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DEHYDROGENASE ACTIVITY OF SOME HUNGARIAN SOILS AS RELATED TO THEIR WATER AND AERATION STATUS

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A b s t r a c t. Four horizons (till the depth of 130 cm) of six typical Hungarian soil profiles (Fluvic Gleysol, Vertic Gleysol and Orthic Solonetz) were investigated in order to determine relation between dehydrogenase activity, oxygen diffusion rate (ODR), redox potential (*Eh*) as well as Fe^{+2} content and the soil water status, and to relate them to the soil utilisation and cultivation type. The experiments were performed with the use of undisturbed soil samples preincubated on the water tension plates at 0, 63, 159 and 500 hPa at room temperature.

All the investigated parameters varied widely in the tested soils. Dehydrogenase activity and reduced iron content decreased but ODR and *Eh* values increased with increasing soil water tension. A close relationship between oxygenation indicators (ODR, *Eh* and Fe^{+2}) and dehydrogenase activity was found. The most sensitive oxygenation parameter for describing the relationship between enzyme activity and soil aeration status appeared to be ODR.

The studied soils showed a significant decrease of *Eh* as well as tendency to diminish their ODR, dehydrogenase activity and reduced iron content due to deep-loosening cultivation.

K e y w o r d s: soil aeration, dehydrogenase activity, ODR, *Eh*, reduced iron

INTRODUCTION

Knowledge on the soil enzymatic activity is important as it indicates soil potential to perform basic biochemical processes necessary for maintaining its fertility [8]. Recognition of the effect of the soil aeration status on the enzymatic activity is essential for the understanding of nutrient transformations in the soil. Soil dehydrogenase activity is often used as a biochemical indicator of the biological activity in the soil environment [3]. Endocellular dehydrogenases are the key enzymes in the oxidation of the soil organic matter.

Soil air-water conditions are very important for regulation of the activity of soil microorganisms as they are decisive for the type of soil metabolism. Only few studies on the biochemical aspects of the soils exposed to the controlled water content are available [2,6,13,14,21].

The aim of the present study was to investigate dehydrogenase activity as a function of such oxygenation parameters as oxygen diffusion rate (ODR), redox potential (*Eh*), and reduced iron (Fe^{+2}) content in the undisturbed soil samples (cores) taken from 24 soil horizons of six Hungarian profiles representing three soil types (Fluvic Gleysol, Vertic Gleysol and Orthic Solonetz), and different systems of cultivation. The measurements were performed at differentiated soil water tensions after preincubation of the cores on the water tension plates.

MATERIALS AND METHODS

Soils

The measurements were performed with the use of soils from the central part of the Great Hungarian Plain in the Transtisza Region of Hungary. The investigated area is one of the lowlands of the Carpathian Basin. The investigated sites are situated within the natural geographical region of Nagykunság (Great Kúnság). The profiles selected for the investigation represent three soil units characterized as Fluvic Gleysol, Vertic Gleysol and Ortic Solonetz. The sampling procedure was completed in late autumn1991. Each soil unit was represented by two profiles differing in their cultivation system as follows [20]:

A-1: Abádszalók: Fluvic Gleysol, cultivated, 25-30 cm ploughing yearly; 80 cm deep-loosening every 4th year. Last loosening prior to sampling in 1983.

A-2: Abádszalók: Fluvic Gleysol, non-cultivated in the last 10 years prior to sampling. Both sampling sites are drained by a subsurface drainage system of 90 cm depth and 25 m spacing.

K-1: Kisújszállás: Vertic Gleysol, 25-30 cm normal ploughing yearly.

K-2: Kisújszállás: Vertic Gleysol, 25-30 cm normal ploughing yearly and 60 cm deep loosening every 4th year. Last deep loosening prior to sampling was performed in 1990.

P-1: Karcagpuszta: Orthic Solonetz, non-cultivated, without any profile modification under natural grass vegetation.

P-2: Karcagpuszta: Orthic Solonetz, 15-20 cm chiseling/discing yearly, 60 cm deep-loosening every 4th year. Last deep loosening prior to sampling was performed in 1987. Subsurface drainage at the depth of 100 cm with 25 m spacing.

Their basic properties are presented in Table 1 and full descriptions and characteristics - in the paper of Gliński [10] and Rajkai *et al*. [20].

Measurement methods

Undisturbed soil samples in 100 cm^3 brass cylinders (diameter 5 cm and height 5 cm) were collected in late autumn, 1991 and then transported to Lublin in January 92. The measurements of all the above mentioned parameters were taken after preincubation at the following soil water tensions: 0 hPa (capillary saturation for 7 days for the two heaviest profiles from Abadszalok, and for 2 days for the other profiles), 63 hPa (pF 1.8), 159 hPa (pF 2.2) and 500 hPa (pF 2.7).

Three undisturbed soil samples from each horizon, after capillary saturation, were subjected to the measurements and then they were equilibrated with the tension of 63 hPa on a kaolin tension plate for about 2 weeks. After taking the entire set of measurements at the above water tension, the samples were equilibrated with the next water tension. This procedure was repeated with successive tensions until the tension of 500 hPa. Each time after moisture equilibrium was reached, the aeration parameters, i.e., ODR and *Eh* were determined and the content of Fe^{+2}, as well as the activity of dehydrogenases were assayed.

The ODR method consists in the amperometric measurement of the electric current intensity corresponding to the oxygen reduction on a platinum cathode placed in the soil and negatively polarized with respect to the reference electrode. The indicator is a measure of potential oxygen availability for plant roots. For the ODR measurement, a device described by Malicki and Walczak [16], with an automatic control of the effective reduction voltage was used. Four platinum wire electrodes (0.5x4 mm) were placed at the depth of 2 cm and polarized to -0.65 V versus saturated calomel electrode for 4 min. The principle of the method has been described in detail by Gliński and Stępniewski [15].

The *Eh* of the soil samples was measured potentiometrically using four Pt electrodes (of the same type as for ODR), saturated calomel electrode as a reference, and a laboratory pH meter (Radiometer, Kopenhagen) [15]. The

T a b l e 1. Basic soil characteristics

Profile	Horizon (cm)	Particle size distribution			Bulk density (Mg m^{-3})	pH		O.M. %
		Sand (2000-50 μm)	Silt (50-2 μm)	Clay (<2 μm)		H_2O	KCl	
Abádszalók-plough cultivated and deep-loosened (A-1)	A (0-20)	15.6	36.6	47.8	1.2	5.9	4.8	3.3
	B (21-60)	13.9	32.3	53.8	1.3	6.3	5.1	1.6
	BC (61-80)	17.6	29.8	52.6	1.4	6.7	5.4	0.8
	C (81-120)	43.6	24.6	31.8	1.5	7.2	6.1	n.t.
Abádszalók-uncultivated (A-2)A	A (0-20)	13.7	33.9	52.4	1.2	6.2	5.2	2.5
	B (21-60)	11.7	31.7	56.6	1.3	6.4	5.2	1.3
	BC (61-80)	19.2	28.2	52.6	1.5	6.7	5.5	1.0
	C (81-120)	41.9	23.7	34.4	1.4	6.9	6.0	n.t.
Kisújszállás-plough cultivated (K-1)	A (0-30)	18.6	35.4	46.0	1.3	6.4	5.8	3.2
	B (31-50)	15.8	32.6	51.6	1.4	6.6	5.8	1.9
	BC	13.2	30.8	56.0	1.5	7.3	6.3	0.07
	(51-110)	11.2	45.4	43.4	1.5	7.4	7.0	n.t.
	C (91-110)							
Kisújszállás- plough cultivated and deep-loosened (K-2)	A (0-30)	20.2	35.2	44.6	1.3	6.4	5.8	3.2
	B (31-50)	12.2	42.8	45.0	1.4	7.5	6.7	0.3
	BC (51-80)	10.6	47.6	41.8	1.5	7.7	7.1	0.5
	C (81-130)	28.2	25.8	46.0	1.5	6.7	5.7	n.t.
Karcagpuszta-uncultivated with natural vegetation (P-1)	A (0-20)	24.2	34.0	41.8	1.4	7.4	6.9	1.5
	B (21-40)	13.4	35.2	51.4	1.6	9.0	7.4	0.6
	BC (41-70)	16.0	32.2	51.8	1.6	8.1	6.9	1.2
	C (71-85)	5.4	52.4	42.2	1.6	9.0	7.8	n.t.
Karcagpuszta-cultivated, deep-loosened, chiseling/discing (P-2)	A (0-20)	20.8	34.0	45.2	1.4	7.8	6.9	1.4
	B (21-50)	14.0	29.2	56.8	1.5	8.4	7.1	0.5
	BC (51-70)	12.4	33.2	54.4	1.5	8.7	7.5	0.4
	C (71-95)	11.4	49.2	39.4	1.6	9.0	8.0	n.t.

O.M. – organic matter, n.t. – not tested.

electrodes were placed at the soil depth of 2 cm. The measurements were taken after stabilization of the readings which usually did not exceed 5 min.

The Fe^{+2} content was determined in the extract of 0.05 M H_2SO_4 (2.5 g of the wet soil plus 25 ml of the sulphuric acid solution, shaken for 5 min) with the use of α, α'-dipyridyl in acetate buffer solution of pH 4.5 [1].

Dehydrogenase activity was measured for triplicate samples by the TTC method (2,3,5 -triphenyltetrazolium chloride) reduction to formazan during incubation for 20 h at 30 ^{o}C, at pH = 8.2, according to the procedure of Casida *et al*. [4].

All the analytical results were calculated on the basis of the oven-dry (105 ^{o}C) soil mass.

Statistical analysis

The multifactor analysis of variance and regression analyses were used in the statistical data processing. A linear model (y=a+bx) was used for the description of dehydrogenase activity versus *Eh*, and Fe^{+2} content, while an exponential model ($y=e^{a+bx}$) was the best for the relation against ODR.

RESULTS AND DISCUSSION

The preincubation of the soil material under different, controlled water conditions differentiated physical, physicochemical and biochemical parameters of the investigated soils.

Dehydrogenase activity (Fig. 1) varied widely in the tested soils from 0.00086 to 0.014 nmol formazan g^{-1} min^{-1}. Apart from the soil horizon, the activity was the highest in all the water-saturated soils with the exception of K-2 profile. The highest activity at this water tension was found in the A horizon of the A-1 and P-1 profiles, and in the BC horizons of the A-2, K-1 and P-2 profiles. In general, dehydrogenase activity decreased with the increase of the soil water tension.

Comparison of four soil horizons (down to 130 cm) with respect to their dehydrogenase activity showed that the surface (A) horizons were most biologically active only in the cases of two (A-1 and P-1) profiles. Unusually high dehydrogenase activities showed BC horizons, especially in the cases of the A-2, K-1 and P-2 profiles. Dehydrogenase activity did not decrease distinctly with depth, neither in cultivated nor in uncultivated soil profiles.

Horizons of all the soil profiles showed an increase of ODR (Fig. 2) with soil water tension from 0 to 500 hPa. The highest value (64 g μm^{-2} s^{-1}) was found in the C horizon of A-1 and the lowest (0.5 μg $m^{-2}s^{-1}$) in the A horizon of the P-2 profile.

The *Eh* values (Fig. 3) ranged from 68 mV (in K-2) to 551 mV (in A-2) with the lowest values at 0 hPa. Redox potential in all the horizons of A-1, A-2 and K-1 was not too much differentiated in comparison to other three profiles K-2, P-1 and P-2, and preincubated for 7 days even at full saturation exceeded decidedly 400 mV value.

Concentration of Fe^{+2} in the examined soil horizons is shown in Fig. 4. Abadszalok profiles (A-1 and A-2) were characterised by much higher Fe^{+2} concentration than four other profiles (K-1, K-2, P-1, P-2) nearly at all water suction levels. The nalysed profiles showed a decrease of the Fe^{+2} content with an increase of soil water tension in most of their horizons.

The influence of soil water tension on aeration parameters presented in the form of the analysis of variance in Fig. 5 showed that a decrease of water content (following its changes from 0 to 500 hPa) caused a significant ($p<0.001$) decrease of dehydrogenase activity (Fig. 5a). The range of the average values (from all the soils and horizons) of this activity, was from 0.00686 nmol formazan $g^{-1}min^{-1}$ (for 0 hPa) to 0.00203 nmol formazan $g^{-1}min^{-1}$ (for 500 hPa). The phenomenon of the increase of dehydrogenase activity under saturation with water can be considered as typical for mineral soils, as it was observed earlier by Chendrayan *et al*. [7], Okazaki *et al.* [17], Gliński *et al.* [13,14] and recently by Brzezińska *et al*. [2].

The parameter of oxygen availability in the soil - ODR (Fig. 5b) showed a typical tendency for changes under differentiated air-water conditions [15]. The average ODR value was

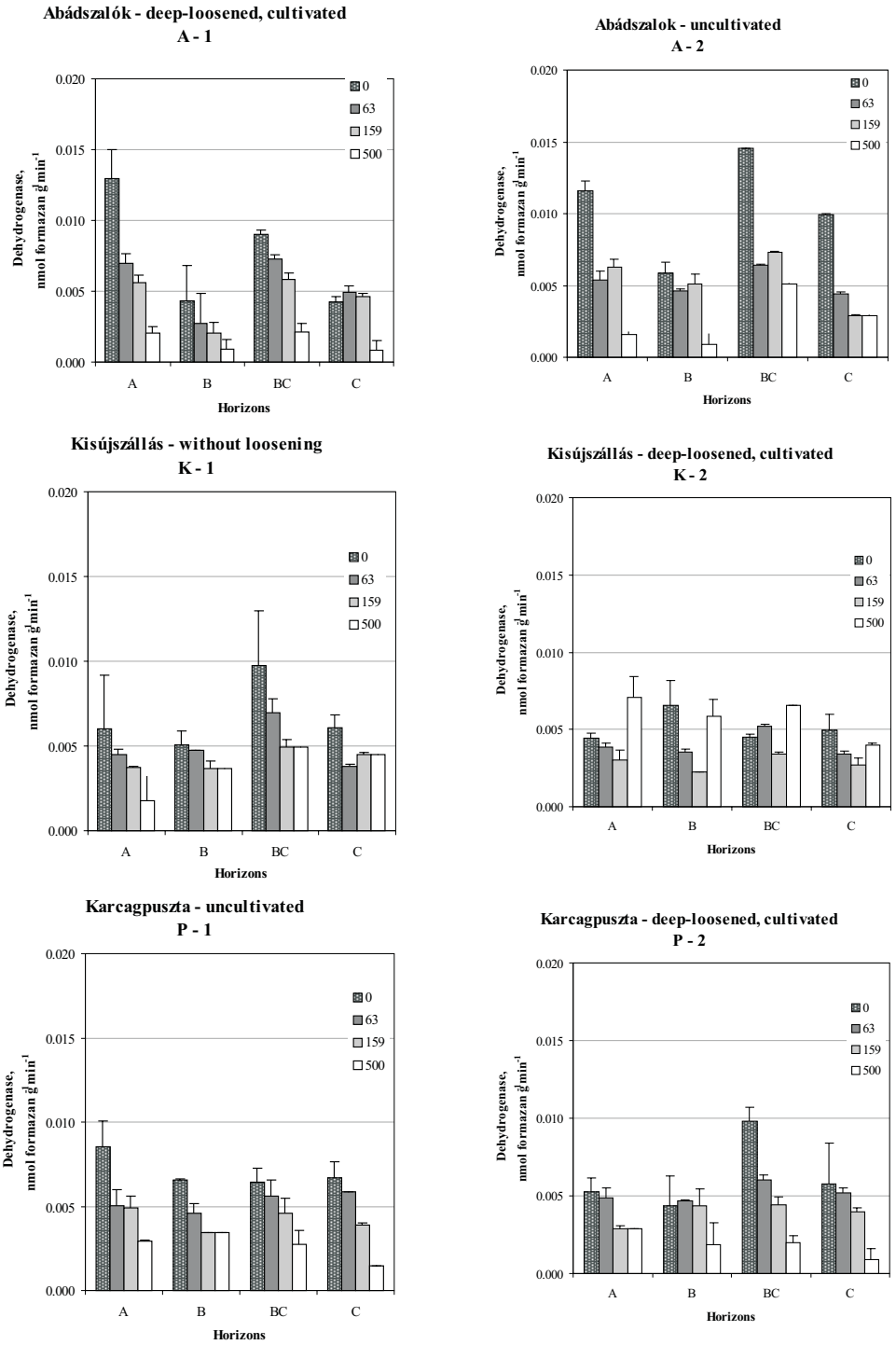

Fig. 1. Dehydrogenase activity for individual soil horizons of the profiles at different soil water tension levels (average values and standard deviations).

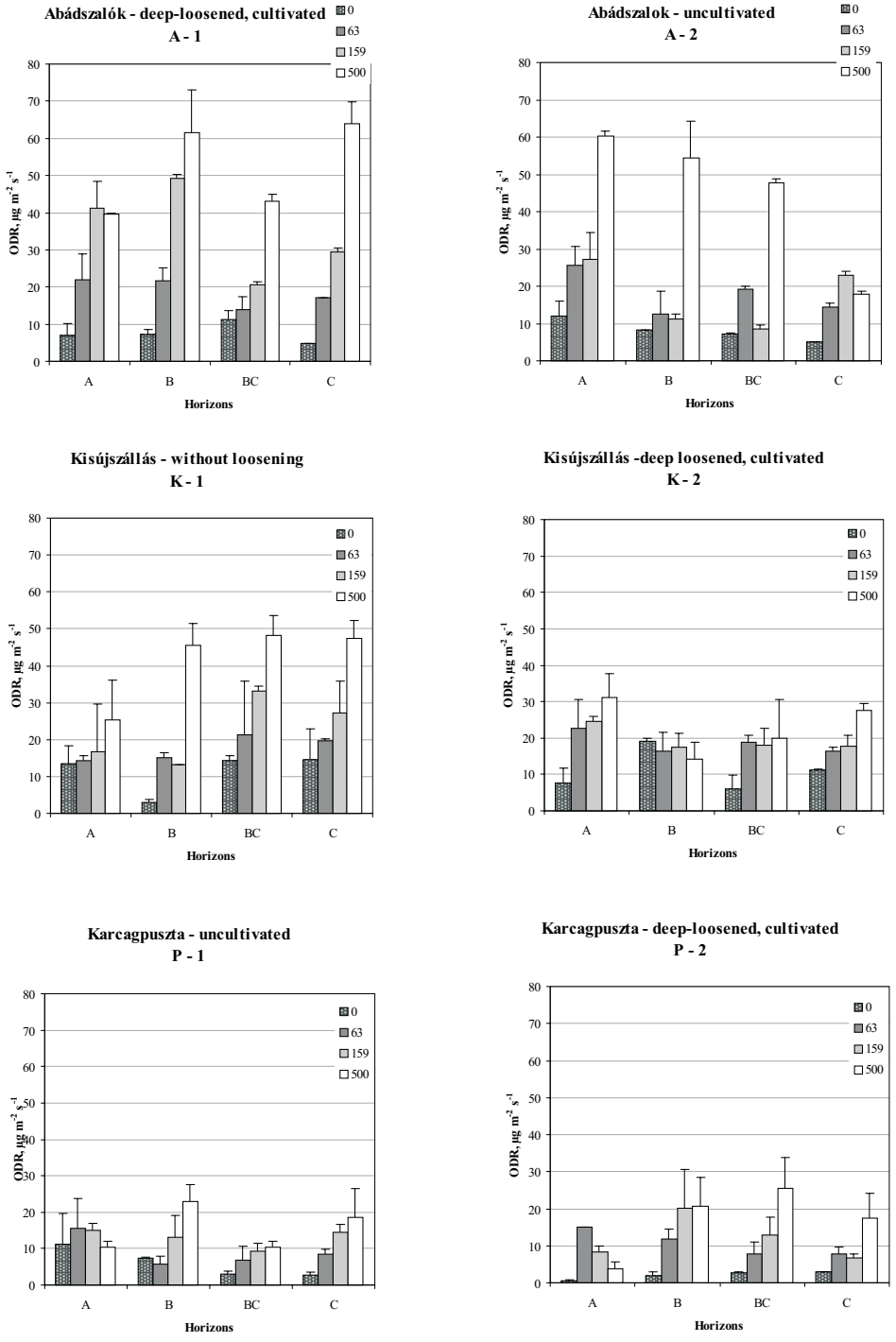

Fig. 2. Values of ODR for individual soil horizons at different soil water tension levels (average values and standard deviations).

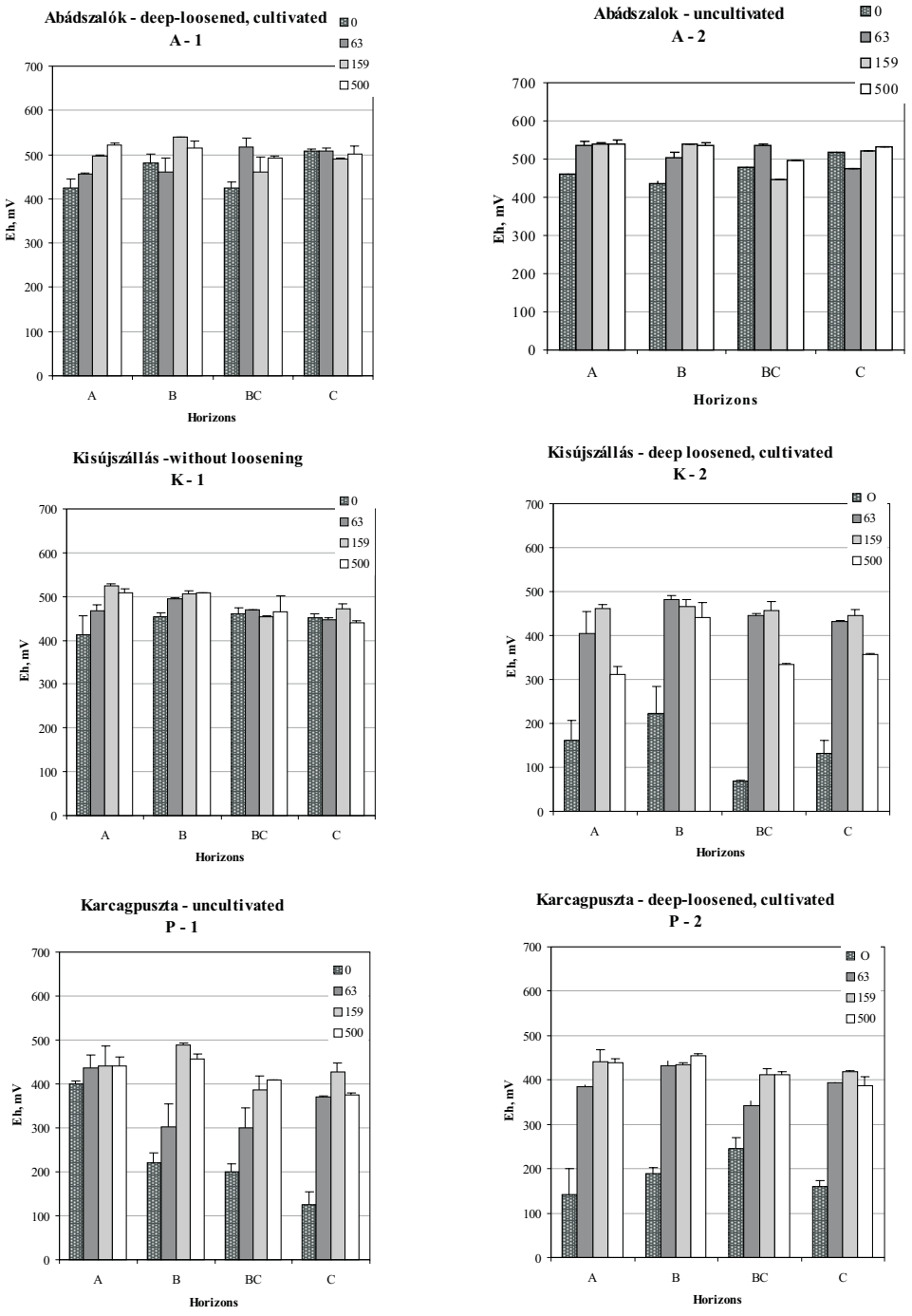

Fig. 3. Values of *Eh* for individual soil horizons at different soil water tension levels (average values and standard deviations).

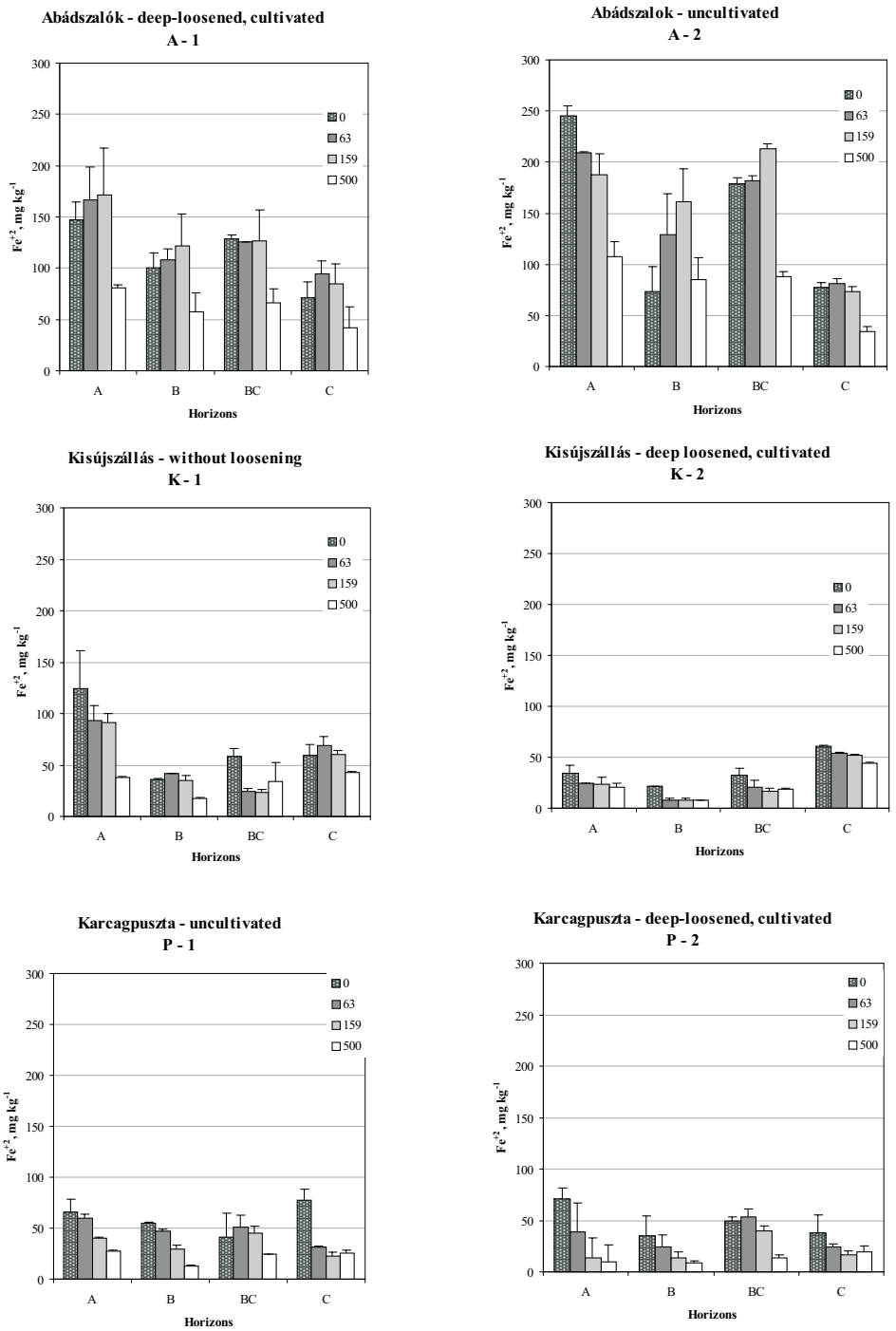

Fig. 4. Fe^{+2} content for individual soil horizons at different soil water tension levels (average values and standard deviations).

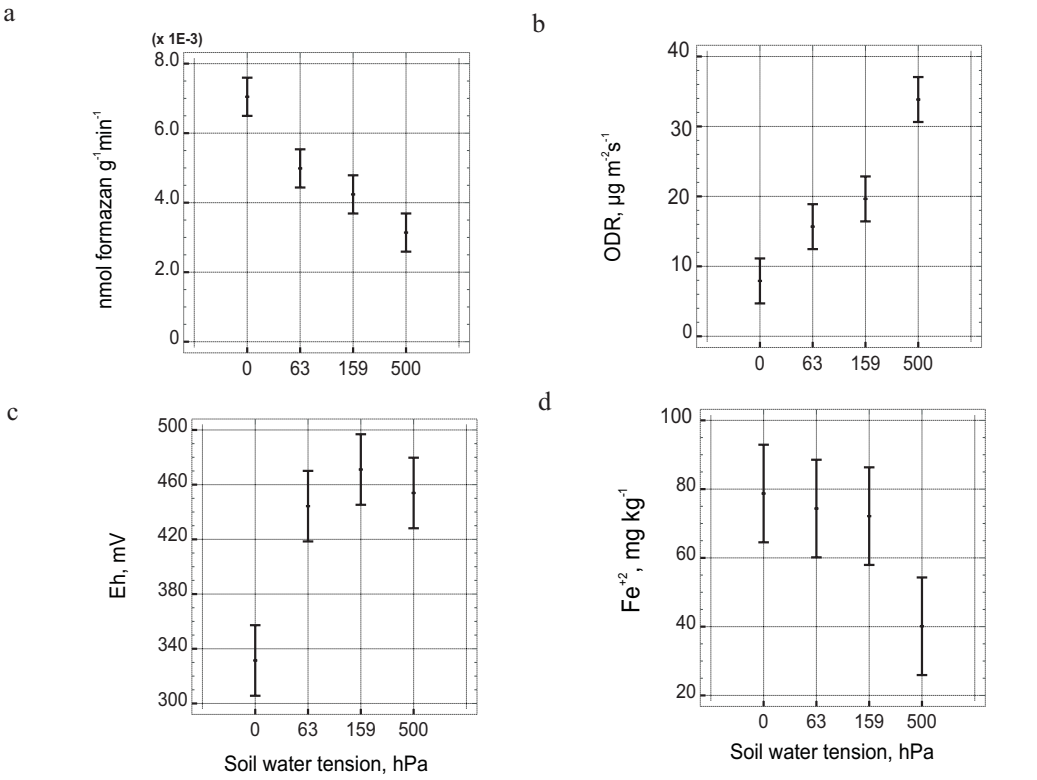

Fig. 5. Dehydrogenase activity (a), ODR (b), *Eh* (c) and Fe^{+2} (d) at individual soil water tension levels (average values of all the horizons of all the six soil profiles). The bars represent LSD at p=0.05.

8.0 µg m^{-2} s^{-1} at 0 hPa and increased to 34 µg m^{-2} s^{-1} at 500 hPa. The critical ODR value which is usually considered to be below 35 µg m^{-2} s^{-1} [15,22,23], occurred in all the studied horizons at 0 and 63 hPa. The Karcagpuszta profiles (P-1 and P-2) and the K-2 profile showed such low ODR values in all the horizons under investigation even at 500 hPa (see Fig. 2). Thus, the favourable values of ODR for the cultivated plants occurred at 159 hPa only in two (A and B) horizons of the A-1 profile and at 500 hPa also in the two deeper horizons of this profile, as well as in three first horizons of A-2 and in deeper horizons of K-1 (except for the A horizon). The most distinct ODR differentiation is visible in the Kisújszállás profiles, where the K-1 profile showed higher ODR values in the B and deeper horizons.

The average *Eh* values ranged from 330 mV at 0 hPa to 470 mV at 500 hPa (Fig. 5c). The most pronounced change ($p<0.001$) occurred in the soils preincubated at 0 and 63 hPa. A relatively small increase of the *Eh* values was observed at the soil water tensions >63 hPa. High redox potential of the three profiles (A-1, A-2 and K-1) at low water tensions (see Fig. 3) suggests a high redox buffering capacity (t_{300}) of these soils. Gliński and Stępniewska [12] defined the index t_{300} as the time needed to lower soil redox potential under flood conditions at a fixed temperature to the level of 300 mV. The above authors found out that some alluvial soils needed more than 15 days of flooding conditions in room temperature to reduce their soil *Eh* below 300 mV. In our experiment, however, Abadszalok alluvial profiles were saturated only for 7 days and that time was not sufficient to lower their *Eh* below 400 mV.

A supplementary indicator of soil oxygenation status is the content of reduced iron (Fe^{+2}).

Figure 5d illustrates average concentrations of Fe^{+2} against soil water tension. This parameter showed a slight decline with an increase of the soil water tension in the range of 0-159 hPa and a significant decrease at 500 hPa ($p<0.001$). Abadszalok profiles, as it was mentioned above (see Fig. 4), created more Fe^{+2} in comparison to other soils. Simultaneously, the A-1 and A-2 profiles maintained their *Eh* above 400 mV, confirming that the presence of reducible iron induced high redox buffering capacity which protects soil against a rapid decrease of *Eh* and mobilisation of more toxic ions, e.g., sulphides [11,19].

Relationships between soil oxygenation indicators and dehydrogenase activity are presented in Figs 6-8. Correlation was negative for ODR and *Eh* (Figs 6 and 7) and positive in the

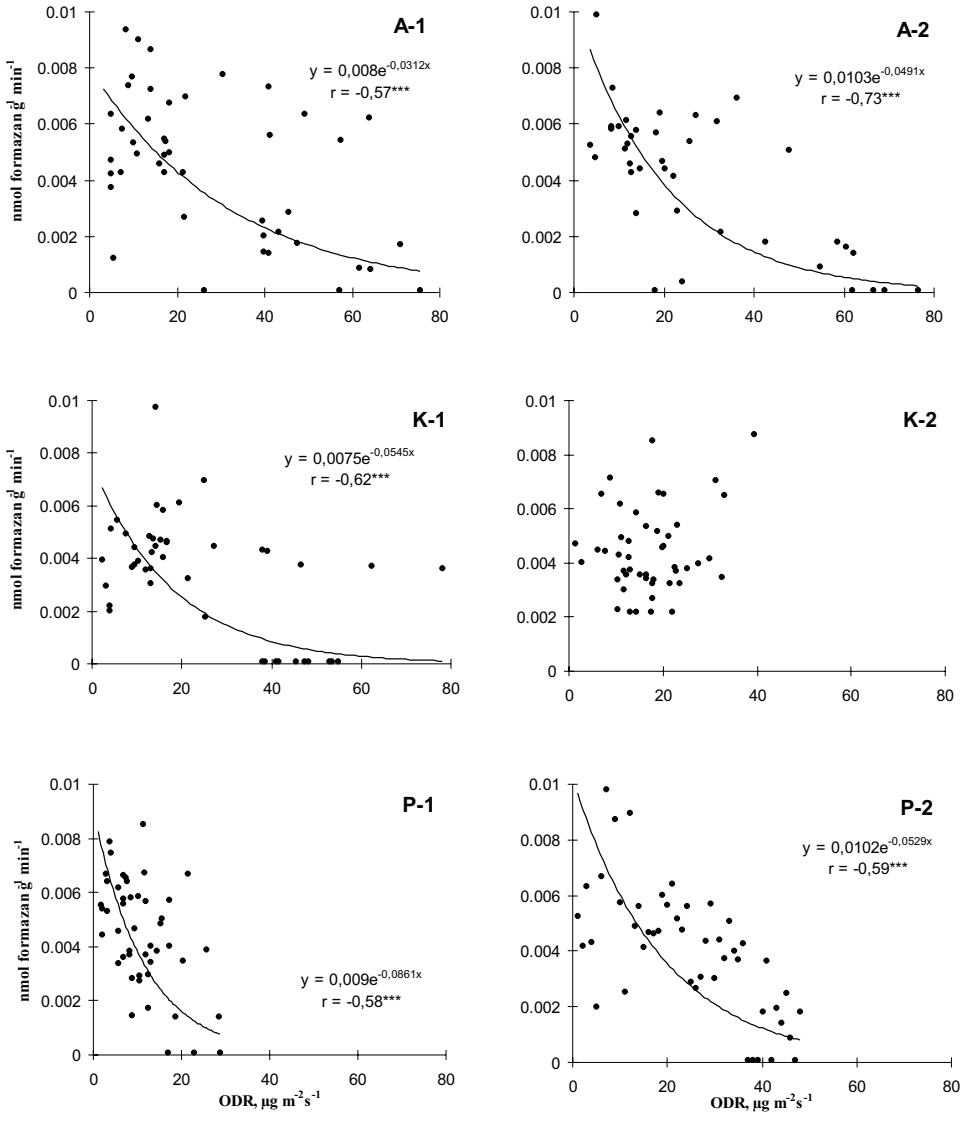

Fig. 6. Relation between ODR and dehydrogenase activity for individual soil profiles (all the horizons for each profile were treated jointly). The lines represent the best exponential fit described by the equation in the case where the correlation was significant.

case of the Fe^{+2} ions (Fig. 8). This confirms the results of Gliński *et al.* [13,14], Stępniewska *et al*. [21], Brzezińska *et al.* [2]. All the profiles exhibited a similar course for the discussed relationships with the exception of the K-2 profile, where very low or any correlation was found. Among the investigated profiles, dehydrogenase activity of the A-2, K-1 and P-2 soil profiles showed the best correlation with ODR (r= -0.73***, -0.62*** and -0.59***, respectively), that of K-2 – with Eh (-0.42**) and that of the P-1 and A-1 profiles – with Fe^{+2} (0.78*** and 0.64***, respectively). The relationship between dehydrogenase activity and oxygenation indicators, when analysed for all the data, showed r=-0.52***, r=-0.27*** and r=0.41*** for ODR, Eh and Fe^{+2}, respectively, and were significant at $p<0.001$.

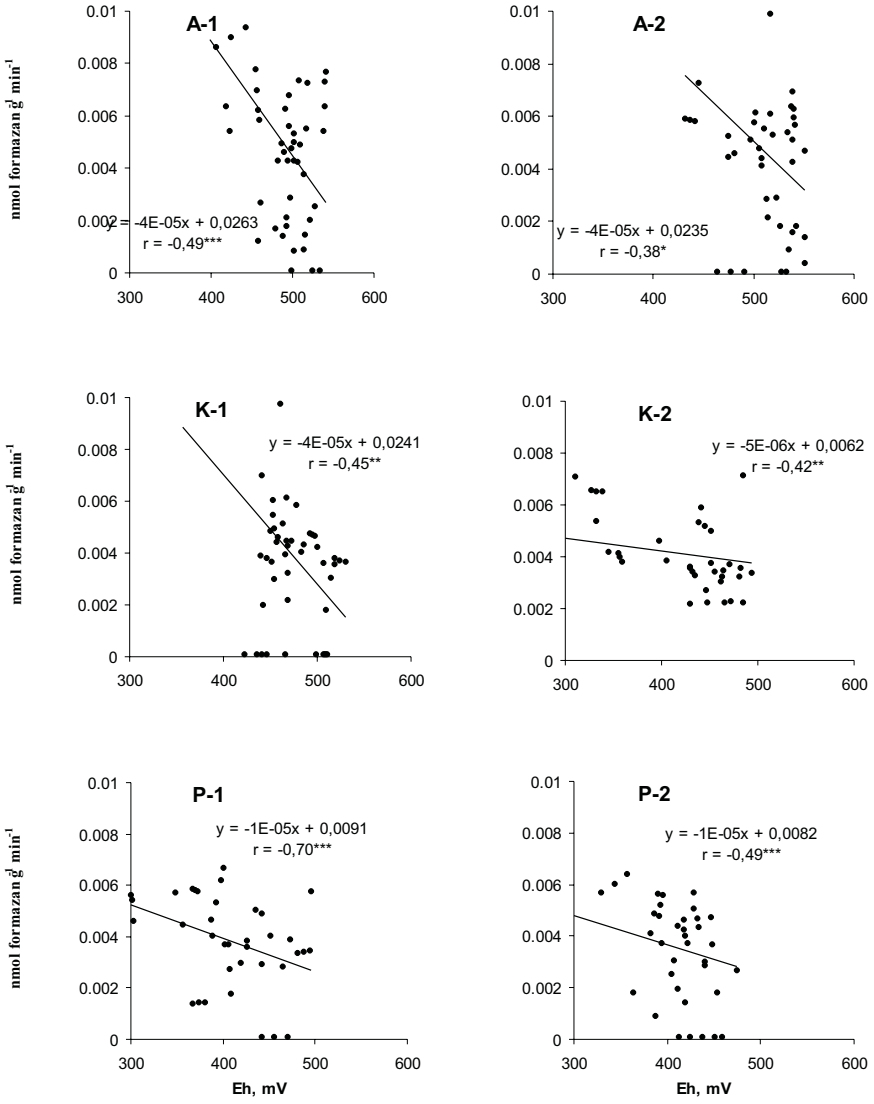

Fig. 7. Relation between *Eh* and dehydrogenase activity for individual soil profiles (all the horizons for each profile were treated jointly). The lines represent the best linear fit described by the equation in the case where the correlation was significant.

A comparison of the data for different cultivation treatments presented in Fig. 9 showed a tendency to diminish dehydrogenase activity after deep-loosening cultivation but a decrease of the activity due to cultivation was statistically significant only in the surface horizon of the Orthic Solonetz (P-1 and P-2). This effect can be attributed to the most drastic differentiation of the treatments in this case which included cheseling/discing yearly, deep loosening, gypsum application and drainage. Similar results have been reported by Doran [9], Ceccanti *et al.,* [5] and Pagliali and De Nobili [18] who observed that the activity of various enzymes in non-tilled plots was higher than in the conventionally tilled ones. A comparison of the soils with respect to ODR and Fe^{+2} indicates that these parameters were not significantly affected

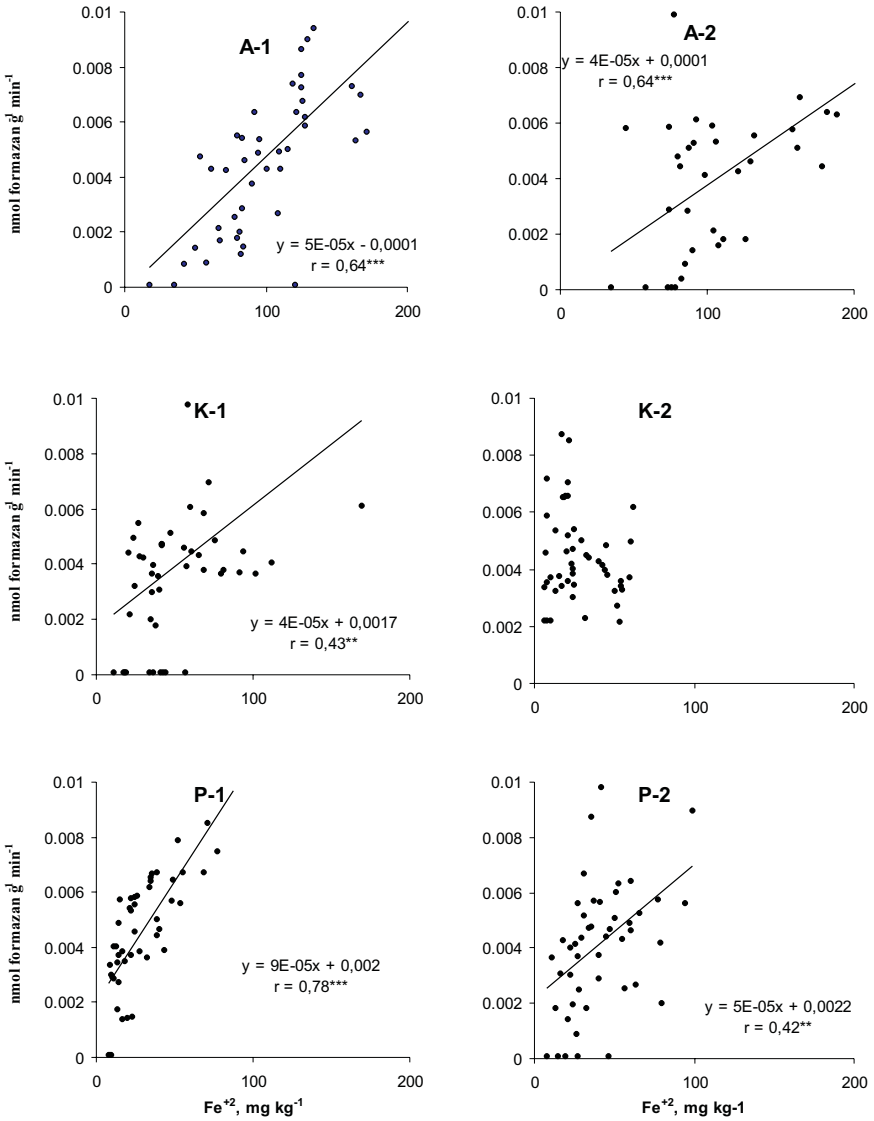

Fig. 8. Relation between Fe^{+2} content and dehydrogenase activity for individual soil profiles (all the horizons for each profile were treated jointly). The lines represent the best linear fit described by the equation in the case where the correlation was significant.

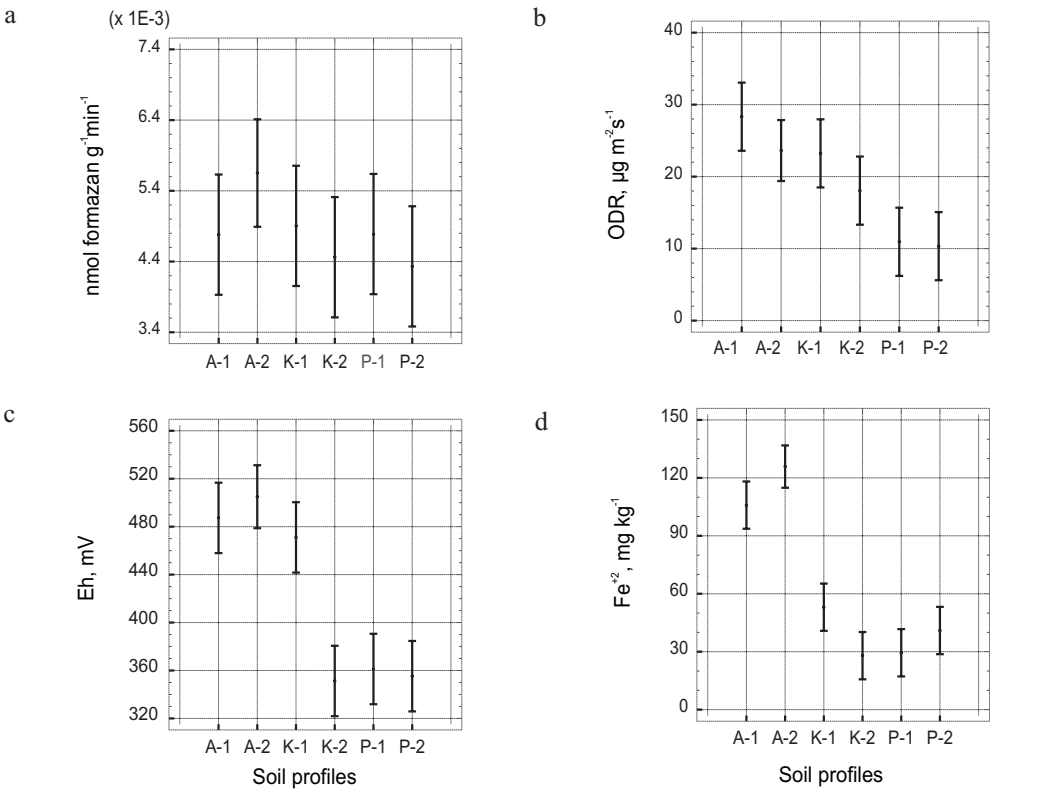

Fig. 9. Differences in dehydrogenase activity (a), ODR (b), *Eh* (c), and Fe^{+2} content between cultivated and uncultivated soils (all the horizons taken together): A-1, K-2, P-2 - profiles cultivated with deep-loosening; A-2, P-1 - uncultivated profiles; K-1 - normal-ploughing.

by the cultivation treatments and only a tendency of diminishing of the studied parameters after soil deep-loosening was observed (Fig. 9). Kisújszállás profiles (K-1 and K-2) showed a significant (p=0.01) decrease of *Eh* due to deep-loosening cultivation when the entire profiles were treated together (Fig. 9) as well as in the examined soil horizons (Fig. 3). The differences between the cultivated and uncultivated variants of the same soils proved to be insignificant also within regard to other soil physico-chemical characteristics [20].

CONCLUSIONS

Analysis of six typical Hungarian soils with respect to their dehydrogenase activity as related to water and aeration status of the soils showed that:

1. Dehydrogenase activity and reduced iron content in the soils decreased but ODR and *Eh* values increased with the increasing soil water tension.

2. A close relationship between oxygenation indicators (ODR, *Eh* and Fe^{+2}) and dehydrogenase activity was found ($r=-0.52^{***}$, $r=-0.27^{***}$ and $r=0.41^{***}$, respectively).

3. Deep-loosening cultivation resulted in a decrease of the soil *Eh*, ODR, dehydrogenase activity and reduced iron content.

4. Further studies should include dehydrogenase activity related to other enzyme activity as well as transformation of C and N under different water and aeration status.

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