Received: 23 December 2020 | Revised: 20 May 2021 | Accepted: 24 May 2021
DOI: 10.1002/ird.2623

RESEARCH ARTICLE

WILEY

Assessing soil quality changes after 10 years of agricultural activities in eastern Hungary*

István Takács[1] | **Mahdis Amiri**[2] | **Kith Károly**[1] | **Safwan Mohammed**[1]

[1]Institute of Land Use, Engineering and Precision Farming Technology, University of Debrecen, Böszörményi út 138, Debrecen, Hungary

[2]Department of Watershed and Arid Zone Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

Correspondence
Safwan Mohammed, Debrecen University Institute of Land Use, Engineering and Precision Farming Technology, Böszörményi út 138, Debrecen, Hungary.
Email: safwan@agr.unideb.hu
https://twitter.com/safwanmohammed4
https://www.linkedin.com/in/safwan-mohammed-b2b80174/

Abstract

In Hungary, soil plays a fundamental role in agricultural production. The main aim of this research was to track the spatial–temporal variations in certain soil properties (soil organic carbon [So], pH, NO_3^-, P, K, Mn, Zn and Cu) between 2000 and 2010 in 55 different farms in the eastern part of Hungary (Hajdú-Bihar region). Soil data were collected from the Soil Conservation Information and Monitoring System. After 10 years of agricultural activities results reveal that the means of pH, So, NO_3^-, and Zn were higher in 2010 than in 2000. Indeed, of nine studied soil characteristics only two (So%, NO_3^-) showed a significant change according to the Wilcoxon *T*-test. The average pH_H_2O increased by 0.13 and reached 7.31 ± 0.12 in 2010. The average NO_3^- (ppm) increased by 4.75 ppm and reached 19.9 ppm in 2010. For other soil nutrients, available P, K and Mg decreased slightly, while Mn decreased from 269 ± 25 ppm to 236 ± 21 ppm in 2010. Interestingly, Zn and Cu showed no change between 2000 and 2010. However, the inverse distance weighting (IDW) showed that the central part of the study area is more prone to changes due to intensive agricultural activities. The output of this research could assist decision makers when making soil conservation plans within the study area.

KEYWORDS
agriculture, Hungary, IDW, monitoring, soil fertility, soil function

Résumé

En Hongrie, le sol joue un rôle fondamental dans la production agricole. L'objectif principal de cette recherche était de suivre les variations spatio-temporelles de certaines propriétés du sol (carbone organique du sol [So], pH, NO_{3-}, P, K, Mn, Zn et Cu) entre 2000 et 2010 dans 55 exploitations différentes dans la partie orientale de la Hongrie (région de Hajdú-Bihar). Les données sur les sols ont été collectées à partir du système d'information et de surveillance sur la conservation des sols. Après dix ans d'activités agricoles, les

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[*] Évaluation des changements de qualité des sols après dix ans d'activités agricoles dans l'est de la Hongrie.

résultats révèlent que les moyennes de pH, So, NO_{3-} et Zn étaient plus élevées en 2010 qu'en 2000. En effet, sur neuf caractéristiques du sol étudiées, deux seulement (So%, NO_{3-}) ont montré un changement significatif au test Wilcoxon *T*. Le pH_H2O moyen a augmenté de 0.13 et a atteint 731 ± 0.12 en 2010. Le NO_{3-} (ppm) moyen a augmenté de 4.75 ppm et atteint 19.9 ppm en 2010. Pour les autres éléments nutritifs du sol, P, K et Mg disponibles ont légèrement diminué, tandis que Mn a diminué de 269 ± 25 ppm à 236 ± 21 ppm en 2010. Fait intéressant, Zn et Cu n'ont montré aucun changement entre 2000 et 2010. Cependant, la pondération à distance inverse (IDW) a montré que la partie centrale de la zone d'étude est plus sujette aux changements dus à activités agricoles intensives. Les résultats de cette recherche pourraient aider les décideurs à élaborer des plans de conservation des sols dans la zone d'étude.

MOTS CLÉS

fonction du sol, agriculture, surveillance, IDW, fertilité du sol, Hongrie

1 | INTRODUCTION

Extensive agricultural activities all over the world, especially in the last few decades, have had a drastic impact on soil quality, which has affected the multifunctionality of soils in agroecosystems. As a consequence, the leading role of soil in ecosystem services (i.e. productivity, biodiversity conservation, environmental quality) as well as its non-ecological functions will vanish. Thus, sustainable agriculture is a key element in maintaining soil quality for ensuring food security and proper crop production. Within this context, Hossain and Salam (2019) reported a significant reduction in soil organic carbon in south-western Bangladesh due to long-term agricultural activities, which had a serious negative impact on global C-sequestration. Similarly, Olorunfemi *et al.* (2018) concluded that cultivated land in south-western Nigeria witnessed a significant reduction in soil quality in comparison with natural forest soils. In Kenya, Willy *et al.* (2019) showed a remarkable decline in certain soil properties, such as soil organic carbon (So), magnesium and others due to agricultural activities over the last five decades. Similarly, Nanganoa *et al.* (2019) noted a considerable reduction in macrofauna and organic matter (OM) in agricultural land in Cameroon.

In Europe, intensive agriculture using conventional approaches has led to severe land degradation, and more than 22% of European soils have been subject to soil erosion (Jones *et al.*, 2012). Kätterer *et al.* (2012) indicated that extensive agriculture has affected the soil carbon balance and minimized the possibility of preserving soil carbon stocks in soils in northern Europe. Bongiorno *et al.* (2019) studied 10 long-term field experiments in different pedoclimatic conditions in Europe and concluded that soil organic carbon in the topsoil can be increased by minimizing agricultural activities (reducing tillage) associated with high OM inputs. In Hungary, soil plays a fundamental role in agricultural production. However, the soil suffers from land degradation such as soil erosion (Waltner *et al.*, 2018; Négyesi *et al.*, 2019) and salinization (Schofield *et al.*, 2001; Mádl-Szőnyi & Tóth, 2009). On a local scale, few studied have been carried out to assess soil properties. In this sense, Puskás and Farsang (2009) evaluated the impact of anthropogenic activities on some soil properties in the south-east part of Hungary (Szeged), and reported a significant impact of human activities on the studied soil parameters. Similarly, Szilassi *et al.* (2006) indicated that long-term agricultural activities in the Kali basin (western Hungary) have badly affected the physicochemical soil properties. Dekemati *et al.* (2019) recommended minimizing tillage intensity in Hungarian fields to enhance soil properties. However, on a national scale, spatial techniques have been used to map some soil properties. For instance, topsoil texture using classification and regression trees (Laborczi *et al.*, 2016), soil texture by ordinary kriging (Adhikari *et al.*, 2009); and other various methods (Pásztor *et al.*, 2018).

The Hungarian agricultural sector has witnessed a dramatic change, as has occurred in many other European countries (Kohlheb & Krausmann, 2009). Historically, a great change in the Hungarian economy from a planned economy (socialist regime) to a European market one has had a remarkable effect on the agricultural sector (Kohlheb & Krausmann, 2009). In this context, under the socialist regime, Hungary witnessed a rapid growth in industrialization and agriculture, during which gross domestic product (GDP) almost doubled (1961–1989) (Kohlheb & Krausmann, 2009). A great change in the agricultural sector occurred when Hungary joined the European Union, in which agrotechnologies were frequently employed, and the infrastructure was improved significantly to maximize the efficiency of the agricultural sector (Kohlheb & Krausmann, 2009). Back in 1997, the sector only contributed 5.7% of total GDP and only 7.7% of total employment (Banse *et al.*, 1999). According to the European Commission, Eurostat and the Directorate General for Agriculture and Rural Development (2019), total employment in the agricultural sector is now 5% (3.9% from the total employment of the EU-28) while it contributes about 3.8% of GDP (Hungarian Central Statistical Office (http://www.ksh.hu/?lang=en).

Even though 83% of Hungarian land is used for agriculture (arable and forest land) (Banse *et al.*, 1999) few studies have been carried out to track the effects of land use on soil characteristics. Thus, the main aims of this research were to: (i) track changes in some selected soil properties (So, pH, NO_3^-, P, K, Mn, Zn and Cu), after 10 years of agricultural activities (2000–2010); and (ii) monitor changes in soil characteristics using geospatial techniques.

2 | MATERIALS AND METHODS

2.1 | Study area

Hungary is located in the centre of Europe, and its climate is influenced by its location in the Carpathian basin (Pepo, 2013; Mohammed & Harsányi, 2019; Mohammed *et al.*, 2020). The Hungarian climate can be characterized as continental, meaning it has warm and dry summers, and cold and wet winters (Ács *et al.*, 2015; Alsafadi *et al.*, 2020).

The county of Hajdú-Bihar in the eastern part of Hungary was chosen as the study area, with an area 6211 km^2 and more than 537 000 inhabitants. The capital of this region is Debrecen, which is the second largest city in Hungary in terms of area and population (Molnár *et al.*, 2020). It is located in the eastern part of Hungary (47.5° N, 21.5° E), 100–150 m + MSL (mean sea level) (Figure 1). The mean annual temperature is 10.5°C, while the yearly average rainfall is 560 mm. Agriculture is one of the main activities in the study area, where the main crops are maize, wheat and sunflower (Figure 2).

2.2 | Data collection

Soil data were collected from the Soil Conservation Information and Monitoring System (SIMS, 1995) program in Hungary, which is a national program covering 1200 locations across Hungary and serves as an up-to-date soil information database (Laborczi *et al.*, 2016). In this

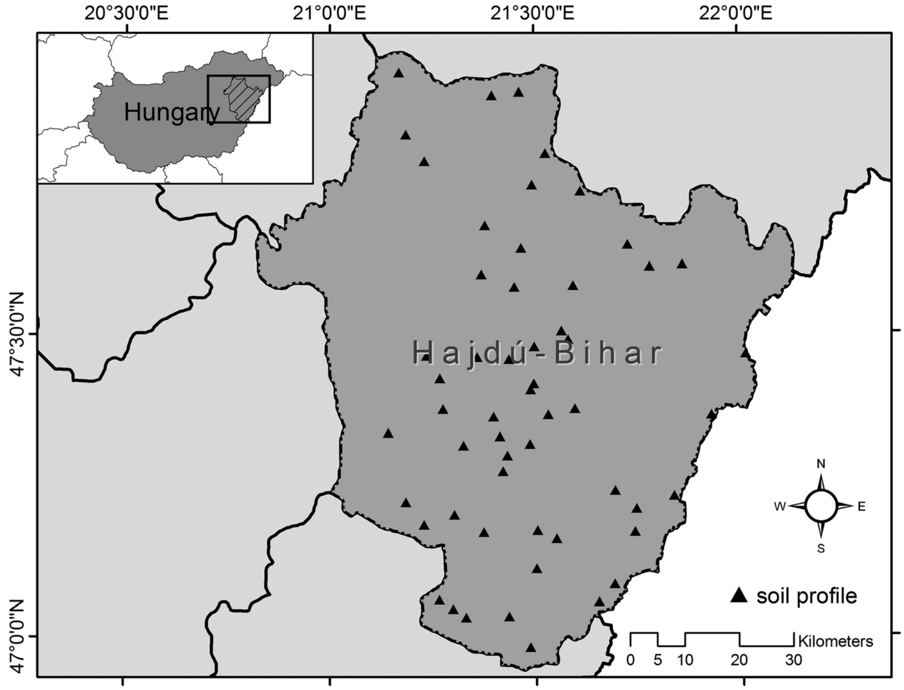

FIGURE 1 Location of the study area

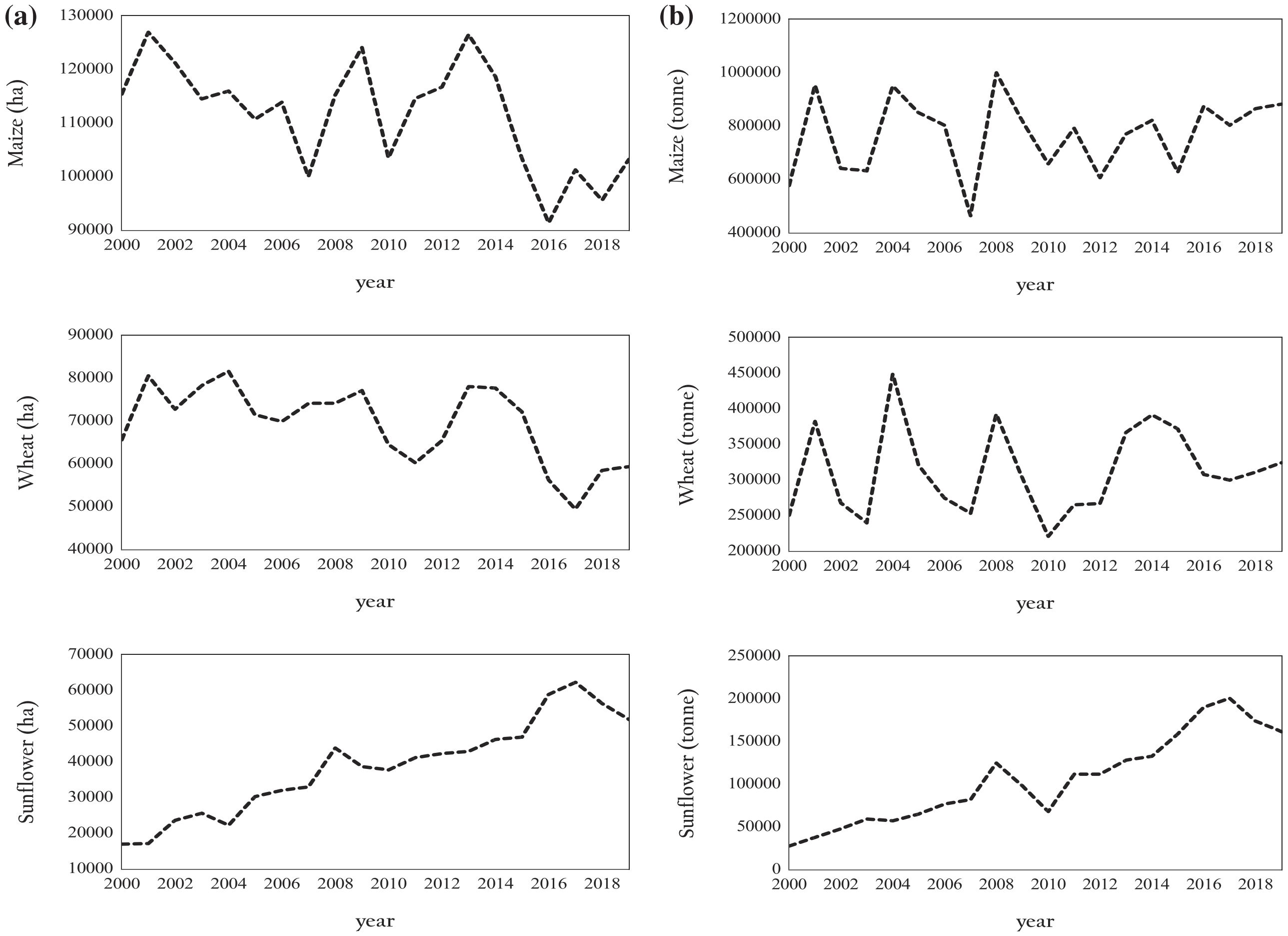

FIGURE 2 Main crops cultivated in the eastern part of Hungary (Hajdú-Bihar region): (a) cultivated area (ha), (b) harvested (t) (Data source: https://www.ksh.hu/?lang=en)

research, data were used from the topsoil (R1 = 30 cm) of agricultural land for 55 soil profiles covering all Hajdú-Bihar county, at two different times: (i) 2000; (ii) 2010. The chosen soil characteristics were pH, soil organic carbon (So), NO_3^-, P, K, Mg, Zn, Mn and Cu. The methodology used for soil analyses is summarized in Table 1.

TABLE 1 Soil analysis methods

	Method reference	Method reference
pH	Digital pH meter (1 : 2.5)	Burt (2014)
So	Wet digestion method	Nelson and Sommers (1983)
NO_3^-	Kjeldahl distillation method	Kjeldahl (1883)
P	Olsen method	Olsen (1954)
K	Flame photometer	Suarez (1996)
Mg	Titration method	Suarez (1996)
Zn	DTPA extraction method	Lindsay and Norvell (1978)
Mn		
Cu		

2.3 | Geostatistical interpolation procedure (GIP)

When the values of a variable are available for a set of sample points in an area, a 'spatial interpolation' (SI) method can be used to determine the value of a variable at any other point. Spatial interpolation can be divided into two main methods: 'Deterministic' methods (e.g. inverse distance weighting (IDW), spline and radial basis functions) and 'geostatistics' (e.g. kriging, hicrarchical models and copula) (Myers, 1994; Henley, 2012; Meng *et al.*, 2013). In deterministic method to calculate the values uses the mathematical function and the calculated value is a definite value. The second method (geostatistical method) also uses probabilistic estimates such as variance (de Oliveira Júnior *et al.*, 2019). The IDW interpolation method is one of the most popular for interpolation of scattered points in space, which is based on the hypothesis that at an interpolation level, the effect of a parameter on the surrounding points is not the same and more near points and fewer distant points are affected. As the distance from the origin increases, the effect of the parameter decreases (Bronowicka-Mielniczuk *et al.*, 2019). Actually, the estimation of the IDW method, which is described as representing the definitive method, is performed at points with an unknown value of $\hat{p}(x_0)$ with the help of the weighted average of all available measurements. Normally the weight is proportional to the inverse of the distance. Therefore, the closest available observations have a greater impact on estimating the unknown value (Huang *et al.*, 2011). Using the following equations in ArcGIS.10.6.1 software, zoning of the soil properties used in the present study can be determined using the measured data (Shukla *et al.*, 2020):

$$P^{\wedge}_{(x_0)} = \sum q(x_j)P(x_j) \tag{1}$$

$$j = |x_j - x_0| \leq {}^{\mathrm{j}_h}\Big/\sum q(x_j) \tag{2}$$

$$q(x_j) = {}^{1}\Big/|x_j - x_0|^S \tag{3}$$

where $\hat{p}(x_0)$ = unknown/passive value at point x_0, $P(x_j)$ = weights that are proportional to the distance between x_0 and x_j. Usually, these weights are selected as a power function of the 'Euclidean distance' between two spatial points, S = the number '2' is considered. However, few studies have applied the IDW technique for interpolation of soil properties in Hungary (Mesoro *et al.*, 2020).

2.4 | Statistical analysis

Statistical analysis was performed for each point using Excel STAT software. The analysis included central tendency (mean), dispersion (standard deviation and coefficient of variation) and distribution (skewness and kurtosis).

In the later stage, and as the paired data from the same locations but for two different years (i.e. 2000 and 2010), the Wilcoxon *T*-test (W-T) (Wilcoxon, 1945) was applied to detect whether the changes in soil properties were significant or not. W-T is a multivariate, nonparametric test (Peterson *et al.*, 1990) recognized as an alternative to the *t*-test, if its assumptions are not met. In this test, $\boldsymbol{H_0}$ indicates the absence of any statistical difference between the two averages of studied groups. In contrast, $\boldsymbol{H_1}$ states a significant difference between the two averages of studied groups (Giammanco & Bonfanti, 2009).

3 | RESULTS

3.1 | pH_H$_2$O changes between 2000 and 2010

The average pH_H$_2$O was 7.18 ± 0.11 in 2000, which increased by 0.16 and reached 7.46 ± 0.12 in 2010. In contrast, the minimum and maximum values decreased by 0.21 and 0.13, respectively (Table 2). However, the average pH_H$_2$O remained at an optimum level for agricultural production (i.e. 6–7.5), where most of the nutrients are available for plant use (Ramırez-Rodrıguez *et al.*, 2005). As can be seen in Figures 3 and 4, most locations have an average pH between 7 and 8. The W-T indicates an absence of statistical difference between measured values of pH_H$_2$O 2000 and measured values of pH_H$_2$O 2010 ($z = 1.3$, $p = 186$) (Table 2). Interestingly, the correlation obtained between the pH in 2000 and 2010 reached $r = 0.77$ ($p < 0.00$) (Figure 3; Table 3).

3.2 | So (%) changes between 2000 and 2010

It seems that the soil of the study area was poor in soil organic carbon (So) (less than 0.5%), with the average not exceeding 0.1% ± 0.02 (Table 2). The W-T showed a significant difference between the values for So in 2000 and 2010 ($z = 2.92$, $p = 0.0033$) (Table 3), which could be explained by intensive fertilization in the study area. Figure 4 shows that higher soil organic carbon values were concentrated in the western part of the study area. However, a weak non-significant correlation ($r^2 = 0.03$ and $p > 0.00$) was detected between So (%) in 2000 and 2010 (Figure 5).

3.3 | NO_3^- (ppm) changes between 2000 and 2010

The average of NO_3^- increased from 15.2 ± 2.3 ppm in 2000 to 19.9 ± 1.6 ppm in 2010 (Table 2). Tracking NO_3^- concentrations in Figure 2 showed a remarkable increase in NO_3^- content in 2010, while the spatial distribution showed an increase of NO_3^- content in the central and

TABLE 2 Statistical analysis of some soil properties in both 2000 and 2010 ($n = 55$)

Soil characteristics	Min	Max	Range	Median	$\bar{x}$	S_x	V. co	Sk.	Ku.	$\bar{x}$ error
pH_H_2O (2000)	5.01	9.40	4.39	7.30	7.18	0.81	0.11	−0.50	0.62	0.11
pH_H_2O (2010)	4.80	9.27	4.47	7.46	7.31	0.85	0.12	−0.72	0.45	0.12
So % (2000)	0.00	0.20	0.20	0.06	0.06	0.04	0.70	0.83	1.87	0.01
So % (2010)	0.02	0.99	0.97	0.04	0.07	0.13	1.87	5.95	37.38	0.02
NO_3^- ppm (2000)	1.00	95.0	94.0	10.0	15.2	16.8	1.11	2.49	7.75	2.29
NO_3^- ppm (2010)	3.12	61.4	58.3	16.7	19.9	11.8	0.59	1.24	1.74	1.61
P ppm (2000)	30.0	3,540	3,510	211	392	624	1.59	4.03	16.5	84.9
P ppm (2010)	21.3	4 070	4 040	187	370	603	1.63	4.47	23.4	82.0
K ppm (2000)	64.0	1 230	1 160	290	350	218	0.62	1.79	3.93	29.7
K ppm (2010)	74.6	989	914	268	336	202	0.60	1.34	1.44	27.5
Mg ppm (2000)	15.0	1 130	1 110	298	375	262	0.70	1.08	0.52	35.6
Mg ppm (2010)	29.6	1 110	1 080	291	351	221	0.63	1.07	1.10	30.0
Zn ppm (2000)	0.30	13.1	12.8	1.50	2.43	2.36	0.97	2.83	9.02	0.32
Zn ppm (2010)	0.26	17.3	17.0	2.10	2.52	2.40	0.95	4.26	23.3	0.33
Cu ppm (2000)	0.40	15.9	15.5	4.30	4.77	2.76	0.58	1.75	4.43	0.38
Cu ppm (2010)	0.42	15.0	14.6	4.52	4.67	2.48	0.53	1.34	3.89	0.34
Mn ppm (2000)	25.3	662	637	273	269	182	0.68	0.25	−1.30	24.8
Mn ppm (2010)	20.7	504	483	198	236	158	0.67	0.17	−1.51	21.5

n: Number of samples/locations; Min: Minimum, Max: Maximum; Med: Median; $\bar{x}$: Average; S_x: Standard deviation, V. co: Variation coefficient; Sk: Skewness (Pearson); Ku: Kurtosis (Pearson); $\bar{x}$ error: Standard error of the mean.

northern areas of Hajdú-Bihar county in 2010 (Figure 4). The W-T reveals that NO_3^- in 2010 was statistically different and higher than NO_3^- (ppm) in 2000 ($z = 3.33$, $p = 0.000$) (Table 3). Furthermore, Figure 5 shows a weak correlation ($r^2 = 0.071$ and $p > 0.00$) between NO_3^- (ppm) in both 2000 and 2010 (Table 4). Regardless of fact that NO_3^- is highly soluble, and could be easily washed in with the soil solution, the main point was to compare the soil content of NO_3^- in the different sampling periods.

3.4 | P (ppm) changes between 2000 and 2010

Within the study area, the average available P decreased from 392 ppm in 2000 to 350 ppm in 2010; the median did not change and remained at almost the same level (Table 2, Figure 3). Interestingly, the W-T showed no statistical difference between P in both years studied (Table 3). However, a weak correlation between P (ppm) in 2000 and 2010 ($r^2 = 0.39$ and $p < 0.00$) (Table 4, Figure 5) was recorded.

3.5 | K (ppm) changes between 2000 and 2010

Like P, K decreased slightly from 350 ppm in 2000 to 336 ppm in 2010; the median decreased from 290 ppm (2000) to 268 ppm (2010) (Table 2, Figure 3). The W-T showed no statistical difference between K values in both the years studied (Table 3). Also, a weak correlation between K (ppm) in 2000 and 2010 ($r^2 = 0.20$ and $p < 0.00$) (Figure 5) was noted. Notably, the spatial distribution showed a higher value (red colour) concentrated in the central part of the study area (Figure 4).

3.6 | Mg (ppm) changes between 2000 and 2010

The average Mg changed from 375 in 2000 to 351 in 2010; nonetheless, the minimum, maximum and median changed by ±10 ppm (Table 2, Figure 3). The spatial distribution showed a higher value (red colour) concentrated in the southern and northern parts of the study area (Figure 4).

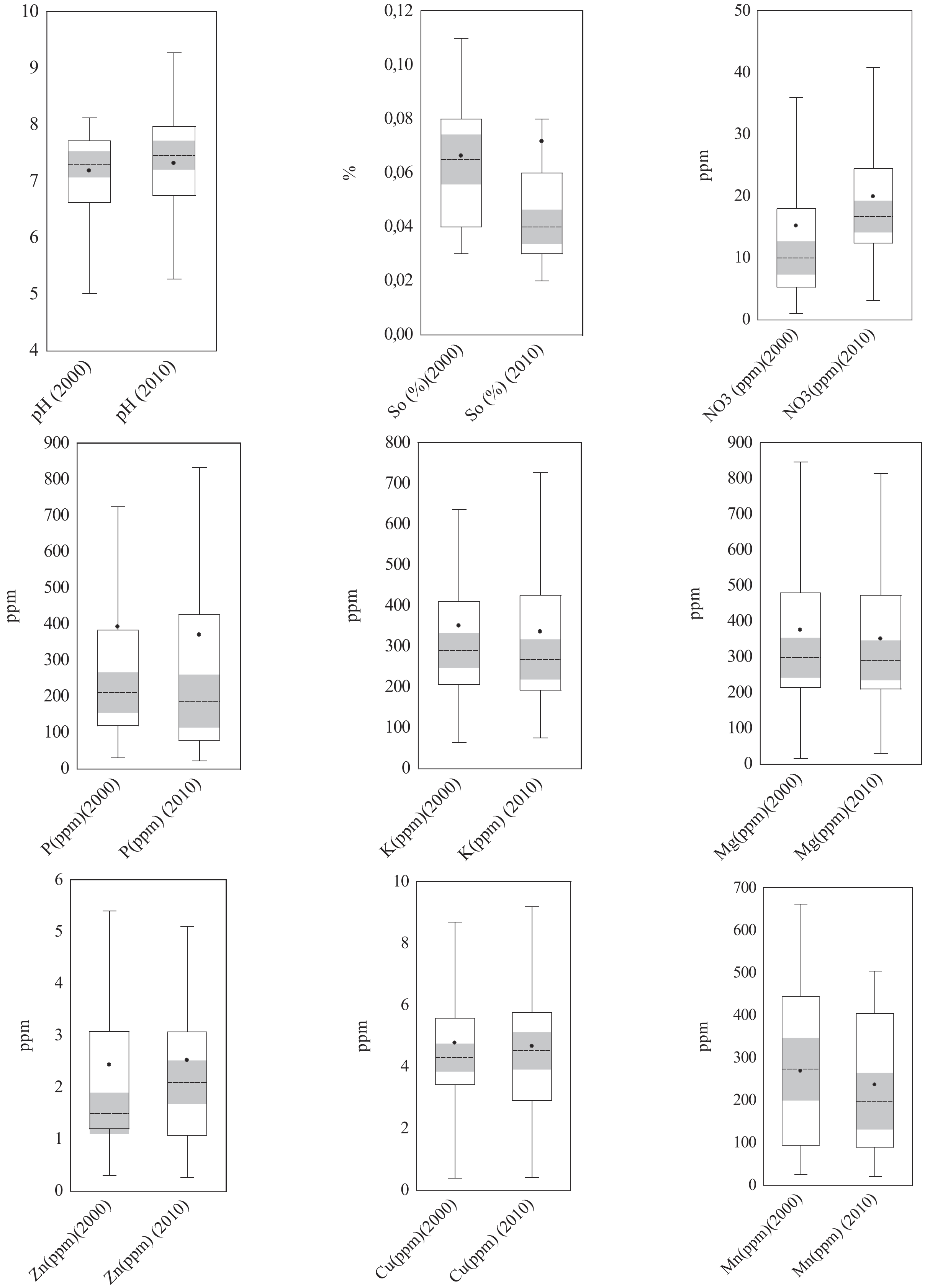

FIGURE 3 Box plot analysis for soil variables studied in 2000 and 2010

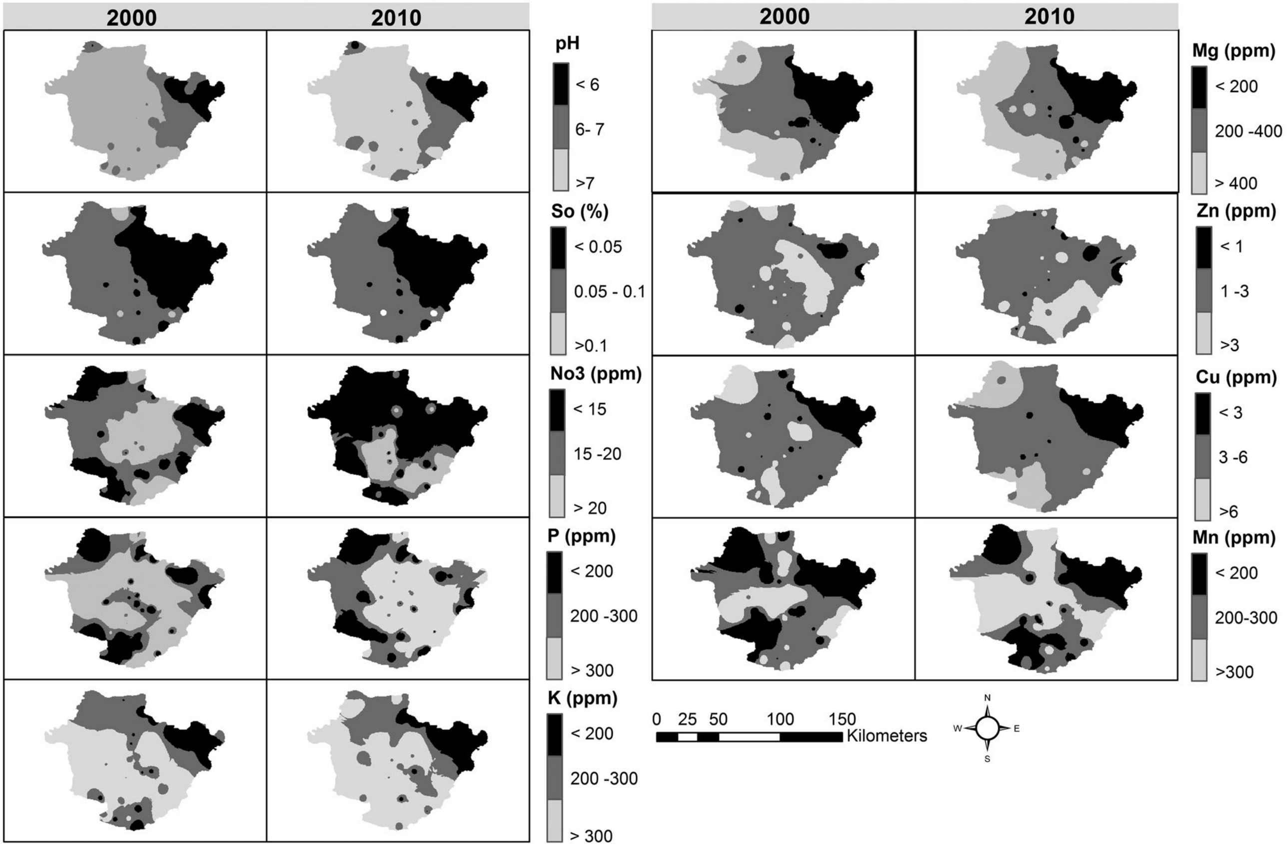

FIGURE 4 Spatial variability of soil variables studied in 2000 and 2010

TABLE 3 Wilcoxon *T*-test analysis for studied soil properties

	W	*Z*	*p*	Sig.
pH$_{(2010)}$ versus pH$_{(2000)}$	1 290	1.32	0.186	-
So$_{(2010)}$ versus So$_{(2000)}$	955	2.93	0.003	**
$NO_3^{-}{}_{(2010)}$ versus $NO_3^{-}{}_{(2000)}$	956	3.33	0.0008	**
P$_{(2010)}$ versus P$_{(2000)}$	1 380	0.765	0.444	-
K$_{(2010)}$ versus K$_{(2000)}$	1 560	0.696	0.487	-
Mg$_{(2010)}$ versus Mg $_{(2000)}$	1 480	0.215	0.830	-
Zn$_{(2010)}$ versus Zn$_{(2000)}$	1 390	0.726	0.468	-
Mn$_{(2010)}$ versus Mn$_{(2000)}$	1 340	1.02	0.307	-
Cu$_{(2010)}$ versus Cu$_{(2000)}$	1 460	0.323	0.747	-

The W-T clearly indicates no statistical difference in Mg concentration between 2000 and 2010 ($z = 0.21$, $p = 0.82$) (Table 3). However, the correlation between the Mg measured in 2000 and in 2010 was good ($r^2 = 0.64$ and $p < 0.00$) (Table 4, Figure 5).

3.7 | Zn (ppm) changes between 2000 and 2010

The average of Zn in the study area did not change between 2000 and 2010, and remained within 2.5 ppm (Table 2, Figure 3). The spatial distribution showed some samples where the Zn concentration was higher in 2000 and then decreased in the central part of the study area, while most samples did not show any changes (Figure 4). However, these changes were not significant (Table 3) and the correlation between Zn (ppm) in 2000 and 2010 was weak ($r^2 = 0.061$ and $p < 0.00$) (Figure 5).

3.8 | Cu (ppm) changes between 2000 and 2010

Similar to Zn, Cu did not change between 2000 and 2010, and the average remained at 4.7 ppm (Table 2, Figure 3). However, some points in the central part showed an increase in Cu concentration (Figure 4) in 2010. Furthermore, the minimum and maximum values remained

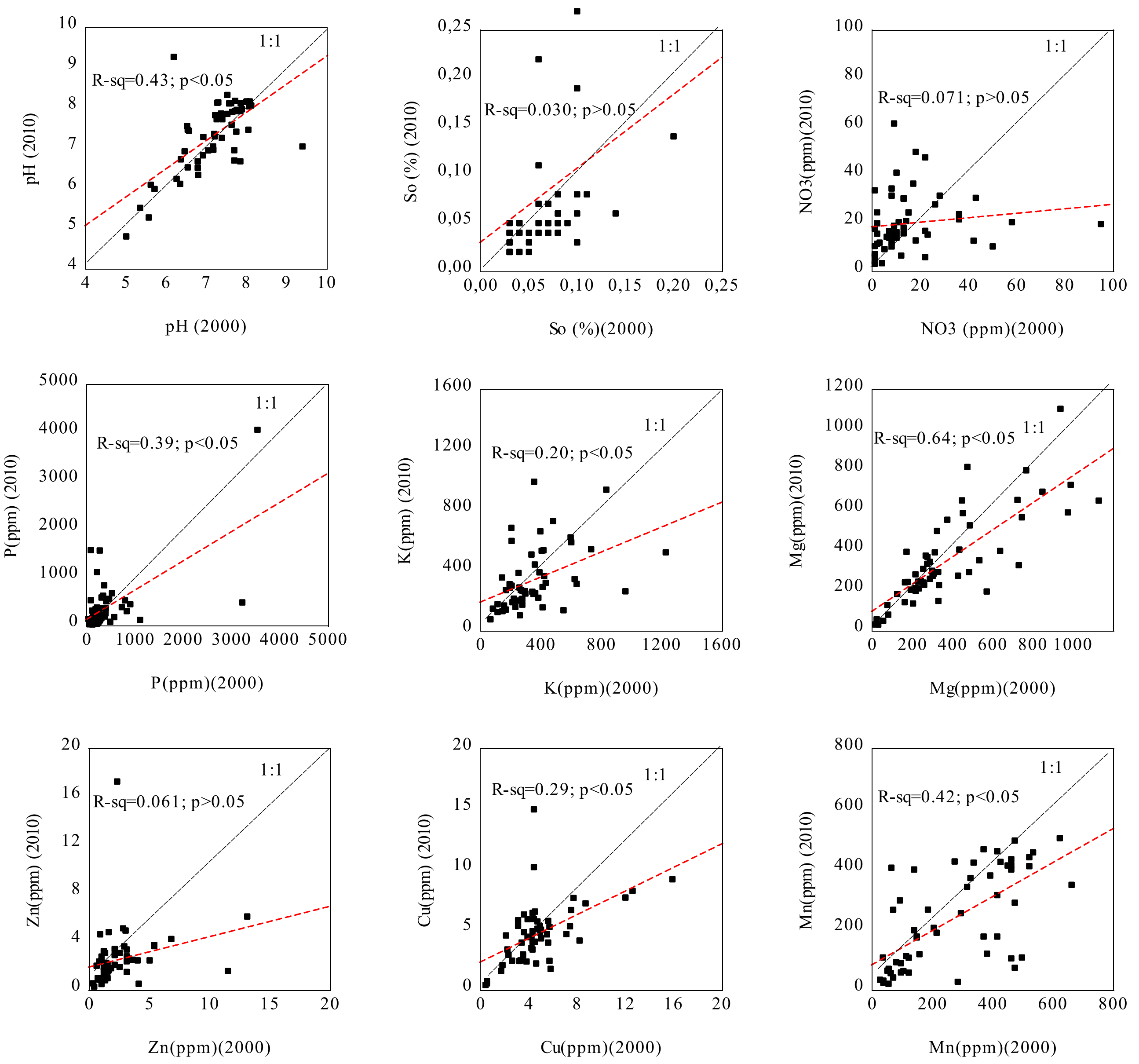

FIGURE 5 Scatter plot between soil measurement data for each characteristic between 2000 and 2010 in the western part of Hungary [Colour figure can be viewed at wileyonlinelibrary.com]

almost the same, with no significant changes detected, as can be seen in Table 3.

3.9 | Mn (ppm) changes between 2000 and 2010

The results in Table 2 show that the Mn concentration decreased from 269 ppm in 2000 to 236 ppm in 2010, although this change was not significant (Table 3). The correlation between Mn concentrations obtained in 2000 and 2010 was weak ($r^2 = 0.42$ and $p < 0.00$) (Figure 4).

4 | DISCUSSION

Soil plays a fundamental role in agricultural production in Hungary. The main goal of this research was to investigate the impact of agricultural activities on certain soil characteristics. Of many physical and chemical soil characteristics, in this study the soil properties were selected on the following bases:

- availability of the data for the same locations/soil sample for each property (i.e. pH, So,…) in both 2000 and 2010;

TABLE 4 Regression analysis between each soil variable in 2000 and 2010

Regression equation	*R*-sq	*p*	Sig.
$pH_{(2000)} = 2.616 + 0.6242\ pH_{(2010)}$	0.43	**0.00**	**
$So_{(2000)} = 0.06307 + 0.03983\ So_{(2010)}$	0.03	0.245	-
$NO_3^-{}_{(2000)} = 11.43 + 0.1880\ NO_3^-{}_{2010)}$	0.071	0.335	-
$P_{(2000)} = 151.7 + 0.6495\ P_{(2010)}$	0.39	**0.00**	**
$K_{(2000)} = 188.4 + 0.4827\ K_{(2010)}$	0.20	**0.001**	**
$Mg_{(2000)} = 42.08 + 0.9501\ Mg_{(2010)}$	0.64	**0.00**	**
$Zn_{(2000)} = 1.822 + 0.2428\ Zn_{(2010)}$	0.061	0.069	-
$Cu_{(2000)} = 1.940 + 0.6064\ Cu_{(2010)}$	0.29	**0.00**	**
$Mn_{(2000)} = 91.75 + 0.7498\ Mn_{(2010)}$	0.24	**0.00**	**

- the chosen soil properties were expected to have changed over time in the agricultural agroecosystem. In other words, some soil characteristics such as %clay, % sand and many others need considerable time to change in the soil, while the database has data only for a 10-year period. To the best of the authors' knowledge, few studies (i.e. Nagy, 2018) in Hungary have addressed the impact of intensive agriculture on the agroecosystem.

Indeed, of nine soil characteristics studied only two (So %, NO_3^-) showed a significant change according to the W-T test. Thus, the discussion will mainly focus on these characteristics, while the other properties will be discussed briefly.

After 10 years of agricultural activities results reveal that the means of pH, So, NO_3^- and Zn were higher in 2010, while the means of the rest of the properties studied were lower, as can be seen from the box plots in Table 2, and Figure 3. From the agricultural point of view, increased N and C content in the soil revealed a high input (fertilization) in the agroecosystem, especially that the main crop is maize (*Zea mays L.*). The decrease in P mean could be explained by leaching from the topsoil by irrigation and/or rainfall, and also in some locations a high concentration of $CaCO_3$ may have affected the availability and mobility of P in the soil (data not shown).

Soil serves as a major pool for carbon; thus, changes in soil carbon due to agricultural activities could alter the global climate (Luo *et al.*, 2010). In this study agricultural activities significantly affected the So (%) content in the soil for many reasons: (i) preparing soil for sowing requires deep tillage as the main crop in Debrecen is maize, and this crop has an extensive root system which enhances the soil's organic carbon; despite this, tillage could increase the decomposition of So and release CO_2 into the atmosphere; (ii) most agricultural management systems in Debrecen recycle plant residuals, which significantly increases So inputs. In contrast, many reports clearly indicate the negative impact of agricultural activities on total N and So (%) in soil in comparison to pasture or forest lands (Lemenih & Itanna, 2004; Yimer *et al.*, 2007; Arnhold *et al.*, 2015). However, the ultimate interaction between agroecosystem components, namely, climate, soil and crop management, influences the So content in the soil.

A decrease in Mn concentration was noted in 2010. This could be clearly understood as a consequence of the increase in pH and So (Figure 4), where there is a possibility of unavailable Mn for plants due to Mn-chelates. Also, an antagonism between Zn and Mn had been previously reported by Aref (2012) which could affect the availability of Mn in the soil.

A growing body of literature has indicated the negative impact of traditional agricultural activities on soil quality (Mohammed *et al.*, 2021a, b); for instance, Hossain and Salam (2019) in Bangladesh; Zalidis *et al.* (2002) in the Mediterranean region; Yimer *et al.* (2007) in Ethiopia; Arnhold *et al.* (2015) in Kenya; Luo *et al.* (2010) in Australia.

One of the limitations of this study is that soil samples were collected and analysed only for the topsoil/top horizon (0–30 cm), and the rest of the soil horizons (i.e. B, C) were not studied due to a lack of data. However, comparing changes over time in different layers could provide a comprehensive picture of what has happened in each location and could give a better understanding of nutrient movement. Also, it could offer differing explanations, information about $CaCO_3$ cycle in each location. In other words, if we have full soil profile data, $CaCO_3$ could be easily tracked from A to B, or even to C horizons. This open question will motivate future projects to focus on collecting data from all soil horizons, not just from the top layers. On the other hand, 10 years is a relatively short period for indicating a significant change in soil properties; however, this research has successfully indicated some significant changes due to agricultural activities. Also, one of the negative impacts of agricultural activities is subsoil compaction in the B-horizon due to tillage (Arnhold *et al.*, 2015); however, this vital consequence was not investigated.

Farmers, stakeholders, agricultural planners and decision makers may be interested in the output of this research, which can be useful in areas where more attention should be paid to the sustainability of land use and natural resources, as well as to the creation of a constructive plan for monitoring and measuring the inputs and outputs of the agricultural biosystem in Debrecen, taking into consideration the drastic impact of intensive agriculture in the study area. However, a new generation of precision agriculture and low-input sustainable agriculture (LISA) seems to offer a promising management approach to soil sustainability in Hungary (Debrecen) (Nagy, 2012; Riczu *et al.*, 2012; Schmidt *et al.*, 2012; Birkás, 2018; Sisák *et al.*, 2018; Takács *et al.*, 2020).

5 | CONCLUDING REMARKS

This study was a technical report on the changes in certain soil properties between 2000 and 2010. The key findings of this study can be summarized as follows:

- the pH of the study area increased slightly and reached 7.5; however, it remains at the optimum level for most crops;
- agricultural activities significantly affected the soil content of So%, NO_3^-;
- of soil macronutrients (N, P, K), only N changed significantly in the soil, while the others decreased;
- except for Mn, soil micronutrients (Zn, Cu, Mn) did not change between 2000 and 2010.

Nevertheless, the future projection of land availability and biosphere-sustainable land-use management is essential for maintaining proper soil quality and health for future crop production.

ACKNOWLEDGEMENTS

The authors would like to thank Debrecen University for their support. Special thanks go to the Hungarian Soil Information and Monitoring System (SIMS) (Nemzeti Élelmiszerlánc-biztonsági Hivatal; Növény-, Talaj- és Agrárkörnyezet-védelmi Igazgatóság, Fenntartható Gazdálkodás Osztály), namely Mr Joseph Hefler (soil conservation officer) and Mr. Gulyás Edit for providing the original data. Also, the authors grateful to Professor Szabo Szilard for his comments on the early version of this paper before submission. Open access funding was provided by the University of Debrecen.

ORCID

Safwan Mohammed https://orcid.org/0000-0003-2311-6789

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How to cite this article: Takács, I., Amiri, M., Károly, K. & Mohammed, S. (2021) Assessing soil quality changes after 10 years of agricultural activities in eastern Hungary. *Irrigation and Drainage*, 1–13. Available from: https://doi.org/10.1002/ird.2623