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ASSESSMENT OF THE BIOLOGICAL ACTIVITY OF SOILS UNDER VEGETABLE CULTURES OF SUBTROPICAL ZONE OF AZERBAIJAN

Research article

Abstract

It were studied the enzymatic activity, the microbial population and the intensity of nitrification, ammonification, CO2 emission and cellulose decomposition in gray-brown, meadow-sierozemic, alluvial meadow-forest and yellow-gley (zheltozem) soils in the subtropical zone of Azerbaijan under vegetable cultures in crop rotation and permanent crops. On this basis, the biological diagnostics of these soils were suggested and the soil ecological health was evaluated. It was shown that properly chosen crop rotation systems on irrigated lands make it possible to preserve the fertility of the meadow-forest alluvial and zheltozem-gley soils and to improve the fertility of the gray-brown and meadow-sierozemic soils.

Keywords: soils of the subtropical zone, crop rotation, permanent crops, biological activity of irrigated soils, biological diagnostics of soils, integral index of the biological soil status.

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ОЦЕНКА БИОЛОГИЧЕСКОЙ АКТИВНОСТИ ПОЧВ ПОД ОВОЩНЫМИ КУЛЬТУРАМИ СУБТРОПИЧЕСКОЙ ЗОНЫ АЗЕРБАЙДЖАНА

Научная статья

Аннотация

В орошаемых серо-бурых, лугово-сероземных, аллювиально-лугово-лесных и желтоземно-глеевых почвах субтропической зоны в севообороте под овощными культурами, также при бессменном выращивании этих культур и целинных вариантах изучены ферментативная активность, численность микроорганизмов, интенсивность нитрификации, аммонификации, выделения углекислого газа и разложения целлюлозы. На основе биохимических показателей дана биодиагностика и комплекс биологических параметров определен интегральный показатель эколого-биологического состояния изучаемых почв. Результаты анализов показали, что использование научно-обоснованных севооборотов в условиях орошения позволяет сохранить плодородие аллювиально-лугово-лесных и желтоземно-глеевых почв, а на серо-бурых и лугово-сероземных почвах даже повысить.

Ключевые слова: почвы субтропической зоны, севооборот, бессменные культуры, биологическая активность орошаемых почв, биодиагностика почв, интегральный показатель биологического состояния почв.

Abstract

Abstract text, minimum 500 characters with spaces.

Keywords: keyword, keyword, keyword.

1. Introduction

Biological properties are important indicators of soil fertility. Soil is a natural medium in which microbes live, multiply, and die [17]. The soil organisms vary in number from a few per hectare to many millions per gram of soil. The density of population is determined by food supply, moisture, temperature, physical condition, and the reaction of the soil. In neutral soils, bacteria dominate over other types of microscopic life. If the soil is acidic and rich in organic matter, fungi predominate. Soil enzyme activities are often used as indices of microbial growth and activity in soils. Quantitative information concerning which soil enzymes most accurately reflect microbial growth and activity is lacking [17]. Enzymes are biologically produced proteinic substances, having specific activation in which they combine with their substrates in such a stereoscopic position that they cause changes in the electronic configuration around certain susceptible bonds. In plant nutrition, their role cannot be substituted by any other substance and their function is quite pragmatic in solubilizing and dissolving the much needed food in ionic forms for the very survival of the animal and plant kingdom. Enzymes are the key to understanding below-ground biochemistry and the role of soil in the global carbon cycle [17]. Soil enzymes play key biochemical functions in the overall process of organic matter decomposition in the soil system. They are important in catalyzing several important reactions necessary for the life processes of microorganisms in soils and the stabilization of soil structure, the decomposition of organic wastes, organic matter formation, and nutrient cycling [25]. Categories of soil enzymes include: 1. Enzymes associated with living, metabolically active cells in soil; found in cell's cytoplasm, bound to cell wall or as extracellular enzymes that have been recently produced by the cell. 2. Enzymes associated with viable but non-proliferating cells (such as spores) 3. Enzymes that are attached to dead cells or to cell debris, or which have diffused away from dead/dying cells that originally produced them. 4. Enzymes that are "permanently" immobilized on soil clay and humic colloids. Such enzymes can remain active for long periods of time. Such immobilized soil enzymes can arise from either eukaryotic or prokaryotic cells [17].

The assessments of soil biological activity and fertility are similar in their essence, and the index of the total biological activity may be used for the purposes of soil monitoring and bioindication and for studying the anthropogenic impact on soils [4]. Knowledge of soil properties and their relationships with one another and with the environmental factors is necessary to improve soil fertility and crop yields. The biochemical and microbiological soil properties are of particular importance in this context. In this paper, the results of a long-term comparative study of the biological properties of subtropical soils of Azerbaijan under crop rotation systems and permanent crops are analyzed in order to understand the role of crop rotation in the improvement of soil fertility and crop yields.

2. Objects and methods

Gray-brown and meadow sierozemic soils of the arid subtropical zone, meadow-forest alluvial soils of the semiarid subtropical zone, and zheltozem-gley (yellow-gley) soils of the humid subtropical zone were studied.

Irrigated gray-brown soils (Irragric Gypsic Calcisols in the WRB). The Gray-brown soils were formed as a result of many-century long irrigation combined with the Caspian Sea level fluctuations. The climatic conditions are characterized by a sufficient heat supply and a long growing season for crop cultivation upon irrigation.

The irrigated gray-brown soils have 1.5–1.9% humus, an alkaline reaction (pH 8.3–8.5), and the chloride-sulfate type of salinization.

Irrigated meadow-sierozemic soils (Irragric Calcisols in the WRB). The genesis of meadow-sierozemic soils is closely related to the hydrological conditions, the groundwater regime and level, and the duration and intensity of the irrigation. The morphological features of salinization and gleyzation are often seen in the profiles of meadow-sierozemic soils. The humus content in the plow layer varies from 1.3 to 2.8% and generally increases from the recently cultivated soils to the long cultivated soils in the oases. In the poorly cultivated soils, the content of exchangeable sodium increases in the deep layers (>30–40 cm), which, together with the high alkalinity of these soils, favors the development of solonetzic processes.

Irrigated meadow-forest alluvial soils (Irragric Mollic Luvisols in the WRB). Meadow-forest alluvial soils are formed under the moderately warm climatic conditions of the subarid subtropical zone. Their irrigated variants are characterized by a humus content of 3.0–3.5%, the presence of carbonates in the entire profile, a slightly alkaline reaction (pH 8.0–8.1), and the absence of salinization.

Irrigated zheltozem-Gley Soils (Irragric Gleyic Luvisols in the WRB). Zheltozem-gley soils are formed under conditions of a humid subtropical climate. The soil moistening is excessive in the spring and autumn and is insufficient in the summer. The humus content in the upper horizons of irrigated zheltozem-gley soils is 2.5–5.0%, and the soil reaction is acid (5.5–6.5 and pH KCl 5.0–5.5).

The effect of crop rotations and permanent crop growing on the biological activity was studied for irrigated gray-brown soils in a six-field vegetable–forage (1—lucerne of the first year, 2—lucerne of the second year, 3—watermelons, 4—potatoes, 5—garlic, and 6—cabbage + tomatoes) and five-field vegetable–legume (1—tomatoes, 2—haricots, 3—water melons, 4—potatoes, and 5—haricots) crop rotation. Meadow-sierozemic soils were studied in a four-field vegetable–forage (1—lucerne of the first year, 2—lucerne of the second year, 3—cucumbers, and 4—tomatoes) crop rotation. Meadow-forest alluvial soils were studied in asix-field vegetable–forage (1—lucerne of the first year, 2—lucerne of the second year, 3—onions, 4—cucumbers, 5—cabbage, and 6—green grass + tomatoes) crop rotation.

For irrigated zheltozem-gley soils, a five-field vegetable– legumes crop rotation was chosen (1—tomatoes, 2—cabbage + corn for silo, 3—onions, 4—haricots, and 5—haricots).

The CO2 emission from the soils was determined in the field according to the method suggested by Makarov, and the intensity of the cellulose decomposition was determined according to the method of Vostrov and Petrova. In the laboratory, we studied the enzymatic activity according to Khaziev, the nitrification intensity according to Bolotina and Abramova, the ammonification intensity according to the method proposed by Tepper with coauthors, and the number of microorganisms by the inoculation method. All the analyses were performed in three replicates. The obtained data were treated using routine statistical methods.

3. Results and discussion

We studied invertase, phosphatase, and urease among the hydrolytic enzymes and dehydrogenase and catalase among the oxidoreductases. The enzymatic activity is an important biochemical characteristic [11] and an indicator of soil fertility [7, 15, 25].

Invertase Activity. b-Glucosidase is a common and predominant enzyme in soils [31]. It is named according to the type of bond that it hydrolyses. This enzyme plays an important role in soils because it is involved in catalyzing the hydrolysis and biodegradation of various glucosides present in plant debris decomposing in the ecosystem [18]. β-glucosidase is characteristically useful as a soil quality indicator, and may give a reflection of past biological activity, the capacity of soil to stabilize the soil organic matter, and can be used to detect management effect on soils [21].

The changes in the invertase activity of different soil types of Azerbaijan with respect to the season, the water and temperature conditions, the plant cover, and the chemical composition and physicochemical properties of the soils have been comprehensively studied [11, 25]. With respect to the soil-ecological conditions, the invertase activity in the plow and subplow horizons varies within 6.4–15.3 and 5.4–11.8 mg of glucose/g of soil per day in the irrigated gray-brown soils under crop rotation and upon permanent crop growing, respectively. The corresponding values for the meadow-sierozemic soils are 6.2–12.6 and 3.7–8.8 mg of glucose/g of soil per day; for the meadow-forest alluvial soils, 7.0–12.2 and 4.0–8.6 mg of glucose/g of soil per day; and, for the zheltozem-gley soils, 8.3–15.4 and 6.7–13.2 mg of glucose/g of soil per day, respectively. The high invertase activity in the irrigated zheltozem-gley soils should be noted. According to this index, the soils may be arranged into the following sequence: zheltozem-gley > gray-brown > meadow-forest alluvial > meadow-sierozemic soils.

Urease Activity. Urease enzyme is responsible for the hydrolysis of urea fertilizer applied to the soil into NH3 and CO2 with the concomitant rise in soil pH. Urease extracted from plants or micro-organisms is rapidly degraded in soil by proteolytic enzymes [36]. Urease activity in soils is influenced by many factors. These include cropping history, organic matter content of the soil, soil depth, soil amendments, heavy metals, and environmental factors such as temperatures [35].

The urease activity in the soils of Azerbaijan has been studied sufficiently well [25]. In the upper 50 cm, it varies within 2.0–4.2 and 1.4–2.9 mg of NH3/g of soil per day in the irrigated gray brown soils under crop rotation and upon permanent crop growing, respectively; in the meadow-sierozemic soils, within 1.7–5.0 and 0.9–2.4 mg of NH3/g of soil per day; in the meadow-forest alluvial soils, within 73.1–5.4 and 2.5–3.9 mg of NH3 /g of soil per day; and in the zheltozem-gley soils, within 2.2–3.9 and 2.0–3.5 mg of NH3/g of soil per day, respectively. The lowest urease activity is typical of the zheltozem-gley soils, and the highest urease activity is observed in the irrigated meadow-forest alluvial soils.

Phosphatase Activity. Phosphatases are a broad group of enzymes that are capable of catalyzing hydrolysis of esters and anhydrides of phosphoric acid [32]. Apart from being good indicators of soil fertility, phosphatase enzymes play key roles in the soil system [13]. In soil ecosystems, these enzymes are believed to play critical roles in P cycles [29] as evidence shows that they are correlated to P stress and plant growth. The amount of acid phosphatase exuded by plant roots has been shown to differ between crop species and varieties, [20] as well as crop management practices [20, 33]. For instance, research has shown that legumes secrete more phosphatase enzymes than cereals [34]. This may probably be due to a higher requirement of P by legumes in the symbiotic nitrogen fixation process as compared to cereals. In their studies, Li et al. [16] reported that chickpea roots were also able to secrete greater amounts of acid phosphatase than maize.

Contrary to the invertase and urease activities, the dependence of the phosphatase activity on the cultivated crops and ecological factors is less pronounced. The mean phosphatase activity in the plow and subplow horizons of the irrigated gray-brown soils in the crop rotations and under the permanent crops varies within 1.6–2.8 and 0.7–1.9 mg of P_2O_5/10g of soil per h, respectively; the corresponding values for the meadow-sierozemic soils are 0.7–2.3 and 0.2–0.3 mg of P_2O_5/10 g of soil per h; for the meadow-forest alluvial soils, 0.5–1.2 and 0.3–0.5 mg of P_2O_5/10 g of soil per h; and for the zheltozem-gley soils, 1.5–2.4 and 0.6–1.5 mg of P_2O_5/10 g of soil per h, respectively. The phosphatase activity in the irrigated gray-brown, meadowsierozemic, and zheltozem-gley soils is higher than that in the meadow-forest alluvial soils.

Catalase Activity. The catalase activity determines the soil fertility and is an important diagnostic characteristic of the biological activity. It was studied in the irrigated gray-brown soils under crop rotation and under permanent cultures, in the irrigated meadow-sierozemic soils, in the meadow-forest alluvial soils, and in the irrigated zheltozem-gley soils [25]. In the irrigated gray-brown soils under crop rotation and upon permanent crop growing, the catalase activity in the upper 50 cm varies within 7.8–16.9 and 5.9–11.2 cm 3of O_2 /g of soil per min; in the meadow-sierozemic soils, within 3.3–8.6 and 1.9–4.1 cm 3 of O_2 /g of soil per min; in the meadow-forest alluvial soils, within 4.9–9.1 and 3.0–6.5 cm 3 of O_2 /g of soil per min; and in the zheltozemgley soils, within 2.5–6.1 and 1.6–4.7 cm3 of O_2 /g of soil per min, respectively. The highest catalase activity is typical of the irrigated gray-brown soils, and the lowest catalase activity is observed in the meadow-sierozemic and zheltozem-gley soils. The catalase activity may be inhibited by the salinity of the meadowsierozemic soils and by the acidity of the zheltozemgley soils.

Dehydrogenase Activity. The dehydrogenase enzyme activity is commonly used as an indicator of biological activity in soils [30]. This enzyme is considered to exist as an integral part of intact cells but does not accumulate extracellularly in the soil. Dehydrogenase enzyme is known to oxidize soil organic matter by transferring protons and electrons from substrates to acceptors. These processes are part of respiration pathways of soil microorganisms and are closely related to the type of soil and soil air-water conditions [22]. Studies on the activity of dehydrogenase enzyme in the soil are very important as it may give indications of the potential of the soil to support biochemical processes which are essential for maintaining soil fertility [17]. Dehydrogenase catalyzes the reaction of hydrogen detachment in various organic substances (carbohydrates, organic acids, amino acids, spirits, etc.). The dehydrogenase activity was studied in the irrigated gray-brown and meadow-sierozemic [25] soils. According to our data, it varies within 3.7–8.7 and 2.0–5.4 mg of triphenylformazan/10 g of soil per day in the upper (0–50 cm) layer of irrigated gray-brown soils under crop rotation and upon permanent crop growing, respectively. The corresponding values for the meadow-sierozemic soils are 4.2–5.9 and 1.6–3.8 mg of triphenylformazan/10 g of soil per day; for the meadow-forest alluvial soils, 2.8–6.0 and 1.6–3.8 mg of triphenylformazan/10 g of soil per day; and for the zheltozem-gley soils, 7.9–15.5 and 5.8–8.9 mg of triphenylformazan/10 g of soil per day, respectively.

The dehydrogenase activity in the irrigated soils changes with respect to the soil type and the biological characteristics of the cultivated crops. The highest dehydrogenase activity is typical of the zheltozem-gley soils, which is probably favored by the anaerobic conditions in these soils. Investigations performed under different pedoclimatic conditions indicate that the activity of enzymes under vegetable crops in rotation systems is generally higher than that upon permanent crop crowing [25].

Our study shows that the activity of hydrolytic enzymes is more stable as compared to oxidation–reduction enzymes and is mainly dictated by the growth of the crops. The oxidation–reduction processes are more dynamic and sensitive to changes in the environmental conditions.

Biogenic features of irrigated soils. The activity of microorganisms in soils is related to the formation and mineralization of soil humus and inactivation of substances released from plants and inhibiting substances entering the soils with applied chemicals. The living activity of microorganisms affects the properties of the soil air and gas exchange processes. Investigations performed under different pedoclimatic conditions indicate that the crops exert different effects on the composition and number of microorganisms [6, 12, 13, 23, 24, 26]. The analysis of the soil microflora includes the determination of the total number of microorganisms in the soil and the populations of particular physiological groups. It is also important to determine the total biological activity diagnosed by the amount of carbonic acid released from the soil and the soil capacity for accumulation of nitrates and cellulose decomposition [5].

In the irrigated gray-brown soils used in rotation systems with different crops, the numbers of microorganisms in the upper 50 cm of the soil profiles varies within the following values: 736–2016 thousand CFU/g of dry soil for bacteria, 111–197 thousand CFU/g of dry soil for spore-forming bacteria, 262–594 thousand CFU/g of dry soil for actinomycetes, and 1.4–3.8 thousand CFU/g of dry soil for microscopic fungi. The corresponding values for meadow-sierozemic soils are 1027–1300, 302–396, 478–621, and 3.9–4.9 thousand CFU/g of dry soil, respectively; for meadow-forest alluvial soils, 2199–3171, 81–100, 394–459, and 26–62 thousand CFU/g of dry soil, respectively; and for zheltozem-gley soils, 1643–2101, 248–300, 511–547, and 23–52 thousand CFU/g of dry soil, respectively. In the gray-brown and meadow-sierozemic soils of the dry subtropical zone under monocultures, the amount of microorganisms is the lowest. These data attest to the low effect of the soil type on the rhizosphere microflora and to the considerable effect of the cultivated crops on the number and composition of the soil microbial community.

Nitrification capacity. The nitrate-forming bacteria are generally confined to the top 25–30 cm of the soil, where the content of organic matter is also more. These organisms are most active between 25 and 38^0C and under favorable conditions of tillage, aeration, neutral soil reaction, and moisture content at field capacity. The bacteria cease or reduce their activity when the pH value of the soil falls below 5.0 [17].

Soil ammonifiers, nitrifiers, and denitrifiers play an important role in the transformation of nitrogen compounds. The intensity of the nitrate accumulation under crops due to the activity of nitrifying bacteria has been studied by many authors [25]. It has been shown that the intensity of the nitrification in gray-brown soils during the growing season changes in dependence on the biological specificity of the crops, the soil water and temperature regimes, and the applied agrotechnologies [25]. In the upper 50 cm of the irrigated gray-brown soils in rotation systems, the nitrification intensity varies within 27.5–96.9 mg of N-NO_3/kg of soil per 14 days and, in the meadow-sierozemic soils, within 8.4–13.6 mg of N-NO_3/kg of soil per 14 days. Under permanent crops, it is somewhat lower. In the irrigated meadow-forest alluvial soils in rotations, it varies within 13.2–50.0 mg of N-NO_3/kg of soil per 14 days, while, under permanent crops, within 9.8–23.2 mg of N-NO_3/kg of soil per 14 days. In the zheltozem-gley soils, the corresponding values are 13.1–33.7 and 8.1–19.8 mg of N-NO_3 /kg of soil per 14 days. The mineralization of nitrogen compounds in the latter soils is relatively low.

Ammonification capacity. The ammonification processes under cultivated crops have been studied by many scientists [25]. The activity of ammonifying bacteria in the upper 50 cm of irrigated gray-brown soils in rotations and under permanent crops varies within 10.6–29.0 and 7.0–20.8 mg of N-NH_4/kg of soil per 14 days, respectively. In meadow sierozems in rotations, the intensity of the ammonification in the plow and subplow layers varies within 33.9–54.1 and 24.8–45.4 mg of N-NH_4 /kg of soil per 14 days, respectively, while, for permanent crops, it varies within 19.1–30.6 and 13.8–21.8 mg of N-NH_4 /kg of soil per 14 days, respectively. The ammonification intensity is the highest upon crop rotations. In the upper 50 cm of irrigated meadow-forest alluvial soils, it varies within 22.0–54.5 mg of N-NH_4 /kg of soil per 14 days. In the irrigated zheltozem-gley soils in rotations and under permanent crops, the corresponding values are 88.1–131.7 and 80.6–121.4 mg of N-NH_4/kg of soil per 14 days, respectively. Thus, according to this index, the studied soils may be arranged into the following sequence: irrigated zheltozem-gley > meadow-forest alluvial > graybrown> meadow-sierozemic soils.

The intensity of the CO_2 emission from the soil. The emission of carbon dioxide from soils is due to root respiration, the living activity of microorganisms (bacteria, fungi, algae, and protozoa), and physicochemical and chemical soil processes [4, 5]. This characteristic depends on the soil temperature [3, 5, 12], the moisture content [12, 27, 28], the stage of the plant development [18], the water and temperature regime [8, 9, 10], the soil type and its use [8], the degree of the soil cultivation and the character of the applied agrotechnology [1, 10], and the soil fertility [1]. Therefore, the amount of CO_2 produced in the soil can be used as an indicator of the soil microbiological activity [5]. The biological activity of the soil may be judged from the intensity of the soil respiration [1, 2]. Many papers are devoted to the CO_2 emission from soils under different crops [1, 25].

The CO_2 emission from the irrigated gray-brown soils under the vegetable–forage and vegetable–legumes crop rotations varies within 2.5–4.2 and 2.6–4.0 kg of CO_2 /ha per h, while, under the permanent cultivation of the same crops, it varies from 2.3 to 3.5 kg of CO_2/ha per h.

In the irrigated meadow-sierozemic soils in rotations and under permanent crops, the CO_2 emission varies within 1.5–2.1 and 1.5–2.6 kg of CO_2/ha per h, respectively, while, in the irrigated meadow-forest alluvial soils, within 2.4–4.5 and 2.1–3.4 kg of CO_2/ha per h, respectively. In the irrigated zheltozem-gley soils inrotations, it varies within 4.0–8.1 kg of CO_2/ha per h, while, under permanent crops, the intensity of the CO_2 emission is somewhat lower.

The intensity of the cellulose decomposition. Cellulose is the most abundant organic compound in the biosphere, comprising almost 50% of the biomass synthesized by photosynthetic fixation of CO_2 [19]. The growth and survival of micro-organisms that are important in most agricultural soils depend on the carbon source contained in the cellulose occurring in the soils [14]. Studies have shown that activities of cellulases in agricultural soils are affected by several factors. These include temperature, soil pH, water, and oxygen contents (abiotic conditions), the chemical structure of organic matter and its location in the soil profile horizon [14], quality of organic matter/plant debris and soil mineral elements [14, 30] and the trace elements from fungicides [14].

Linen tissue placed into soil is gradually decomposed under the impact of microorganisms, including cellulosedecomposing bacteria. Cellulose is decomposed to monomers (glucose) by different enzymes. The biological activity of the soil may be judged from the intensity of linen tissue decomposition and from the accumulation of amino acids. The intensity of cellulose decomposition in soils has been studied by many authors [25]. In the irrigated gray-brown soils under six-field and five-field vegetable–forage crop rotations, the intensity of the linen tissue decomposition varies within 4.6–15.9 and 4.8–14.5%, respectively. Under permanent crops, it varies within 4.4–11.2%.

In the meadow-sierozemic soils, it varies within 18.3–36.5% upon crop rotations and within 15.6–28.8% under permanent crops; in the irrigated meadow-forest alluvial soils, within 8.9–33.5 and 7.2–22.0%, respectively; and, in the irrigated zheltozemgley soils, the corresponding values are 11.1–34.4 and 14.1–28.5%, respectively. The lowest intensity of the cellulose decomposition is observed in the irrigated gray-brown soils.

The analytical data show that the activity of the biochemical processes varies widely with respect to the biological specificity and the phase of development of the crops, the ecological state of the soil, and the soil type. It is somewhat higher in the irrigated soils used in crop rotations than under the permanent crops. In the irrigated gray-brown, meadow-sierozemic, and meadow-forest alluvial soils, the biological activity is the highest under lucerne. In the irrigated zheltozemgley soils, it is the highest under haricots and the lowest under garlic and onions. Under the other crops, the soil biological activity is intermediate. The data on the different indices of the biological activity of the studied soils are summarized in the table.

Integral index of the biological soil status (IBSS). At present, there are no universal methods for the appreciation of the biological activity of soils, and the use of some particular characteristics is insufficient for this purpose. An integral index of the bioecological status is recommended in [4]. For its calculation, the highest value of each characteristic in the studied soils is taken as 100%, and the same characteristic in the remaining soils is expressed in percent of the maximum value:

$$B_1 = (B_x/B_{max}) \times 100, \quad (1)$$

where B_1 is the relative value of the studied characteristic and B_x and B_{max} are its actual and maximum absolute values, respectively. The relative values of many characteristics can be summed up, whereas their absolute values cannot be summed up because of the different measurement units:

$$B_m = (B_1 + B_2 + B_3 + \ldots + B_n)/N, \quad (2)$$

where B_m is the mean relative value of the number of characteristics, and N is the number of characteristics.

The integral characteristic of the soil biological status is calculated similarly to Eq. (1):

$$IBSS = (B_m/B_{max}) \times 100, \quad (3)$$

where B_m and B_{max} are the mean and maximum relative values of all the characteristics.

This approach makes it possible to integrate several biological characteristics [4]. Changes in the soil fertility can be judged from the IBSS values. An integral characteristic of the bioecological status of the studied soils used in crop rotation systems and for permanent crop growing has been determined on the basis of the particular characteristics of their biological activity.

Earlier, the same work was done for the virgin gray-brown and meadow-sierozemic soils of arid subtropical regions, the meadow-forest alluvial soils of semiarid subtropical regions, and the zheltozem-gley soils of humid subtropical regions [25]. In the cultivated gray-brown soils, it varies within 63–100% upon the six-field crop rotation (Scheme I), 65–73% upon the five-field crop rotation (Scheme II), and 42–67% under the permanent crops. In the cultivated meadow-sierozemic soils, it varies within 86–100% upon the four-field crop rotation and 67–77% under the permanent crops. In the rotation with tomatoes and cucumbers, it varies within 47–53% and is somewhat higher than that under the permanent crops. In the irrigated meadow-forest alluvial soils, the IBSS varies within 67–100% in the six-field crop rotation and reaches the highest values under the lucerne of the second year and the lowest values under cucumbers. Under the permanent crops, it varies within 49–60% with the lowest values under onions. In the zheltozem-gley soils, the IBSS varies within 70–100% in the rotation system and within 53–77% under the permanent crops with the highest values under haricots and the lowest values under onions. Thus, the changes in the IBSS values depend on the character of the soil management.

The IBSS values for the irrigated gray-brown soils in the vegetable–forage crop rotation (Scheme I) are 18% higher than those in the virgin soils and 34% higher than those under the permanent crops. In the vegetable–legumes rotation (Scheme II), they are higher by 12% and 30%, respectively. In the irrigated meadow-sierozemic soils, the highest IBSS values (100%) are observed in the crop rotation; in the virgin soils, they are lower by 15%; and, under the permanent crop growing, they are lower by 35%. These data suggest that the irrigation of gray-brown and meadow-sierozemic soils and their use in crop rotation systems create more favorable soil-ecological conditions in comparison with those in the virgin soils with a corresponding rise in the soil biological activity and the number of soil microorganisms. In the virgin meadow-forest alluvial soils, the IBSS is 100%; it is lower by 2% upon the crop rotations and by 40% upon the permanent crop growing. In the zheltozem-gley soils, it is 100% in the virgin soils, 92% upon the crop rotations, and 70% upon the permanent crop growing.

A five-grade scale has been suggested for the biological assessment of soils by Kazeev with coauthors [4]. In our case, the IBSS values in the virgin soils and in the soils used in the crop rotation systems vary from 82 to 100%; consequently, these soils may be qualified as soils with very high biological activity. Under permanent crops, the IBSS values vary within 60–70%, which corresponds to high and moderate biological activity. The results of this analysis show that the biological soil parameters may be regulated via using appropriate crop rotation systems. The biological assessment of soils shows that the soil fertility in the subtropical zone may be preserved and even increased upon irrigation and rational soil management.

4. Conclusions

Chemical and biological properties of a soil are indicators of soil quality, while soil fertility can be determined by its biological activity. Soil provides natural environment for the survival of microorganism and they need favorable physical and chemical conditions for their optimal function. An imbalance of soil microorganisms, nutrient deficiency, and change in physicochemical properties, like a decrease in pH, can result in decreased soil fertility and crop productivity.

Understanding other possible roles of soil enzymes is vital to soil health and fertility management in ecosystems. These enzymes may have significant effects on soil biology, environmental management, growth, and nutrient uptake in plants growing in ecosystems.

The integral index of the bioecological status of the studied gray-brown, meadow-sierozemic, meadow-forest alluvial, and zheltozem-gley soils varies within 82–100% upon crop rotations and in the virgin soils and within 60–70% upon permanent crop growing. The soils used in the rotation and virgin soils are assigned to the group of soils with very high biological activity.

The soils under permanent crops are characterized by their high and moderate biological activity. In the semiarid and moderately humid subtropical regions, the biological activity of the soils is preserved upon their cultivation with irrigation; in the dry subtropical zone, the biological activity of irrigated soils is higher than that in their virgin analogues.

Conflict of Interest

None declared.

Конфликт интересов

Не указан.

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Table - Biodiagnostics of soils of subtropical zone

Variant	Invertase, mg of glucose/g of soil per day	Urease, mg of NH_3/g of soil per day	Phosphatase, mg/10 g of soil per h	Catalase, cm_3 of O_2/g of soil per min	Dehydrogenase, mg of triphenylformazan/ 10 g of soil Per day	Nitrification, mg of N-NO_3/kg of soil per 14 days	Ammonification, mg of N-NH_3/kg of soil per 14 days	CO_2, kg/ha per h	Cellulose decomposition rate, %	Number of micro-organisms, thousand CFU/g of soil	IBSS, %
Arid subtropical zone. Gray-brown soils, Scheme I (six-field vegetable–forage crop rotation)											
Virgin plots	11,40	4,10	1,91	10,8	4,38	46,8	17,8	2,50	8,4	1318	82
Crop rotation (Scheme I)	11,77	3,14	2,65	13,2	6,08	65,1	21,2	3,36	10,3	2157	100
Permanent crops	8,97	2,20	1,55	8,7	3,48	34,2	14,8	2,74	7,7	1214	66
Arid subtropical zone. Gray-brown soils, Scheme II (five-field vegetable–legumes crop rotation)											
Virgin plots	11,40	4,10	1,91	10,8	4,38	46,8	17,8	2,50	8,4	1318	88
Crop rotation (Scheme II)	11,24	3,09	2,70	12,3	5,71	55,6	20,4	3,32	10,0	1822	100
Permanent crops	8,97	2,20	1,55	8,7	3,48	34,2	14,8	2,74	7,7	1214	70
Arid subtropical zone. Meadow-sierozemic soils, four-field vegetable–forage crop rotation											
Virgin plots	7,29	2,13	2,56	4,8	6,81	8,9	52,7	1,87	17,8	1385	85
Crop rotation	9,34	3,46	1,64	7,0	5,55	11,7	42,4	2,28	28,0	2328	100
Permanent crops	6,74	1,79	0,28	3,8	3,27	7,1	23,3	1,94	22,0	1106	65
Semiarid subtropical zone. Meadow-forest alluvial soils, six-field vegetable–forage crop rotation											
Virgin plots	12,8	5,6	1,48	6,2	6,75	25,7	50,4	4,90	17,4	2836	100
Crop rotation	9,69	4,24	0,93	7,1	4,88	31,2	35,6	3,39	19,5	3661	88
Permanent crops	6,64	3,03	0,48	5,6	2,81	16,5	23,3	2,80	13,9	2617	60
Humid subtropical zone. Zheltozem-gley soils, five-field vegetable–legumes crop rotation											
Virgin plots	13,7	3,8	2,86	4,5	16,03	23,9	132,8	8,40	29,5	2869	100
Crop rotation	12,6	3,39	2,30	4,9	14,08	26,7	118,1	6,07	23,9	3185	92
Permanent crops	10,3	2,72	1,22	3,6	11,46	15,5	101,4	5,06	19,9	2718	70