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THE CHANGES OF SELECTED SOIL CHEMICAL PARAMETERS AFTER CONVERSION OF SOIL USE

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Abstract
The changes in selected chemical parameters in the soil were observed in the Gleyic Fluvisols soil type. The field experiment was established with four energy crops (*Arundo donax, Miscanthus x giganteus, Elymus elongatus, Sida hermaphrodita*) in 2012. The energy crops were fertilized with phosphorus at a rate of 40 kg ha^{-1} and potassium at a rate of 60 kg ha^{-1} each year in spring. Nitrogen fertilization was not carried out. Soil samples were taken at the beginning of the experiment in the autumn of 2012 and every autumn (2013–2018) at a depth of 0–0.3 m. The development of selected soil parameters in the time series was evaluated by trend analysis. Land management conversion influenced changes in selected chemical parameters. The annual increase in soil carbon was 0.44 t ha^{-1} year^{-1} for the *Arundo*, 0.46 t ha^{-1} year^{-1} for the *Elymus*, and 0.43 t ha^{-1} year^{-1} for the *Sida*. The content of soil organic carbon was preserved during the cultivation of *Miscanthus*. Since the establishment of the experiments, an increase in total nitrogen (155.7 kg ha^{-1} year^{-1} N for the *Arundo*, 99.0 kg ha^{-1} year^{-1} N for the *Miscanthus*, 83.7 kg ha^{-1} year^{-1} N for the *Elymus*, and 50.0 kg ha^{-1} year^{-1} N for the *Sida*) was observed. A reduction in available phosphorus (with the exemption of *Arundo*) and potassium, as well as reduction in soil reaction in the soil of the monitored energy crops, were found. The linear trends detected in energy crops experiments indicate the increase of carbon sequestration after conversion from conventional crop to energy crop cultivation.
Keywords: energy crops, Gleyic Fluvisols, trend analysis, soil organic carbon, total nitrogen, available nutrients, soil reaction

INTRODUCTION

The production of bioenergy has become an acceptable alternative to fossil fuels. In recent years, producing renewable energy from energy crops has been one of the key components of European policies, for reducing greenhouse gas emissions. Perennial energy crops have been at the centre of interest for their high yield potential and lignocellulose biomass quality (Manzone *et al.* 2014, Larsen *et al.* 2018) and have become a promising option to mitigate the effect of greenhouse gases (Schweier *et al.* 2017).

It is assumed, that the consequences of climate change in agriculture will be an increase in the number of economically significant pathogens; changes in the temperature security of agricultural plants; elongation of a main vegetation period (T above 10 °C) by 43 days in southern Slovakia and 84 days in the north of Slovakia until 2075; changes in phenological conditions; changes in precipitation distribution and humidity security and also changes of soil physical and chemical properties; accelerated decomposition of organic matter, accelerated growth of the root system; increased wind erosion, and new plant species (Ministry of the Environment of the Slovak Republic 2014).

Climate change results in soil organic matter degradation and soil degradation. In Slovakia, degradation threatens up to 70 % of the soil (Kobza 2014). Soil degradation has a gradual and cumulative character. The threat to the soil is also the decline in available nutrients related to their negative balance, and the deterioration of other chemical and physical parameters of the soil.

There are a lot of strategies to increase the soil carbon stock and two of them are energy crop cultivation and no-till soil management (Lal 2004). Perennial energy crop cultivation combines both of the mentioned strategies, because there is no soil cultivation during productive years, besides cultivation before planting. This is also why the proposed adaptation measures for preserving and increasing the amount of organic carbon in the soil (Ministry of the Environment of the Slovak Republic 2014) include planting permanent crops.

The ecological reasons for growing energy crops include their beneficial effect on the structural condition of the soil, improvement of soil water management, so limitation of unproductive water evaporation from the soil with mulch from plant residues on the soil surface, reduction of water and wind erosion, limitation of leaching of mobile forms of nitrogen during long-term exposure crops on one location, increase in content of soil organic matter, etc. (Hůla & Procházková 2002). Growing energy crops has the potential to mitigate carbon dioxide emissions by the replacement of fossil fuels and also by storing carbon in the soil due to land use change (Don *et al.* 2012, Zimmermann *et al.* 2012).

Biomass, as one of the renewable energy sources, has suitable soil-climatic conditions in the conditions of the regions of Slovakia and a wide range of uses. The advantage is that energy crops can be located in temporarily or permanently unusable areas, which cannot be used for the primary production of commodities intended for food purposes (Mandalová *et al.* 2017).

Miscanthus x giganteus is the most widely cultivated energy crop with a positive impact primarily on reducing greenhouse gas emissions (Anderson-Teixeira *et al.* 2009, Hillier *et al.* 2009). Currently, attention is paid to other types of energy crops (*Panicum virgatum*, *Camelina sativa*, *Elymus elongatus*, *Sorghum* spp., *Amaranthus* spp., *Arundo donax*).

Carbon accumulation under energy crops is similar to under perennial grasses (Anderson-Teixeira *et al.* 2009) or under native pasture (Dondini *et al.* 2009). Carbon sequestration or carbon loss from the soil in the conversion of used agricultural land or natural stands to energy crops depends on plant species (Schneckenberger & Kuzyakov 2007, Hillier *et al.* 2009, Cattaneo *et al.* 2014, Impagliazzo *et al.* 2017, Martani *et al.* 2021).

The conversion of agricultural land to stands of energy plants appears to be a better way of storing carbon in the soil than the destruction of natural vegetation for purposes of their cultivation. Soil carbon losses from agricultural land conversion, as well as natural vegetation conversion, are dependent on the type of energy plant (Anderson-Teixeira *et al.* 2009, Hillier *et al.* 2009). Volk *et al.* (2004) recommend that carbon sequestration under energy crops should be at least 0.25 t ha^{-1} $year^{-1}$ C. Estimates of carbon sequestered under energy crops, according to Sartori *et al.* (2007) range between 0.6–3.0 t ha^{-1} $year^{-1}$ C. The positive influence of converting arable land into stands of energy plants, and therefore increasing organic carbon in the soil is possible, due to the high amount of crop residues entering the soil when growing energy crops (Toenshoff *et al.* 2013, Wachendorf *et al.* 2017).

This study aimed to evaluate the changes of selected soil chemical parameters in long-term experiment of the energy crops cultivation on the soil type Gleyic Fluvisols.

MATERIAL AND METHODS

The field experiment of the permanent energy crops was initiated in 2012 at the experimental station of the National Agricultural and Food Centre – Plant Production Research Institute – Institute of Agroecology in Michalovce. The experimental workplace is situated in Milhostov (48°40'02.3"N. 21°43'51.2"E), located in the central part of the East-Slovak Lowland at the altitude of 101 m a.s.l.

The monitored location is included in the climatic region T 03 (Linkeš *et al.* 1996), which is characterized as warm, very dry, lowland. The long-term normal for the annual air temperature in Milhostov (1981–2010) is 9.4 °C (16.6 °C during the growing season) and the long-term normal for precipitation is 567 mm (374 mm during the growing season) (Mikulová *et al.* 2020).

Changes in selected chemical properties of the soil were monitored for the energy crops *Arundo donax*, *Miscanthus x giganteus*, *Elymus elongatus*, *Sida hermaphrodita*. The energy crops were fertilized with phosphorus at a rate of 40 kg ha^{-1} and potassium at a rate of 60 kg ha^{-1} each year in spring and the nitrogen fertilization was not carried out. The variant size was 12 m^2 for *Arundo*, *Miscanthus*, and *Sida* and 9 m^2 for *Elymus*, whereas each variant was three times repeated.

The soil type was Gleyic Fluvisols (IUSS Working Group WRB 2015). According to the Novak classification scale (Zaujec *et al.* 2009) this soil subtype belongs to medium-heavy and loamy soils. Soil particle size distribution before establishment of experiments with energy crops is shown in Table 1. The average content of clay particles was 40.3 %.

Table 1

Soil particle size distribution before experiment establishment

Soil fraction	**Arundo**	**Miscanthus**	**Elymus**	**Sida**
1st fraction [%] clay (< 0.001 mm)	20.6	20.8	20.8	21.6
2nd fraction [%] soft and middle silt (0.001–0.01 mm)	19.0	18.8	18.8	20.0
3rd fraction [%] crude silt (0.01–0.05 mm)	28.7	29.5	29.5	28.6
4th fraction [%] soft sand (0.05–0.25 mm)	25.6	24.7	24.7	23.8
5th fraction [%] middle sand (0.25–2 mm)	6.1	6.2	6.2	6.0
Content of particle I. category (< 0.01 mm)	39.6	39.6	39.6	41.6
Soil evaluation	medium-heavy loamy soil	medium-heavy loamy soil	medium-heavy loamy soil	medium-heavy loamy soil

Before starting the experiments, the average value of the total sorption capacity was high, in terms of the degree of saturation of the sorption complex, the soil was fully saturated. According to Hraško *et al.* (1962), a higher degree of saturation of the sorption complex is in soils located in dry areas, and therefore the values found for loamy of Gleyic Fluvisols located in Milhostov were also high. The dominant component in the soil was fulvic acids, and therefore the humus is of lower quality (Table 2).

Table 2

The chemical properties of the topsoil before starting the experiment

Parameters	***Arundo***	***Miscanthus***	***Elymus***	***Sida***
Soil total acidity [mmol kg^{-1}]	13	10	11	9
Amount of exchange basic cations [mmol kg^{-1}]	335	313	313	303
Total sorption capacity [mmol kg^{-1}]	348	323	324	312
Degree of saturation of the sorption complex [%]	96.3	96.9	96.6	97.1
Total nitrogen content [mg kg^{-1}]	1516	1554	1561	1609
Available phosphorus content [mg kg^{-1}]	103.9	98.4	87.5	95.3
Available potassium content [mg kg^{-1}]	214.0	231.2	227.7	237.5
Available magnesium content [mg kg^{-1}]	247.9	294.9	315.3	328.5
Exchangeable calcium content [mg kg^{-1}]	4758	4655	4755	4664
Soil reaction in KCl	6.82	6.69	6.68	6.65

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Parameters	*Arundo*	*Miscanthus*	*Elymus*	*Sida*
Soil organic carbon [g kg^{-1}]	14.27	14.67	14.64	14.86
Carbon content of humus substances [g kg^{-1}]	4.10	4.52	4.38	4.37
Carbon content of humic acids [g kg^{-1}]	2.03	2.05	2.03	2.18
Carbon content of fulvic acids [g kg^{-1}]	2.08	2.47	2.35	2.19
Ratio of carbon of humic acids to carbon of fulvic acids	0.98	0.83	0.86	1.00
Ratio of carbon to nitrogen	9.41	9.44	9.38	9.24

Soil samples were taken from a depth of 0 to 0.3 m before starting the beginning of the experiment in the autumn 2012 and annually in the autumn (2013–2018). The disturbed soil samples were analyzed using well-known methodologies to determine the following chemical soil parameters: soil organic carbon was determined by Tjurin method (ISO 14235 1998), total nitrogen contents by Kjeldahl method (Hrivňáková & Makovníková *et al.* 2011), available phosphorus and potassium by Mehlich III method (Mehlich 1984) and exchange soil reaction in 1 mol dm^{-3} KCl solution was determined using potentiometric method (ISO 10390 2005). The development of selected soil chemical parameters in the time series was evaluated by trend analysis. A linear trend was used, in which the coefficients were estimated by the linear equation $y = a \times x + b$ (Chajdiak 2005), based on which can be assumed the trend of the development of the observed soil parameters (soil organic carbon, total nitrogen, soil exchange reaction, available phosphorus, and potassium) in a seven-year time series.

Differences between treatment means were assessed by the least significant difference (LSD) test. All statistical analyses were performed using the Stat-graphics software package. Interrelationships between monitored parameters were evaluated using regression analysis. The time series were displayed by line graphs.

RESULTS AND DISCUSSION

Soil organic matter is the most important supply of organic carbon in the biosphere and, depending on conditions can eliminate or sequestrate greenhouse gases in the environment (Barančíková *et al.* 2019). In our climatic conditions, the decomposition processes are dependent on the chemical composition of plant residues. It is assumed that the change in land use, so the transition to the cultivation of perennial energy crops will enable the retention and even storage of carbon in the soil. In the seven years, the organic carbon content in the soil of energy crops ranged from 14.03 g kg^{-1} to 15.95 g kg^{-1} (Table 3), and after conversion to the humus, its content corresponded to the medium stock (Fecenko & Ložek 2000).

The content of soil organic carbon was statistically significantly dependent on the energy crop and highly significantly on the year (Table 3). The highest average soil organic carbon contents were recorded in 2018. In terms of crops, the highest average organic carbon contents were found when growing *Sida* (14.90 g kg^{-1}) and *Elymus* (14.78 g kg^{-1}).

Table 3

Changes in the organic carbon content [g kg^{-1}] in the cultivation of energy crops

Year	*Arundo*	*Miscanthus*	*Elymus*	*Sida*	Average
2012	14.27	14.67	14.64	14.86	**14.61**
2013	14.31	14.80	14.77	14.69	**14.64**
2014	14.29	14.61	14.86	14.99	**14.69**
2015	14.22	14.69	14.42	14.59	**14.48**
2016	14.29	14.03	14.29	14.56	**14.29**
2017	14.46	14.57	14.52	14.77	**14.58**
2018	15.08	15.01	15.95	15.84	**15.47**

The influence of different soil uses on changes in its properties is manifested only after a long time. Time series analysis over five years or more years can provide a more objective view of the development evaluation of a specific soil property and can form the basis for various analyses and forecasting. Chajdiak (2005) considers as a time series a set of values of the evaluated parameter, that occur over some time. When modelling the time series, the trend component is used, which indicates the direction of development of the evaluated indicator over time. The development trend of soil organic carbon in energy crops was determined using a regression model expressed by the linear equation $y = ax + b$ (Chajdiak 2005), based on which the main development trend can be predicted.

The trend in the development of soil organic carbon content (Figure 1) was expressed by the linear equation $y = 0.0975x + 14.027$ for *Arundo*, $y = -0.0007x + 14.629$ for *Miscanthus*, $y = 0.1021x + 14.37$ for *Elymus* and $y = 0.0954x + 14.519$ for *Sida*. The trend of the development of the content of soil organic carbon for individual energy crops shows its annual increase by 0.098 g kg^{-1} C for *Arundo*, by 0.102 g kg^{-1} C for *Elymus*, and by 0.095 g kg^{-1} C for *Sida*.

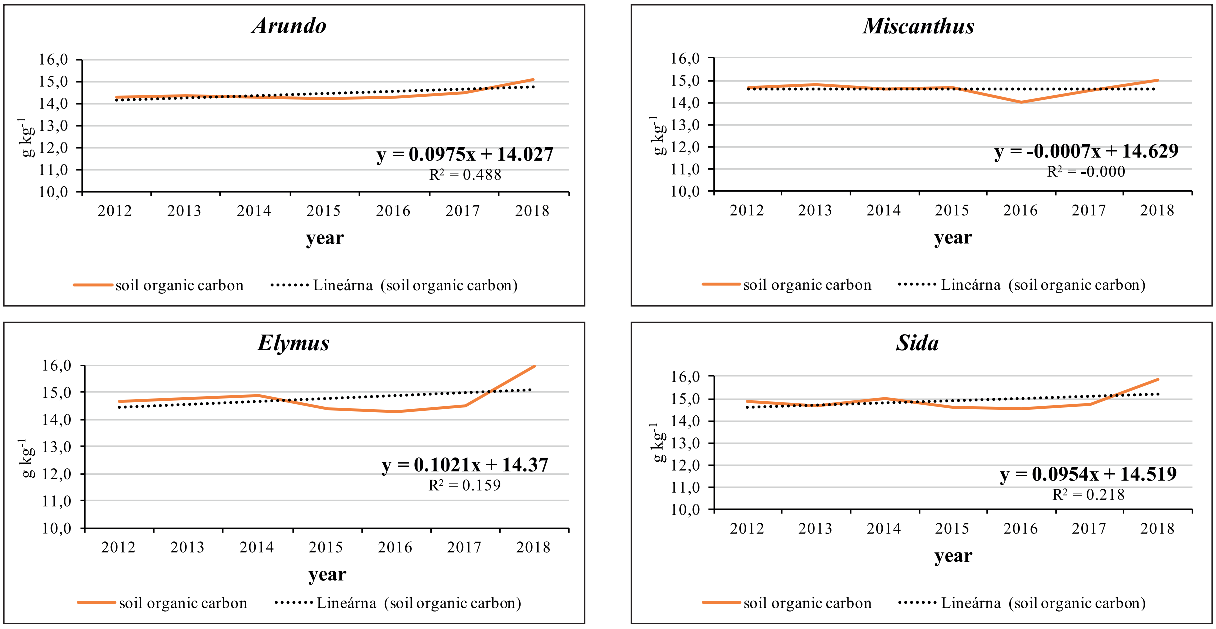

Figure 1 The development trend of soil organic carbon in energy crops

The annual increase in soil organic carbon for the mentioned crops after conversion to the content in topsoil up to 0.3 m and at an average bulk density of the soil of 1 500 kg m^{-3}, represents an annual increase of 0.44 t ha^{-1} C for *Arundo*, 0.46 t ha^{-1} C for *Elymus* and 0.43 t ha^{-1} C for *Sida*, which exceeds the minimum carbon values of 0.25 t ha^{-1} year^{-1} for carbon sequestration recommended by Volk *et al.* (2004). Similarly, Fagnano *et al.* (2015), Impagliazzo *et al.* (2017) and Martani *et al.* (2021) found, that the *Arundo* cropping can have a positive effect on the storage of carbon in the soil due to the absence of soil tillage and abundance of crop residues that every year return to the soil. The soil organic carbon sequestration rates in the 0–0.3 m layer of *Arundo* agree with research by Cattaneo *et al.* (2014); Monti and Zegada-Lizarazu (2016), Martani *et al.* (2021). The annual carbon sequestration of *Arundo*, *Elymus*, and *Sida* approaches the values reported by Sartori *et al.* (2007). The indicated trend in the soil organic carbon content indicates the possibility of carbon sequestration after converting agricultural soil into energy crops.

The linear trend of the development of soil organic carbon at the *Miscanthus* indicates the maintenance of its original content in the soil. This finding contrasts with the results of Rowe *et al.* (2024), who when growing *Miscanthus* for five years found out that surface soil organic carbon stocks were increased. According to Martani *et al.* (2021), *Miscanthus* soil organic carbon sequestration rates were lower than for *Arundo*.

Changes in soil organic carbon content due to different soil uses are relatively small compared to large soil organic carbon reserves (Bhattacharyya *et al.* 2013).

Statistical evaluation of selected soil parameters in the energy crops is shown in the Table 4.

Table 4

Statistical evaluation of selected soil parameters in the energy crops

Source variability	Factor	Observed parameter				
		C [g kg^{-1}]	N [mg kg^{-1}]	pH/KCl	P [mg kg^{-1}]	K [mg kg^{-1}]
Crop	*Arundo*	14.42 a	1492 a	6.70 c	100.3 c	223.1 a
	Miscanthus	14.63 ab	1542 b	6.67 c	95.0 b	227.6 ab
	Elymus	14.78 b	1534 b	6.62 b	84.3 a	229.7 b
	Sida	14.90 b	1533 ab	6.57 a	87.7 a	233.0 b
Year	2012	14.61 a	1560 cd	6.71 e	96.3 c	227.6 a
	2013	14.64 a	1428 a	6.67 de	94.4 bc	233.6 a
	2014	14.69 a	1415 a	6.71 e	89.5 a	221.0 a
	2015	14.48 a	1586 d	6.66 cd	90.3 ab	246.4 b
	2016	14.29 a	1497 b	6.60 bc	89.3 a	224.0 a
	2017	14.58 a	1516 bc	6.60 b	88.7 a	221.2 a
	2018	15.47 b	1676 e	6.53 a	94.1 bc	225.0 a

where: C – soil organic carbon, N – total nitrogen, pH/KCl – exchange soil reaction, P – available phosphorus, K – available potassium, letters (a, b, c, d, e) between factors refer to statistically significant differences (a = 0.05) – LSD test

At energy crop plots the average content of total nitrogen was in the range from 1334 to 1697 mg kg^{-1} (Table 5). The soil total nitrogen content was statistically highly significantly dependent on the year.

Table 5

Changes in the total nitrogen content [mg kg^{-1}] in the cultivation of energy crops

Year	*Arundo*	*Miscanthus*	*Elymus*	*Sida*	Average
2012	1516	1554	1561	1609	**1560**
2013	1334	1456	1478	1445	**1428**
2014	1368	1456	1447	1388	**1415**
2015	1543	1596	1550	1653	**1586**
2016	1485	1512	1499	1490	**1497**
2017	1530	1524	1508	1502	**1516**
2018	1669	1695	1697	1641	**1676**

On average, the highest contents of total nitrogen were recorded in 2018 analogously to soil organic carbon, because the content of total nitrogen is closely related to the content of soil organic carbon. Significantly positive dependence ($r = 0.52$; $n = 28$) was confirmed between soil organic carbon and soil total nitrogen. A linear correlation between organic carbon and total nitrogen in the topsoil with the value of the correlation coefficient $r = 0.94$ was recorded by Růžek *et al.* (2009) and $r = 0.50$ Wang *et al.* (2009). The increase in total nitrogen content in the 0–0,3 m layer when growing energy crops is a consequence of the increase in soil organic carbon content in the same soil layer as confirmed by Kahle *et al.* (2013) and Ferrarini *et al.* (2021).

Analogy, the development trend of the total nitrogen content in the soil of the energy crops was also determined using a regression model expressed by the linear equation $y = ax + b$ (Chajdiak 2005). The development trend of the total nitrogen content (Figure 2) was expressed by the linear equation y = 34.5714x + 1353.9 for *Arundo*, y = 21.964x + 1454 for *Miscanthus*, y = 18.571x + 1460 for *Elymus* and y = 11.143x + 1488 for *Sida*. The development of the total nitrogen content in individual energy crops results in its increase. The annual increase in total nitrogen was 34.6 mg kg^{-1} in *Arundo*, 22.0 mg kg^{-1} in *Miscanthus*, 18.6 mg kg^{-1} in *Elymus*, and 11.1 mg kg^{-1} in *Sida*. The annual increase in total nitrogen after conversion to the content in the topsoil up to 0.3 m and at an average bulk density of the soil of 1 500 kg m^{-3}, represents an increase of 155.7 kg ha^{-1} $year^{-1}$ N for *Arundo*, 99.0 kg ha^{-1} $year^{-1}$ N for *Miscanthus*, 83.7 kg ha^{-1} $year^{-1}$ N for *Elymus*, and 50.0 kg ha^{-1} $year^{-1}$ N for *Sida*.

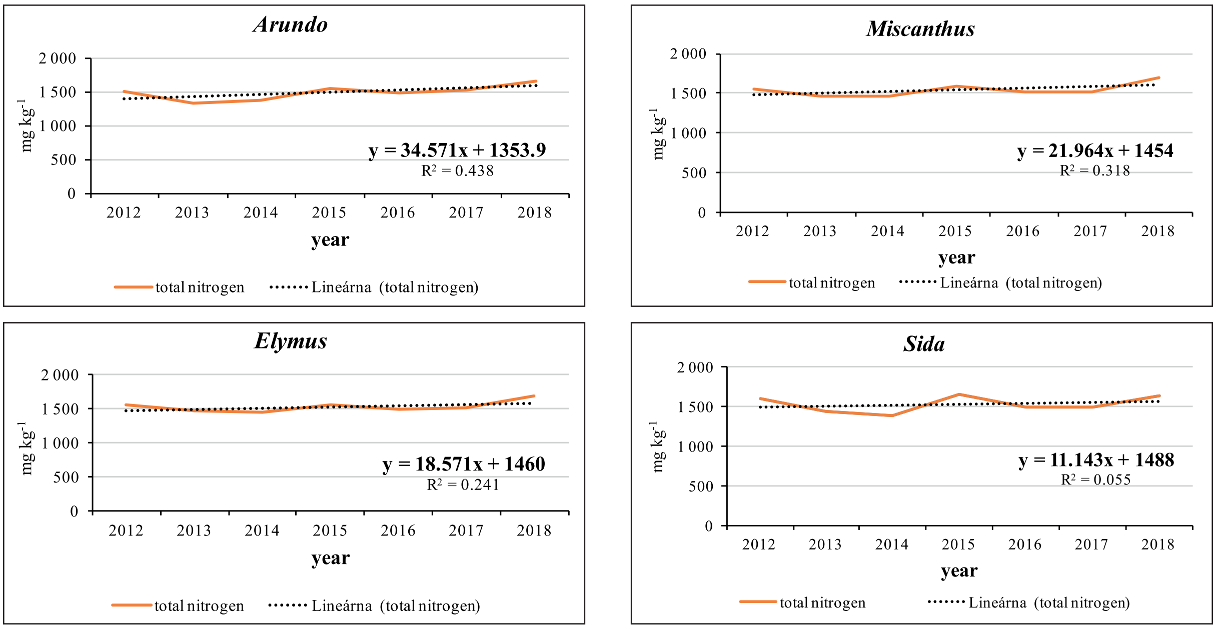

Figure 2 The development trend of total nitrogen in the energy crops

We calculated a rate of nitrogen fixation of 155.7 kg ha^{-1} $year^{-1}$ N for *Arundo* and 99.0 kg ha^{-1} $year^{-1}$ N for *Miscanthus*, which is consistent with the results of Martani *et al.* (2021), who found nitrogen fixation of 160 kg ha^{-1} $year^{-1}$ N for *Arundo,* and 120 kg ha^{-1} $year^{-1}$ N for *Miscanthus*.

Fagnano *et al.* (2015) reported that organic nitrogen in the topsoil is higher, mainly because environmental constraints, like summer drought, may have reduced the mineralization thus enhancing its accumulation in soil organic matter. In monitoring years average annual temperature during vegetation was higher from 0.6 to 2.6 °C and the average annual rainfall was lower than the long-term normal from 1981 to 2010 therefore the content of total nitrogen in the soil could increase in the monitored period. This trend of the increase in total nitrogen in the soil after the conversion of agricultural soil to energy crop cultivation is related to the sequestration of carbon in the soil, as nitrogen is part of the created organic matter.

An important indicator of agrochemical characteristics of soils is the soil reaction, which affects the growth and development of cultivated plants, and the activity of microorganisms in the soil and has great importance in the soil-forming process (Ložek *et al.* 1995). Soil acidity affects the mobility and accessibility of the most important plant nutrients, especially phosphorus and potassium.

The exchange soil reaction ranged between 6.47 to 6.82 (Table 6) in the soil under cultivated energy crops and this range is classified as slightly acidic to neutral concerning the assessment criteria (Slovak Republic, Regulation No. 151/2016 2016). This exchange soil reaction is optimum for energy crops. Di Tomaso (1998) found out, that *Arundo* can grow in all types of soils, from clay to sand, with soil pH ranging from 5.0 to 8.7.

Table 6
Changes in the values of exchange soil reaction in the cultivation of energy crops

Year	*Arundo*	*Miscanthus*	*Elymus*	*Sida*	Average
2012	6.82	6.69	6.68	6.65	**6.71**
2013	6.77	6.70	6.62	6.60	**6.67**
2014	6.76	6.74	6.72	6.63	**6.71**
2015	6.71	6.66	6.64	6.61	**6.66**
2016	6.67	6.66	6.57	6.51	**6.60**
2017	6.62	6.65	6.58	6.54	**6.60**
2018	6.54	6.59	6.51	6.47	**6.53**

The values of the exchange soil reaction were statistically highly significantly dependent on the energy crop and year. In terms of the cultivated crops, significantly higher average values of exchange soil reaction were found when growing *Arundo* (6.70) and *Miscanthus* (6.67) and the lowest when growing *Sida* (6.57).

The trend of the development of exchange soil reaction values for all four energy crops (Figure 3) points to its slight decrease. The development of soil reaction values was expressed by the linear equation $y = -0.0439x + 6.8743$ for *Arundo*, $y = -0.0171x + 6.7386$ for *Miscanthus*, $y = -0.0264x + 6.7229$ for *Elymus*, and $y = -0.0279x + 6.6843$ for *Sida*. The higher soil reaction was measured at the beginning of the experiment (in 2012). Insufficient replacement of annual calcium losses caused a moderate decrease in soil reaction in 2018 (Figure 3). The higher decrease in soil reaction was found in *Arundo* and the lowest decrease in soil reaction was found in *Miscanthus*. Annual losses of calcium from the soil, by leaching and by fertilizers are reported by Bizík *et al.* (1998) at level 350 kg ha^{-1} CaO. With the current trend, the soil reaction may be reduced in the following years.

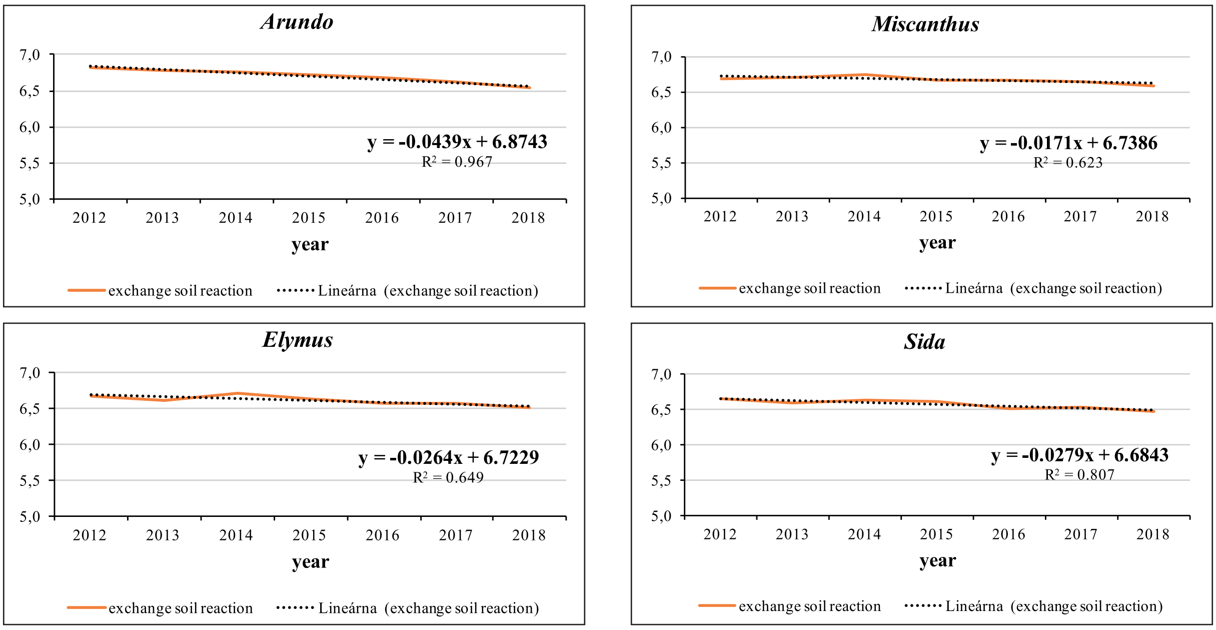

Figure 3 The development trend of the values of the exchange soil reaction in the energy crops

The optimal soil reaction for growing *Miscanthus* is in the range of 5.5–6.7, and a reduction in yield was observed at a soil reaction above 7.0 (Strašil 2009). For *Sida*, the optimal soil reaction is neutral (Piszczalka & Macák 2009). Siaudinis *et al.* (2017), however, found that *Sida* responded positively to fertilization and liming even when grown on acidic soil. On acidic soils, before planting energy crops, it is necessary to implement crop-producing measures, that is, to implement not only fertilization but also liming of the soil, so acid soil reaction does not limit the achieved yields even in the case of long-term cultivation of energy crops.

The nutrient contents belong to the soil parameters affecting its fertility. The contents of accessible phosphorus were in the range of 78.0–103.9 mg kg^{-1} (Table 7). In terms of criteria for the evaluation of chemical analysis of the arable soils (Slovak Republic, Regulation No. 151/2016 2016), content of available phosphorus in the soil ranged from satisfactory to good.

The content of available phosphorus was highly statistically dependent on the energy crop and year (Table 7). The highest average contents of available phosphorus in the cultivated crops soils were found in the cultivation of *Arundo* (100.3 mg kg^{-1}) and the lowest in the cultivation of *Elymus* (84.3 mg kg^{-1}) and *Sida* (87.7 mg kg^{-1}).

Table 7

Changes in the available phosphorus content [mg kg^{-1}] in the cultivation of energy crops

Year	*Arundo*	*Miscanthus*	*Elymus*	*Sida*	Average
2012	103.9	98.4	87.5	95.3	**96.3**
2013	101.3	93.3	92.2	90.8	**94.4**
2014	98.2	94.7	83.6	81.5	**89.5**
2015	98.5	96.4	80.7	85.5	**90.3**
2016	100.7	92.6	78.0	86.0	**89.3**
2017	97.5	93.6	79.7	83.8	**88.7**
2018	101.8	95.7	88.2	90.8	**94.1**

Nutrient availability is affected by soil reaction. When growing selected energy crops, a decrease in available phosphorus was found at higher soil acidity (r = 0.47). The relationship between soil reaction values and phosphorus in soil was also noted by Dong *et al.* (2009).

The trend of development of available phosphorus contents in all energy crops (Figure 4) points to its slight decrease in the soil. The development of accessible phosphorus contents was expressed by the linear equation $y = -0.4071x + 101.9$ for *Arundo*, $y = -0.3429x + 96.329$ for *Miscanthus*, $y = -1.0179x + 88.343$ for *Elymus*,

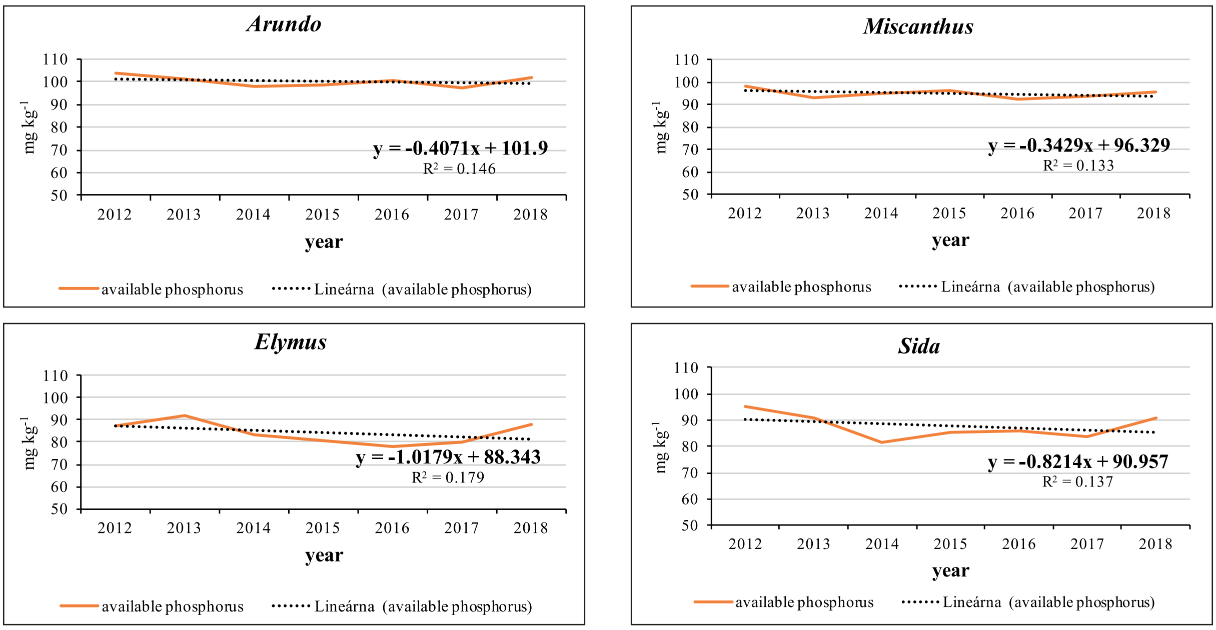

Figure 4 The development trend of available phosphorus in the energy crops

y = -0, 8214x + 90.957 for *Sida*. The annual decrease of accessible phosphorus at a depth of up to 0.3 m was only in units of kilograms per hectare (*Arundo* – 1.8 kg ha^{-1} P, *Miscanthus* – 1.5 kg ha^{-1} P, *Elymus* – 4.6 kg ha^{-1} P, *Sida* – 3.7 kg ha^{-1} P).

Energy crops were fertilized annually with phosphorus at a rate of 40 kg ha^{-1}, and despite this, the content of accessible phosphorus in the soil slightly decreased during their cultivation. This is probably related to the continuous changes in the forms of organic and mineral phosphorus in the soil. Cultivation due to intensive mineralization of organic compounds increases the content of accessible phosphorus and decreases the content of total phosphorus (Fecenko & Ložek 2000). When growing energy crops, there is no annual cultivation, and it is uncultivated land. Therefore, when growing energy crops, there is no mineralization, but the incorporation of phosphorus into the organic components of the soil, which results in the fact that even with a positive balance of phosphorus, the content of its mineral component has decreased. McLaren *et al.* (2020) confirmed that soil organic phosphorus can accumulate in fertilized soil which contributes to an agricultural inefficiency use of phosphorus.

From the point of view of crop nutrition, sufficient potassium in the soil must be present in a form available to plants. The content of available potassium in the soil of energy crops (Table 8) ranged from 204.1 mg kg^{-1} to 253.2 mg kg^{-1}. In terms of criteria for the evaluation of chemical analyses of arable soils (Slovak Republic, Regulation No. 151/2016 2016), the content of available potassium in the soil in energy crops was classified as good.

Table 8

Changes in the available potassium content [mg kg^{-1}] in the cultivation of energy crops

Year	*Arundo*	*Miscanthus*	*Elymus*	*Sida*	Average
2012	214.0	231.2	227.7	237.5	227.6
2013	224.0	235.4	240.0	234.8	233.6
2014	204.1	224.0	229.4	226.5	221.0
2015	234.3	248.1	250.2	253.0	246.4
2016	226.9	219.0	218.9	231.0	224.0
2017	228.5	215.7	219.7	220.7	221.2
2018	230.1	219.9	222.1	227.7	225.0

The trend of the development of accessible potassium (Figure 5) contents in *Arundo* between 2012 and 2018 points to its slight increase (y = 2.8607x + 211.69). From the linear trend, an annual increase of available potassium in the soil by 12.9 kg ha^{-1} was recorded. The trend of the development of accessible potassium content in the soil of other energy crops was expressed by the linear equation y = -2.7964x + 238.8 for *Miscanthus*, y = -2.425x + 239.41 for *Elymus*, and for y = -1.8964x + 240.61 for *Sida*. The development of the contents of available potassium in the soil during the cultivation of these energy crops points to its slight decrease of 12.6 kg ha^{-1} $year^{-1}$ K for *Miscanthus*, 10.9 kg ha^{-1} $year^{-1}$ K for *Elymus*, and 8.5 kg ha^{-1} $year^{-1}$ K *for Sida*.

The content of accessible potassium in the soil depends on the uptake of potassium by cultivated energy crops. In the fourth to sixth year of cultivation, there was a failure of *Arundo*, the yields were much lower, and thus the intake of potassium from the soil, and this is one of the reasons why the potassium content of the soil increased slightly. In the case of other energy crops, there was a decrease in available potassium in the soil, which was probably related to its higher intake due to insufficient potassium fertilization, or also to the leaching of potassium, of which 0.2–10 kg ha^{-1} is leached annually in conditions of moderately heavy soils.

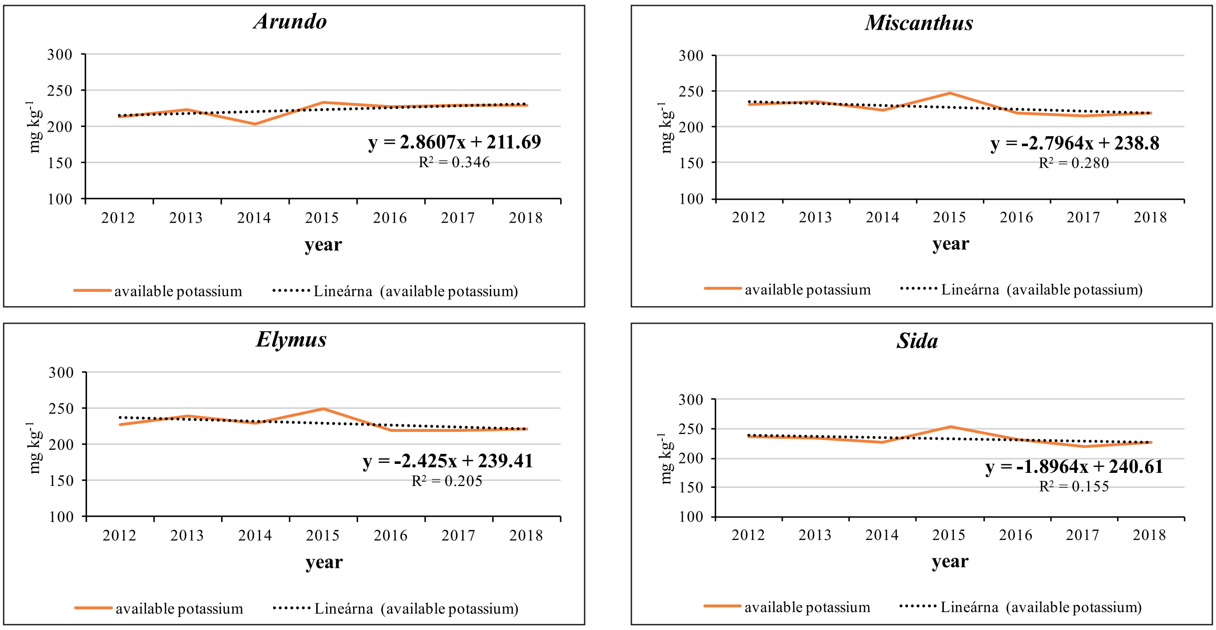

Figure 5 The development trend of available potassium in the energy crops

CONCLUSIONS

The change in land management, so the conversion from the cultivation of classic annual crops to the cultivation of perennial energy crops, affected the contents of selected soil parameters. The development trends of the content of selected soil parameters in the grown energy crops, which were determined using a regression model expressed by the linear equation pointed out the assumed development of the given soil parameter.

In the case of energy crops *Arundo*, *Elymus*, and *Sida*, an increase in soil organic carbon was detected since the establishment of the experiments, while the increase was 0.44 t ha^{-1} year^{-1} C for *Arundo*, and 0.46 t ha^{-1} year^{-1} C for *Elymus*, and 0.43 t ha^{-1} year^{-1} C for *Sida*. During the cultivation of *Miscanthus*, the original content of soil organic carbon was preserved.

An increase in the total nitrogen content in the soil was detected with the monitored energy crops. The increase in total nitrogen in the soil was 155.7 kg ha^{-1} year^{-1} N for *Arundo*, 99.0 kg ha^{-1} year^{-1} N for *Miscanthus*, 83.7 kg ha^{-1} year^{-1} N for *Elymus*, and 50.0 kg ha^{-1} year^{-1} N for *Sida*.

The development of exchange soil reaction values for all four energy crops in the monitored period showed a decrease. Analogously, in the monitored period, a decrease in the contents of available phosphorus and potassium was also recorded, except for available potassium during the cultivation of *Arundo*.

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