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SYSTEM IDEAS OF FUNCTIONS OF SOIL ORGANIC MATTER FROM THE PERSPECTIVE OF ALLELOPATIC RESEARCH IN UKRAINE

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INTRODUCTION

Since many scientific fields develop they experience the conceptually rethinking. The role of reductionism can hardly be exaggerated at the initial stages of any given field – when it is important to set the boundaries of the system, which is the subject of study. The subsequent steps of the development of the areas of study bring better results under the collaboration with the other branch of science.

The history of – from the reductionism to systemic (holistic) views – has not been spared allelopathy. Thus, the endeavors to separate the factor of allelopathy from the other factors (which are similar to allelopathy as how they influence on plant) dominated most of the 20th century. To this end plant often was removed from inherent ecosystem and was set in the conditions of laboratory, greenhouse or microplot field experiments. Under the observation of allelopathic phenomena in the natural conditions the non-allelopathic factors were intently written down, because these factors as usual were believed to be the source of artefacts. The lasts skew the interpretation of results. Such ideas were employed as the principle in the research of personalities, who stood at the origins of allelopathic science.

The substances, so called agents, which exhibit the bioactivity towards the plant organism, were the prime focus under the elaboration of the definitions of allelopathy on the first decades since the date of its birth. Notably, the ability to induce various biological effects in plants has featured these agents – the allelochemicals.

In recent decades it became clear, that the allelopathic processes should not be studied apart from the broader system, namely, soil organic matter (SOM). Different species within SOM exhibit the series of functions, particularly a) the long-term storage of carbon (in other words, the isolation from the biogeochemical flows); b) the bioactivity in microdoses towards the plants and other soil inhabitants; c) the source of carbon nutrition for both heterotrophes and plants; d) prolongation of inorganic nutrition – retention of nutrients from the loss beyond the boundaries of ecosystems[1]; e) water retention; f) binding of the mechanically separate organic and mineral particles into the micro- and macroaggregates. The last process plays the significant role in the formation of the system of soil capillaries, and in such a way provides moisture conductivity and thermal conductivity[2,3]. The performance of some functions by certain kinds of substance makes it impossible to perform the other functions. E. g., the substances, forming the recalcitrant skeleton of biochar, a priori couldn't serve as the source of carbon nutrition and prolong inorganic nutrition. Apparently the function of carbon storage hardly work with the binding. At least, this is because the biopersistent substances tend to be hydrophobic and binding substances (particularly, gel-forming polysaccharides) vice versa tend to interact actively with water.

To date the role of allelochemicals in the structural-functional organization of the soil as the system of diverse species of organic and inorganic compounds remains purely understood. Currently the Ukrainian school of allelopathy draws special attention to the research of this issue.

1. Achievements of the Ukrainian school of allelopathy

The transaerial migration (beyond the soil environment – through the atmosphere) of volatile plant metabolites is known to be one of the ways of realization of allelopathic processes. Soil along with the atmosphere plays the role of the carrier of volatile allelochemicals[4,5,6,7].

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[1] Kerzhentsev A. S. Functional Ecology. Moscow : Nauka, 2006. 259 p. (in Russian) ISBN. 5-02-034277-7.

[2] Franzluebbers A. J. Water infiltration and soil structure related to organic matter and its stratification with depth. *Soil and Tillage Research*. 2002. Vol. 66, Iss. 2. P. 197–205. doi.org/10.1016/S0167-1987(02)00027-2

[3] Bronick C. J, Lal R. Soil structure and management: a review. *Geoderma*. 2005. Vol. 124, Iss. 1–2. P. 3–22. doi.org/10.1016/j.geoderma.2004.03.005

[4] Yurchak L. D. Ecological bases of allelopathic interaction and afteraction of essential plants in agrophytocenoses: Extended abstract of doctor sci. diss. (Agriculture) on specality 03.00.16 / Institute of Agroecolgy and Biotechnology of Ukainian Academy of Agrarian Sciences. Kyiv, 2002. 35 p. (in Ukrainian)

[5] Yurchak L. D., Yunosheva O. P. Role of plant excretions of spicate lavender in formation of allelopathic regime of soil. *Phytopathogenic bacteria. Phytoncidology. Allelopathy*: Collected papers of participants of internat. conf. Kyiv, 2005. P. 302–307 (in Ukrainian).

[6] Yunosheva O.P., Ellanska N.E. Specificity of microbial communities of introduced plants Lavandula angustifolia Mill. *Soil science*. 2015. Vol.16, No 1–2. P. 66–74 (in Ukrainian).

[7] Zaimenko N. V., Hnatyuk N. O., Ivanytska B. O. Allelopathic activity of secretions of plant mass and soil from the form of Monard double (Monarda didyma L.). *Ukrainian Journal of Ecology*. 2020. Vol. 10, Issue 2. P. 141–145. doi: 10.15421/2020_77

The aforementioned reasons explain the efforts, aimed by the Ukrainian school of allelopathy. In recent decades these efforts have been aimed rather at the ascertainment of the phenomena, concomitant with allelopathy, than at the allelopathic processes as such.

The soil environment is enriched with the bioactive substances, produced not only by plants, but also by the heterotrophic soil inhabitants. Bacterial and fungal toxins are known by the ability to initiate the distinct biological effects with too lower active concentrations comparing with the bioactive substances of plant and animal origin[8]. It is not by chance that allelopathic research centers scrutinized the soil microbiologic activity since 1970s[9,10]. This is because bioactive microbial and fungal metabolites could mimic the actions of plant-derived bioactive compound, including allelochemicals.

In recent decade the researchers of M.M.Gryshko National Botanical Garden of the NAS of Ukraine (NBG) comprehensively explored the mode of action of several fungal metabolites, especially the exometabolites (cultural broth) of *Penicillium roseopurpureum*. This micromycete is known to produce curvularin with the exhibition of fungistatic activity. The cultural broth was shown to improve system resistance of tomato *Lycopersicon esculentum* to the infestation by the phytopathogenic fungi *Fusarium culmorum*, *F. oxysporum* and *F. solani*[11].

The other objectives of microbiology in allelopathic research include:

1. The unraveling of how the soil microbiota modifies the intensiveness of allelopathic processes. On the one hand the allelopathic effects could be alleviated due to the metabolization of allelochemicals by the microorganisms: both within the cells and with the involvement of exstracellular enzymes, such as laccase. On the other hand the aggravation

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[8] Starodub N. F., Savchuk M. V., Székács A., Marty J.-L. Peculiarities of sample preparation for the determination of certain mycotoxins in grain products and fruits by immunobiosensor analysis. *World Journal of Engineering Research and Technology*. 2018. Vol. 4, Iss. 3. P. 174–185.

[9] Grodzynskyy A. M. Fundamentals of Chemical Interaction of Plants. Kyiv : Naukova Dumka, 1973. 207 p. (in Ukrainian)

[10] Rice E. L. Allelopathy / 2nd edition. New York : Academic Press, 1984. 422 p. ISBN: 9780080925394.

[11] Zaimenko N. V., Ellanska N. E, Didyk N. P, Pavliuchenko N. A., Yunosheva O. P., Ivanytska B. O., Zakrasov O. V., Rositska N.V. Effect of analcite and exometabolites of fungus Penicillium roseopurpureum on the resistance of tomato to fusarium and on microbiological and allelopathic properties of soil. *Reports of the National Academy of Sciences of Ukraine*. 2016. No 11. P. 93–98 (in Ukrainian). doi: doi.org/10.15407/dopovidi2016.11.093

of the effects could be supposed because a) the microbiota competes with the plants for inorganic nutrients and water; these resources become the determinants for the successful undergoing the stress, evoked both in allelochemical mode and by the unfavorable transient weather conditions[12]; b) the microbiota, being the subsequent to plants link of metabolic conveyor, modifies the chemical structure of molecules toward the elevation of their ability to interact with the molecular targets in plant metabolism.

2. The clarification of microbiota's impact on the competition within plant community. Some plants are relatively indifferent for the nitrogen species supplied: either nitrate or ammonia. The other plant species prefer one of these two forms of nitrogen. Evidently, some plants produce the elevated level of urease – they have the advantage when nitrogen is on the intermediate stages of mineralization – under the considerable pool of nitrogen-organic substances in the soil. Besides, some plants (e. g., large part of genus Amaranthus[13]) are well known to be megatrophic, whereas the others (certain conifers[14]) – to be oligotrophic.

Plant-microbe symbioses are the mechanism enabling plants to escape the competition for the exogenous inorganic nutrients and water. As the example of great interest in this regard the mycorrhiza must be given. Often under water scarcity and phosphorus limitation the mycorrhiza-forming plants drive out non-mycorrhiza-forming ones away from the plant community, as the last of these competitors get helpless in such conditions[15].

3. The plant-microbe symbioses are known to enhance the stress adaptability of plants. Allelochemicals belong to the stressors. However, far not every plant species as well as far not every condition is relevant for the purpose of the intentional induction of distinct allelochemical stress by an experiment. For instance, purple alfalfa *Medicago sativa*, unlike many other plant species, exhibits good ecological flexibility due to its

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[12] Rositska N. V. Influence of drought on allelopathic properties of Pinus sylvestris L. *Plant Introduction*. 2020. Iss. 85/86. P. 41–49. doi.org/10.46341/PI2019001

[13] Chernov I. A. Amaranth – Physiological and Biochemical Fundamentals of Introduction. Kazan : Kazan University Press, 1992. 89 p. (in Russian). ISBN 5-7464-0834-4.

[14] Didukh Y. P. Sketches of Phytoecology. Kyiv : Aristey, 2008. 268 p. (in Ukrainian). ISBN 978-966-8458-96-5.

[15] Dzyba O. I., Derevyanko V. A., Solyanyk O. V. Physiological and biochemical peculiarities of seeds of species of Rhododendron L. Genus. *Plant Introduction*. 2000. No 1(5). P. 148–150 (in Ukrainian).

adaptability to the wide range of the influences of various factors. Furthermore, the experimentations within the close ecosystems deal with the challenge, as many factors in such conditions are adjusted to optimized levels in contrast to the open ecosystems, where it is often occurred the extreme levels of same factors. The search of effective allelochemicals in the close ecosystem conditions would take much time. For this reason stress in plants was initiated by means of microgravity, that is the verified stress inductor on the one hand, and not such severe as the radioactive exposure on the other hand. Microgravity, being the stressor, works on a number of targets. One of the most vulnerable of them is the plant-microorganisms and plant-viruses interactions[16].

Applying the method of simulated microgravity, our research group believed it was possible to extrapolate the obtained results to the allelochemical stress. The aspects of alfalfa life, not directly related with the rhizobial symbiosis, were found to be more sensitive as compared with the processes of the symbiosis formation and with the symbiotic bacteria *Synorhizobium meliloti*[17]. Generally speaking, in the case of alfalfa the allelopathic depression doesn't pose a challenge for agriculture. Nevertheless, the further domestication and introduction may deal with the allelochemically vulnerable species of legumes, particularly able to interact with rhizobia. This supports the value of our findings for the perspective.

The progress of the allelopathic processes could more or less mediately influence on the physical, physicochemical and chemical properties of soil. The alternation of these properties could be the source of artefacts under the conduction of allelopathic investigations. For instance, soil colonization by plants, hyphal system formation, and hole making by burrowing animals, fed with the biological yield of plants, enhance the parameter of soil porosity. This, in turns, improves the growth conditions for the plant species, which are fastidious to soil conditions. Consequently these species could win the advantage over the high tolerant plants-

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[16] Mishchenko L. T., Polishchuk V. P., Taran O. P., Hordeychyk O. I. Viral Infections of Potato and Their Progression under Conditions of Simulated Microgravity. Kyiv : Fytosotsiotsentr, 2011. 144 p. (in Ukrainian).

[17] Viter A. V., Zakrasov O. V., Ellanska N. E., Kryvorchuk H. I., Yunosheva O. P. Development of roots and root nodules in symbiotic system purple alfalfa – Sinorhizobium meliloti under clionorotation. *The Scientific Issues of Ternopil Volodymyr Hnatiuk National Pedagogical University. Series: Biology*. 2010. No 4(45). P. 13–18 (in Ukrainian).

competitors. Nearly such simplified scheme often is employed under the explanation of the phenomenon of succession[18].

Almost at the first stages of the development of allelopathic science it became evident the necessity of the information on soil properties, including their dynamical changes, for the discernment of true allelopathic processes and the rejection of artefacts, resulting from the alternations of soil properties.

The physical and physicochemical properties of soil were in large focus in the research of E.Rice[19]. He paid respect to the hydrophobicity and hydrophilicity of allelochemicals as the prerequisite for the repellency by the soil minerals or vice versa for their sorption and consequently accumulation by the soil. A. M. Grodzynskyy[20] proposed the surface of soil solid phase to be the resource for the competition between the molecules of allelochemicals and water molecules under the adsorption. V. P. Grakhov[21,22,23] made the substantial contribution for the allelopathic science, as his scientific interests were largely focused on the methods of the extraction of allelochemicals from the soil. The knowledge of these methods helps to model the behavior of the given groups of allelochemicals under various ecological conditions.

The modern Ukrainian school of allelopathy pays extra attention to the content of inorganic micronutrients in soil and their movement toward the plants in order to find out the impact of these substances on the production of allelochemicals by plants, the formation of target plants' response to the allelochemical influence, as well as on the modification of the activity of allelochemicals before their reaching the targets.

The research, related with the design of man-made substrates for the cultivation of plants, particularly in the close ecosystem conditions, could

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[18] Rice E. L. Allelopathy / 2nd edition. New York : Academic Press, 1984. 422 p. ISBN: 9780080925394.

[19] Ibid.

[20] Grodzynskyy A. M. Fundamentals of Chemical Interaction of Plants. Kyiv : Naukova Dumka, 1973. 207 p. (in Ukrainian).

[21] Grakhov V. P., Moroz P. A. On phenolic factor of peach (Persica vulgaris Mill.) allelopathic afteraction. *Reports the National Academy of Sciences of Ukrainian SSR: Series B.* 1990. No 8. P. 62–64. (in Russian).

[22] Grakhov V. P., Bezmenov A. Y., Moroz P. A. Phenolcarboxylic acids of plant residues and litter of peach trees. *Physiology and Biochemistry of Cultural Plants*. 1991. Vol. 32, No 5. P. 462–468 (in Russian).

[23] Grakhov V. P., Moroz P. A. On the problem of allelopathic afteraction of peach. *Cycling of Allelopathic Active Substances in Biogeocenoses* / Ed. I.N.Gudkov et al. Kyiv : Naukova dumka, 1991. P. 46–56 (in Russian).

be considered one of the preceding steps for the development of the scientific worldview of allelopathy. These conditions are distinct with the relative poorness, firstly, of inorganic compounds in the soil-substitutes, secondly, of the diversity of microbiota species in root-inhabited environment as compared with the natural soils. The complete removal of microorganisms is routinely undertaken as the preliminary step before the launching of close ecosystems. As consequence the elimination of plant exometabolites in root-inhabited environment becomes more difficult. The elaboration of the soil-substitutes for the greenhouses in spacecraft conditions substantially contributed to the study of this problem. Furthermore, the composition of greenhouse atmosphere was surveyed in order to screen plant excretions and to examine the plant ability to purify the air[24]. The simple mineral composition together with the given in advance mechanical structure of soil-substitutes provides the fruitful model for tracing the fate of plant metabolites after they escape from plants into the external environment. In physical terms the allelochemicals mostly share the common routes of migration with other plant metabolites. Therefore, the findings from the examinations of soil-substitutes in the close ecosystems, are of great value for the modeling in allelopathy. Although it goes without saying that the blanket extrapolation to the open ecosystems will be incorrect.

The detailed survey of the properties of soil organic substances coupled with the comprehensive analysis provides the ascertainment, firstly, of the artefacts, misrepresenting the results of the allelopathic investigations, secondly, of the factors, modifying the allelopathic influence. The turning point for the Ukrainian school of allelopathy was the adoption of methods of the fractionation of total SOM[25], but not only the organic matter of plant extract and the allelochemicals, extracted from the soil by means of the orthodox methods. Allelochemicals are not the only soluble substances within SOM. In the allelopathic processes there are some additional modes of the action of various organic substances. Organic compounds play the following roles in soil: a) the precursors of allelochemicals; b) the

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[24] Zaimenko N. V. Scientific principles of structural and functional design of artificial biogeocenosis (in the system: soil-plant-soil): extended abstract of doct. sci. diss. (Biology) on specality 03.00.16 / Dnipropetrovsk National University. Dnipropetrovsk, 2001. 36 p. (in Ukrainian)

[25] Partyka T. V., Bedernichek T. Y., Hamkalo Z. H. Application of method of multistage chemodestructive fractionation for assessment of qualitative content of soil organic matter. *Submontane and Hill Agriculture and Animal Husbandry*. 2015. Vol. 58. Iss. 2. P. 78–85.

stimulators of the inactivation of allelochemicals (by the modes of irreversible binding and microbial cometabolization); c) the depot of allelochemicals (due to the transient binding, that is the reversible process). Each fraction of SOM could contribute specifically (not similarly to other fraction) to each of the roles.

When the fractionation methods began to be involved by the Ukrainian researchers, SOM was separated between two ‘poles’: ‘labile’ and ‘stable’ organic substances[26]. However, from year to year it is adopted the methods of the obtaining of the larger number of substances’ groups from the common pool of SOM, e. g. polysaccharides[27]. Perhaps, in future this will help to attribute the observed allelopathic phenomena to these new fractions, instead being restricted to the search of the correlations between the allelochemicals of “orthodox methods’ (first of all, the compounds of phenolic metabolism) and the allelopathic effects.

The incarnation of E.A.Holovko’s ideas about the induction of dissimilar allelopathic effects by the allelochemicals with different chemical nature became the milestone in the development of the Ukrainian school of allelopathy. E.A.Holovko pursued ‘painting the portrait’ of each allelochemical or, at least, of each group of allelochemicals and then building the ‘portfolio’ through the expanding the spectrum of plant metabolites, described in such a way. It should be explained, that in earlier decades it was accepted the limited number of markers of allelochemical activity such as phenolic substances and terpens, as it may be concluded from the publications of that period[28,29]. Nevertheless, a great body of collected facts provides the evidence that plant metabolites (even within each chemical class) could considerably differ (up to opposites) by the scenarios of the response, they induce in target plants[30].

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[26] Bedernichek T. Y., Hamkalo Z. H. Labile Soil Organic Matter: Theory, Methodology, Indicative Role. Kyiv : Kondor, 2014. 180 p. (in Ukrainian). ISBN 978-966-2781-39-7.

[27] Bedernichek T., Partyka T. Content of water-soluble carbohydrates as a quality indicator of cryogenic soils. *Proceedings of the State Natural History Museum*. 2018. Iss. 34. P. 43–48 (in Ukrainian). doi: 10.5281/zenodo.2532061

[28] Rice E. L. Allelopathy / 2nd edition. New York : Academic Press, 1984. 422 p. ISBN: 9780080925394.

[29] Grodzynskyy A. M. Fundamentals of Chemical Interaction of Plants. Kyiv : Naukova Dumka, 1973. 207 p. (in Ukrainian).

[30] Moroz P. A. Allelopathy in Orchards. Kyiv : Naukova dumka, 1990. 208 p. (in Russian).

E. A. Holovko's ideas were taken up by L. S. Akhov[31] and O. I. Dzyuba[32]. The last initially sorted the extracts from plant material by the fractions (phenolic compounds, phenolcarboxylic acids, amino acids, saponins) and subsequently tested each obtained fractions on the set of target plants, served as the test-objects: wheat *Triticum aestivum*, purple amaranth *Amarantus cruentus=paniculatus*, cress *Lepidium sativum*, radish *Raphanus sativus*, and cucumber *Cucumis sativus*. The order of the test-objects in the rate of sensitivity to any of fractions was not the same with the orders of those rates to other fractions.

Developing the E. A. Holovko's ideas about the allelopathic screening for the broad spectrum of plant metabolites, O. I. Dzyuba emphasizes on the identification of secondary metabolites. The researcher believes, that the quantitative and especially qualitative composition of secondary metabolites' pool in plant indicates, firstly, the occurrence of the stress state of plant, secondly, plant's stress adaptability. This idea comes from the fact of higher content of alkaloids, flavonoids, and saponins in relict plants comparing with phylogenetically younger species. This argues, that these compounds assisted the plants not to be eliminated by the severe stressors, which broke out repeatedly throughout millennia and consequently provided the natural pressure.

As known, the progress of stress in plants is accompanied by the variations of the ratio of photosynthetic pigments (PSPs). However, the changes both in the quantitative content of PSPs and in their molecular structure seem to be hazardous, since these compounds are indispensable for one of the main function – the photosynthesis. This makes it reasonable the conservation of PSPs' metabolism in phylogenetic scale. While the secondary metabolites don't contain basic information for plant life, the organization of metabolic pathways and the levels of the expression of corresponding genes could be altered with too lower risk than under the modification of PSPs' metabolism. Throughout millennia the possibility to modify secondary metabolism supported the search of plants' strategy, aimed at the protection against abiotic and biotic disturbing agents.

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[31] Akhov L. S. Steroidal saponins of nodding onion (Allium nutans L.) and their biological activity: Extended abstract of cand. sci. diss. (Biology) on specality 03.00.12 / Taras Shevcenko Kyiv National University. Kyiv, 2000. 19 p. (in Ukrainian).

[32] Dzyuba O. I. The physiological and biochemical properties of Rhododendron luteus Sweet: allelopathic analysis: Extended abstract of cand. sci. diss. (Biology) on specality 03.00.12 / Institute of Plant Physiology and Genetics of the NAS of Ukraine. Kyiv, 2001. 20 p. (in Ukrainian).

The research direction at the expansion the spectrum of substances, offered for the investigation, not only enriched the fundamental scientific field, but also was beneficial for the practice. The screening of plants with the allelopathic potential was followed by the offering of the plant-based preparations with herbicidal potential[33].

The spectrum of investigated substances with allelochemical activity was expanded alongside with the deepening of the knowledge about the functional properties of one of the groups of long familiar, so called ‘classic’, allelochemicals – the derivatives of phenol. The research team of N. A. Pavliuchenko[34,35,36] collected the information on the conditions of metabolic regulation in plants (first of all lilacs), particularly in connection with PSP metabolism, and also on the effect of phenol-containing excretes and plant postmortem leachates on the physicochemical and chemical state of the soil, plant test-objects and soil microbiota.

2. Some perspectives of allelopathy

To date many scientists and practitioners adhere to the conservative opinion on the soil as the simplified system has been reinforced amongst many scientists and practitioners. With accordance to this belief only two things have to be done in order to prevent the depletion of soil fertility: the replenishing of inorganic nutrients and the providing of the non-negative balance of organic matter. We assert the view that in order to conserve soil fertility it is insufficiently to apply only the total amount of carbon: in the form of either industrial and animal wastes, or green manure, or the biomass of single-cell organisms, or biochar. The ill-considered providing of total intake brings the risk of the deterioration of the conditions of root-inhabited environment or nondurable recovery of these conditions without

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[33] Orel L. V. Plant Preparations for Weed Control. Odessa : Mayak, 1997. 136 p. (in Ukrainian).

[34] Pavliuchenko N. A., Dobroskok V. A., Krupa S. I. Dynamics of allelopathic activity of decay products of plant residues of Syringa josikaea Jacq. f., S. microphylla Diels. and S. persica L. *Plant Introduction*. 2014. Iss. 64. P. 77–84. doi.org/10.5281/zenodo.1576069

[35] Pavliuchenko N. A. Physiological and biochemical parameters of soil-plant system under allelopathic stress: diagnostic analysis and control. *Plant Introduction*. 2015. Iss. 67. P. 94–100. doi.org/10.5281/zenodo.2527009

[36] Pavliuchenko N. A., Dobroskok V. A., Krupa S. I. Allelochemicals from Syringa josikaea Jacq. f., S. microphylla Diels. and S. persica L. introduced species: plant residues–soil relationships. *Agrobiodiversity for Improving Nutrition, Health and Life Quality*. Nitra, 2015. Part II. P. 535–538. ISBN 978-80-522-1380-4.

the gaining of long-term system effect. Thus, the application of the materials with high content of readily metabolized compounds (green manure, food processing wastes) can boost the transient spike of soil microbiota activity, followed with the depletion of pool of the stable fractions of SOM, the loss of biogens beyond the ecosystem, because of weathering.

In the beginning of this paper we delineated the set of functions, which are performed by various organic substances in soil, including the functions of long-term storage and binding. A great body of natural and man-made frameworks exists due to the principle of the association of hard recalcitrant blocks with more resilient materials, which provide their aggregation. In the course of soil genesis initially the role of these blocks is taken by the mineral particles of soil-forming rock. With the subsequent colonization of the soil-forming rock by plants the organic and organo-mineral colloids (from amongst the most biopersistent) also begin to act in this role.

Sollins et al.[37] review the set of binding agents: as fungal polysaccharides, exudates from corn and bromegrass roots, glucose, several humic preparations. In order to be stabilized polysaccharides need to interact with tannins.

The matrix, formed with recalcitrant blocks and binding agents, provides favorable environment, for the water exchange and the consequent movements of biogens, biologically inactive and active organic substances through the soil solution on the one hand. On the other hand, such environment could slow down the rate of the long-distance migration of these substances due to the sorption on matrix' surface. Therefore, the rest of organic matter's functions (bioactivity; carbon nutrition; prolongation of nutrition; water retention), rather depends on the successfulness of the evolvement of the matrix.

Soils could not be entirely conservative systems. They permanently experience the dynamic process of the partial destruction (of organic molecules, soil aggregated, pores) alongside with the reconstuction of the destructed matter. Humanity face the challenge of the bringing the fertility to deserts, the remediation of lost soils, and, that is more to the point, the constant support of the fertility and health of living soils.

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[37] Sollins P., Homann P., Caldwell B. A. Stabilization and destruction of soil organic matter: mechanisms and controls. *Geoderma*. 1996. Vol. 74. P. 65–105.

The substantial array of the developments in the spheres of the design of soil-substitutes[38], artificial soils (constructozems)[39], and mine reclamation[40] strikes out any question on the design of substrates, optimized for the living of plants on macrolevel. However, a new question rises – on the molecular level of the design of soil and the optimization of their properties.

Currently, it is increasingly spoken about the diverse strategies of the greenhouse gases removal from the atmosphere with the subsequent utilization of soils for carbon sequestration[41]. It should be realized, that the exclusive utilization of any material (e. g., biochar, algal or terrestrial plant biomass) brings the risk of improper development of one SOM's functions alongside with the disturbance of other ones, in other words this could be explained as the disharmony between the functions.

Not only raw material, given for the adding in the soil, but also the ways of its pretreatment manages the functional properties of soil. Let us say, the high-temperature processing of raw material, first of all the pyrolysis, ensures the yield of the substances, which are unattractive for the degradation by biota, but likely reduces the yield of the compounds with the ability to swell, to serve as the binding agents and to exhibit the other colloidal properties. Vice versa the additional biosynthesis of gellike and binding agents could take place under the certain conditions of microbial fermentation. But this could need the decomposition of the biopolymers, contributing for the formation of non-biodegradable particles. The most of the procedures, applied for the preparation of organic material before adding to soil, alter the amount and structures of the molecules with the property to make the biota to respond with the distinct effects. These molecules could be represented by plant-derived

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38 Zaimenko N. V. Scientific Principles of Structural and Functional Design of Artificial Biogeocenosis in the System Soil-Plant-Soil. Kyiv : Naukova Dumka, 2008. 303 p. (in Ukrainian). ISBN 978-966-00-0716-1.

39 Smagin A. V. Theory and Practice of soil engineering. Moscow : Moscow State University Press, 2012. 544 p. (in Russian). ISBN 978-5-211-06299-3.

40 Zabaluev V. O. Edapho-phythocenotical basing of sustainable agroecosystems formation and functioning on reclaimed land in Steppe zone of Ukraine: Extended abstract of doctor sci. dissertation (Agriculture) on specality 03.00.16 / National Agrarian University of Ukraine. Kyiv, 2005. 40 p.

41 Hamkalo Z. G., Shpakivska I. M., Maryskevych O. G. Lithogenic potential of pedosphere carbonization: theoretical-methodological, methodical and ecosystem approaches. *AgroChemistry and Soil Science*. 2021. Vol. 92. P. 41–51. doi:10.31073/acss92-05 (in Ukrainian).

toxins, plant growth and development regulators, and the regulators of soil microbiota.

The properties of the materials, offered for soil application, and the opportunities of their pretreatment technologies open up new interesting horizon to be investigated from the perspective of soil biochemistry, soil microbiology, and allelopathy.

CONCLUSIONS

After the extending prevalence of reductionistic views in allelopathy at the turn of 20th and 21st centuries the holistic trends began to flourish. Particularly this reflects in the endeavor to consider SOM as the system of species with dissimilar properties. Some of them provide long-term removal of carbon from biogeochemical fluxes, others – the bioactivity, also others – the influence on the regimes of soil functioning. The recent alelopathic research of NBG have paid attention to the microbiological studies, including the experimentation with plant-microbe symbioses, the examination of physicochemical and chemical properties of soils, from the consideration that these phenomena could mimic true allelopathic processes. The milestone in Ukrainian allelopathy was the expanding of the spectrum of the substances, which were supposed to possess the allelochemical activity, and the acquiring of new knowledge on the functions of phenolic substances in plants and soil. Both the elaboration of soil-substitutes, particularly for the space greenhouses, and the recent adoption of new methods of SOM fractionation will give the tool for the subsequent investigation of the allelopathic processes along with the related phenomena within plant-soil system.

The search of the ways of the creation of organo-mineral skeleton of soil, well suited for the soil fertility, sounds to be perspective for soil biochemistry, microbiology and allelopathy. This includes the examination of the technologies of the preparative processing of different organic materials, as well as the elaboration of the management of their spreading over soil.

SUMMARY

The balance of soil organic matter provides only the partial assessment of the soil state. Inherent in soil organic substances fulfill the set of non-interchangeable functions, including a) resource for heterotrophic nutrition; b) long-term carbon storage; c) bioactivity; d) supporting the depots of water and inorganic nutrients; e) binding of solid soil particles. In reliance on the current scientific quality it is important to characterize

organic matter by the fractions with the consideration of the function of each of them. The role of allelochemicals in the structural-functional organization of the soil as the system of diverse species of organic and inorganic compounds remains purely understood. For the deepening of this knowledge the Ukrainian school of allelopathy conducts the microbiological experiments, particularly related with plant-microbe symbioses, and agrochemical analysis, models closed ecosystems and soil-substitutes, determines the bioactivity of various pools of substances, obtained by means of the fractionation of the extracts from plant material and soil. Currently, the challenges of the carbon sequestration in soil as well as the management of the physical, physicochemical and chemical parameters of soil fertility take increasing importance. The need of the making of optimal decision requires the further studies on the dependence of the listed functions on the kinds of materials, meant for soil treatment, and ways of their pretreatment.

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