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Effect of ecological and conventional management to quantity and quality properties of organic matter, and microbial properties of sandy soils in Nyírség region

Theses of PhD dissertation

Ibolya Demeter

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Doctoral school

Name: Doctoral School of Biological Sciences

Discipline: Biological sciences

Leader: Dr. Zoltán Nagy
Institute leader, professor, DSc
SZIU, Faculty of Agricultural and Environmental Sciences
Institute of Botany and Ecophysiology

Supervisor: Dr. Katalin Posta
Professor, DSc. habil
SZIU, Faculty of Agricultural and Environmental Sciences
Department of Genetics, Microbiology and Biotechnology,
Microbiological and Ecotoxicology Group

....	....
Approval of the leader of the Doctoral School	Approval of the supervisor

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1. THE BACKGROUND AND OBJECTIVES OF THE STUDY

1.1. Background

The sandy soils have unfavourable structure and water management properties, however, due to their large area expansion, their agricultural use is unavoidable. This is especially true for those regions where the predominant soil type is sandy soil, as the areas studied by me in the Nyírség region.

KLÉH and SZŰCS has already reported the typical micro-topographical relations of Nyírség region in 1954 , but the possible impacts to soil quality and activity and composition of soil microbial community previously have not been investigated, nor did they conducted research on the effect of meteorological changes to microbial community. Although the effects of ecological and conventional farming on soil quality and the microbial community have also been studied by many researchers on sandy soils, the parameters were not monitored in so diversified way, taking into account the micro-topographic features and meteorological factors in Nyírség region, as within the framework of the current research, so a more complex examination of the relationships were realized. This was made possible by the fact that since 1997 in the Research Institute of Nyíregyháza, IAREF, University of Debrecen has been going on arable crops in accordance with the ecological farming methods on an area of 53 ha, so I could study conventional and ecological farming systems parallel with the related or identical plant species.

1.2. Objectives

The aim of my research presented in my doctoral dissertation is the comparative determination of ecologically and conventionally managed sandy soils, based on the mechanical and chemical properties of the soil and the activity and composition of the soil microbial community. Within this, I set the following goals:

1. Investigation of the effect of micro-topography on the studied soil mechanical, soil chemical and microbial parameters.
2. Examination of changes in the composition of the microbial community depending on the management system and micro-topographic location.

3. Exploration of the differences, caused by the recycling of plant residues between the examined ecologically and conventionally managed areas.
4. Investigation of meteorological parameters and their effect on soil microbial biomass.
5. Searching for connections between soil enzyme activities and PLFA markers, showing the composition of the microbial community.

2. MATERIAL AND METHODS

2.1. General and topographic characterization of the study areas

The study areas are acid sandy soils (Arenosols) located on the outskirts of Nyíregyháza, belong to the Research Institute of Nyíregyháza, IAREF, University of Debrecen. This area is characterized by topographic heterogeneity (in the case of the study areas I measured a 5 meter level difference in both the ecological and conventional plots), therefore in the interest of the representative sampling, sampling occurred from both the upper and lower part of slope, as well as on-site soil respiration measurements. The bands, which are the characteristic of Nyírség region can be observed in both plots. In the ecological site, traces of animal mixing can be observed in both the upper [Lamellic Arenosol (Raptic, Turbic)] and the lower part of slope [Calcaric Arenosol (Protocalcic, Turbic)], and the presence of lime in the lower part of slope. In the conventional plot, however, neither animal mixing nor lime was found in the soil sections, but in contrast to the upper part of slope [Lamellic Arenosol], in the lower part of slope [Arenosol (Humic)] a buried humus level was present.

2.2. Soil tillage and grown plants

In the ecological farming fields of Research Institute of Nyíregyháza, the main plant varieties come from those breedings in the institute, partly for food, ecological seed and fodder production. In both examined plots, mainly cereals (spelt, rye, and oats) were grown sometimes in association with hairy vetch, oil radish and rapeseed were grown as green manure. While in the ecological plot only pesticides and mechanical plant protection which are allowed to use in ecological management, in conventional management chemicals were used in both plant protection and nutrient supply. In April 2013, liming soil improvement was carried out in the lower part of slope of the conventional plot at a dose of 5 t/ha. During the study period, deep ploughing took place once in both plots, and in organic farming tried for using of coupled tillage devices.

2.3. Soil sampling and field measurements

Soil samples were collected from the designated areas with the help of the staff of the Research Institute of Nyíregyháza as follows:

In the case of each sampling area, four sampling points were separated, within which average samples were prepared from three drilled subsamples from both the 0-30 cm and 30-60 cm layers, and then the samples were divided into freezer bags. Samples taken for microbiological testing were immediately placed in a cooler bag, and after the delivery to the laboratory prior stored at -20 ˚C to investigations. Samples of soil chemistry and soil mechanics studies were stored under air-dry conditions until analysis. Soil respiration was determined using an LCi-SD (ADC BioScientific Ltd.) open system infrared gas analyser. After the device warmed up and the calibration was recorded, the measured values of the net CO_2 exchange ($NCER = \mu mol\ CO_2 / m^2 / s$) were recorded at each sampling point until equilibrium was reached.

2.4. Meteorological observations

Meteorological observations were performed using a μ-Metos (Pessl Instruments GmbH) meteorological station located at the area of Research Institute of Nyíregyháza. From among the parameters recorded by the device every two minutes, in my dissertation I present the air and soil temperature data (the latter were measured at a depth of 15 cm in the upper 20 cm soil layer). In addition, a conventional (measuring vessel) reading of the daily precipitation was performed on each rainy day.

2.5. Laboratory investigations

2.5.1. Determination of soil moisture content

The moisture content of the soil samples was determined with gravimetric method, which for I used freshly frozen samples of enzyme activity assays. The tests were performed in two replicates, based on the measured wet and obtained dry masses, the moisture content of the samples was determined in m/m% dry matter.

2.5.2. Determination of main soil chemical parameters

The main chemical properties of the soil samples were determined from air-dried samples by 8-parameter, limited soil testing in the Soil and Plant Testing Laboratory of the Faculty of Horticulture of College of Kecskemét, in accordance with the current Hungarian standards. During the investigations were determined the aqueous and potassium chloride pH of the samples, the plasticity index according to Arany, the total salt and $CaCO_3$ content, the amount of humus and nitrite nitrate-N, and the AL-soluble P_2O_5 and AL -K_2O amount.

2.5.3. Determination of quality of soil organic matter by E4:E6 method

Determination of organic matter quality occurred in the Soil Biology Laboratory of the Research Institute of Nyíregyháza based on PAGE et al. (1982), in four repetitions. Organic matter was extracted from 4.00 g of air-dried soil samples with 0.5 M NaOH solution. Photometric measurements of absorbances were performed from a 10-fold dilution of the extracts against a blank of 0.5 M NaOH at 465 and 665 nm using an U2001 (Hitachi High-Tech Corporation) spectrophotometer. The E4:E6 ratio given by the quotient of the absorbances measured at the two wavelengths, from the value of which we can deduce the ratio of relatively small molecules of fulvic and humic acids and larger molecules of better quality humic acids.

2.5.4. Determination of total carbon and nitrogen content of samples, and the C:N ratio

The total carbon and nitrogen content and the C: N ratio of the soil samples were determined from air-dried soil samples using a Duma combustion element analyser (varioMax CNS, Elementar Analysensysteme GmbH) in the Soil Biology Laboratory of Research Institute of Nyíregyháza. The perfect combustion of the 900-1000 mg soil samples weighed into the ceramic crucibles was facilitated by the addition of 300 mg of WO_3 catalyst. After the measurement, the results were obtained in m/m%.

2.5.5. Soil mechanical investigations

The grain composition was determined by dry sieving separation from soil samples taken in autumn 2012 (Soil and Agrochemical Test Methodology Book 1.1.7.5), by dry sieving and sedimentation method from soil samples taken in autumn 2013 (MSZ-08-0205:1978 Hungarian standard method) in the Soil and Plant Examination Laboratory of the Faculty of Horticulture of College of

Kecskemét. Furthermore, the water resistance of the structure was determined from the soil samples of autumn 2013 by wet sieving, which took place in the Soil Quality Laboratory of the Measurement and Diagnostic Service Center of the Georgikon Faculty of the University of Pannonia from the total amount of samples. The amount of waterproof soil fractions was expressed as a percentage of the results obtained by dry sieving.

2.5.6. Soil enzyme activity investigations

Enzyme activity investigations (except for phosphatase) and sample preparation for PLFA assays were performed in the Soil Biology Laboratory of Research Institute of Nyíregyháza. Plant residues were removed by sieving (Ø=2 mm) and tweezers if necessary before each investigations. Samples were weighed on an Explorer Pro (Ohaus GmbH) analytical balance, during the photometrical measurements (excluding acid phosphatase assays) an U2001 (Hitachi High-Tech Corporation) spectrophotometer was used.

2.5.6.1. Determination of soil invertase activity

The studies were performed based on MIKANOVÁ et al. (2001) method, in four repetitions. Starting from 15 g soil sample with original moisture content, the amount of glucose formed by the invertase enzyme of the soil, formed from the sucrose substrate which was added to the sample, was measured using a dinitrosalicylic acid indicator. The colour intensity of the samples was measured at 508 nm wavelength. The results corrected for the value of the “control” samples and the moisture content of the soil samples were obtained in mg glucose/1 g dry soil/4 hours.

2.5.6.2. Determination of soil dehydrogenase activity

The dehydrogenase activity of the soil samples was determined according to the MSZ-08-1721/3-1986 Hungarian standard method, in four repetitions. Starting from 3.00 g $CaCO_3$-treated 20.00 g soil samples with original moisture content, the intensity of the red colour of triphenylformazan produced by the dehydrogenase enzyme in the soil from the TTC (2,3,5-triphenyltetrazolium chloride) solution was added to the sample was measured at 485 nm wavelength against ethanol. The results corrected for the value of the sterilized “control” samples and the moisture content of the soil samples were expressed in mg formazan/1 g dry soil/1 day.

2.5.6.3. Determination of soil catalase activity

The catalase activity of the air-dried soil samples was examined according to the guidelines of the MSZ-08-1721/4-86 Hungarian standard method, in four replications. Starting from 2.00 g air-dried soil sample, the amount of O_2 formed per unit time from the H_2O_2 added to the samples by the catalase enzyme in the soil was measured by $KMnO_4$ titration. The activity of the catalase enzyme was corrected with the factor of $KMnO_4$ measuring solution and the value of the sterilized “control” samples, and was determined in mg O_2/1 g soil/1 hour.

2.5.6.4. Determination of soil phosphatase activity

During our experiments, using the method of TABATABAI and BREMNER (1969) in the Laboratory of WESSLING International Research and Educational Center, considering that the study areas have acidic pH, we measured the acidic phosphatase activity in four repetitions. Starting from 1.00 g air-dried soil sample, the amount of PNP (p-nitrophenol) formed in the soil by phosphatase enzymes from the solution of PNPP (p-nitrophenyl phosphate) added to the samples was determined at 400 nm wavelength using an Evolution 300 (Thermo Fisher Scientific Company) spectrophotometer. The results corrected for the values of the “control” samples were expressed in μmol PNP/1 g dry soil/1 hour.

2.5.7. Determination of structure of soil microbial community by phospholipid-derived fatty acid (PLFA) method

Based on the results of invertase activity, the preparation of soil samples best representing the given sampling area was performed by the single-phase Bligh-Dyer method (BLIGH and DYER 1959) modified on the basis of practical experience (WHITE et al. 1979). In the first step, I extracted the fatty acids starting from 10.00 g in the soil sample with original moisture content. From the obtained lipid extract, phospholipids were separated from the other lipid phases by means of a silica gel-loaded SPE column. During the “saponification” I formed methyl esters from the obtained phospholipid fatty acids.

Finally, the samples transferred to hexane were supplemented with 20 ng/µl concentration methyl-nonadeconate standard solution, and stored at -20 ºC until measurement.

Gas chromatography-mass spectrometry measurements of the prepared phospholipid fatty acid methyl ester extracts was performed from the autumn 2012 and spring 2013 samples at the Institute of Materials and Environmental Chemistry of the Hungarian Academy of Sciences, and from the later samples at the Laboratory of WESSLING International Research and Educational Center. Each fatty acid methyl ester was identified based on specific fatty acid methyl ester standard mixtures and individual standards as well as mass spectra.

The amount of identified phospholipid fatty acids (corrected for soil moisture content) were expressed in nmol PLFA/1g dry soil unit.

2.6. Processing and evaluation of the obtained results, applied statistical methods

During the data processing and evaluation, I used the 2013 and 2016 versions of Microsoft Office Excel and the IBM SPSS Statistics 22.0 software package. Measurement results were expressed in mean ± standard error (SE) format. In the statistical analyses, I used three internal repetitions ($n=12$) except for the PLFA studies, where there were no internal replicates due to the high cost ($n=4$). During the statistical analyses were used $P<0.05$, and in case of the correlation investigations $P<0.05$ and $P<0.01$ significance levels. In the analysis of variance (ANOVA), I used Tukey's-b and Games-Howell tests (as a function of the results of homogeneity tests) to compare the results of different sampling areas. The correlations between the measured parameters were examined by Pearson's correlation, the influencing effect of different environmental factors (temperature, precipitation, cultivation mode, micro-topography, sampling depth) to the examined soil chemical and microbial parameters were examined by principal component analysis (PCA).

3. RESULTS

3.1. Results and discussions

Comparing the results of soil respiration in the study areas, I measured significantly higher values in the upper part of slope for both farming methods, except in autumn 2012 and spring 2013 in the ecological plot. Comparing the two farming methods, can not be observed trend, although with the exception of the results of autumn 2012 and summer 2014, I always measured the highest soil respiration in the upper part of slope of conventional plot. At the same time, the seasonal dynamics of soil respiration can be observed, according to which the intensity of soil respiration was the lowest in autumn and the highest in summer.

Among the measured meteorological data, in case of the annual average mean air temperature in the study period was the lowest in 2013 at 11.06 ˚C, followed by the year 2012 with 11.11 ˚C, and in 2014 was the highest at 12.10 ˚C. The extreme cold March was Highlighted in 2013, when the daily average temperature was below freezing for eight days. Contrary to air temperature data, the monthly average soil temperature was not below freezing in any month during the study period, and even in March 2013 there was not drastic decrease in monthly mean soil temperature, and the temperature did not below freezing point in the coldest days, which is probably can be explained by the protective effect of the thick snow layer covering on soil. In terms of the annual amount of precipitation in the study period, 2012 was the driest year with a total amount of 382.62 mm of precipitation, which is well below the range of 500-750 mm typical of Hungary. This was followed by 2013 with an annual rainfall of 485.6 mm and 2014 was the wettest with an annual rainfall of 516.1 mm. It is highlighting in July 2014, when the amount of precipitation on this month's 16 rainy days was 148.40 mm, which was almost a third of the annual rainfall.

In terms of soil moisture, there was no significant difference between the moisture contents of the two sampling depths, however, based on my results, the 30-60 cm soil layer is more difficult to get wet, but its moisture retention capacity is better. As the upper part of slope areas are more exposed to the drying effects of solar radiation and wind, furthermore was measured lower humus content on the upper part of slopes, and the higher sand content and lower silt and clay content are conducive to erosion, I measured significantly higher soil moisture in the soil samples which were collected from the lower part of slope.

Based on the obtained results, the favourable effect of organic farming on soil quality was confirmed. The higher organic matter input provided by recycled plant residues resulted significantly higher aqueous and potassium chloride pH; higher organic carbon content; nitrite, nitrate-N content; humus content; total carbon and nitrogen content; and C:N ratio in both sampling depths of upper part of slope area of ecological plot, compared to conventional site.

In the case of the studied areas by me, I did not observed a positive effect of organic fertilization to the quality of organic matter, because the performed E4:E6 investigations showed in 65% of the cases that less stable, relatively small molecule fulvic and humic acids are in the majority in the studied sandy soils.

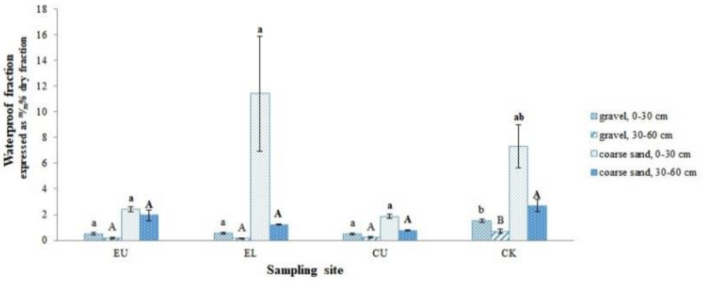

Figure 1: Distribution of waterproof fractions of the studied soil samples in autumn 2013

EU: ecological upper part of slope, EL: ecological lower part of slope, CU: conventional upper part of slope, CL: conventional lower part of slope

[1] Above the columns the letters represent the differences (small letters in 0-30 cm soil depth and capital letters in 30-60 soil depth) by one-way ANOVA followed by Tukey’s-b test ($P < 0.05$).

In point of the soil mechanics investigations, the proportion of gravel fraction compared to the other examined fractions was the highest in the ecologically managed plot. As a result of the topographic exposure and the resulting erosion were washed/transported some of the finer grains from the upper part of slope to the lower part of slope. The ratio of sand fraction compared to silt and clay fraction was significantly higher in upper part of slope in case of both farming methods and sampling depths, while that of silt fraction was significantly higher in the lower part of slope.

The amount of clay fraction was higher in the lower part of slope in case of both plots and sampling depths. Higher organic matter input also favourable affected the soil's resistance to water erosion, in the ecological site the amount of waterproof soil fractions did not differ significantly between the upper and lower part of slope, while in the conventional table the difference was significant ($P<0.05$).

In general, in case of invertase, dehydrogenase and catalase enzymes higher values were measured from samples collected from the upper 30 cm sampling depth, and in point of micro-topography, the samples, which were collected from lower part of slope, had higher enzyme activity.

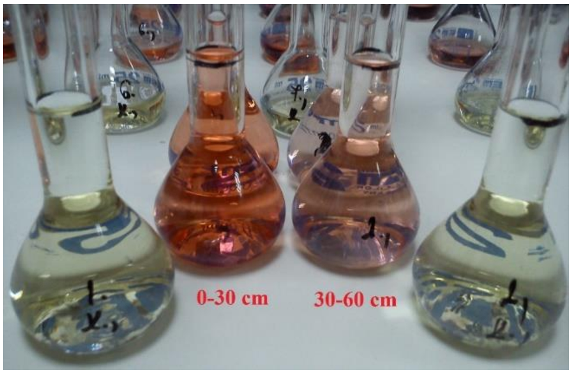

Figure 2: Visible difference in colour intensity between samples from two sampling depths soil extracts prepared for dehydrogenase measurement

Comparing the two management methods, the beneficial effect of recycling plant residues can be observed, according to which in general I measured higher invertase, dehydrogenase and catalase activity in the ecological plot compared to the conventional site, which was most pronounced in the case of dehydrogenase enzyme. In the case of invertase, seasonal dynamics of the enzyme activity can be observed, according to which higher activities can be measured in autumn and spring than in summer, while dehydrogenase enzyme, unlike invertase, generally showed higher activity in spring and summer than in autumn. Catalase enzyme activity did not show as much seasonal variability as invertase and dehydrogenase. Comparing the two management methods, I measured significantly higher acidic phosphatase activity in the ecological than in the conventional plot. In terms of micro-topography, the phosphatase activity in the ecological plot was significantly higher in the lower part of slope areas during the whole study period, while in the conventional plot this trend was observed only in the autumn 2012 and spring 2013 investigations. Phosphatase enzyme activity measured in soil showed seasonal dynamics with changes in environmental factors, which was more pronounced in the ecological plot than in the conventional one.

In general, during the PLFA investigations, the concentration of all measured PLFA markers was higher in the upper 30 cm soil layer compared to the sampling depth of 30-60 cm. The amounts of bacterial, G^+ and G^-, as well as Aktinomyceta and total PLFA markers were remarkably high in the upper 30 cm soil layer during the autumn 2012 sampling. Regarding the micro-topography, I usually measured significantly higher values in case of the samples taken from the lower part of slope. In point of the type of management, a trend was observed in case of samples collected from the upper part of slope, according to which the amount of bacterial, G^+, Aktinomyceta and total PLFA markers was higher in the ecological plot. The amount of fungi was higher on upper part of slope in both sampling depths, similar to the particles in the sand fraction, which is explained by the fact that the fungi are located in larger pores and on the surface of aggregates, making them much more sensitive to environmental influences, which is a sensitizing factor to changes of soil moisture. The positive relationship between the sand fraction and the amount of fungi was also confirmed by the correlation analysis ($r=0.434$, $P<0.05$). As a result of the liming applied in April 2013, the amount of fungi increased with increasing pH in the lower part of slope in conventional site, as well as in the lower part of slope in ecological plot due to the higher nutrient content, after that, except of the results of 2013 autumn I measured significantly higher fungal PLFA marker concentrations in the lower part of slope. The PLFA results showed seasonal dynamics, according to which I generally measured higher PLFA concentrations in autumn and spring than in the case of summer sampling.

From the relative proportions of the individual PLFA markers, and from the spatial and temporal distribution, I was able to deduce was in which phase of organic matter decomposition in soil of studied areas at the given time. In the case of organic farming, in general, the G^+:G^- ratio was higher in samples which were collected from the upper part of slope, thus the lower G^+:G^- ratio indicates a higher amount of easily available, less stable carbon forms in the ecological upper part of slope, however in the conventional plot this trend was not observed. The easily available carbon forms were present in larger quantities at both sampling depths in autumn, at the same time as/after the harvest, and their amount decreased significantly in summer, which is supported by the seasonal dynamics (except for autumn 2012 sampling), according to which the proportion of G^+ bacteria compared to G^- bacteria was higher in autumn in the bacterial community of studied soil samples, while this proportion was lowest in summer. In autumn and spring, the fungi:bacteria ratio was significantly higher on the upper part of slope at both sampling depths and both farming systems, despite the fact that the amount of measured organic matter was significantly lower on the upper part of slope. Generally, the Aktinomyceta: bacteria ratio was significantly higher in the lower part of slope at both sampling depths and farming systems, so in the lower part of slope not only was higher the amount of microbial biomass, but the microbial degradation processes were also more intense. Regarding the bacterial cell number results calculated on the basis of PLFA markers can be said generally, that the samples which collected from the lower part of slope had a higher bacterial cell number, which is consequence due to the more favourable nutrient supply.

The results correlate with the observation that the lower pH is unfavourable for bacteria, because after liming in the conventional plot there was a significant increase the bacterial cell number in the lower part of slope of the conventional plot, which was much more pronounced in case of the 30–60 cm sampling depth. In terms of seasonal dynamics, the bacterial cell number was lowest in samples, which were collected in summer, and highest in samples, which were collected in spring.

Soil moisture content showed significant positive correlation with the investigated enzyme activities in the total study period, and in some times with the total PLFA content. At the same time, soil moisture was a less determinative parameter during summer sampling than in autumn and spring, when it was moderately close-close positive significant correlation with the studied carbon and nitrogen forms and the studied enzyme activities ($P<0.01$).

In the case of the studied sandy soils in Nyírség region, pH_{KCl} showed a moderately close-close, positive, significant correlation with the studied carbon and nitrogen forms and the majority of microbial biomarkers also ($P<0.01$).

In most cases the organic and inorganic carbon and nitrogen content, as well as the C:N ratio of the soil samples showed a moderately close-close, positive, significant ($P<0.01$) correlation with the examined enzyme activities.

There was generally significant positive relationship between the examined enzyme activities, but strength of this varied. With respect to biomarkers, invertase activity, with the exception of sampling in summer 2014, showed a moderately close, positive, significant ($P<0.01$) correlation with most PLFA markers and the bacterial cell numbers calculated from them. Catalase activity showed a similar trend to invertase, with the exception of sampling in autumn 2012. Dehydrogenase activity showed a significant positive correlation with the examined PLFA markers and the bacterial cell number calculated from them in case of the autumn 2012 and the two spring sampling. In most cases, phosphatase enzyme activity showed positive, significant relationship only with the activity of invertase and catalase enzymes ($P<0.01$).

Based on my results, the bacterial, G^+, G^-, and Aktinomyceta PLFA markers were significantly negatively, while the C18:2n6 fungal PLFA marker and the bacterial cell number calculated from the PLFA markers were significantly positively correlation with the annual amount of precipitation ($P<0.01$).

The influencing effect of temperature on microbial activity was observed in the studied sandy areas, according to which the soil respiration and invertase enzyme activity increased ($P<0.01$) with the increase of the annual average soil and air temperatures, however these correlated significantly negatively to the amount of bacterial biomass in the soil of lower part of slope study areas ($P<0.01$).

During the principal component analysis, bacterial, G^+, G^-, Aktinomyceta and total PLFA markers, and bacterial cell number calculated from PLFA markers were dominant parameters with significant factor weights, in contrast to traditional enzyme activity investigations. In the case of the graphical representation of the results, we can see to what extent the results differ according to the different selection factors (cultivation mode, micro-topography, year, season, and sampling area).

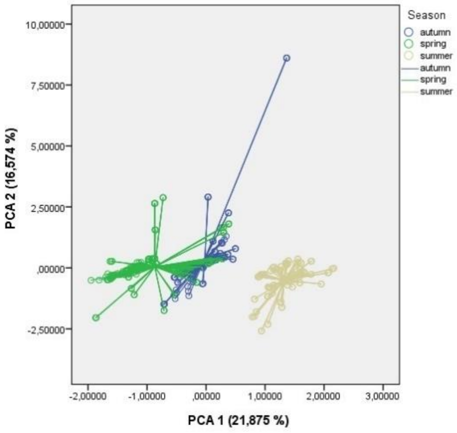

Figure 3: Seasonal distribution of results over the entire study period

Taking into account the whole study period, the results were less separate according to the cultivation method, while the results were markedly separate according to the topography, sampling depth, year and season. Furthermore, treating the results of the two sampling depths separately, the results of the different sampling areas were separate at each study time point, the most significant differences showed by the results of summer sampling. These results also support the need to interpret the investigation results in a complex system.

My results confirmed that micro-topographic exposure affects soil quality as well as microbial community activity and composition, and that meteorological parameters should be taking into account when interpreting microbial biomass activity data, as their changes affect the life processes of soil microorganisms, which can show different trends depending on local soil and climatic conditions compared to general observations.

3.2. New scientific results

1. I was the first who verified the effect of micro-topographic exposure to soil quality in the case of acidic sandy soils characteristic of Nyírség region. Most of the main chemical parameters were significantly separated for both farming methods, and the distribution of waterproof soil fractions in the conventional plot was significantly different between upper and lower part of slope at both sampling depths ($P<0.05$).

2. I was also the first who verified the effect of micro-topographical characteristics of Nyírség region to microbial activity (in the case of soil respiration, dehydrogenase, catalase and acidic phosphatase activity, $P<0.05$).

3. By PLFA analysis of the soil samples, I was the first who verified the influencing effect of micro-topographical exposure to the composition of the microbial community of acidic sandy soils in Nyírség region.

4. In my research, I was the first who verified the beneficial effect of ecological farming to the amount of water-resistant soil fractions, because in contrast to the conventional plot, there was no significant difference in the results of the areas with different micro-topographic exposure in the ecological plot.

5. In the course of my research, I was the first who verified the influencing effects of meteorological parameters to the activity and composition of the microbial community of acidic sandy soils in Nyírség region. Annual precipitation significantly correlated with soil respiration, enzyme activities, and PLFA results. The increase in soil and air temperature measured in the month of sampling and previous month had a significant negative effect on the amount of bacteria in the lower part of slope ($P<0.01$).

6. I confirmed the moderately close-close, positive, significant ($P<0.01$) relationship between the soil invertase and catalase activity as well as the phospholipid fatty acid markers extracted from the soil microorganism community and the bacterial cell number with statistical analysis.

4. CONCLUSIONS AND SUGGESTIONS

In addition to achieving the right yields, we must also strive to preserve and to improve it as much as possible the health and productivity of the soil. In a soil with gradually deteriorating productivity, the desired yields can be achieved in the long term only with significant additional costs, more time and labour input, and beyond one point they do not guarantee the achievement of the required yield. It is therefore inevitable to implement the sustainable management approach as widely as possible. Unfortunately, there are areas where, in addition to organic farming methods, efficient agricultural production is currently not possible (for example, due to climatic conditions, the large number of pests), but here we must strive for reasonable, well-thought-out farming, minimizing adverse effects as well.

In addition to the traditional soil chemistry, soil mechanics and microbial investigations, using the PLFA method I had the opportunity to monitor of the different phases of organic matter decomposition and the quality of the added organic matter (easily or difficult to decompose forms). Based on the obtained results, the results of PLFA investigations provide useful information for monitoring the degradation processes coordinated by the microbial community of the soil, in addition to observing the changes in the microbiological status of the studied soils.

Meteorological conditions often ignored in soil microbial community studies, despite the fact that microbial activity and the resulting decomposition of organic matter depend on the optimum values for themes of temperature and soil moisture, since microbes in the soil are so living organisms, which are extremely sensitive to changes in certain meteorological parameters.

The measurement results of the meteorological stations usually cover a larger area; however, the results I obtained show that even in the case of a level difference of a few meters, significant differences can be measured between the mechanical, chemical and microbial activity/community composition results of each sampling area.

It is no different the case for meteorological parameters either, but due to the significant cost of acquiring measuring stations, it is not typical to place more such station within a narrower area, for example in the upper and lower part of slope of the same plot. At the same time, in my opinion, we could gain valuable and instructive results from these observations.

Based on the results of the present doctoral dissertation and my practical experience, I formulated the following proposals in connection with the studies used to characterize the effectiveness of different landscape units and farming methods:

1. When designing the investigations, the aim should be to have as much usable data as possible about the given area, which should not be achieved with the large number of samples collected at one time, but with the minimum number of samples that are still representative of the examined area, and by extensive complex analysis of these samples. During the planning and implementation of the sampling, I also recommend taking into account the micro-topographic features of the given region (separation of upper and lower part of slope).
2. Enzyme activity assays include investigation of at least one extracellular and one intracellular soil enzyme (since the former are generally easier to measure, while intracellular enzymes are more sensitive and therefore provide a more accurate picture in time), taking into the potential disturbing effects of the soil matrix.
3. During the interpretation of microbial investigations, taking into account of changes in meteorological parameters, in particular air and soil temperatures and the amount and distribution of precipitation.
4. Among microbiological investigations, the supplementation of classical enzyme activity assays with PLFA and DNA/RNA-based molecular assays.
5. Development of a unified, standardized test protocol, from sampling design and execution to evaluation of results.

In addition to my suggestions above, I consider promising to install new meteorological stations, taking into account the micro-topographical features.

5. APPEARED PUBLICATIONS IN THE SUBJECT OF THE DISSERTATION

International, reviewed scientific publications

1. **Demeter I.**, Makádi M., Tomócsik A., Aranyos T. J., Michéli E., Posta K. (2018) Chemical and microbiological properties of Hungarian sandy soils under different management practices Applied Ecology And Environmental Research 16:3. 3473-3488. pp.
2. **Demeter I.,** Makádi M., Tomócsik A., Aranyos T. J., Posta K. (2016) Microbial community profiles in response to different soil managements in sandy soil. Agriculture And Forestry / Poljoprivreda I Sumarstvo 62:4. 11-17. pp.

National, reviewed scientific publications

1. **Demeter I.**, Makádi M., Aranyos T., Ferenczy A., Posta K. (2013): Az ökológiai és konvencionális művelés alá eső nyírségi talajok mikrobiológiai és talajkémiai vizsgálatai, Tájökológiai Lapok 11 (2): 311- 320.pp.

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