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Evaluation of biological activity of chernozems with the use of multivariate statistical analysis

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A b s t r a c t. In this study biological activity of soils was examined, and the results were interpreted with the use of multivariate statistical analysis – analysis of principal components. The material for the investigation consisted of 52 samples taken from humus levels of chernozems situated in Grzęda Sokalska region (south-east part of Poland). In the soils the activity of the following soil enzymes was marked: alkaline phosphatase, dehydrogenase, and catalase. Statistical analysis of principal components was used to separate one factor that comprised activities of the analysed soil enzymes. This method allowed to simultaneously explain nearly 87% of observed variability of these attributes. Calculating synthetic variable value for each analysed object and group them depending on their agricultural use. Also, the analysis of enzyme activity of chernozems was performed, depending on their geographical location – 4 'islands' where chernozems occurred in the area of Grzęda Sokalska were singled out and characterized.

K e y w o r d s: chernozems, principal components method, soil enzymes

INTRODUCTION

Chernozems are commonly treated as one of the best type of soils available for Polish agriculture. It is believed, that chernozems have a remarkable natural ability to self-reproduce, which can be seen in spontaneous regeneration of resources of substances that are indispensable for growth of plants cultivated in these soils.

High intensity of agriculture in the areas where chernozems are situated can be seen in significant simplifications in the structure of agroecosystems. This leads directly to a decrease in regeneration capabilities as well as regulation capabilities of soil environment. A consequence of such changes is a decrease of natural capabilities to store nutrients in the system, and in agricultural practice it leads to a break-down of high yield of agricultural plants which is obtained presently.

In the enzymatic studies of soil the tendency is to recognize such enzymes which activity may be used as a marker-indicator of soil fertility (Dick, 1994). For many years enzymatic tests have been treated as one of the most sensitive indicators of system functioning (Ryszkowski, 1992). For this reason there is a necessity to analyse tests and treat them as an 'alarm' warning against negative changes taking place in soil environment. The causes of such situation may be natural factors, as well as anthropogenic factors (meteorological conditions, system ant technology of growth, fertilization) (Koper *et al*., 1999; Koper and Piotrowska, 1999).

So far such studies have been carried out by analysis of separate, individually treated enzymes. Therefore, these studies do not reveal the real image of soil processes – their mutual activity and interaction of different factors.

The aim of this study is to use multivariate statistical analysis – principal component analysis to separate a factor (component) constituting a proper indicator of evaluation of biological activity of soils.

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MATERIAL AND METHODS

The study was carried out in the areas where chernozems occur in Grzęda Sokalska – a part of West-Wołyń Highland, situated within the borders of Poland. Chernozems in this area did not constitute a uniform surface, and occurred as an island form among brown soils. In total 52 samples were taken from humus level of chernozems that were in different use. The amount of samples that were taken depended on the way in which chernozems were used and the area where they were situated. The samples were taken proportionally to the surface occupied by chernozems in a given area, applying the same rules in the case of all uses of soil – arable fields, meadows, and forests.

Soils were taken in the summer, according to the rules of Polish norm PN-ISO 1998. In the soil samples activities of phosphatase (Kucharski, 1997), urease (Nowak, 1983), and proteases (Kaliszewska-Rokicka, 2001) were marked.

Principal component analysis is a statistical multivariate method (Krzyśko, 2000; Morrison, 1990; Narayan and Giri, 1996). It is basic aim is to reduce a set of variables that describe a given phenomenon or process, allowing for as small loss of information as possible. This method is based on orthogonal transformation of p-dimensional set of variables describing multivariate observation into a new set of variables that are not correlated, the so called principal components. Principal components account for the total variance of initial variables, consecutive principal components account for smaller and smaller percent of initial variables.

Quantitative results of the investigated enzymes were analysed statistically with the use of Statistica packet Pl 6. The data obtained were used for principal component analysis. The method that was applied enabled to separate one component that determined activity of all three soil enzymes. On basis of the obtained data contribution of each component to account for the total variation of attributes was estimated (Kamińska *et al*., 2007).

RESULTS AND DISCUSSION

Quantitative characteristics of all enzymes were determined, as well as correlation coefficients between them. Of all the investigated enzymes the lowest value of variability coefficient was obtained for phosphatase (28.24%), whereas the remaining two enzymes showed high variability (dehydrogenase = 52.29%, catalase = 46.27%). Significant correlations between the investigated attributes were observed at level.

It was observed, that 86.27% of total variability of three separate attributes can be accounted for by one principal component Z_1 (Table 1). This principal component was useful because, according to Kaiser's criterion, its own value exceeded 1. Two remaining components Z_2 and Z_3 together account for almost 14% of the variability.

The quotation was defined for principal component Z_1:

$$Z_1 = 0.592X_1 + 0.563X_2 + 0.577\,X_3. \qquad (1)$$

Component Z_1 was strongly bound with all three attributes, values of correlation coefficients exceeded 0.9, which proves equally large contribution of all 3 attributes to building up this factor.

Using values Z_1 reaches for all objects, they were order according to decreasing values of generated indicator. Calculating variable Z_1 for each of the analysed objects allowed to order them according to biological activity of the investigated soils.

From the obtained indicators Z_1 four groups (A,B,C,D) were separated according to the values within the range from -0.1 to +4. There was a natural division among the analysed results on groups with separated values of this indicator.

The highest values of the indicators (from +2 to +4) was in samples taken from lowest quality chernozems treated as medium-quality meadows and pastures, or situated near forests. They constitute 84% of the group and belong mainly to complex II of grasslands (medium), and chernozems in the vicinity of forests.

A small contribution to this group had the samples from arable soils that belong only to complex II of arable soils (worse).

On the opposite end there were groups within the range of the indicator from -1 to 1 (group C), and from -1 to - 0.1 (group D). In the case of group III 84% of the samples included samples taken in arable soils of complex I of arable soils, and some samples from complex II of arable soils. In the case of group IV 87% of the samples were taken in cultivated soils, mainly complex I.

Quite ambiguous with respect to indicator Z_1 was group B. Values within the range from +1 to +2 was observed in equal percent in arable soils and near meadows. Values of the indicator Z_1 from this group were also observed in 3 out of 6 samples taken in forest soils.

The way the soils were used (soil management) had a clear influence on the value of the indicator Z_1. In group A – at high positive indicator Z_1 was dominated mainly by samples taken in relatively worst usability soil complexes, namely: complex II – grasslands in which human influence on soil environment was limited. In the case of groups C and D, at negative values of Z_1, their composition was dominated by arable soils from the best complex I (61%) which is used most intensely by human.

In the Table 2 results of the analysis are given according to obtained values of the indicator Z_1, with regard to geographical situation of chernozems in Grzęda Sokalska. In this way, four surfaces named after the nearby village were separated in the investigated area.

Table 1. Values of indicator Z_1 in number of samples, depending on complex of agricultural suitability of the soils and the way the soils were used

Place	Soil group (A-D) depending on value of indicator Z_1			
	A (4 – 2)	B (2 – 1)	C (1 – -0.1)	D (-0.1 – -1)
	Number of samples (% in group)			
Arable complex I	-	1 (9%)	10 (62%)	7 (63%)
Arable complex II	2 (16%)	4 (36%)	5 (26%)	3 (27%)
Meadow complex I	-	1 (9%)	1 (6%)	1 (10%)
Meadow complex II	8 (61%)	3 (27%)	-	-
Forest	3 (23%)	2 (19%)	1 (6%)	-
Samples in total	13	11	17	11

Table 2. Mean value of the indicator Z_1 depending on geographical situation of the chernozem-spot where the samples were taken from, with regard to natural quality and the way the soils were used

Place	Spots			
	Dołhobyczów	Poturzyn	Telatyn	Ulhówek
Arable complex I	-0.816	-1.344	- 1.029	-0.390
Arable complex II	-0.234	-0.039	-0.374	-0.625
Meadow complex I	-	-	-	-0.160
Meadow complex II	+2.378	+2.341	+2.588	+4.359
Forest	+1.741	-	+3.029	-
Algebraic difference in value	+3.070	+0. 960	+4.220	+3.500

In these areas the ways the soil is used, as well as soil quality (according to complexes of agricultural usability of soil) were determined. Values given in the table are arithmetical means of the indicators. The data clearly reveals, that in the investigated groups the mean value of the indicator Z_1 for the soil that is under human influence had negative values. Interpretation of the mark '-' at the values of the indicator Z_1 proves that these data are in accordance with the statement found in literature that intense cultivation causes a decrease in the number of enzymes in soil and limits their influence on soil. In the case of soils that are not cultivated – especially soils near meadows showed positive values of the indicator Z_1.

The quoted data allow to show that at least when quantity and quality of the influence of enzymes in soil environment are taken into consideration, individual patches of chernozems were different from one another. These differences are noticeable in spite of close vicinity of the investigated areas. Therefore, it can be claimed that these areas are equally influenced by environmental factors which are not connected with human activity. For this reason, it seems that quality and quantity of enzymes activity in soil environment is a result of differences that can be put down to either local agricultural condition or intensity of agricultural activity. Moreover, the knowledge of the local agriculture allows to put forward a statement that agricultural condition in these areas is at similar level. Because of that, the main cause for variation of the indicator should be attributed to intensity of agricultural production. On such basis, is can be claimed that chernozems situated near Telatyn are more similar to natural soil environment. However, it should be noted that such average evaluation of the analysed area was influenced by limited presence of soil environments that were close to natural, namely grasslands and forests. The area most affected by anthropogenic changes in soil environment, based on assessment of quantity and activity of enzymes, was the area near Poturzyn. This area had no forests, and showed little presence of chernozems only in grasslands. The area occupied by chernozems around Poturzyn included mainly arable soils belonging to complex I of agricultural usability.

The results of the above statistical analysis also prove that the present condition of soil environment of chernozems in arable fields is significantly different from chernozems from natural grasslands or sparse forests found there, as far as quantity and activity of enzymes are concerned.

Modern methods of statistical studies can be used in soil science. This results from the fact, that soil science studies often involve analysis of numerous properties such as, for instance quantitative analysis of some soil enzymes implemented into this study. Such analysis have been carried out so far and dealt with quantity and influences of each of the elements individually. This contradicts the basic fact that activities of enzymes take place in one soil environment, thus there are interactions both boosting and weakening individual effects.

Application of the suggested method of statistical analysis of the results that were obtained allowed for much greater possibilities of drawing conclusions from these results. The studies of enzymes as a biological indicator of soil environment of chernozems proved that chernozems differ in biological properties, not only in macro scale of areas they occur in Poland, for example: Hrubieszów chernozems, Tomaszów chernozems, of Przemyśl chernozems. When more sensitive and less conventional diagnostic methods are applied, it can be shown that chernozems also differ in geographical micro-scale. An example of this are diversified conditions of biological environment of chernozems situated in Grzęda Sokalska. The study that was carried out proves earlier conclusions concerning diversity of activity and quantity of enzymes in soil, depending on the way the soil is used. In this study, chernozems that were most intensely used for agricultural purposes, and belonged to complex I (the best) of agricultural usability showed negative values of the indicator Z_1. This proves limited quantity and activity of enzymes in such environment. However, chernozems that were more similar to natural environment, near meadows and forests, showed positive values of this indicator – up to +4 units.

From methodological point of view, it seems purposeful to eliminate seemingly natural division of groups into II and III. This way, two categories of soils will be left, one which is more similar to natural biological properties of soil environment and is marked as '+', and the other which artificial and anthropopressed – marked as '-'. This study doesn't clearly state whether numeric values attributed to the indicator Z_1 with the correct mark (+/-) can serve as quantitative characteristic of environment, as far as natural condition of environment or anthropogenic changes taking place in environment are concerned.

CONCLUSIONS

1. Multivariate statistical analysis of principal components that was suggested, can be used in soil science studies, especially for analysis of many factors, including studies on soil enzymes.

2. The study that was carried out prove the fact that biological environment of chernozems, as far as soil enzyme activity is concerned, differs in properties, not only when geographical distances of the areas chernozems occur are taken into consideration, but also in small scale in the closest spots of chernozems.

3. Enzymatic properties of chernozems are significantly influenced by the way the soil is used and intensity of agricultural production. In the case of strong anthropopression the indicator (principal component Z_1) takes negative values, and in the case of more natural environment – positive.

4. This study does not estimate how much numeric values of the implemented indicator allow to assess the degree of anthropogenisation or naturalness of the investigated chernozem environments.

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