Bioconsolidation of soil microflora and subsequent increase in the efficiency of humification of cereals plant residues

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Abstract. An experimental and theoretical study of the technology of using the micromycete-bacterial biopreparation Mycobact (St. Petersburg Biotechnologies LLC), designed to intensify the processes of humification of straw and stubble of grain crops in natural field conditions, as well as to reduce the level of concomitant release of greenhouse gas CO_2 from the soil, As a result of the study, it was found that the configuration biosystem image of the biopreparation Mycobact can persist in it for a long time, and when inoculated with a biopreparation of grain straw, it can provoke the unification of native soil microflora into effective biosystems that control humification processes with a low level of release of greenhouse gas CO_2 from the soil. Neural network computing tools have succeeded in converting fractal profiles of soil microorganisms by converting fractal profiles of microorganisms into CSIcon, CSIgum, CSIco2 indices, which provide an opportunity for quantitative comparison of experiment options and selection of agricultural practices that meet increased requirements for the intensity of humification processes in the soil and the level of CO_2 release into the atmosphere. According to the results of the study, it can be argued that the use of the microbiological preparation Mycobact accelerates the processes of humification of straw and stubble of grain crops in natural field conditions and helps to reduce the release of greenhouse gas CO_2 from the soil into the atmosphere.

1 Introduction

The humification of plant residues by microorganisms is one of the key processes in the carbon cycle in agricultural ecosystems. Microbiological humification, carried out during the inter-vegetation period of the year, contributes to the accumulation of organic matter in soils and increases soil fertility [1-3]. Nevertheless, the processes of microbiological transformation of organic substrates are accompanied by undesirable release of greenhouse gases into the atmosphere [4]. The volumes of CO_2 released by microorganisms during the transformation of straw and stubble of grain crops can be reduced if effective microbial biosystems are formed in the soil, including the most efficient and highly productive

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microorganisms [5]. Consequently, the more precisely the microbial biosystem is tuned to the transformational function, the lower the energy costs for the biochemical processes produced by microorganisms during the transformation of organic substrates, which means that the volumes of CO_2 released into the atmosphere will be lower.

Among the microbiological preparations for the humification of cereals plant residues, two-component biopreparations of the Mycobact brand (manufacturer St. Petersburg Biotechnologies LLC) are distinguished [6-8]. Two-component biopreparations demonstrate the ability to store and distribute in soil microbial communities a configuration image of a biosystem configured to perform the target function of converting plant residues into humic substances [9]. The configuration image of the biosystem can be formed in the Mycobact biopreparation by the method of its repeated passaging, which comes to the transfer of two biological agents (bacteria of the genus *Micrococcus luteus* and micromycetes of the genus *Penicillium*) from the finished biological product produced in the previous technological cycle to the environment of the biological product produced in the current technological cycle. The organization of the native soil microflora in accordance with the configuration image of the biosystem reduces the stage of microbial biosystem assembly in the soil, and the biosystem formed in this way becomes capable of rapidly humifying plant residues without excessive energy losses and with reduced release of greenhouse gas CO_2 into the atmosphere.

The purpose of the study was a neural network analysis of fractal profiles of soil microorganisms and an assessment of the impact of the Mycobact biopreparation on the bioconsolidation of soil native microflora, on the rate of humification of cereals plant residues and on reducing greenhouse gas emissions into the atmosphere.

2 Materials and methods

2.1 Fractal profile of microorganisms

The frequencies of occurrence of soil microorganisms can be arranged in a numerical series, in which the frequencies will be arranged in decreasing order of their values. As a result, a taxonomically impersonal fractal profile of microorganisms is formed (Fig. 1) [10, 11]. In case when the frequencies of microorganisms form a geometric decreasing power series (for example: 10^{-1}, 10^{-2}, 10^{-3}, ...) [12], this is where the ideal fractal profile of microorganisms takes place. We need a theoretical ideal fractal profile of microorganisms to calculate the Euclidean distances between it and empirical fractal profiles of microorganisms. The Euclidean distances between these profiles will then be used to assess the level of bioconsolidation of soil microorganisms in the resulting biosystems and the intensity of biochemical processes controlled by microorganisms.

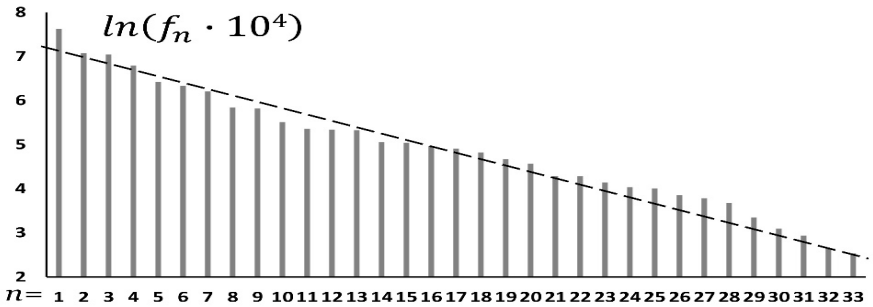

Fig. 1. Fractal profile of soil microorganisms. The values of the logarithms of the frequencies of microorganisms (f_n) are deposited along the Y axis. The ordinal numbers of the positions of microorganisms in the numerical series are laid down along the axis X. The dotted straight line represents the ideal fractal profile of microorganisms.

We assume that the ideal fractal profile of microorganisms corresponds to the best biosystem self-organization of microorganisms (dotted line, Fig. 1), and when external factors affect the biosystem, we assume that the Euclidean distance will increase. Considering this we introduce three indices of cognitive significance (Cognitive Salience Index; = 0...10 b/r) for the fractal profile of microorganisms [13]: (1) CSIcon – index of biosystem consolidation of microorganisms; (2) CSIgum – intensity index of the humification process of plant residues; CSIco2 – intensity index of CO_2 release into the atmosphere.

Before calculating the Euclidean distances, the data of the initial fractal profiles (f_n) are logarithmed and transformed by the difference WaveLet procedure [14].

$$W_k = (F_{k+1} - F_k)/2 \quad (1)$$

where $F_k = \ln(10^4 f_k)$ – the logarithmic frequencies of the fractal profile of microorganisms f_k; $k = 1...N$ – the ordinal numbers of the position of microorganisms in the fractal profile; N – number of microorganisms in the fractal profile.

2.2 The neural network configuration

To calculate the indices CSIcon, CSIgum, CSIco2, we used a neural network (Excel environment, VBA, Fig. 2) [15, 16], so initially the algorithm for converting fractal profiles of microorganisms into the desired indices was unknown, and in neural networks in training mode it is possible to find an algorithm for calculating indices and calculate their values.

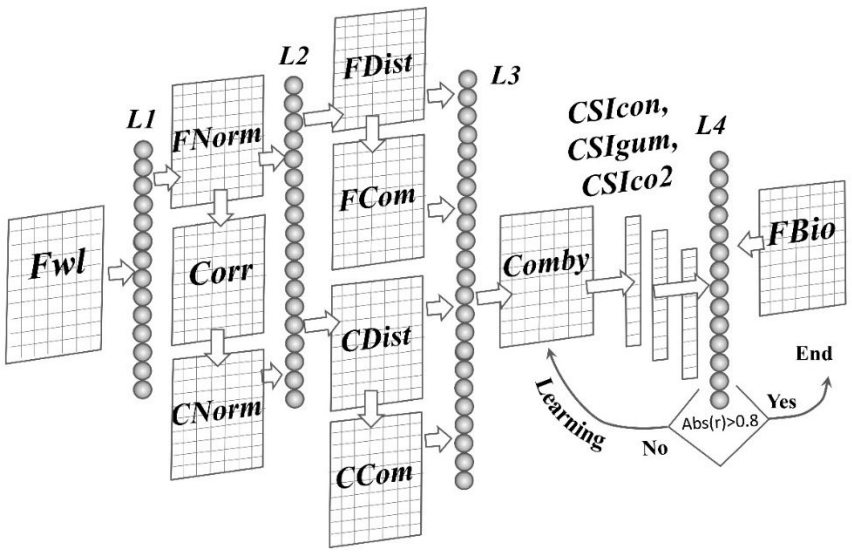

Fig. 2. Neural network for calculating CSIcon, CSIgum, CSIco2 indices from WaveLet data (Fwl matrix). FNorm – a matrix containing normalized data of the Fwl matrix; Corr – correlation coefficients between columns of the FNorm matrix; CNorm – normalized data of the product of the FNorm×Corr matrices; FDist, CDist – Euclidean distances between columns of the FNorm, CNorm matrices; FCom, CCom – eigenvectors of the FDist, CDist matrices. Learning – a neural network learning cycle using a database of Comby algorithms and empirical data on the humification of organic substrates and the release of CO_2 (Bio matrix).

2.3 Stages of neural network computing

1) The L1 neuron layer performs line-by-line normalization of the Fwl matrix data using the standard *Normalization()* [17] function and records the normalization results in the FNorm matrix.

$$\text{FNorm} = \textit{Normalization(}\text{Fwl}\textit{)} \tag{2}$$

2) The L1 neuron layer calculates the Corr matrix using FNorm matrix data and the standard *Correlation()* procedure.

$$\text{Corr} = \textit{Correlation(}\text{FNorm}\textit{)} \tag{3}$$

3) The L1 neuron layer performs line-by-line *Normalization()* of the product data of FNorm×Corr matrices, and writes the normalization results to the CNorm matrix.

$$\text{CNorm} = \textit{Normalization(}\text{FNorm x Corr}\textit{)} \tag{4}$$

4) The L2 neuron layer calculates the FDist and CDist Euclidean distance matrices using digital data located in the columns of the FNorm and CNorm matrices and the standard computational procedure *EuclidDistance()* [18].

$$\text{FDist}_{kl}=\textit{EuclidDistance}(\text{FNorm}_{1k},\ldots,\text{FNorm}_{Nk};\ \text{FNorm}_{1l},\ldots,\text{FNorm}_{Nl}), \tag{5}$$

$$\text{CDist}_{kl}=\textit{EuclidDistance}(\text{CNorm}_{1k},\ldots,\text{CNorm}_{Nk};\ \text{CNorm}_{1l},\ldots,\text{CNorm}_{Nl}). \tag{6}$$

where $k, l = 1,...,M$; N – number of columns and rows in the FNorm and CNorm matrices; *EuclidDistance()* – standard procedure for calculating Euclidean distances between columns of matrices.

5) The L2 neuron layer calculates the FCom and CCom matrices using data from the diagonal symmetric matrices FDist, CDist and the standard procedure *EigenVectors()* [19].

$$FCom=EigenVectors(FDist), \quad (7)$$

$$CCom=EigenVectors(CDist) \quad (8)$$

6) The L3 neuron layer calculates the values of the CSIcon, CSIgum, CSIco2 indices using data from the FDist, CDist, FCom, CCom matrices and the Comby algorithm database.

7) The L4 neuron layer analyzes the values of the correlation coefficient (r) of the CSIcon, CSIgum, CSIco2 indices with the Fbio matrix data in Learning cycles. The exit from Learning cycles was performed at Abs(r)>0.7 (Table 1).

3 Results and discussion

In laboratory experiments, rye straw (at the rate of 3 g/kg of soil) was introduced into the upper layer (0-5 cm) of sod-podzolic soil (from the arable horizon of the fields of the Detskoselsky agricultural enterprise), after preliminary inoculation with Mycobact biopreparation and native soil extract [6]. During the experiment, the soil release of CO_2 and the rate of straw humification were measured using standard methods. The fractal profiles of soil microorganisms according to the experiment options and in the liquid medium of the Mycobact biopreparation were determined by the standard molecular genetic method of sequencing the 16S-rRNA gene (GS Junior "Roche"). The obtained fractal profiles were processed by a neural network, and as a result, the values of the desired indices were obtained according to the experiment options and in the production environment of the Mycobact biopreparation (Table 1).

Table 1. The values of the indices of cognitive significance of fractal profiles of soil microorganisms CSIcon, CSIgum, CSIco2 for experiment options and the Mycobact production environment.

Indices of cognitive significance	Production environment of Mycobact	Soil	Soil with rye straw	Soil with rye straw and Mycobact	Soil with rye straw and native extract
CSIcon, SE=±0.1	6.8	1.9	5.0	6.8	4.5
CSIco2, SE=±0.1	3.8	8.7	3.8	4.0	4.6
CSIgum, SE=±0.1	1.2	5.5	6.1	6.1	6.0

The conducted neural network analysis of fractal profiles of microorganisms demonstrated the unique capabilities of computational neural networks capable of extracting the necessary information from empirical microbiological data. Neural network analysis also proves that not only the abundance of microorganisms in the soil, but also the ratio of physiological and taxonomic groups of microorganisms in the soil contain information on the level of soil microflora bioconsolidation, on the intensity of the processes of rye straw humification in the soil and on the intensity of greenhouse gas CO_2 release into the atmosphere.

The neural network, by computational transformation of fractal profiles of microorganisms into CSIcon, CSIgum, CSIco2 indices, provides an opportunity for quantitative comparison of experiment options and the choice of an agricultural approach based on inoculation of rye straw with Mycobact biopreparation, which, as shown by neural network analysis, contributes to the bioconsolidation of soil microflora and the formation of a microbial biosystem corresponding to the configuration image of the biosystem of Mycobact biopreparation (CSIcon = 6.8, Table 1). The same value of the index of bioconsolidation of microorganisms is observed in the production environment of the Mycobact biopreparation (CSIcon = 6.8, Table. 1), which proves the fact that the Mycobact

biopreparation spreads the configuration image of the humification biosystem among native soil microorganisms and, in accordance with this image, forms a microbiological biosystem with the best humification indicators, with: minimal release of CO_2 (CSIco2 = 4.0, Table. 1) and the maximum intensity of humification processes in soil with rye straw (CSIgum = 6.1, Table 1).

The native soil extract contains a microbial soil community in which local microbial biosystems with a lower level of bioconsolidation of microorganisms have formed on the arable lands of the Detskoselsky agricultural enterprise over the years of field operation (CSIcon = 5.0, 4.5, Table. 1), but with a high intensity of humification processes (CSIgum = 6.1, 6.0, Table 1) and a low intensity of CO_2 emission (CSIco2 = 3.8, 4.6, Table 1). In the absence of straw in the soil, chaotic biochemical processes occur without the organization of biosystems (CSIcon = 1.9, Table. 1), with a high level of $_{CO2}$ release from the soil (CSIco2 = 8.2, Table. 1) and a reduced level of humification processes (CSIgum = 5.5, Table 1).

4 Conclusion

The latest information technology based on the use of computational neural networks has made it possible to solve the rather difficult task of calculating cognitive significance indices that quantify the intensity of humification processes and the associated greenhouse gas CO_2 release, as well as calculating the level of bioconsolidation of soil microorganisms into a biosystem configured for effective humification of plant residues in natural field conditions.

Based on the conducted neural network analysis of fractal profiles of soil microorganisms and calculated values of the CSIcon, CSIgum, CSIco2 indices, it was possible to show that the use of the microbiological preparation Mycobact accelerates the processes of humification of straw and stubble of grain crops in natural field conditions, and at the same time the level of greenhouse gas CO_2 release into the atmosphere is reduced.

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