ОБЗОРНАЯ СТАТЬЯ

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A.A. Kurmanbayev[1]*, K.K. Mussayeva[1], Sh.G. Yermek[1]

SOIL BIOLOGICAL ACTIVITY AND ITS INDICATORS IN SOIL QUALITY MONITORING: MINI - REVIEW

[1] Kazakh Research Institute of Soil Science and Agrochemistry named after U.U. Uspanov, 050060, Almaty, al-Farabi avenue, 75 B, Kazakhstan,
**e-mail: wberel@gmail.com*

Abstract. The presented mini-review shows a systematic picture of the biological activity of soils in its connection with physical and chemical properties, and, ultimately, with soil fertility and crop yields. The biological activity of soils is due to the lifetime activity of soil biota, mainly microbiota and root systems of plants, as well as the action of soil enzymes. It has been shown that individual BAP tests can be used as simple and accessible biological fertility indices BFI.

Key words: soil biological activity, soil fertility indicators, enzymes, soil health, soil quality.

Biological activity is the intensity (intensity) of all biological processes in the soil. The biological activity of the soil (BAP) determines the total content of a certain amount of enzymes in the soil, which are released both during the vital activity of plants and soil microorganisms, and accumulated by the soil after the destruction of dead cells.

The intensity of the processes of processing organic substances and the destruction of minerals, as well as the scale and direction of the processes of transformation of energy and matter in terrestrial ecosystems determine the biological activity of the soil.

It is customary to separate the actual and potential biological activity of soils. Potential biological activity is determined in optimal conditions for a specific biological process under study in a laboratory experiment. Actual or field biological activity is determined directly in the field and characterizes the actual activity of the soil in natural conditions [1].

Based on the parameters of the biological activity of the soil, it is possible to judge the direction of the processes of transformation of matter and energy and their scale in the natural ecosystems of the land, the activity of the processes of processing the remains of organic substances and the decomposition of minerals.

Soil fertility is determined by the biochemical processes underlying soil formation [2].

The total microbial activity of soils serves as a good general measure of the circulation of organic substances in the natural habitat, since more than 90 % of the energy flow passes through microbial reducers. The criteria are respiratory activity, dehydrogenase activity, heat generation, FDA test, cellulase activity, nitrifying activity, etc. [3, 4].

Following the new concept of soil quality, due to the multifunctionality of soils, the question of choosing the necessary set of biological activity tests for assessing the control effects on the soil is acute. Biological assessments should go beyond the search for a universal minimum data set and adopt a more nuanced approach to selection based on soil biology. The authors emphasize that biological characteristics should not be considered in isolation, but along with the chemical and physical characteristics of the soil, as well as in the context of management and the environment [5].

This approach is closely implemented within the Cornell Soil Condition Test framework and the Biofunctool tool [6, 7]. Both tools use a minimal data set approach that combines chemical, biological and physical indicators to determine soil quality. According to experts, these tools have advanced soil quality assessment in agricultural and forest systems.

It is important to understand that the number of microorganisms in the soil constantly changes. It has recently been found that in response to disruptive effects on the soil microbiota, it reacts with wave-like fluctuations in abundance and activity, and this process has a universal character and has been confirmed by numerous experiments. The concept of the wave-like nature of the dynamics of the soil microbiota, its universality in natural conditions and its connection with disturbing influences should be considered in modern microbiological and biochemical studies of soils. This implies a mandatory study of the dynamics of the studied indicators for 3-5 days at least and the use of instrumental research methods. The parameter of soil respiration, estimated by carbon dioxide emissions, plays an essential role in assessing BAP. Based on this parameter, several indices and soil health can be evaluated. So, Semenov A.M. based on this concept, offers the following formula for soil health:

$$PO = |(Lcp - Lip):Lcp|,$$

Where Lcp is the width at the half–height of the peak of the control soil sample, and Lip is the width at the half–height of the peak of the studied soil sample.

The resistance of MS in soil samples to HB is calculated according to Griffith et al. [8] as the ratio of the CO2 emission intensity of the experimental soil sample to the control one 24 hours after HB. The calculation of the stability indices RS and elasticity RL of the soil is carried out according to the equations proposed by Orwin and Wardle [9]:

$$RS = 1 - 2|D| : (C+|D|),$$

$$RL = 2|D| : (|D(t)|+|D)|) - 1,$$

Where D is the difference between the maximum peak height of the control and the measured sample, C is the peak height of the control sample (without HB), D(t) is the difference between the test sample and the control after time t, at the end of peak attenuation. In our experiments, the t value was assumed to be 3 days. The figure taken from the author's article well illustrates the undulating dynamics of soil respiration for intensive farming system (ISS) and biological farming systems (BSZ) (figure 1) [10].

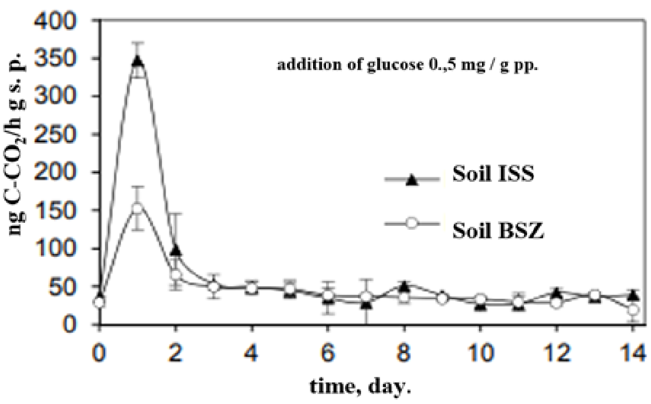

Figure 1 - Lack of caption of the figure presented, and source where the chart comes from

Considering further the activity of the microbial community, it is necessary to consider that in any soil difference, there is a specific pool of microorganisms, which is not provided with the energy substance necessary for continuous reproduction, However, it ensures the soil's survival of different types of microorganisms. In this inactive pool, the number of cells is much smaller, but their biodiversity is higher, and it does not have a significant role in metabolic processes at the initial stages of the destruction of S, However, it may be necessary to ensure processes at other stages of succession or when environmental conditions change.

When assessing the control effects on the soil, tests for the total activity of the soil microbiota, determined by the initial or final products, are most often used. Such tests include the determination of soil respiration by the release of carbon dioxide; nitrogen fixation activity (by acetylene reduction); microcalorimetric measurements to study the level of thermogenesis; application methods using unique materials (cellulose, photographic paper, cellophane) to assess the rate and degree of their decomposition and accumulation of microbial waste products, for example, amino acids [11].

Another source of BAP is soil enzymes that are immobilized on clay minerals, humus, and organo-mineral colloids, which allows them to maintain their activity for a long time [12]. In conditions when the vital activity of the microbiota is suppressed, due to the activity of the enzyme pool, the metabolism of the soil is preserved. Therefore, the importance of enzymes in extreme conditions, such as intense chemical pollution, becomes leading in ensuring the biological activity of soils and their self-purification from various anthropogenic xenobiotics [13].

Enzymes are highly effective: 1 enzyme molecule catalyzes the transformation of 102 – 106 substrate molecules in 1 min. [14].

Thanks to the action of microorganisms and extracellular enzymes, biochemical mechanisms are created in the soil that leads to self-renewal, to self-reproduction of fertility properties. This forms the basis of soil metabolism. Soil metabolism unites all the constituent components of the soil into one whole in interrelation and interdependence. Individual constituent substances and processes are functionally dependent on each other. Enzymes determine the functional connections of those elements and soil processes associated with its material and energy properties [15].

The enzymatic activity of soils is an integral indicator of the functional activity of soil biota and its ability to perform various biochemical transformations. This indicator of the biological activity of soils is relatively stable, characterized by a small error, ease of determination, and high sensitivity to external influences [16].

The activity of soil enzymes affects the most important cycles of transformation of carbon, nitrogen, phosphorus, sulfur and other elements for soil formation, as well as redox processes.

The activity of enzymes can also reflect both the activity of the whole microbial community – dehydrogenase, esterase, phosphatase, FDA test, and the activity of its individual groups – polyphenol oxidase, cellulase, chitinase, nitrogenase, denitrifying, etc.

The transformation of various kinds of organic compounds in the soil is determined by the composition of the enzyme complex of the soil, because enzymes affect all biochemical processes occurring in the soil. About 40 enzymes have been found in soils. The variety and richness of enzymes make it possible to carry out sequential biochemical transformations of organic residues entering the soil [17].

Redox enzymes and enzymes of the hydrolase class give the most complete characteristic of the biological activity of the soil. Enzymes belonging to the class of oxidoreductases catalyze redox reactions that play a leading role in biochemical processes in the cells of living organisms, and soils. Redox reactions are the main link in the synthesis of humic substances in the soil [18].

An essential role in the synthesis of humic substances is played by polyphenol oxidases involved in the transformations of aromatic compounds. They catalyze the oxidation of mono, di, and tri phenols to quinones in air oxygen or hydrogen peroxide. Under appropriate conditions, quinones, when condensed with amino acids immobilizing carbon in soil humus, preventing its accumulation in the atmosphere in carbon dioxide [19].

The conditional humification index (CCH) can be calculated by the activity of the enzymes polyphenol oxidase (PFD) and peroxidase (PO) according to Chunderova A.I.:

CCH = (PFD/PO)×100 % [20].

Dehydrogenases catalyze dehydrogenation reactions of organic substances and act as intermediate hydrogen carriers in respiration. Therefore, their activity can serve as an indicator of general microbial respiration. Dehydrogenases are involved in the process of catabolism of all types of nutrients.

Among the enzymes involved in the respiration processes of soil microflora, dehydrogenase activity is of great importance, which is informative, since the level of this indicator depends on the intensity of nitrification, nitrogen fixation, respiration, and oxygen absorption by the soil [21]. According to E.E. Gross and coauthors [22], its dehydrogenase activity decreases even with a low level of technogenic load on the soil. The enzyme is synthesized by bacteria, among which representatives of the genus Pseudomonas prevail.

Biological mineralization of various organic compounds of proteins, carbohydrates, fats and several other components is accompanied by the accumulation of peroxide, the decomposition of which is carried out by catalase. Catalase is an indicator of the degree of oxidative processes in the soil. Soil microorganisms secrete the enzyme, is highly resistant, accumulates and persists in the soil for a long time, which is why the activity of this enzyme can be considered as an indicator of the functional activity of the soil microflora and may reflect soil fertility [23].

Hydrolases are widespread and play an important role in enriching them with mobile and accessible nutrients for plants and microorganisms, destroying high-molecular organic compounds and thereby enriching soils with mobile nutrients in a form accessible to plants and microorganisms. Among the hydrolases, urease, protease and amylase are distinguished. The action of urease is associated with hydrolysis and conversion of urea nitrogen into an available form. The latter can be formed in significant quantities in soils as intermediate products of the metabolism of nitrogen organic compounds, especially nitrogenous bases of nucleic acids, and can also enter the soil as part of manure and as nitrogen fertilizer. The action of urease is strictly specific: it hydrolyzes only urea and is produced by a group of urobacteria. In the soil, urease activity has a positive correlation with the content of organic carbon and mobile nitrogen [24].

M.S. Upendra et al. established a close relationship between the activity of β -glucosidase and N-acetyl-β-glucosaminedase with most physical, chemical, biological and biochemical properties, as well as with crop yields. Since BG is a C-cycle enzyme and NAG is an N-cycle enzyme, their high activity indicates increased microbial activity, which leads to increased carbon sequestration and nitrogen availability, which are important for improving soil health and fertility and growing crops [25].

In the technical manual of the USA Department of Agriculture - USDA for 2019 "Soil Health Technical Note No. 450-03 Recommended Soil Health Indicators and Associated Laboratory Procedures", it is recommended to determine the activity of β-glucosidase [BG] [26] and N-acetyl-β-glucosaminidase [NAG] [27] to assess the overall microbial activity. To assess the activity of phosphorus and sulfur cycles, the activity of the enzymes phosphomonoesterase [PME] and aryl sulfatase [AST], respectively, is studied [28].

Considering the activity of individual soil enzymes, it is impossible to miss attempts to use BAP indicators in assessing soil fertility or the degree of soil degradation when contaminated with xenobiotics according to biological fertility indices (BFI – biological index of soil fertility).

The following indices of soil microbial activity are known:

pedotrophy index = number of microbes on soil agar/number of microbes per MPA;

oligotrophy index = number of microbes diluted in 10-100 media / number of microbes on full-fledged media;

the coefficient of mineralization and immobilization = the number of microorganisms per KAA / the number of microorganisms per MPA cited by [29].

To characterize the efficiency of the use of available carbon by the microbial community, a metabolic quotient (qCO_2) was used. The metabolic quotient (qCO_2) serves as an indicator of microbial community stress. The lower the qCO_2 values, the better the state of the microbial community, i.e., microorganisms spend less energy on the maintenance and formation of a unit of biomass. The metabolic quotient is calculated by the formula: $qCO_2 = V_{basal}/V_{SIR}$, where bas is basal respiration, sir is substrate induced respiration [30].

To assess the biological activity of the soil, an integral indicator (IPBS) is used. The formula for calculating And IPBS has the following form:

$$IPBS = (B_{sr}/B_{sr\ max}) \times 100,$$

where B_{sr} is the average evaluation score of all indicators ($B_{sr} = (B_1 + B_2 + ... + B_n)/N$), $B_{sr\ max}$ is the maximum evaluation score of all indicators ($B_{sr\ max} = (B_{1\ max} + + B_{2\ max} + ... + B_{n\ max})/N$); B_1, B_2 ... is the relative score of each indicator (%), N is the number of indicators. When calculating IPBS and other indices, the most informative indicators of soil biological activity are used, each reflecting a particular direction of biological and biochemical processes. As a rule, the decrease in the IPBS index is directly dependent on the degree of impact of the anthropogenic factor [31].

In soil enzymology, the indicator of geometric mean enzymatic activity (GMea) is widely used [104], which is calculated by the formula:

$$G_{mea} = \sqrt[n]{X1 \times X2 \times ... Xn}.$$

Where X_1, X_2...X_n are relative scores for each enzymatic activity indicator in %.

To calculate relative scores, use the formula:

$$X1 = (X_{1\ fact} / X_{1nesager})\ 100\ \%,$$

where $X_{1\ fact}$ is the actual value of the indicator of enzymatic activity, $X_{1nesager}$ is the value of the indicator of enzymatic activity in uncontaminated soil.

The GMea indicator smooths out the diversity of the response of enzymes. It accurately reflects the totality of processes occurring in the soil, which makes it possible to use it for bioindication and assessment of the state of contaminated soils, since the value of integral indices and indicators of contaminated soils decreases even in cases when the activity of individual soil enzymes increases. The sensitivity, simplicity and accuracy of methods of enzymatic analysis, the ability to obtain valuable information about the intensity and direction of biochemical processes so important for soil health, indicate the prospects of using indicators of enzymatic activity for diagnostics of soil cover.

Three enzymes play a significant role in the decomposition of plant residues, which are united by the common name cellulase: endoglucanase (EC 3.2.1.4), cellobiohydrolase (EC 3.2.1.91) and betta glucosidase (3.2.1.21). Celluloses are synthesized by many bacteria and micromycetes, among them *Cellulomonas, Clostridium, Bacillus, Thermomonospora, Aspergillus, Trichoderma* ets are the most active [32].

Based on the activity of cellulases, a simple method of tea bags is proposed to assess the soil quality.

The mass loss of the RM (initial mass – the remaining mass after incubation) was used to calculate the decomposition rate (k), using a negative exponential decay model:

$M_t/M_0 = e^{-kt}$, where M_0 is the initial dry mass, M_t is the remaining dry mass at time t (90 days), and k is the daily decay constant expressed in 1 day [33].

Using Lipton Green and Red Tea decomposition values, it is possible to calculate the index of soil decomposition of cellulose as the ratio of the degree of decomposition of red tea to green. Since red tea has a ratio of C to N equal to 43, and green tea 12, respectively, the decomposition rates of tea will be different, so the closer to unity this ratio is, the healthier the soil will be [34].

Several variants of BFI are proposed for consideration in the scientific literature. The simplest in our opinion is the option proposed by A. Saviozzi et al., which is expressed by the formula:

BFI = (Dehydrogenase + k Catalase)/2,

where k is a proportionality factor equal to 0.01 [35].

Polish researchers studied the influence of farming systems on the physicochemical and biological properties of the soil. They determined *the Metabolic potential index (MPI) as the ratio of dehydrogenase activity to the content of soluble organic carbon.* MPI values confirmed an increase in soil metabolism in organic farming compared to the soil of traditional intensive farming. There was also an increase in the content of organic matter, plant residues, humic substances, water-soluble carbon and carbon of microbial biomass in the soil and dehydrogenase activity compared to the conventional system, especially in the upper soil layer, 0-5 cm [36].

The activity of soil enzymes is an informative factor in diagnosing the degree of soil dysfunction caused by pollution and monitoring the restoration of soil functions in soil improvement. Many studies have shown that simultaneous measurement of the activity of several enzymes in the soil can be more reliable than measuring a single enzyme [37].

To generalize the obtained data on biological activity indicators, T.O. Poputnikova offers a formula for calculating the transformation index of biological properties of soils (ITB), which characterizes the degree of multidirectional deviations of the set of biotic indicators in the studied samples from the background values according to the formula:

$$I_{tb} = \sum_{i-1}^{n} |1 - C/Cbackdrop| /n$$

Where C is the absolute value of the indicator, $C_{backdrop}$ is the background value. The calculation of the IHB was carried out according to the multiplicities of the deviation of biological indicators from background values (both in the positive and negative sides) according to the formula reflecting the total degree of deviation of the biological response from the background in the range of values from 0 to 1.

To determine the value of the ecological norm of the studied soils, it is necessary to determine some threshold difference between the total biological indicator and the background. At the same time, the general principle of determining acceptable values of soil quality for the entire set of lands for various economic purposes is to determine the soil's ability to self-heal, which persists until the loss of no more than 30 % of the biological potential of the soil. At this level, there is a threshold of resistance of the soil ecosystem to anthropogenic impact and the limit of retention of toxicants by soils within the boundaries of the contaminated site, respectively, there is no massive removal of them into adjacent environments. Therefore, a 30 % loss of the soil's natural (biological) state, calculated by the total index of transformation of biological properties, can be taken as a threshold value of the ecological quality of the soil [38].

The most straightforward index used in the literature is the metabolic coefficient (qCO2) (the respiration ratio to microbial biomass). Physiologically, this indicator characterizes the substrate mineralized per unit carbon of microbial biomass. The metabolic coefficient is widely used to monitor the development of the ecosystem, during which the indicator decreases, and in case of violation it increases, acting as an indicator of the ecosystem's maturity. There is a decrease in qCO_2 in soils under monoculture compared to soils under continuous crop rotation, due to the richness of organic carbon under different crops, which has a beneficial effect on respiration. This is a good indicator of changes occurring in the soil due to heavy metal pollution, deforestation, temperature changes or changes in soil management methods [39].

Koper and Piotrowska developed a biochemical index of soil fertility to compare the effects of organic and mineral fertilizers. This indicator made it possible to classify soil fertility into four categories (3-4 — low fertility; 4-5 — average; 5-6 — high; 6-7, very high fertility).

Biochemical index of soil fertility $(B) = C_{org}+N_{total}+DH+P+PR+AM$

where C_{org} (organic carbon content, %), N_{total} (total nitrogen content, %); DH (dehydrogenase activity cm^3 H_2 kg^{-1} 24 h^{-1}); P (phosphatase activity, mmol n-nitrophenyl phosphate g^{-1} h^{-1}); PR (protease activity, mmol NH_4–N kg^{-1} h^{-1}); AM (amylase activity, mg of decomposed starch h^{-1}) [40].

Thus, the biological activity of soils is the most essential criterion of soil health, due to the activity of the soil microbiota, mesobiota and root systems of plants, as well as the action of soil enzymes. Many authors are searching for simple, accessible and informative biological fertility indices BFI following the research objectives.

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ТҮЙІН

А.А. Құрманбаев[1]*, К.К. Мусаева[1], Ш.Ғ.Ермек[1]

ТОПЫРАҚ ДЕНСАУЛЫҒЫНЫҢ КОНЦЕПЦИЯСЫ ЖӘНЕ ҚАЗІРГІ ТОПЫРАҚ ДЕНСАУЛЫҒЫНЫҢ КӨРСЕТКІШТЕРІ: ҚЫСҚАША ШОЛУ

[1] Ө.О. Оспанов атындағы Қазақ топырақтану және агрохимия ғылыми-зерттеу институты, 050060, Алматы қ., әл-Фараби даңғылы, 75 В, Қазақстан,

**e-mail: wberel@gmail.com*

Ұсынылған шағын шолуда топырақтың биологиялық белсенділігінің оның физикалық және химиялық қасиеттерімен, сайып келгенде, топырақ құнарлығымен және ауылшаруашылық дақылдарының шығымдылығымен байланыстылығының жүйелі көрінісі көрсетілген. Топырақтың биологиялық белсенділігі топырақ биотасының, негізінен микробиотаның және өсімдік тамыр жүйесінің тіршілік әрекетіне, сонымен қатар топырақ ферменттерінің әрекетіне байланысты. Жеке BAP сынақтарын қарапайым және қол жетімді биологиялық құнарлылық индекстері BFI ретінде пайдалануға болатыны көрсетілді.

Түйінді сөздер: топырақтың биологиялық белсенділігі, топырақ құнарлылығының көрсеткіштері, ферменттер, топырақ саулығы, топырақ сапасы.

РЕЗЮМЕ

А.А. Курманбаев[1]*, К.К. Мусаева[1], Ш.Г.Ермек[1]

БИОЛОГИЧЕСКАЯ АКТИВНОСТЬ ПОЧВЫ И ЕЁ ИНДИКАТОРЫ В МОНИТОРИНГЕ КАЧЕСТВА ПОЧВ: МИНИОБЗОР

[1]Казахский научно-исследовательский институт почвоведения и агрохимии имени У.У. Успанова, 050060, г. Алматы, пр. аль-Фараби, 75В, Казахстан,

**e-mail: wberel@gmail.com*

В представленном миниобзоре показана системная картина биологической активности почв в ее связи с физико-химическими свойствами, и, в конечном итоге, с плодородием почв и урожайностью сельскохозяйственных культур. Биологическая активность почв обусловлена прижизненной активностью почвенной биоты, главным образом микробиоты и корневых систем растений, а также действием почвенных ферментов. Показано, что отдельные тесты БАП могут быть использованы в качестве простых и доступных биологических индексов плодородия BFI.

Ключевые слова: биологическая активность почв, индикаторы плодородия почв, ферменты, энзимы, здоровье почвы, качество почвы.

INFORMATION ABOUT THE AUTHORS

1 Kurmanbayev Askar Abylaikanovich – Chief Researcher of the Department of Fertility and Biology and Soils, Doctor of Biological Sciences, Professor,
e-mail: wberel@gmail.com

2 Mussayeva Kuralay Kenzhebayevna – Analytical engineer of the Department of Saline Soil Reclamation, Master of Agricultural Sciences, e-mail: mkuralay_97@mail.ru

3 Yermek Shugyla Galymzhankyzy - Analytical engineer of the Department of Fertility and Biology and Soils, B.Sc., e-mail: shugyla.yermek@mail.ru