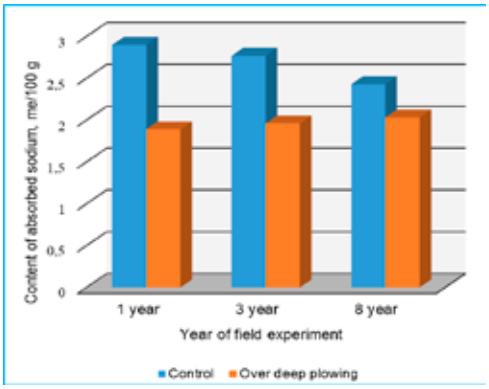

Figure 5. Content of absorbed sodium in the chernozem ordinary (0-50 cm)

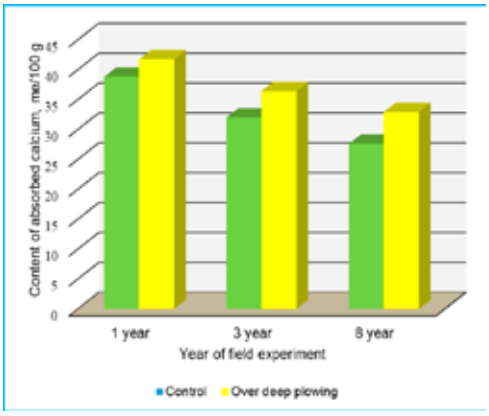

Figure 6. Content of absorbed calcium in the chernozem ordinary (0-50 cm)

The content of absorbed calcium in the plantage plowing soil was higher than in the control. This trend was clearly observed throughout the eight-year period of the experiment. No cessation of the positive effect of the over deep plowing was established.

At the same time with an increase in the duration of the aftereffect of plowing its concentration increased. Content of absorbed calcium in 1 year increased by 6%, in 3 years by 14%, in 8 years by 19% compared to control. In the soil of control variant, the content of absorbed sodium and potassium was 6.6-7.0% of the sum of absorbed cations. The soil was characterized by medium degree of alkalinity. In the variant with plantage plowing its content decreased to 4.3-5.2% of the sum of absorbed cations. The soil alkalinity decreased to a low degree.
Improvement of the cationic composition of the soil absorbing complex on the 3th variant had a positive effect on the physical, physico-chemical properties of chernozem ordinary.
Researcher Naydenova determined the microbiological activity of the soil in this field experiment. The degree of soil degradation decreased with the use of ameliorative over deep plowing (Vorotyntseva et al., 2012).
The results showed that in the plantage plowing soil with the manure the indicators were initially lower than in the control. With an increase in the duration of the aftereffect of this agroameliorative method the number of microflora increased and the degree of degradation decreased.
The lower efficiency of the plantation in the first years is associated with a decrease in the humus content in the layer of 0-25 cm and, consequently, a decrease in the total number of microflora. One of the indicators of the effectiveness of agroameliorative methods in the experiment is the yield of grown crops. In the control the yield of crops was lower than on the variant with plantage plowing.
In field experiment the increase of yield of cultivated crops in the 3th variant with over deep plowing was 21-38% (Figure 7).
The growth of green mass of alfalfa 2 years of cultivation was the highest than other crops. It amounted to 38%. This is due to the fact that alfalfa has a long root system. It penetrates deeper horizons and uses nutrients. The root layer has increased in the plantage plowing soil. The lower horizons are characterized by a high content of humus and nutrients. This had a positive effect on the growth of crops. Other crops grown in the field experiment were characterized by a less deep root system. Therefore, the increase in yield was lower.

Figure 7. Increase of yield crops in the 3th Variant with over deep plowing (in relation to control)

In a field experiment during eight years the aftereffect of a single over deep plowing on chernozem ordinary was traced. And the termination of its action was not determined. Our studies have established that the aftereffect of chemical ameliorants on this soil lasted from 1 to 5 years depending on their dose.

CONCLUSIONS

Long-term studies in the field experiment was established over deep plantation plowing (with the introduction of 100 t/ha of humus) is an effective technique for reclamation of salt-affected soils. This technique is called self-amelioration of soils. During the over deep plowing soil layers and horizons were moved. This led to a change in the natural structure of the profile of common chernozem ordinary and its morphological indicators.

Deep plowing brought to the surface a carbonate accumulation horizon. In the control carbonates content in the arable layer was

insignificant. $CaCO_3$ was 1.6-2.0%. In the bowels of their content increases. In the variant with plantation plowing, the content of carbonates increased sharply to 8.3-8.7% in the 0-50 cm layer.

An increase in the content of $CaCO_3$ in the soil contributed to the improvement of the properties of salt-affected chernozem ordinary. In variant 3 soil decompaction, improvement of water-physical properties and an increase of the humus horizon were established.

The reclamation effect of over deep plowing in the direction of soil desalinization was established.

In 3th variant compared the 2th variant and control, the profile distribution of humus changed due to the movement of the upper humus layers in the lower ones. As a result the thickness of the humus horizon increased. This has a positive effect on plant growth.

On irrigated by saline water alkalinization develop in the soil. On the content of alkaline sodium and potassium cations the soil of control was characterized by middle level of alkalinization. Prior the field experiment soil was used in the intensive irrigated crop rotation long time. In the plantage soil significant qualitative and quantitative changes in the soil absorbing complex took place. This affected on the soil processes and the fertility of chernozem ordinary. In 1 year after over deep plowing, the saturation of the soil absorbing complex with calcium increased, and the saturation of sodium on the contrary decreased (layer 0-50 cm).

The content of absorbed calcium in the plantage plowing soil was higher than in the control. This trend was clearly observed throughout the eight-year period of the experiment. The content of absorbed sodium and potassium cations decreased from 6.6-7.0 to 4.3-5.2% of the total absorbed cations. The degree of soil degradation decreased with the use of ameliorative over deep plowing.

The increase of yield of cultivated crops in the variant 3 with over deep plowing was 21-38%.

In a field experiment during eight years the aftereffect of a single over deep plowing on chernozem ordinary was traced. The termination of its action was not determined. The aftereffect of chemical ameliorants on this soil lasted from 1 to 5 years depending on their dose.

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