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Comparison of biological and chemical properties of arable and pasture Solonetz soils

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Abstract

Soil samples were collected from salt-affected soils (Solonetz) under different land uses, namely arable (SnA) and pasture (SnP), to investigate the effects of land use on microbiological [basal soil respiration (BSR), microbial biomass carbon (MBC), dehydrogenase activity (DHA) and phosphatase activity] and chemical properties [organic carbon (OC), humic ratio (E4/E6), pH, electrical conductivity (EC), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), available forms of phosphorus (P_2O_5), potassium (K_2O), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+)] and on the moisture content.

The results showed that the two sites, SnA and SnP, were statistically different from each other for all the microbiological and chemical parameters investigated except Na^+ and moisture content. Higher values of MBC (575.67 µg g^{-1}), BSR (9.71 µg CO_2 g^{-1} soil h^{-1}), DHA (332.76 µg formazan g^{-1} day^{-1}) and phosphatase activity (0.161 µmol PNP g^{-1} hr^{-1}) were observed for the SnP soil. Great heterogeneity was found in SnP in terms of microbiological properties, whereas the SnA plots showed more homogeneous microbiological activity due to ploughing. 75.34% of variance was explained by principal component one (PC1), which significantly separated SnA and SnP, especially on the basis of soil MBC and P_2O_5. Moreover, it was concluded that the pasture land (SnP) was microbiologically more active than arable land (SnA) among the Hungarian salt-affected soils investigated.

Keywords: salt-affected soil, land use, soil microbiology, chemical properties, heterogeneity

Introduction

Salt-affected soils are one of the most characteristic soil formations in the Carpathian Basin. The total geographical coverage of these soils in Hungary is approximately 10 %, which is an unusually high value (SZABOLCS & VÁRALLYAY 1978). Comprehensive and detailed knowledge on the chemical, mineralogical, physical, hydraulic and botanical properties of salt-affected soils and on their classification, reclamation and amelioration has been published since the 1800's (e.g. HERKE 1949; ARANY 1956; SZABOLCS & JASSÓ 1959; ÁBRAHÁM & BOCSKAI,

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1971; TÓTH et al., 1998; VÁRALLYAY 1999; TÓTH & VÁRALLYAY 2001; TÓTH et al., 2001; KUTI et al., 2002; SZENDREI & TÓTH 2006; BALOG et al., 2014; TÓTH et al., 2015). However, the microbiological properties of salt-affected soils and the consequences of salinization and sodification processes were not widely investigated in Hungary (BIRÓ et al., 2002; MUCSI et al., 2017). An increase in some microbial groups was reported by BIRÓ et al. (2002) at higher salt content (10 g^{-1}). KHALIF et al. (2005) investigated the effect of increasing salt content on soil enzyme activities in the rhizosphere of bean varieties, while a few papers mainly reported the microbiological properties of salt-affected lakes (BORSODI et al., 2005, 2007; FELFÖLDI et al., 2009; SOMOGYI et al., 2009; SZABÓ et al., 2004) or focused on plant-microbe interactions in salt-affected soils (FÜZY et al., 2003; FÜZY et al., 2008; SZILI-KOVÁCS et al., 2017). MUCSI et al. (2017) investigated the catabolic activity of soil samples taken from four sites representing different vegetation types, using the MicroResp method.

The research published in the international literature focused on the effects of soil reclamation, and the amelioration of salt-affected soils. According to SUMNER (2000) the chemical properties of soils are affected by the presence of high soluble salt concentrations, which alter the soil osmotic potential and adversely affect soil microbial communities and enzyme activities (REITZ & HYNES, 2003; SARDINHA et al., 2003). The negative impact of salinity on the size and activity of soil microbial biomass and biochemical processes was also reported by TRIPATHI et al. (2006) and YUAN et al. (2007). Microbial activities (microbial biomass C, microbial biomass N and basal soil respiration) are reduced under high salinity, resulting in a reduction in the rate of organic matter decomposition and the mineralization of C, N and P (IWAI et al., 2012). The activity of dehydrogenase and phosphatase in the soil was also reported by BATRA & MANNA (2007) and JING et al. (2013), respectively, to be considerably reduced by an increase in soil salinity.

Various specific indicators of soil microbial activity have been proposed to assess soil status (BASTIDA et al., 2008; LUCAS-BORJA et al., 2011; HEDO et al., 2015), including the activity of several enzymes specifically related to the cycles of nitrogen, phosphorus, carbon and sulphur (urease, alkaline and acid phosphatase, β-glucosidase and arylsulphatase, respectively) and general microbial indicators such as dehydrogenase activity and soil respiration.

The effects of land use on soil quality, soil functions and ecological processes due to the modification of the physical, chemical and biological properties of soils were reported by POUYAT et al. (1995) and BENDING et al. (2002). Similarly, BALOTA et al. (2003) reported that less intensive management results in higher microbial activity. Microbial activity plays a key role in the ecological function of soils and in maintaining the ecological quality and productivity of soils (GROVER et al., 2011; IWAI et al., 2012). Improper land management practices may cause environmental stress in cultivated fields, such as a loss of soil nutrients, soil organic carbon and microbial activity, compaction, erosion and salinization (EUROPEAN COMMISSION, 2007).

ÁBRAHÁM & GINÁL (1967) investigated the effects of about 15 years of cultivation on the chemical properties of soils of former Solonetz pasture. TÓTH et

al. (2009) and TÓTH & FARKAS (2010) found higher CO_2 emission and biological activity on pasture land than on arable land in the case of Mollic-Cambisol and Chernozem soil types in Hungary, but overall little literature is available in Hungary on the effects of land use on soil microbiological properties.

The aim of the study was to investigate and compare the microbiological and chemical properties of Solonetz soils under different land uses, and thereby to provide relevant information for other salt-affected areas with a similar soil type. The soil profile at each site was described and classified to confirm that the two sites were covered by the same reference soil group. With respect to land use, one was arable land (SnA, used for maize production) and the other was pasture land (SnP, with grassy vegetation). The hypothesis was that significant differences in terms of microbiological and chemical properties should be observed between the two sites due to the land use system. It was also expected that the use of fertilizer on the arable site (SnA) would result in higher nutrient contents in comparison to the pasture site (SnP), which could decrease the microbiological activity on the arable site (SnA). High moisture content and organic carbon content were expected on the SnP site. It was also assumed that, due to cultivation, no great differences in microbiological and chemical properties would be observed amongst the plots at the SnA site, while great differences would be expected amongst those at the SnP site, where the values of microbiological properties were expected to be favourable.

Materials and methods

Study sites

The research was carried out in the vicinity of Nádudvar (Hajdú-Bihar County, Hungary) at two sites with Solonetz soils. The two representative soil profiles were excavated, sampled, described and classified using international standards (FAO, 2006; IUSS WORKING GROUP WRB, 2015). The ploughed arable site (SnA) had an elevation of 83 m above sea level and the geographical coordinates were N 47.458999° and E 21.195950°. This site was ploughed to a depth of 30 cm and 400 kg ha $^{-1}$ NPK (18:7:7) fertilizer was applied to the maize crop. The non-ploughed pasture site (SnP) had an elevation of 85 m above sea level and the geographical coordinates were N 47.468497° and E 21.172774. The site has not been cultivated for more than 30 years.

Soil samples were collected from a depth of 0-15 cm on eight 100 m^2 (10 m*10 m) plots at each site (SnA and SnP) in June 2016. Ten soil subsamples were randomly collected from each plot and combined to make a well mixed composite sample. In total, eight composite soil samples were collected (within a 60 m radius of the soil profile) from each site (*Figure 1*).

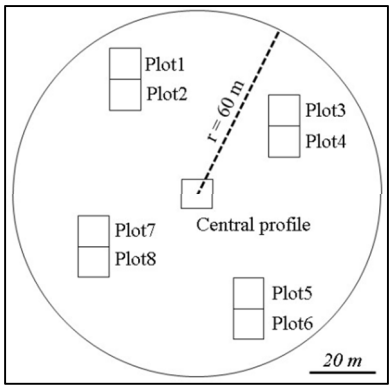

Figure 1
Schematic figure of plots and soil profile within the sampling sites (SnA and SnP).

Chemical and biological analyses of the soils

The samples were sieved (<2 mm) to obtain well homogenized samples, stored at -20ºC and then transferred to 4°C before analysis for microbiological properties. For chemical analysis the soils were air dried and stored at room temperature. All the analyses were done in triplicate. Besides the basic chemical parameters, selected microbiological parameters were investigated to collect a complex database and therefore obtain more detailed information about the processes taking place in the soils.

Soil pH was measured in a soil:water suspension (1:2.5) and electric conductivity (EC) was measured in K_A paste according to BUZÁS (1988). Soil organic carbon (OC, %) was determined by the Walkley-Black method (WALKLEY & BLACK, 1934). Humic material (E4/E6) was determined by the method given by PAGE et al. (1982). Ammonium (NH_4-N) and nitrate (NO_3-N) nitrogen were determined from $CaCl_2$ extract (KANDELER, 1996), while AL (ammonium lactate)-P_2O_5, AL-K_2O, magnesium (Mg^{2+}), calcium (Ca^{2+}) and sodium (Na^+) were extracted according to EGNER et al. (1960). Soil moisture content was determined using the gravimetric method (BUZÁS, 1993).

Soil microbial biomass carbon (MBC) was estimated with the chloroform fumigation-extraction method (VANCE et al., 1987; BROOKES et al., 1985). Basal soil respiration (BSR) was measured as the CO_2 evolved at optimum water content (60% field capacity) (CARTER, 1993; CHENG et al., 2013). The activity of the alkaline phosphatase enzyme was measured as described by TABATABAI & BREMNER (1969). Dehydrogenase activity (DHA) was determined from the transformation of 2,3,5-triphenyl tetrazolium chloride (TTC) to 1,2,5-triphenyl formazan (TPF) (CASIDA et al., 1964).

Soil profile: Samples from different layers of the profiles were sieved (<2 mm), air dried and stored for chemical and physical analysis. The above-mentioned methods were used for the chemical analysis of organic carbon (OC), EC and pH, whereas cation exchange capacity (CEC) and exchangeable basic cations (S value)

were determined based on the Mehlich method (MEHLICH, 1953). The exchangeable sodium percentage (ESP %) was calculated as exchangeable Na / CEC *100 (USDA 1954). The $CaCO_3$ content was measured with the Scheibler gas-volumetric method (BUZÁS, 1988), while particle size analysis was conducted using the pipette method (BUZÁS, 1993).

Statistical analysis

Basic descriptive statistical parameters were calculated from all the measured parameters of all the sampled composite plots (i.e. min, max, mean). The two sites were compared using the T-test for independent samples at the 0.01 and 0.05 significance levels. The differences within each plot were determined by one-way ANOVA using Tukey's HSD post hoc test at the $p<0.05$ level. Pearson's correlation coefficients were calculated to determine correlations between the microbiological and chemical variables (SPSS statistics vs. 23.0.). All the composite samples were used for principal component analysis (PCA) at the $p<0.05$ level (PAST vs. 3).

Results

Site characterization

Based on the field investigations and laboratory analyses the two profiles were classified as Solonetz soils. In the case of the SnA site (*Table 1*), the soil was Mollic SOLONETZ (Cutanic, Endoloamic, Hypernatric, Endoprotosalic, Episiltic, Endoprotovertic, Bathiprotocalcic, Bathigleyic).

Table 1
Representative soil profile data for the Solonetz arable (SnA) site

Master horizon	Depth	pH_{H2O}	Ca CO_3	SOM	Sand	Clay	Ca^{2+}	Mg^{2+}	Na^+	K^+	CEC	ESP	Salt cont.
	cm		%	%	%	%	$cmol^+ kg^{-1}$				$cmol^+ kg^{-1}$	%	%
Ap1	0-18	7.8	<0.1	2.18	14.56	28.78	17.7	4.0	1.1	1.5	26.8	4.2	0.07
Ap2	18-40	7.9	0.3	2.31	10.18	29.18	17.8	3.8	2.0	1.3	27.9	7.2	0.08
Bthng	40-70	8.9	0.2	2.24	13.86	27.58	18.7	5.9	9.0	0.5	35.1	25.7	0.20
2Bthing	70-100	9.2	0.6	1.15	6.17	42.91	11.4	5.4	12.0	0.3	30.2	39.9	0.32
3BCl	100-130	9.4	<0.1	0.57	8.81	39.81	8.9	5.1	12.2	0.3	27.4	44.4	0.35
3Ckl	130-150	9.5	10.2	0.46	6.96	35.71	10.9	5.2	11.9	0.2	28.3	42.0	0.29

In the case of the SnP site (*Table 2*) the soil was Katocalcic Salic SOLONETZ (Epiclayic, Endoloamic, Cutanic, Humic).

Table 2
Representative soil profile data for the Solonetz pasture (SnP) site

Master horizon	Depth	pH_{H2O}	$CaCO_3$	SOM	Sand	Clay	Ca^{2+}	Mg^{2+}	Na^+	K^+	CEC	ESP	Salt cont.
	cm		%	%	%	%	$cmol^+ kg^{-1}$				$cmol^+ kg^{-1}$	%	%
Oi	-2-0	na	na	na	na	na	na	na	na	na	na	na	na
A	0-5	5.9	1.9	3.45	12.05	15.23	6.8	2.2	3.6	0.2	15.3	23.6	0.10
Btng	5-15	7.7	<0.1	0.95	7.84	42.54	7.2	5.3	13.4	0.6	30.8	43.4	0.35
Bthng	15-40	9.2	<0.1	0.84	4.96	45.07	10.3	5.2	14.5	0.7	32.6	44.5	0.61
Bthkn	40-55	9.7	18.3	0.51	7.36	40.16	9.0	6.2	21.1	0.6	37.3	56.4	0.88
BCk	55-100	10.1	19.9	0.40	5.73	35.63	11.2	4.6	18.2	0.3	34.3	53.2	0.90
Ck	100-120	10.2	15.2	0.23	10.23	30.96	9.8	4.8	17.5	0.3	32.4	54.1	0.86

na = not available

Microbiological and chemical characterization of the two sites

The basic statistical parameters (minimum, maximum and mean with standard deviation) for soil samples taken at a depth of 0-15 cm at the two sites and the results of the t-test for independent samples can be seen in *Table 3*.

Higher microbiological values were recorded on the SnP plots than on the SnA plots. The soil MBC values ranged from 69.60 to 74.95 µg g^{-1} and from 369.08 to 949.62 µg g^{-1}, BSR values from 1.2 to 8.2 µg CO_2 g^{-1} soil h^{-1} and from 4.4 to 15.3 µg CO_2 g^{-1} soil h^{-1}, DHA values from 54.7 to 148.77 µg formazan g^{-1} day^{-1} and from 198.72 to 575.59 µg formazan g^{-1} day^{-1} and phosphatase activity from 0.044 to 0.148 µmol PNP g^{-1} h^{-1} and from 0.064 to 0.263 µmol PNP g^{-1} h^{-1} at the SnA and SnP sites, respectively. The values of OC and E4/E6 were also higher for SnP, ranging from 4.84 to 6.96 % and from 4.44 to 5.14 %, respectively (*Table 3*).

Among the chemical properties, pH and EC were higher at the ploughed SnA site (*Table 3*). Soil pH values ranged from 6.10 to 7.8 for SnA and from 5.1 to 6.2 for SnP, while soils collected from both sites showed a distinct variation in soil EC values, which ranged from 255 to 480 µS cm^{-1} for SnA and from 139 to 377 µS cm^{-1} for SnP. The concentration of K_2O varied from 256 to 490 mg kg^{-1} and from 100 to 296 mg kg^{-1}, that of Mg^+ from 34.9 to 74.6 mg kg^{-1} and from 26.4 to 41.3 mg kg^{-1}, that of Ca^+ from 768 to 1666 mg kg^{-1} and from 436 to 846 mg kg^{-1} and that of Na^+ from 114 to 630 mg kg^{-1} and from 128 to 626 mg kg^{-1} at the SnA and SnP sites, respectively. The P_2O_5 concentration varied from 322 to 1479 mg kg^{-1} and from 130 to 371 mg kg^{-1} for SnA and SnP. The values of NH_4-N were higher for SnP, with a mean of 8.77 mg kg^{-1} compared to 4.22 mg kg^{-1} for SnA, while the values of NO_3-N were higher for SnA, with a mean of 39.03 mg kg^{-1} compared to 3.78 mg kg^{-1} for SnP.

Table 3
Descriptive statistics and the results of t-tests for independent samples for the two sampling sites (n=8 for each site; depth 0-15 cm)

Property	Unit	SnA			SnP			Sig. 2-tailed
		min	max	mean(SD)	min	max	mean(SD)	
Basal soil respiration	(µg CO_2 g^{-1} soil h^{-1})	1.20	8.20	5.12 (2.15)	4.40	15.30	9.71 (2.48)	0.000 **
Microbial biomass carbon	(µg g^{-1})	69.60	74.95	73.74 (1.14)	369.08	949.36	575.64 (180.64)	0.000 **
Dehydrogen-ase activity	(µg formazan g^{-1} day^{-1})	54.70	148.77	103.26 (31.91)	198.72	575.59	332.76 (109.11)	0.000 **
Alkaline phosphatase activity	(µmol PNP g^{-1} h^{-1})	0.044	0.148	0.107 (0.03)	0.064	0.263	0.161 (0.08)	0.003 *
Organic carbon	(%)	3.03	4.32	3.83 (0.38)	4.84	6.96	5.52 (0.63)	0.000 **
E4/E6		3.94	4.28	4.11 (0.10)	4.44	5.14	4.71 (0.18)	0.000 **
pH		6.10	7.80	6.77 (0.55)	5.10	6.20	5.55 (0.35)	0.000 **
Electrical conductivity	(µS cm^{-1})	255	480	358.29 (65.18)	139	377	224.71 (67.70)	0.000 **
NH_4-N	(mg kg^{-1})	2.2	6.1	4.42 (1.26)	6.0	13.0	8.77 (2.46)	0.000 **
NO_3-N	(mg kg^{-1})	23.6	49.3	39.03 (9.65)	1.4	7.0	3.78 (2.05)	0.000 **
P_2O_5	(mg kg^{-1})	322	1479	671.71 (273. 88)	130	371	233.67 (69.99)	0.000 **
K_2O	(mg kg^{-1})	256	490	383.42 (59.32)	100	296	177.25 (62.51)	0.000 **
Mg^{2+}	(mg kg^{-1})	34.9	72.6	44.07 (9.81)	26.4	41.3	32.63 (4.13)	0.000 **
Ca^{2+}	(mg kg^{-1})	768	1666	1075.63 (216.56)	436	846	606.38 (99.17)	0.000 **
Na^{+}	(mg kg^{-1})	114	630	288.83 (181.74)	128	626	279.83 (130.49)	0.845
Soil moisture	(%)	19.94	23.27	21.72 (0.89)	18.54	24.66	21.27 (1.69)	0.258

*,**: Significantly different at the 0.05 and 0.01 levels, respectively

Soil microbial activity in salt-affected soils

Table 4 shows the results obtained for the upper 15 cm soil layer of each plot at the two sampling sites, SnA and SnP. The data revealed that soil microbial activity was greatly influenced by the land use system. Great heterogeneity was observed for the microbiological properties of the pasture site (SnP). This heterogeneity was decreased by the soil cultivation on arable land. At the two sites, the highest value of MBC was recorded for SnP-8 (897.64 µg g^{-1}) and the lowest for SnA-5 (71.38 µg g^{-1}). Similarly, DHA was the highest for SnP-8 (575.57 µg formazan g^{-1} day^{-1}) and the lowest for SnA-4 (71.61 µg formazan g^{-1} day^{-1}). The

values of MBC and DHA were lower in all plots for SnA than for SnP. The BSR values were higher for SnP (5.51 to 12.87 µg CO_2 g^{-1} soil h^{-1}) than for SnA (1.54 to 7.61 µg CO_2 g^{-1} soil h^{-1}). The phosphatase acitvity was the highest for SnP-6 (0.263 µmol PNP g^{-1} h^{-1}) and the lowest for SnA-5 (0.044 µmol PNP g^{-1} h^{-1}).

Table 4

Microbiological properties of the 0-15 cm layer of the two sites (SnA and SnP) (means with SD in brackets) and the results of Tukey's test for individual sampling plots (1-8) within each sampling site. Letters indicate significant differences between the parameters for each plot (n=3 for each plot).

Plot No.	Basal soil respiration	Microbial biomass carbon	Dehydrogenase activity	Alkaline phosphatase activity
	(µg CO_2 g^{-1} soil h^{-1})	(µg g^{-1})	(µg formazan g^{-1} day^{-1})	(µmol PNP g^{-1} h^{-1})
SnA-1	7.61 (0.55) de	74.25 (0.60) a	78.99 (0.17) c	0.123 (1 x 10^{-4}) j
SnA-2	5.59 (0.48) bcd	73.78 (0.28) a	54.72 (0.03) a	0.130 (2.3 x 10^{-4}) k
SnA-3	2.66 (0.32) ab	74.09 (0.41) a	148.60 (0.15) h	0.148 (0.9 x 10^{-4}) l
SnA-4	7.33 (0.39) de	74.23 (0.46) a	71.61 (0.38) b	0.093 (1.2 x 10^{-4}) d
SnA-5	6.69 (0.55) cd	71.38 (1.99) a	96.82 (0.01) d	0.044 (0.8 x 10^{-4}) a
SnA-6	1.54 (0.31) a	74.02 (0.39) a	125.42 (0.06) f	0.101 (0.4 x 10^{-4}) g
SnA-7	5.53 (0.83) bcd	73.77 (0.13) a	112.08 (0.05) e	0.094 (1.9 x 10^{-4}) e
SnA-8	3.97 (0.58) abc	74.36 (0.05) a	137.84 (0.13) g	0.122 (0.9 x 10^{-4}) i
SnP-1	5.51 (1.13) bcd	370.09 (0.87) b	303.23 (0.00) k	0.196 (0.1 x 10^{-4}) m
SnP-2	10.01 (1.56) efg	443.49 (73.74) b	229.78 (0.02) j	0.220 (1.4 x 10^{-4}) n
SnP-3	8.25 (0.64) def	418.10 (42.45) b	198.74 (0.02) i	0.987 (0.5 x 10^{-4}) f
SnP-4	8.16 (0.24) def	663.28 (73.85) c	319.79 (0.15) m	0.263 (2.3 x 10^{-4}) p
SnP-5	10.16 (1.20) efg	441.66 (0.55) b	378.54 (0.06) o	0.110 (0.3 x 10^{-4}) h
SnP-6	12.87 (2.31) g	686.61 (41.74) c	345.02 (0.72) n	0.252 (0.5 x 10^{-4}) o
SnP-7	11.73 (1.56) g	684.25 (42.50) c	311.39 (0.28) l	0.088 (0.9 x 10^{-4}) c
SnP-8	11.03 (0.14) fg	897.64 (45.67) d	575.57 (0.03) p	0.064 (0.6 x 10^{-4}) b

Letters a-p indicate significant differences between means according to Tukey's test ($p<5$)

Table 5 shows that BSR and DHA were positively correlated with MBC, whereas the phosphatase activity showed no correlation with the other microbiological properties. BSR, MBC and DHA were positively correlated with OC and E4/E6 and negatively correlated with pH and EC. A strong negative correlation was also found between microbiological properties (BSR, MBC and DHA) and NO_3-N, K_2O and Ca^{2+}, while, P_2O_5 showed a negative correlation with MBC and DHA.

Table 5
Correlation matrix of the chemical and microbiological soil properties (n=16).

	Basal soil respiration	Microbial biomass carbon	Dehydrogenase activity	Alkaline phosphatase activity
Microbial biomass carbon	0.758**			
Dehydrogenase activity	0.622**	0.916**		
Alkaline phosphatase activity	0.189	0.322*	0.201	
Organic carbon	0.553**	0.854**	0.866**	0.191
E4/E6	0.669**	0.931**	0.894**	0.241
pH	-0.615**	-0.829**	-0.764**	-0.190
Electrical conductivity	-0.672**	-0.806**	-0.681**	-0.135
NH_4-N	0.369**	0.529**	0.488**	0.317*
NO_3-N	-0.696**	-0.850**	-0.778**	-0.341*
P_2O_5	-0.479**	-0.716**	-0.690**	-0.180
K_2O	-0.647**	-0.833**	-0.791**	-0.154
Mg^{2+}	-0.609**	-0.525**	-0.471**	-0.291*
Ca^{2+}	-0.663**	-0.779**	-0.696**	-0.315*
Na^+	-0.175	-0.184	-0.115	0.189
Soil moisture	-0.443**	-0.261	-0.301*	0.361*

Pearson's correlation $p<0.05$. *,**: Significant at the 0.05 and 0.01 levels, respectively.

The results of PCA (*Figure 2*) showed that the arable and pasture plots formed two well-defined point clouds. PC1 explained 75.34% of the variance based on MBC and P_2O_5, while PC2 explained 16.30% of the total variance based on P_2O_5, Ca^{2+} and Na^+, so the two sampling sites could be divided by PC1 based on the MBC and P_2O_5.

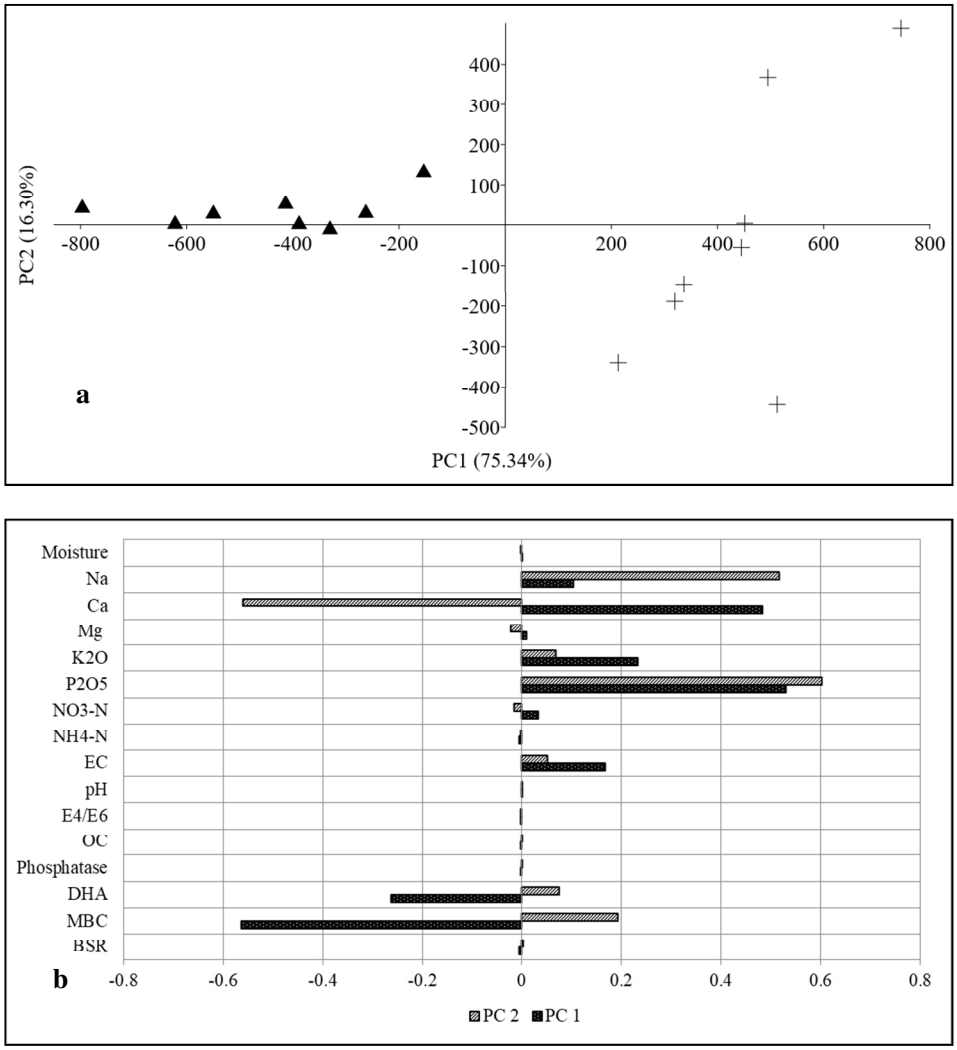

Figure 2
Results of principal component analysis. a: PC factor scores along PC1 and PC2. ▲ SnA; **+** SnP; b: PC factor loadings of PC1 and PC2

Discussion

It could be concluded that the two sites were statistically different from each other for all the parameters investigated, except for Na and moisture content (*Table 3*). Based on the preliminary hypothesis, higher moisture values were expected for SnP, but similar moisture content was observed at both sites, presumably due to the heavy rain that occurred before sampling. In a study performed by ÁBRAHÁM & GINÁL (1967) no effect on the exchangeable Na content could be detected after 15

years of cultivation. Due to regular fertilization the nutrient content (NO_3-N, P_2O_5, K_2O, Mg^+ and Ca^{2+}) was higher at the SnA site. This confirmed the results of ÁBRAHÁM & GINÁL (1967), who found an increase in P_2O_5 on cultivated plots. In the present work there was an increase in K_2O, in contrast to the decrease in K_2O and total nitrogen reported by ÁBRAHÁM & GINÁL (1967). NH_4-N was higher at the SnP site, presumably due to the poorer aeration on the uncultivated grass land. These differences in soil properties between the soils of arable (SnA) and pasture (SnP) sites (*Table 3*) can be explained by differences in the land use system and by the fertilizers applied at the SnA site.

The soil mean pH was relatively low (5.55) at the SnP site, while the microbiological activity (BSR, MBC, DHA and phosphatase) was higher compared to the SnA site. It was hypothesized that ploughing had a more direct influence on microbiological properties than pH in the case of salt-affected soils, although NEALE et al. (1997) reported that the effect of pH was found to be one of the most important environmental factors for soil microbes. Non-ploughing and the continuous plant coverage resulted in higher organic matter content at the SnP site, leading to an increase in microbial enzyme activities (TEJADA et al., 2006). ÁBRAHÁM & GINÁL (1967) reported that after 15 years of ploughing the OM content of the ploughed soil layer of a Solonetz pasture in Hungary decreased by 12-22%. The lower values of phosphatase at the SnA site could be the result of inorganic fertilizer application and higher pH and EC. SAHA et al. (2008) also reported decreased phosphatase activity after inorganic fertilization and KHALIF et al. (2005) found that phosphatase was sensitive to salt concentration. The values of E4/E6 were lower on the SnA plots, suggesting the higher quality of organic matter. However, E4/E6 values less than 5 were also measured on the SnP plots, indicating that both areas were characterized by humic acids (STEVENSON, 1994).

The higher values of microbiological properties indicated that the non-ploughed SnP plots were microbiologically more active. The higher SD values calculated for the microbiological parameters at the SnP site suggested that the area was more heterogeneous in terms of microbiological activity, presumably due to the greater root mass of the permanent grassy vegetation, while ploughing may have decreased and homogenized the soil microbiological activity at the SnA site (*Table 3*).

Despite the great heterogeneity of the microbiological properties (*Table 4*), overall, higher values were found in the case of SnP, indicating that this site was biologically more active. The MBC content seemed to be homogeneous on the ploughed SnA plots, whereas this property showed great variance on the SnP plots. Dehydrogenase activity was very heterogeneous, as dehydrogenase is an intracellular enzyme (KANDELER, 2007) and is usually correlated with the microbial biomass. Nevertheless, very variable dehydrogenase activity was associated with similar MBC values at the SnA site, indicating that the species composition or the microbial activity at different points of the SnA site were different. KHALIF et al. (2005) stated that DHA was less sensitive to salt concentration up to 0.4% NaCl content than phosphatase activity. The latter was significantly different for each

sampling plot. No clear tendency could be observed based on the present results. Thus, the phosphatase activity of the SnA and SnP plots could not be distinguished. Different plant species occupy different microhabitats on salt-affected soils according to the local salt content of the soil. FÜZY et al. (2008) found different arbuscular mycorrhizal fungi (AMF) colonization rates for different plant species. The colonization rate also depended on the salt content of the soil. Moreover, heavy rainfall decreased the AMF colonization rate of the roots, while drought increased it.

When relationships between the chemical and microbiological parameters were studied, strong positive correlations were found between most of the microbiological parameters (BSR, MBC and DHA) and OC and E4/E6 (*Table 5*). The positive correlations with E4/E6 suggest higher microbial biomass and activity, possibly due to greater amounts of more labile organic matter, which might serve as a nutrient source for microbes. High doses of NPK fertilizers could decrease the enzyme activities in the soil (GUANGMING et al., 2017). Similarly, the increase in available macronutrients resulted in strong negative correlations with microbiological properties (BSR, MBC and DHA) except for NH_4-N, which had a significant positive correlation with MBC and DHA in this study. Moreover, the increase in EC in the soil reduced the activity of alkaline phosphatase and other enzymes (RIETZ & HAYNES, 2003). The alkaline phosphatase activity was independent of the inorganic P_2O_5 concentration in the soil. Similar results were found by TURNER & HAYGARD (2005), who stated that phosphomonoesterase activity was strongly correlated with organic phosphorus (P) but not with the inorganic P content. Organic P is abundant in soils and contributes to the P nutrition of plants and microbes following hydrolysis and the release of free phosphate (CONDRON et al., 2005).

Conclusions

This study on salt-affected soils showed that microbial activity was negatively influenced by the land use system and the use of fertilizers on arable land, as indicated by the lower values of MBC, BSR, DHA and phosphatase activity. In terms of microbiological properties, the SnP site showed great heterogeneity, whereas the SnA site was more homogeneous in terms of microbiological activity. Overall, the land use system had significant effects on the microbiological and chemical properties of salt-affected soils.

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