



Biological degradation of chernozems under irrigation

Oksana Naydyonova *, Sviatoslav Baliuk

National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky",
Kharkiv, Ukraine

Abstract

We studied the changes in the state of microbial cenosis of Ukraine's chernozems under irrigation. Considerable part of Ukraine's chernozems is located in the areas where humidification is insufficient and unstable. Irrigation is a soil-reclamation measure for chernozems of Ukrainian Forest-steppe and Steppe which enables getting the assured yield, especially vegetable and fodder crops. At the same time, irrigation is a powerful anthropogenic factor that affects the soil, causes a significant transformation of many of its properties and regimes including biological ones. Often these changes are negative. The purpose of our investigation was to identify changes in the state of microbial cenoses of chernozem soils under irrigation which depend on such factors as the quality of irrigation water, the duration and intensity of irrigation, the initial properties of soil, the structure of crop rotation, usage of fertilizing systems and agroameliorative techniques. We identified direction and evaluated a degree of changes in biological properties of chernozems under influence of irrigation in different agro-irrigational and soil-climatic conditions. In the long-term stationary field experiments we identified the following biological indices of irrigated soils and their non-irrigated analogues: a number of microorganisms which belong to main ecological-trophic groups, activity of soil enzymes (dehydrogenase, invertase, phenol oxidase), soil phytotoxic activity, cellulose destroying capacity of soil, indices of oligotrophy and mineralization, summary biological index (SBI) and index of biological degradation (BDI). Results of researches showed that irrigation unbalanced the soil ecosystem and stipulated the forming of microbial cenosis with new parameters. Long-term intensive irrigation of typical chernozem (Kharkiv Region) with fresh water under condition of 4-fields vegetable crop rotation led to the degradation changes of its microbial cenosis such as reduction the number of microorganisms and the diversity of fungi species, repression of cellulose destroying capacity, decrease invertase activity and the rate of humification, intensifying mineralization processes and soil toxicity increasing. Long-term irrigation of ordinary chernozem (Kharkiv Region) with fresh water in moderate regime under 7-field crop rotation including alfalfa caused no disturbances of microbial cenosis. In this case parameters of biological indices did not deviate from the level of its non-irrigated analogue. Irrigation with saline water causes more profound negative changes of microbial cenosis of chernozem, which not always can be corrected using agroameliorative techniques. Intensive irrigation with saline water with total mineralization from 1.2 to 2.2 g/l of ordinary chernozem (Odesa Region) for 13 years has led to a significant degradation changes in the structure and functioning of its microbial cenosis, its radical alteration such as oppression of microflora, decrease in the number of its main groups by 30 – 40 %, intensification of its mineralization function. Application of agroameliorative techniques (such as annually use of phosphogypsum 3 t/ha) or /and complex measures (phosphogypsum 3 t/ha annually + N₁₅₀P₉₀K₆₀ + manure 18 t/ha of crop rotation)) enable to regulate of soil biodynamic processes and partially or completely eliminate the phenomena of biological degradation. It was stated that after the cessation of irrigation the degradation changes of ordinary chernozem's biological properties caused by irrigation with saline water were gradually restored.

Keywords: irrigation, chernozem, microbial cenosis, biological indices, soil biological degradation, ecological-trophic group of microorganisms, soil fermentative activity

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* Corresponding author.

National Scientific Center "Institute for Soil Science and Agrochemistry Research, Chaykovska str., 4, Kharkiv, Ukraine

Tel.: +3805770416692

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E-mail address: oxana9soilmicrob@gmail.com

Introduction

As a result of the execution of international research project "Global Assessment of Soil Degradation" in 1990 it was found that the degradation processes were distributed on an area of about 2 billion hectares (Oldeman et al., 1990, 1992). One of factors that could lead to the degradation of the soil is irrigation. The degradation of irrigated soils is currently observed in many countries (Garcia and Hernandez, 1996; Vlek et al., 2008). Condition of irrigated soils in some regions of Ukraine also is far from satisfactory.

Considerable part of chernozems of Ukraine is located in the zones of the insufficient and unsteady moistening. Irrigation is a reclamative measure on chernozems of Forest-steppe and Steppe of Ukraine, which allows getting the assured harvests of agricultural cultures especially vegetable and forage crops. At the same, time irrigation is a powerful anthropogenic factor of affecting soils, stipulating substantial transformation of many their properties and modes. Often these changes are negative. Currently it is universally recognized that efficiency of irrigation of chernozems appeared to be lower than estimated one (Anikanova, 1980; Gogolev et al., 1992; Baliuk, 1996; Pozniak, 1997, Nosko, 2006, Krasecha, 2006). Degradation phenomena in irrigated chernozems are fixed even more often, that determines the necessity to study regularities of transformation of their properties. Transformation of chemical, physical- chemical and agrophysical properties of irrigated chernozems studied quite adequately, while data regarding influence of irrigation on biological properties of chernozems available in literature is ambiguous and contradictory due to distinctions of soil-climatic terms, quality of irrigation waters, structure of crop rotations and other terms of carrying out experiments, and also different methodological and methodical approaches.

Degradation processes in irrigated chernozems develop slowly and gradually in most cases, sometimes they could not be diagnosed clearly, therefore these processes rarely could be revealed on the early stages. Microbiological indices enable early diagnostic and allow estimating the depth of influence of the anthropogenic loading on biological properties of soils (Dobrovolsky, 1986; Medvedeva et al., 2006; Entry et al., 2008). Soil microorganisms and processes caused by them are sensitive indicators of changes of the modes and properties of soils, because microorganisms first react on the changes of habitat by alteration of structural and functional organization (Andreyuk et al., 1988), that enables to identify the tendencies of change of soils properties before the appearance of degradation symptoms (Andreyuk et al., 1988, 2001; Kolesnikov et al., 1999, 2001; Dobrovolsky et al., 2002; Medvedeva et al., 2003; Svirskene; 2003; Entry et al., 2008). The high informativity of biological indices determines the necessity of their including for the system of indices for the estimation of soils quality (Parinkina et al., 1995; Medvedev, 2002). Therefore, biological criteria must be taken into account during the control and estimation of the state of irrigated chernozems, when the degree of their degradation is identified. So, the study of changes of biological properties of chernozems under irrigation becomes the actual task of modern soil science.

The purpose of this work was to identify changes in microbial cenosis state of chernozem soils at their irrigation depending on quality of irrigation waters, duration and intensity of irrigation, initial properties of soil, structure of crop rotation, and also systems of fertilizers and agroamelioration measures used, to determine the direction and estimate the degree of change in biological properties of chernozems under influence of irrigation in different agriirrigational and soil-climatic terms.

Material and Methods

Microbiological researches were conducted in the samples of the soil selected from the land plots of the studied variants long-term stationary and the small-plot field experiments.

The influence of intensive irrigation with fresh water on the microbial cenosis of typical chernozem was studied in the long-term stationary field experiments conducted by the Institute of Vegetables and Melon Growing of the National Academy of Agrarian Sciences of Ukraine (IVM NAAS), Kharkov District Kharkov Region. Studied variants were as follows: the field with an intensive vegetable crop rotation: irrigation, control without fertilizers; irrigation, $N_{82}P_{88}K_{115}$ (285 kg of active substance /ha) annually (afteraction); irrigation, $N_{60}P_{60}K_{85}$ (205 kg/ha) annually and manure, 15 t/ha of crop rotation area (afteraction); field with the reconstructed crop rotation including perennial leguminous grasses: irrigation, control without fertilizers; irrigation, $N_{120}P_{75}K_{90}$ (285 kg of active substance /ha) annually; irrigation, $N_{120}P_{75}K_{90}$ (285 kg/ha) annually and manure, 16 t/ha of crop rotation area. Irrigation with water of the river Mzha with general mineralization of a 0.6 – 0.8 g/l by irrigation norms from 1500 to 3500 m³/ha was conducted during 30 years.

Influence of moderate irrigation with fresh water on the microbial cenosis of ordinary chernozem was studied on the productive fields of Collective agricultural enterprise "Communard" (Pervomaysk district of the Kharkov Region). Field crop rotation, 7-fields including sowing of perennial leguminous grasses (alfalfas). Irrigation with water of Berekskoye water reservoir which has general mineralization a 0.8 – 0.9 g/l was conducted during 20 years. An irrigation norm varied from 300 – 500 to 1000 – 1500 m³/ha.

We studied the influence of irrigation with saline waters on microbial cenosis of ordinary chernozem of the Steppe zone in scientific-production experiment in Collective agricultural enterprise named after Kutuzoff (Tatarbunars district of the Odesa Region, Danube- Dniester irrigation system); the issues of soil biological properties renewal were studied there also after stopping of irrigation. A crop rotation used in experiment was 7-fields including sowing of perennial legumes. Variants that were studied were as follows: irrigation, control; irrigation, phosphogypsum (3 t/ha, annually); irrigation, complex of measures (phosphogypsum 3 t/ha annually N₁₅₀P₉₀K₆₀ (300 kg of active substance /ha) and manure, 18 t/ha of crop rotation area). Irrigation with saline water of Sasyk water reservoir with general mineralization a 1.2 – 2.2 g/l in the intensive mode was lasted for 13 years, after that the irrigation in experiment was stopped together with chemical and complex land reclamation of soil of corresponding variants, and subsequent seven years we were conducted the researches aimed at the study of renewal of soil microflora degraded as a result of irrigation with saline water and afteraction of reclamative measures. In addition, researches was conducted in the small-plot field experiment in Collective agricultural enterprise named after Kalinin (Tatarbunary district of the Odesa Region), in order to investigate the influence the irrigation with Sasyk's water on southern chernozem. A crop rotation in experiment was 7-fields, grain-fodder crop rotation including perennial leguminous grasses. The mode of irrigation is moderate, watering norms were 250 – 375 m³/ha, duration of irrigation was 13 year. On the productive fields of Agricultural Firm named after Gorky (Maryinsky district Donetsk Region) in irrigated crop rotations it was studied how the microflora of ordinary chernozem is impacted by irrigation with saline water of Kurahovskoe water reservoir with general mineralization 2 – 3 g/l for 15 years in vegetable-fodder crop rotation, and irrigations with saline water of more unfavorable irrigational quality from the ash pond of Kurahov thermal power plant for about 30 years in vegetable crop rotation.

We determined the following biological indices of soil: the number of microorganisms belonging to basic ecological-trophic, taxonomical and physiological groups by methods, generally accepted in soil microbiology (Zvyahintsev et al., 1980), activity of soil enzymes (dehydrogenases by the method of Karyahina and Mihaylovskaya (1986), invertases by the method of Galstyan (Chazyiyev, 1976), phenol oxidase on methodology, expounded Zvyahintsev et al (1980), phytotoxic activity of soil extraction, cellulose destroying ability of soil, olygotrophy index on Aristovskaya and Chudiakova (1977) and mineralization index on Mishustin (1975), integral biological indices (summary biological index (SBI) by the method of relative values according to Azzi (1959) and index of biological degradation (BDI) – arithmetic average of the deviations of indices of quantity of microflora as a percentage from control – the sum of deviations was divided by the total number of indices obtained).

Results and Discussion

The results of researches showed that irrigation disturbs the equilibrium state of chernozems soil ecosystem's and stipulates forming of microbial cenosis with new parameters. The changes in number, structures and functioning of soil microorganisms associations took place in accordance with the changes of terms of their habitation such as hydrothermal conditions, chemical, physical-chemical and agrophysical properties of soils. Direction and degree of changes depend on combination of factors in particular conditions: durations and intensities of irrigation, quality of irrigation waters, structure of crop rotation, initial properties of soils, system of fertilizers and applied agroameliorative measures.

Effect of irrigation with fresh water on chernozems microbial communities.

The orientation and depth of changes of biological properties of chernozem under irrigation with fresh waters depend on intensity of irrigation and, to a great extent, from the structure of crop rotation.

Research results in the stationary field experiments of IVM NAAS

Intensive irrigation with fresh water of typical chernozem for 30 years in the conditions of short vegetable crop rotation resulted in the decline of a number of microorganisms of main ecological-trophic groups, diversity of fungi species, potential capacity for decomposition of cellulose, invertase activity, rates of humification, strengthening of the Mineralization processes, development of toxicosis of soil.

In the soil of control sample field with intensive vegetable crop rotation the population of microflora was lower by 37-48 % than the same in non-irrigated soil. The number of bacteria using organic nitrogen was by 37 % lower, the number of microorganisms assimilating mineral nitrogen by 41 % lower, actinomycetes – by 48 %, oligotrophic microorganisms – by 41 %, fungi – by 48 %.

Inhibition of seed germination by 44-63 % and reduction in the length of test culture roots for 47-57 % in the irrigated control samples indicated the accumulation of toxic substances in the soil that could be considered a metabolite of anaerobic microorganisms and fungal microflora. Soil toxicity decreased in the soil samples from variants with fertilizers and aftereffect of fertilizers and especially after the simultaneous use of manure and fertilizers.

Mineral and organic fertilizers activated a microflora for some extent, however indices do not reach non-irrigated soil level. The reconstruction of crop rotation to 8-fields with introduction of sowing of perennial leguminous grasses reduced negative changes, especially at the joint bringing of mineral and organic fertilizers, in this case the parameters of microbial cenosis reached the level of non-irrigated control and some separate indices even exceed this level. In a Table 1 the estimation of degree of change of biological properties of soil is given after 30 of irrigation, taking into account the number of microorganisms belonging to all investigated ecological-functional groups.

Table 1. Influence of long-term irrigation, fertilizers and structure of crop rotation on the integral biological indices of typical chernozem (field experiments of Institute of Vegetables and Melon Growing of the National Academy of Agrarian Sciences of Ukraine)

Variants	SBI, %	BDI, %	
Intensive vegetable crop rotation (a cucumber – a tomato – a cabbage – a onion), irrigation	Control	56	-43
	NPK	73	-24
	NPK + manure	78	-19
Reconstructed crop rotation, including sowing of alfalfa, irrigation	Control	71	-27
	NPK	69	-29
	NPK + manure	86	-11
Productive fields, without irrigation (alfalfa)	Irrigation terminated	85	-13
	Without irrigation	97	0

Research results in productive fields of CAE “Communard”

Moderate irrigation with fresh water of ordinary chernozem for 20 years in the conditions of 7-fields field crop rotation including perennial leguminous grasses (alfalfa) did not cause serious violations of microbial cenosis, parameters of biological indices do not deviate from the level of non-irrigated analogue. It is known that growing of alfalfa in irrigated crop rotations causes positive effect on development of microflora in soils (Boldyrev, 1980).

Effect of irrigation with saline waters on chernozems microbial communities

Many researchers emphasize the particular danger for development of degradation processes in chernozems their irrigation with saline waters (Andreyuk et al., 1988; Ryazanova et al, 1975, 1997; Chruslova et al., 1991; Anikanova, 1998; Zimovets et al., 1998; Lozovitsky, 2001, 2003; Mirtskchulava, 2001; Nikolaeva and Rozov, 2002; Prihodko, 2005). In the south areas of Ukraine the deficit of water resources, especially sources with suitable for irrigation water, induces to use such waters for watering, because of that in the droughty Steppe zone of Ukraine about 80 percents of irrigated soils make the irrigation-degraded soils.

Character and degree of changes in the state of microbial cenosis chernozems at irrigation with saline waters depend also on duration and intensity of irrigation, quality of irrigation waters, structure of crop rotation. Irrigation with saline waters causes the deeper negative changes of biological properties that not always could be corrected by means of agroamelioration measures. General direction of negative changes of microflora is oppressing of microbial cenosis, increase of oligotrophy, strengthening of mineralization function, and in vegetable crop rotations – microbial toxicosis.

Research results in small-plot field experiment in CAE name after kalinin and scientific-production experiment in CAE name after Kutuzoff

Irrigation with saline waters of southern chernozem during 13 years in the moderate mode did not cause negative effect on the state of microflora. Number of microorganisms in irrigated soil was higher than the

same of similar non-irrigated soil, but at the same times oligotrophy of microbial cenosis was higher. Irrigation of ordinary chernozem in a similar crop rotation with water from the same source during the same period, but in more intensive mode, resulted in deep negative changes in a structure and functioning of its microbial cenosis, his native alteration such as oppressing of microflora, to declining of number of its basic groups on 30-40 % strengthening of its mineralization function. Agroameliorative measures allow regulating the processes of soil biodynamics, so that the phenomena of biological degradation were partly or fully removed (Table 2). The number of bacteria utilizing organic nitrogen in irrigated control sample was on average 2 times lower than in bogharic sample, the number of microorganisms assimilating mineral nitrogen was lower by 30-44 %, actinomycetes by 28-36 %, fungi by 20-46 % oligotrophs by 31-46 %, eutrophs by 37-47 % lower, respectively depending on observations years.

Table 2. Assessment of impact of intensive irrigation with saline water on the microbial cenosis of ordinary chernozem and efficiency of application of agroamelioration measures (scientific-production experiment, collective agricultural enterprise named after Kutuzoff)

Variants of experiment	Integral biological indices			
	SBI, %		BDI, %	
	duration of irrigation, years			
	12	13	12	13
Without irrigation, control	92	84	0	0
Irrigation, control	53	57	-42	-35
Irrigation, phosphogypsum	81	90	-12	-10
Irrigation, complex of measures	92	91	-8	0

It was identified that after the temrmination of irrigation the number and structure of microbial cenosis of ordinary chernozem was renewed after they were impaired due to irrigation with saline water. Thus, in the first years after the termination of irrigation the process of biodegradation has inforced, then in the course of time the state of microbial association gradually went back to initial level and approached an non-irrigated analogue (Table 3). However, seven years seem to be not sufficient period for complete renewal of biological properties of the irrigation degraded soil. In the sixth year of termination of irrigation, the number of basic ecological-trophic groups of microbial cenosis was restored, but indices reflecting its functional state did not reach the level non-irrigated soil. According to the indices of oligotrophy and mineralization, the trophic mode remained worst, and tension of the mineralization processes more intensive.

Positive impact of afteraction of reclamative measures on the microbiological state of the soil after the termination of irrigation was quite short-termed; the positive tendencies were noticeable only during the first years after termination of irrigation. The afteraction of phosphogypsum on the number of microflora during the fourth year did not show up already, during the sixth year it was evident only as the improvement of the trophic mode and declining of mineralization potential, however, the number of microflora falled. The afteraction of complex of measures was not much longer, during the sixth year the indices of number of microflora also were not better than the control sample where the irrigation was terminated. Soil of control sample where chemical soil-reclamation was not used demonstrated that the number of microflora was restored faster.

Table 3. Dynamics of renewal of integral biological indices of the irrigation degraded ordinary chernozem after the termination of irrigation

Variants of experiment	SBI, %					BDI, %				
	years after the cessation of irrigation									
	2	4	5	6	7	2	4	5	6	7
Without irrigation, control	99	97	74	70	95	0	0	0	0	0
Control	39	58	61	98	82	-59	-42	-18	-2	-18
Phosphogypsum	36	52	75	39	76	-62	-45	-15	-35	-19
Complex of measures	49	48	86	70	71	-49	-49	-9	-7	-25

Research Results in Production Fields of Agrarian Firm named after Gorky

Long-term irrigation with saline water of ordinary chernozem caused worsening of biological properties of soil, which degree increased simultaneously with increase of irrigation duration and with the decline of irrigation water quality. Irrigation of the field with a vegetable-fodder crop rotation for 15 years led to the reduction in number of basic groups of microflora on 16-37 %. The number of all investigated groups of microorganisms (except fungi) in long-term irrigated soil (for 15 years) was significantly lower than in non-irrigated one: organotrophic bacteria by 23 % of microorganisms assimilating mineral nitrogen by 20 % of actinomycetes by 37 % oligotrophs by 16 % eutrophs by 21 % lower.

Irrigation of the field with a vegetable crop rotation for 30 years with water of worst quality caused the deeper changes of microflora, a decline of quantity was 17-56 %. The number of bacteria utilizing organic nitrogen in long-term irrigated soils was lower than in non-irrigated ones by 40 %, microorganisms assimilating mineral nitrogen by 37 %, actinomycetes – by 56 % oligotrophs by 51 %, eutrophs by 38 %. Soil gained phytotoxic properties.

Conclusion

Long-term irrigation with fresh water leads to the average degree biological degradation in case of intensive irrigation of typical chernozem in condition of vegetable short crop-rotation. However, in case of moderate irrigation of ordinary chernozem in condition of crop-rotation included alfalfa soil biological properties are not getting worse. Irrigation with saline water causes more profound negative changes of microbial census of chernozem, which cannot be always corrected using agroameliorative measures. Degradation changes of biological properties of soil resulted from irrigation with saline water would be restored after irrigation is cancelled. Long-term irrigation ordinary chernozem with saline water caused biological degradation of the soil, the degree of which increases with increasing duration of irrigation and the deteriorating quality of irrigation water. It is expedient to plug in the system of indices of the ecological-ameliorative monitoring of irrigated soils the biological indices used by us, and also it is reasonable to use them for the ecological-agroameliorative inspection of irrigated soils. These indices will allow more exactly and objectively to estimate the state of irrigated soils, character and degree of changes of soil-biological processes in irrigated soils, to estimate efficiency of measures on prevention of degradation processes and fertility-improving of irrigated chernozems.

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