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Soil health – ecosystem health: from problem identification to diagnosis and treatment

Semenov Aleksander Mihailovič [1], **Dragutin A. Đukić** [2]

[1] *Faculty of Biology, Department of Microbiology, M. V. Lomonosov Moscow State University, Leninskie gori, 1/12,119234, Moscow, Russia Federation.*
[2] *Faculty of Agronomy, Department of Biology, Microbiological Biotechnology, University of Kragujevac, 32000, Cara Dušana 34, Čačak, Serbia.*
*Corresponding author: amsemenov@list.ru

Abstract: The need for the general use of the category "soil ecosystem" (SE) as objectively more comprehensive and more specific than the laconic term "soil" is discussed and supported by arguments. Agroecosystem soils in organic and intensive farming are compared. Soil health (SH) as a new, basic property of SE is commented upon. Methods for determining SH and its characteristic parameters are specified. The need to assess the health of SEs depending on their type and utilization is emphasized. The topics covered include soil health maintenance and protection options, natural and induced suppressiveness of SEs, and potential routes to diagnosis and treatment of soils in modern agroecosystems.

Key words: soil ecosystem, protection and treatment of soil ecosystem, soil health, health parameters, agroecosystem.

Introduction

The existing body of knowledge in this field is sufficient to ensure that the term "soil ecosystem" (SE) is argumentatively accepted and employed instead of the simple traditional term "soil". The concept of soil ecosystem most completely reflects the content of the systemic natural formation traditionally termed "soil", and provides a more objective characterization of this biological system from

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scientific, practical and other standpoints. It instantly directs both theoreticians and practitioners towards the need to distinguish between several classes of soil ecosystems, at least between natural soil ecosystems and soil ecosystems utilized by humans. In its technogenically transformed agroecosystem, the modern sociosystem uses intensive (conventional agriculture), organic (organic agriculture) and/or transitional – combined (low input) technologies. Depending on the SE utilization system, different quantities and qualities of products are obtained and a multitude of risks and problems associated with SE utilization are expected. Depending on the intended use of a SE, users are obliged to build a strategy for its maintenance, development and protection from natural, technogenic and social effects (Van Bruggen, Semenov, 2015).

The objective of this paper is to treat some current environmental problems related to soil ecosystem health in different SEs, and take a look at different approaches to solving these problems on a fundamental level and in practical terms i.e. with respect to soil ecosystem treatment.

To implement the objective, the meaning of the concept of soil ecosystem is discussed, and categories of SEs are specified in terms of their intended use, utilization, cultivation, and related problems. Traditional characteristics of soil and their association with soil health as a new characteristic of SEs are discussed. Ways to solve problems associated with soil health, parameters typical of this biological category, and the specificity of diagnostics, treatment and maintenance of soil health in modern agroecosystems are presented.

1. Soil as an ecological system

Soil is the object of research by geologists, pedologists, agrochemists, agronomists, ecologists, microbiologists and other scientists. Soil is examined from different aspects, often using the same or similar methods, with different goals and tasks implemented. There are different definitions of this research object traditionally termed “soil”. When studying and investigating the soil, its evolution is addressed, and mostly physicochemical notions and characteristics are manipulated. While not diminishing the role of existing knowledge on soil as a physicochemical substance, it is important to devise a definition of soil which would, considering the contemporary knowledge, reflect the external image of soil as a multiphase system, which is essential to its biological diversity (Јемцев, Ђукић, 2000).

It is suggested that the soil be treated as the product of long-term mutually assimilating and dissimilating activities of microorganisms, plants and transformed mineral-organic matter (Ђукић и сар., 2007). Contemporary soil is a natural organomineral product formed under particular naturally occurring climate conditions and maintained by the incessant interaction between microorganisms and plants, on the one hand, and the essentially quantitatively dominating inorganic substance, on the other. This product comprises living biological organisms, dead material and metabolites, subjected to continuous enzymatic and chemical transformations, and accumulate biophilous elements. It is the site of major biological and physicochemical processes – biogeochemical cycles of elements and microorganisms. This product acts as an important buffer against a range of stressors, provides nutrients to plants and heterotrophic microorganisms, and is a source of biophilous elements and biological diversity (Јемцев, Ђукић, 2000; Ђукић и сар., 2007; Семенов, 2015; Семенов, Соколов, 2016). It is this very biological component of a SE that ensures its major functions – productivity, environment formation, and maintenance of the genetic fund and unique diversity of living organisms in the soil. Therefore, biological and ecological characteristics such as soil health and/or soil pathology are appropriate and applicable to the normally functioning SE.

The modern definition of the soil must be based on its biological origin and biodynamic essence, with soil health as its legitimate biological and ecological characteristic.

As generally known, soil microorganisms themselves integrate and produce a complex of enzymes and metabolites, which, in the long run, at different rates, has the capacity to either hydrolyze organic monomers and polymers into simple ingredients or subject them to transformation, including conversion into non-assimilating or inert forms.

It is well known that higher organisms can survive only for a short period of evolutionary time without microorganisms, whereas some microorganisms, particularly prokaryotes, can survive indefinitely without higher organisms.

2. Categories of soil ecosystems

The contemporary global SE is classified into two categories: natural SE and anthropogenic SE (agroecosystem).The results of research on the natural SE underlie numerous studies in general ecology, microbial ecology and pedology. The key factor in the proper functioning of the natural SE is minimum social interference.

In a contemporary agroecosystem, different technologies are used. While ensuring high plant productivity, the dominant intensive farming system (conventional agriculture) has led to the disturbance and, in many cases, even to the degradation of the SE. Therefore, under contemporary conditions, a precise classification of agroecosystems is required. In accordance with the combined natural and social approach, an agroecosystem comprises two mutually related subsystems, the first as a major subsystem (including global super-subsystems i.e. biological, lithological, climatological systems) used in the interest of the second, minor subsystem – the sociosystem. Based on its potential and interactions, the minor subsystem exhibits long-term distinct effects on both the agroecosystem and the geoecosystem. The agroecosystem is an attribute of the sociosystem, but it is of secondary importance to geoecosystems or ecospheres.

Neither the sociosystem nor the agroecosystem can exist without the geoecosystem.

Therefore, nowadays, agroecosystems are managed using intensive technologies (conventional agriculture), organic technologies (organic agriculture) and transitional, mixed-type technologies (low input agriculture) (Семенов и др., 2016; Семенов и др., 2016a). Certainly, the geoecosystem covers the soils utilized not only in agrosystems, but also in sociosystems – soils located in populated areas (construction ground) and soils in manufacturing districts. The recovery of degraded agroecosystems involves their conversion into the sphere of natural ecosystems over a period of time by specific non-biological and biological methods and technologies (Ђукић и сар., 2013).

2.1. Intensive agriculture as a traditional form of agroecosystem utilization

Historically, prior to the mass production and use of mineral fertilizers and agrochemicals, agriculture was, of course, "organic". However, in the 20th century, priority was given to conventional i.e. intensive agriculture (IA). To achieve high stable yields, IA involves a massive input of mineral fertilizers, primarily macroelements (N, P, K), into the SE, as well as the use of intensive farming technologies and practices. In intensive agriculture, there has also been a long-term use of elements essential for plant growth such as Si, B, Mg, Zn, V, etc. However, an improper use of mineral fertilizers leads to a gradual degradation of the agroecosystem, as manifested through intensive humus degradation, acid-base imbalance (acidogenesis), reduction in microbial counts and biomass, changes in the microbial cenosis structure of the SE (predominance of acidogenic and acidoresistant microorganisms, primarily toxigenic ones), intensification of denitrification processes, reduction in potential nitrogen fixing activity and total biogenicity i.e. soil fertility, release of high amounts of nitrogen oxides and occurrence of methemoglobinemia, cyanosis, and mutagenic, teratogenic, carcinogenic and other effects (Ђукић, Мандић, 1995; Ђукић, Мандић, 1997; Ђукић , Мандић, 1997a; Ђукић, Мандић, 2000; Ђукић, Мандић, 2004). Therefore, the massive incorporation of mineral fertilizers into the soil is the first indicator of intensive agriculture.

To protect high crop yields (resulting from the intensive use of mineral fertilizers) against harmful organisms, a wide range of chemical pesticides have been recommended. They have played a positive role in crop and yield protection. Nevertheless, regardless of microbial and natural pesticide detoxification, excessive and frequent pesticide use inhibits numerous enzymatic reactions and the growth of cells and entire microbial populations, disturbs the species composition of SE microbial communities, etc. (Ђукић, Мандић, 1997; Ђукић, Мандић, 1993, 1998; Ђукић, Мандић, 2000; Мандић, Ђукић и сар., 2011; Ђукић и сар. 2015; Ђукић, Пешаковић., 2016). Some pesticides have exhibited high persistence, due to which they have started to accumulate in the SE and living organisms. Some compounds proved dangerous to non-target organisms, including domestic animals and humans. Therefore, massive pesticide use is the second indicator of intensive agriculture.

The third indicator of intensive agriculture relates to the production of genetically modified organisms (GMO) of plant cultivars. Their transgenes serve as codes for the biosynthesis of substances which are non-toxic to humans and warm-blooded animals, and which ensure GMO crop resistance to phytopathogens, phytophages and non-selective herbicides (Семенов и др., 2016; Семенов и др., 2016a).

Nevertheless, intensive agriculture methods, which lead to the disturbance and, even, degradation of soil agrosystems, cause doubt about the argument put forward by conventional farming advocates that mankind will starve if it converts to organic farming agrosystems (organic agriculture).

2.2. Organic agriculture

In everyday reasoning, organic agriculture is the cultivation of soil to produce acceptable amounts of high-quality crop yield without the use of inorganic, industrial fertilizers and synthetic chemical substances (pesticides, etc), except substances used to optimize soil pH. Organic farming bans the use of genetically modified organisms (GMOs). Based on its "ideology", organic farming is practiced primarily by individual farmers (individual farming). It also originates from biodynamic farming developed by Rudolf Steiner (1861-1926). Steiner's main tenet was "feed the soil, not the plants", and we might add: feed the microorganisms, as they are the most biogeochemically active component of the SE, without which it would be unproductive. Based on our own experience and experimental data of other scientists, we have made sure to point to the potential of alternative farming systems, their advantages and disadvantages, ways to reduce and eliminate adverse environmental and ecological effects associated with high-productive farming, and the optimal combination of factors related to biological and traditional farming, primarily keeping in mind the use of crop rotation, organic and microbiological fertilizers, and biological products (Ђукић и сар., 2007).

Official international rules, requirements and characteristics typical of organic farming have been set down. As defined by the IFOAM (the umbrella organization for the organic agriculture movement), organic agriculture is a production system that sustains the health of soils, ecosystems and people, based on ecologically balanced processes adapted to local conditions and harmless sources of soil enrichment with organic matter; harmonizes the cycle of matter and energy; maintains biological diversity; and optimizes the competitive ability of crops with respect to weeds, diseases and pests, while completely giving up the use of agrochemicals and genetically modified organisms (http://www.infoam_eu.org.http:www.ifoam.org).

Historically speaking, the shift from intensive farming to organic agriculture occurred in several stages. Indisputably, mention must be made of the low-input technology. This technology specific to transitional agriculture involves the incorporation of moderate rates or limitation i.e. reduction of application rates of not only mineral fertilizers, but also organic ones. Noteworthy, the terms "moderate", "limited" and "low rates" differ across countries and naturally occurring climate zones. There was the parallel development of the ideology of the sustainable development of agriculture. Moreover, the combined mineral and organic fertilization system was employed, and the natural soil fertility potential of SEs was mobilized.

The truly organic agriculture and "organic" production starts only several years after the termination of the transition period. As estimated, the duration of the transition period is at least 5 to 6 years, provided that the requirements and rules set down by IFOAM are implemented and followed. The transition period begins after the last incorporation of fertilizers, pesticides and GMOs (not only plants, but also other transgenic organisms) into the agroecosystem. The agroecosystem of organic agriculture entails a buffer zone between the organic farming agroecosystem and the intensive farming agrosystem. To maintain soil fertility and quality, no use of manure, compost and other organic substrates produced in intensive farming agroecosystems is allowed.

3. Soil health as a property of the soil ecosystem and its association with the traditional characteristics of the soil

Environmental protection from pollution has long been an international issue. Therefore, huge attention must be given to the state of the environment, particularly in terms of human health protection. Quite obviously, the biogeosphere, soil in particular, should be protected from pollutants, notably pathogenic microorganisms and dangerous chemical substances, all the more so because the soil is still the basic biogeosphere which provides conditions necessary for plant production i.e. for the organization of agricultural production, which is the precondition for the survival of mankind (Ђукић и сар., 2011).

The need to elaborate the new category and characteristic of the soil ecosystem i.e. soil health has arisen as the response of the scientific and social community to the change in the ecosphere and quality of production, principally plant production (indirectly, livestock production). The traditional characteristics of the soil such as soil quality and fertility were not deemed sufficient by the scientific community. The situation was similar and particularly harsh at the time farmers converted to organic farming, when SE biological characteristics and evaluation parameters assumed a specific position relative to traditional physicochemical categories. Gradually, but over a relatively short period in history, understanding of the essence of the soil health concept was shaped, and goals and objectives needed to solve this scientific and practical problem were defined.

Accordingly, “soil health” is a biological category which reflects the state of the dynamic activity of the biotic component in the organo-mineral complex of the soil; this biological category is characterized by a proper naturally occurring climate zone of activities associated with biotic processes (synthesis and hydrolysis), their stability against disturbing impacts (biotic and abiotic stress agents), and a closed cycle of biophilous elements (self-sufficiency) and microorganisms. Another characteristic of a healthy soil in the agrocenosis is that its quality coincides with standardized indicators, and that its fertility level is adequate for the naturally occurring climate zones (Семенов и др., 2011; Семенов, 2015; Семенов, Соколов, 2016; Семеов, Семенова, 2016). The above definition of soil health, which is applicable to any soil (except abnormal soils), integrates, rather than contradicts, the essence of known characteristics and definitions, given that the indicators of the activity dynamics of the biotic component are correlated both with the physicochemical indicators of the soil and with the current level of soil fertility.

4. Soil ecosystem health and natural-scientific parameters of this category

As a manifestation of the function of the soil biotic component and sinusoidal growth laws for soil microbial populations and microbial communities, a quantitative parameter for the determination of soil health has been proposed (Семенов и др., 2011; Семенов, Семенова, 2016; Семенов, Соколов, 2016; http://bankpatentov.ru/node/). The key basis of this method as well as of the following ones is the obligation to: 1) compare the tested soil with the selected healthy (conditionally etalon or conventionally healthy) soil of one and the same genesis and from the same region (the principle of comparison); 2) use only fresh soil samples for the determination of soil health parameters (the principle of nativeness); 3) to apply the same stress agent to the tested soil (the principle of initiation); and 4) to conduct dynamic observations and determinations (the principle of dynamism).

4.1 Heterotrophic parameters of soil health

The heterotrophic parameter of soil health is determined after the disturbing impact of glucose incorporation into the tested and control soil samples (Семенов и др., 2011; Семенов, Семенова, 2016; Семенов, Соколов, 2016;URL www.freepatent.ru/patents/2408885). On a daily basis, for up to 5 days, the dynamics of the velocity (V) of CO_2 evolution from the soil is measured under controlled temperature and optimal moisture conditions (substrate-induced respiration – SIR). Based on the CO_2 emission indicators, V is plotted as a sinusoidal function of exposition time (T). The graph will have a sinusoidal shape with one or two peaks. In these graphs, one of the first, but highest peaks for both the etalon (healthy) and the tested soil is chosen, and full-width (L) of selected peaks at half-maximum is measured. The comparison of parameters for maximum amplitude peaks of SIR ensures that the most active, the most intensive and, hence, the most important microbial populations of the tested soil samples are taken into account. An actual example of soil health parameter calculations is provided by Семенов и сар. (2011) and Семенов и Семенова (2016). The closer the parameter value to zero, the closer the tested soil to standard (control, healthy) soil. If the resulting value of the calculation equation equals zero, the tested soil is considered healthy (Семенов и др., 2011, Семенов, Семенова, 2016; URL www.freepatent.ru/patents/2408885).

It seems that the widespread application of the elaborated method for the quantitative determination of soil health parameters using an automatic computerized device (Семенов и др., 2011: URL www.freepm.ru/90212), along with the creation of a database on health parameters for different soils, has made substantial contributions to the newly developed research direction – environmental biotechnology (Ђукић и сар., 2013, 2017).

4.2. Soil ecosystem's self-sufficiency in biophiles as a soil health indicator

Among the soil health indicators, self-sufficiency of a SE in minerals is of essential importance. This parameter is traditionally termed "a closed nutrient cycle" in the SE or, even more simply, "a closed cycle of biophilous elements" (Семенов, Соколов, 2016). It certainly does not refer to global biogeochemical cycles of elements, matter and energy; it refers to the soil health of a particular SE. As regards biophiles in the SE, self-sufficiency in nitrogen is, certainly, of key importance. Another vital issue is the elaboration of parameters used to assess the capacity of a SE to attain nitrogen self-sufficiency, as the result of the state of balance and closed cycling of nitrogen.

Traditional thinking directs the efforts of researchers in soil quality and fertility toward making a comparison between indicators of nitrogen inflow into the SE through nitrogen fixation and ammonification and those of nitrogen loss through nitrification-denitrification. Russian researchers have proved that this point of view is unacceptable for the assessment of nitrogen self-sufficiency of a SE. As proved, in an unused SE, which is in essence a model of a healthy soil, no significant level of either actual or potential nitrogen fixation is identified. In an intensively used arable soil, which receives up to 180 kg/ha nitrogen per season, in the absence of actual nitrogen-fixing ability, the potential activity of nitrogen fixation is determined. Its occurrence after the incorporation of glucose into soil samples suggests that the SE may have received a "doping" dose. In this case, potential ammonifying activity has identical values both in the uncultivated SE and in the cultivated arable SE, which directly specifies that ammonifying activity is the real mechanism of soil nitrogen supply (Семенов, Соколов, 2016).

These results show that the entrenched opinion and methods for determining "total" nitrogen-fixing activity in the SE cannot be routinely used for obtaining objective results and formulating conclusions on the direction of vectors in the nitrogen supply of the SE. Even more so, the role of nitrogen fixation and its contribution and importance in the daily nitrogen supply of the SE have not been given sufficient critical and objective reconsideration, as was the case with a large number of nitro-bacterial fertilizers which were doomed to an inglorious destiny. Lack of objective evaluation is also observed for the insufficiently estimated contribution of nitrogen fixation to the daily nitrogen supply of the SE.

It is suggested that the state of nitrogen supply vectors be assessed based on the activities of the microbial community after the disturbing impact of soil enrichment with mineral compounds of biophilous elements. The proposed viewpoint, which is based on familiar and logically uncontradictory postulates, has been experimentally confirmed by Семенов и Соколов (2016).

It is well known that the intensity of cycling of biophilous elements in the soil, primarily nitrogen, is dependent on the activities of microorganisms and plants. As opposed to microorganisms, the role of plants (and animals) is basically to consume nitrogen. Accordingly, plants seem to force microbial transformers of N to function more intensively and effectively (Јемцев, Ђукић, 2000). Optimal activity must be manifested in a native, healthy soil. Based on this, it is recommended to determine and compare the dynamic response of the microbial community of the tested and etalon (healthy) soil to nitrogen input, rather than to episodically measure the concentration of nitrogen compounds in the soil (as, for example, total N or N compounds – ammonium compounds, nitrate compounds, ammonia or nitrogen suboxide). As generally known, the dynamics of basic metabolic processes occurring in microorganisms and the resulting emission of carbon and nitrogen metabolites in the SE take place in a sinusoidal manner and temporally coincide with the growth of organisms. Hence, when determining the parameters of soil biological activity, it is appropriate to draw an analogy to soil "enrichment with nitrogen" and to the soil heterotrophic parameter, which characterizes the health of the soil (Семенов, Соколов, 2016). As there is no stable, universal criterion for the characterization of natural and agricultural soils based on biophile supply, a comparable approach is also applicable to the development of such a soil health criterion. This approach helps discover differences in the response of the microbial community – SE activity dynamics – to the temporary enrichment of both the tested and the etalon soil with the biophilous element under study.

To this end, the simultaneous enrichment of soil samples (as in the case of heterotrophic parameter determination) with carbon and nitrogen substrates (and with phosphorus, if necessary) is recommended. Measurements of the SIR of the soil based on the velocity (V) of CO_2 emission, which is induced by the "biophiles", are performed under dynamics conditions. Samples of the soils being compared (the tested soil and the "conditionally healthy" – etalon soil) are incubated at optimal moisture and temperature conditions. Aqueous glucose and ammonium nitrate solutions and, if necessary, secondary potassium phosphate can serve as SIR inducers. SIR is determined on a daily basis, up to 5 days. A SIR indicator can serve as a parameter of SH, which characterizes the intensity of soil carbon, nitrogen and, if necessary, phosphorus metabolism. The experimental determination of the parameter should be made upon receipt of a sinusoidal response in the form of the peak value of SIR until it lowers (reaches a plateau). This is graphically presented by curves with one or two peaks. The calculation of the induced parameter in the V vs. time (T) graph(s) is analogous to the heterotrophic parameter, with only one, the largest, peak used. Calculations are made using the formula:

$$IP=[(Lcp-Lip)/Lcp].$$

The parameter is also calculated using the absolute value. The use of the module of this fraction (and not simply the module of the width difference between the peaks at their half-maximum) ensures that the uniformity of the soil health parameter is eliminated and that the states of the tested and the control sample are properly compared using this parameter. The approach to evaluating the empirical values is the same as for the heterotrophic parameter of soil health: the closer the induced parameter (IP) to zero, the healthier the tested soil. If IP=0, the soil is completely healthy i.e. the activity of the microbial community (as the result of SE enrichment with "biophiles") of the tested soil is analogous to that of the soil etalon.

The experimental determination of the parameter for the evaluation of the activity of the soil microbial community in response to the incorporation of biophilous elements (along with glucose!) has shown acceptable accuracy, sensitivity and reproducibility of the proposed method (Семенов, Соколов, 2016).

5. Elaboration of parameters for the evaluation of suppressive activity and "pathogenesis" control in the SE

When evaluating the functioning of a SE, it was observed a long time ago that the SE spontaneously exhibits the properties which need to be considered, and which can be used in an agroecosystem. One of these important properties is the suppressive activity of the SE. Soil suppressiveness is defined as a set of biological, physicochemical and agrochemical properties of the soil which limit the survival and parasitic activity of soil phytopathogens or other biotic components which are harmful to humans (Ђукић, Мандић, 2000; Ђукић и сар., 2011; Ђукић и сар., 2015; Глинушкин и др., 2016). The most dominant contributors to SE suppressiveness are biological factors, realized by the biota – antagonism, antibiosis, competition, parasitism and predation (Јемцев, Ђукић, 2000). In addition to these biological factors, important effects can be produced by abiotic factors which are unfavorable for the development of some microorganisms (pH, substantial temperature fluctuations, deficiency of organic substances and biophilous elements, etc.). In accordance with the degree of suppressiveness i.e. impact on the development of phytopathogenic populations, soils are classified into the following types: *conducive* soils, in which the size of the phytopathogen population can increase over time, *tolerant* soils, in which the number of phytopathogens remains stable, and *suppressive* soils, in which the size of the phytopathogen population is continuously decreasing (Глинушкин и др., 2016).

There are two types of soil suppressiveness: natural (long-term) and induced (specific). Natural suppressiveness is determined primarily by physicochemical properties of the soil (for example, pH, content of biophilous elements available to microorganisms, organic matter content, etc.). Soil suppressiveness is not crop-dependent, and is not phytopathogen-specific. Induced suppressiveness, characteristic of agroecosystem soils, is more selective; it is determined by the zonal (local) farming system, and is manifested in relation to a particular host-pathogen phytopathological system (Филипчук и др., 1997).

With this knowledge in mind, and considering the importance of this phenomenon, methods for determining general and specific suppressiveness of the soil to plant pathogens have been elaborated and proposed (Торопова, Кириченко, 2013; Глинушкин и др., 2016). For example, the disk diffusion method has been recommended for determining the suppressiveness of a particular soil. To this end, 10 gr of a native soil sample having a moisture content of 60-70% of maximum water-holding capacity is placed in a Petri dish, and a cooled agar medium is poured onto it to culture the tested phytopathogenic object. Blocks of agar 3-4 mm in diameter, cut out of the 7-10-day old pure culture of the test object (for example, phytopathogenic micromycetes), grown on the same type of agar, are placed onto the surface of the agar medium solidified above the soil. Agar-containing medium without soil is used as a control, over which agar blocks containing the test object are spread. Soil suppressiveness is testified by two indicators. Complete suppression of the growth of phytopathogens, for example, fungi, as determined based on the number of tested blocks showing no symptoms of growth of the test object i.e. the zero diameter of the growth zone (GZ) around the test object. Presence of some growth around the tested blocks in comparison with the intensity of growth in the control i.e. presence of some GZ. A numerical indicator of suppressiveness (S) per 1g soil (quantitative characteristic) is calculated using a quite simple formula, as specified in the patent (Торопова, Кириченко, 2013). The interpretation of results is simple. The value of suppressiveness ranges from 100% - complete soil suppressiveness (all blocks without symptoms of growth of the test object) to 0% - conducive soil (all blocks of the test object showing growth at the control level). If, for example, the soil stimulates the growth of phytopathogens, the value of the suppressiveness indicator will be even negative. The greater the soil suppressiveness, the lower the degree of phytopathogen survival and parasytic activity in the soil (Торопова, Кириченко, 2013; Глинушкин и др., 2016).

Another suggested method for soil suppressiveness determination is the use of the coefficient of the parasitic activity of the inducer (CPI) (Глинушкин и др., 2016). An inverse dependence has been identified between the CPI and the degree of soil suppressiveness: the lower the CPI, the higher the degree of soil suppressiveness. Also, both natural and induced suppressive activity of the soil can be determined by a well-known method which uses graphical data for the determination of the dynamics of plant disease progress in the area under the disease progress curve – AUDPC) (He et al., 2012; Семенов, Соколов, 2016).

The abovementioned methods for identifying, assessing and applying knowledge of soil suppressiveness have a number of deficiencies: considerable complexity, long duration of assays, need for a microbiological laboratory and for a qualified analyst. These are constraints to their accessibility for simple farmers. Therefore, the development of rapid simple methods which will always be readily accessible is still a topical issue.

6. Maintenance and preservation of soil health in agrosystems

Mandatory requirements regarding maintenance and preservation of SE health, particularly in organic farming systems, include: 1) incorporation of balanced amounts of "healthy" organic fertilizers into the agroecosystem, and making it impossible for the agrosystem to get into the state of being fallow; 2) cultivation of SE using cost-saving methods which contribute to the stable functioning of living organisms in soil, while not deteriorating its physicochemical and biological characteristics; 3) use of long crop rotations, mosaics of cultivars and plants, and rotation systems with diverse green manure crops, which are suppressive to phytopathogens, repellent to phytophages and competitive for weed control; 4) use of plants forming symbiotic and mycorrhizal relationships in crop rotations; 5) use of soil amendment and/or irrigation practices for optimization of SE agrotechnology; 6) use of aqueous extracts of other plants, compost, "suppressive soils" and selected native microbial communities obtained from soils exhibiting stable suppressive properties in crop protection (Van Bruggen, Semenov, 2015; Семенов и др., 2016); 7) monitoring of physicochemical and biological properties of the SE through conventional methods of qualitative and quantitative analysis of the dynamics of organic matter and the concentrations of biophiles and other macro- and microelements, along with calculations of their balance in the cycling of matter and energy in the SE. These and other judicious operations for healthy soils enable the maintenance of a stable SE development.

7. Ways to diagnose the state of SEs for their remediation and treatment

One way to address biotechnological issues related to a soil ecosystem is to elaborate methods which ensure the selection of approaches in SE recovery (rehabilitation and treatment) based on the heterotrophic parameter of soil health and the parameters for the assessment of SE's self-sufficiency in biophilous elements.

In the social sphere, the concepts of treatment and health maintenance are used alongside the concept of health. Treatment is applicable practically only to an individuum (an individual). SE is a biological, principally microbial, community. Nevertheless, even for the SE microbial community, it is important to initially identify its need of treatment and whether treatment is possible, on the basis of its fundamental laws and functions, and SE's physical and chemical properties. Therefore, soil recovery i.e. rehabilitation and, even more so, soil treatment require a correct diagnosis of disease. However, it is important to realize that there are diseases which are difficult to diagnose, diseases which are difficult to cure, and even incurable diseases.

When evaluating soil health, the same methods elaborated for the determination of SH parameters must be used, and diagnosing must be based on and consistent with knowledge of the "ideology" of these methods. To diagnose the state of SE, it is important to analyze and interpret the heterotrophic parameter of soil health not only as an indicator of "coincidence" or "difference" between the etalon and the tested soil. The obtained quantitative values of the heterotrophic parameter can be used in SE diagnostics and treatment. The quantitative indicator of the heterotrophic parameter of the tested soil can quantitatively either coincide with, or be higher or lower than the values for the etalon soil. It is quite logical to determine the exact difference in the values between the tested and the etalon soil, and assess the significance of these differences. Data on "drugs", their doses, duration of treatment, etc. are also important; these problems are solved only through data accumulation and a databank on the health of soils belonging to different ecotypes, and based on knowledge of the pre-history of a particular SE.

To obtain a diagnosis of the state of biophile transformation activity in the SE, it is necessary to determine the corresponding parameter for its evaluation. A similar diagnosis will help answer the question of use to the user about whether the SE is exhausted or overfed with biogenic elements, readily available inorganic elements in the form of NH_4^+ and NO_3^-, PO_4^- etc. To this end, based on legitimate indicators, it is necessary to obtain their quantitative estimates for the soils being compared. These quantitative values can be used for SE diagnostics and treatment, by analogy with the approach for determining SE's self-sufficiency in biophilous elements.

SEs can have health problems in terms of maximum, uncontrolled growth of some microorganisms, primarily phytopathogens (Јемцев, Ђукић, 2000; Ђукић и сар., 2007). These problems can be identified through the heterotrophic parameter and the degree of SE's self-sufficiency in biophilous elements. However, this identification requires good knowledge of the pre-history of both the etalon soil and the tested soil. The excessive growth of soil phytopathogens is often the result of a disturbed balance either of C_{org} or of biogenic, readily available inorganic elements, or of both. Similar soils can be "treated": a) by recovering the balance of C_{org} or of biogenic, readily available inorganic elements, or of both; b) by maintaining the balance of other (micro) elements; and c) by phytosanitary practices (Van Bruggen, Semenov, 2015).

In the case of very serious or even "incurable" diseases of the SE, the use of pesticides or total fumigation of the SE remains the only option for their radical treatment.

Conclusion

The suggestion to use the term "soil ecosystems" (SE) to designate soils and, even, agrosphere soils is justified and necessary, at least in the scientific, research and teaching environment. It is essential to clearly specify and classify SEs into natural SEs and agroecosystems, utilized by means of intensive and organic technologies. Health is the sole property of a biological category. Therefore, it is appropriate and necessary to employ approaches and methods which enable the evaluation and quantification of the category SE health. In our opinion, the proposed methods for determining soil health through general parameters (heterotrophic parameter) and specific parameters (parameter for determining soil health for evaluation of SE's self-sufficiency in biophilous elements) ensure proper objective assessment of soil health. Further elaboration of the SE suppressiveness parameters is an important topical issue, regardless of the active development of organic agriculture. The overview of practices and methods for maintaining and preserving the health of soils in modern agroecosystems, particularly in organic farming, should be understood as being essentially important in the continuous adaptation to a particular SE. The proposed ways of diagnosing the state of SE health using elaborated parameters highlight new tasks towards a system of diagnoses and prescriptions essential for the systemic recovery of the SE.

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