Agronomy Research **15**(5), 1971–1982, 2017
https://doi.org/10.15159/AR.17.053

Soil organic carbon in long–term experiments: comparative analysis in Slovakia and Serbia

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Abstract. Soil organic carbon plays an important role in a long-term agroecosystem productivity, in the global C cycle, maintaining a soil nutrient pool and improving its availability. The objective of this study is the assess the impacts of long–term cropping practices on SOC dynamics in Slovakia and Serbia. Soil C sequestration is a complex process that is influenced by many factors, such as agricultural practice, climatic and soil conditions. For the both location the initial SOC decline was followed with the C stabilization and possible increase where proper practices were used. More intensive crop management systems that maintained residue cover provided the greatest benefit towards increasing the quantity of mineralizable nutrients within the active fraction of soil organic carbon (SOC), as well as increasing C sequestration as SOC. Long–term field experiments have contributed significantly to our current knowledge of soil quality and have been used to study the influence of crop management, fertilizer application and tillage practices on SOC content.

Key words: soil organic carbon, long–term experiment.

INTRODUCTION

Agricultural cultivation causes an immediate and rapid loss of soil organic carbon (SOC). The loss of SOC with tillage based on plowing could lasts for decades, reducing carbon (C) pools on agricultural soils up to 50% of their original levels on average (Mann, 1986). Examples of reduced soil organic matter have been observed worldwide regardless of climate, soil type, or original vegetation (Janzen, 2004). Generally, the rate of loss slows as SOC levels reach a new equilibrium that depends on tillage practices (West & Post, 2002) and the amount level of C inputs returned to the soil as crop residue or animal manures (Kirchmann et al., 2004). The quantity of existing soil C is controlled by a complex interaction of processes determined by C inputs and its decomposition rates. Returning crop residues to the field is highly recommended, in order to decrease chemical inputs, and promote soil C sequestration (Turmel et al., 2014). Tillage accelerate SOC oxidation to CO_2 by improving soil aeration, increasing contact between soil and crop residues and exposing aggregate-protected organic matter to microbial decomposition (Birkás et al., 2008). On the other hand, improved agricultural practices have great potential to increase C sequestered in soil (Follett, 2001; Lal, 2006; Dimassi, 2014), and some studies suggest that agricultural activities can elevate SOC content relative to natural systems (Buyanovsky & Wagner, 1998). Likewise, SOC stock is recommended indicators for evaluation of soil quality in EÚ (Michéli et al., 2008). Management practice that includes organic amendments can increase SOC, but the type of organic amendment, method of incorporation, and duration of application required for an elevation of SOC differ in relation to climate and cropping practices (Hoffmann et al., 2002; Woźniak et al., 2014; Rusu & Moraru, 2015; Šařec & Žemličková, 2016). Sequestration of C from plant biomass into organic matter is a key sequestration pathway in agriculture (Macák et al., 2010). Deficiency of macronutrients can be easily compensated with fertilizer application, however building the pool of SOC is a long–term and rather slow process. Similarly to that, physical soil properties, predominantly soil structure and compaction, mutually deteriorate together with SOC and commonly interact in lower production capacity of soil. Relative enrichment of the surface soil with organic matter results in an increase in microbial activity and a concomitant increase in the size and stability of soil aggregates (Carter & Stewart, 1996; Tamm et al., 2016). It is could be anticipated that the cropping technology cannot be fully transformed toward SOC conserving cultivation. However, some adjustments can notably influence SOC in soil, such as shallow plowing after wheat harvest, organic fertilizers, and soil loosening instead of plowing (Lal et al., 1998). For the region of the Central Europe, the critical level of SOC for a significant yield reduction has not been clearly established. Key and Angers (1999) argued that irrespective of soil type the with SOC content less than 1% it may not be possible to obtain potential yield. But generally it may be assumed that the critical limit of SOC in the temperate region is 2% (Loveland & Webb, 2003).

The objective of this study is the assess the impacts of long-term fertilization practices on SOC dynamics in Slovakia and Serbia.

MATERIALS AND METHODS

Experimental site in Slovakia

Field trial were conducted over 12 year at the experimental station of the Slovak University of Agricultural in Nitra in South–Western Slovakia in Dolná Malanta as a key side of monitoring web system for *Luvisols*. We refer results from two periods of trial 1996–2003 as a first period of research (Macák et al., 2010) and 2005–2007 (Candráková et al., 2011), as the second period of trial. The experimental site is located in a warm and moderate arid climatic region. The long-term average annual temperature of the site is 9.9 °C and 16.6 °C during the vegetation period (Table 1).

Table 1. Average monthly air temperatures and precipitation (1951–2000) at the experimental station of the Slovak University of Agricultural (Špánik et al., 2004) and Novi Sad (RHSS, 2017)

Months	Experimental station in Nitra		Experimental station Novi Sad	
	Temperature (°C)	Rainfall (mm)	Temperature (°C)	Rainfall (mm)
January	-1.4	29.1	0.5	38.5
February	0.5	30.1	2.0	30.8
March	4.8	31.6	6.6	34.7
April	10.4	41.6	12.0	48.5
May	15.2	56.0	17,4	58.5
June	18.3	66.2	20,5	91.7
July	20.0	59.3	22,2	77.4
August	19.7	54.2	21.9	66.4
September	15.5	43.1	16.6	60,5
October	10.2	41.0	11.7	61.1
November	4.6	52.2	6.5	61.0
December	0.5	43.2	1.2	52.5
Average	9.9	-	1.6	-
Total		547.6		681.6

The average precipitation is 548 mm, including 323 mm during the vegetation period. Altitude of the site is 175 m. The experimental design was a split-plot with four replicates. The tillage was the main plot factor; the fertilization was the subplot factor. The subplots were 3 m wide by 10 m long with 0.5 m protective stripes on all sides with 2 × 9 m harvest plots. The plots were subjected to primary soil tillage treatments as follows: mouldboard ploughing (CT) to a depth of 22 cm (conventional tillage), and shallow loosening (RT) to a depth of 10 cm (reduced cultivation). Three fertilization treatments as follows: 0–without organic and inorganic fertilization, PH–mineral fertilizers (phosphorus and potassium) calculated to the 3 t ha^{-1} seed yield, PR–incorporation of all above-ground plant material and dose of phosphorus and potassium calculated to the 3 t ha^{-1} seed yield. The amount of preceding above-ground plant material was measures from harvested area of 18 m^2 at each PR treatment with four replication and values were calculated per one hectare. Nutrients were added on the base of balance method according to nutrient content in soil on yield level of 3 t ha^{-1} pea seeds under the normative nutrients with drawing per 1 ton of crop. The same method was used for all crops in crop rotation, nitrogen doses were calculated according to the content of N_{an} in soil samples at spring (Fecenko & Ložek, 2000). Common pea was growing after cereal preceding in spring barley (*Hordeum vulgare* L.) – common pea (*Pisum sativum* L.) – winter wheat (*Triticum aestivum* L.) – maize (*Zea mays* L.) crop rotation and from 2001 in winter wheat – common pea – maize – spring barley – red clever (*Trifolium pratense* L.) crop rotation. The soil samples for basal respiration and C sequestration were collected from the 20 cm topsoil layer by soil auger three times per year (in spring, summer and autumn). The soil samples were incubated at 28 °C and soil respiration was measured 17–18 days according Bernát and Seifert method. SOC content was determined by the Tyrin method. We considered the average values of soil basal respiration from three samples. For organic carbon stock (kg ha^{-1}) calculation, the soil bulk density was determined three times per year in each treatment with four replication from the soil layer from a depth of 5–10 cm by soil core Eijkelkamp sampling kit. The results were subjected to ANOVA analysis and Tukey HSD test by using software STATISTICA.

Experimental site in Serbia

A long–term experiment (LTE) titled 'Plodoredi' (Crop rotation) is situated at the Rimski Šančevi experimental field of the Institute of Field and Vegetable Crops in Novi Sad (N 45° 19`, E 19° 50`) on the southern border of the Chernozem zone of the Pannonian Basin. During the study period, the average annual temperature of 11.6 °C and 681 mm of precipitation was observed (Table 1). The experiment started in 1946/47, to conceptually correspond with the prevailing cropping technology in agricultural area, and to employ the achieved results in yield improvement. (Milošev et al., 2010). The unfertilized treatments were established 1946/47, and fertilized in 1969/70. The following treatments were analyzed: fertilized 3–year crop rotation: winter wheat, maize and soybean (MSWF); fertilized 2–year crop rotation winter wheat and maize (MWF); fertilized wheat monoculture (WWF); unfertilized 3–year rotation winter wheat, maize and soybean (MSW), and unfertilized 2–year rotation winter wheat and maize (MW). Crop rotation was arranged as single crop sequence in which all crops were grown each year according to the experimental design, and plots were divided into three subplots (90 × 30 m) representing the repetitions. Conventional tillage with mouldboard plough (30 cm), harrow disc, and cultivator (Compactor) were performed. Harvest residues were incorporated by ploughing. Winter wheat sowing was done in October, 20, while maize and soybean in April, 10. SOC content was determined by the Tyrin method. In our study the 0–60 cm layer of soil was analyzed as the significant changes were expected in that layer that was divided into 3 sub-layers (0–20 cm, 20–40 cm and 40–60 cm). The samples were collected after crop harvest in a disturbed state and were kept in the laboratory air-dried until the analysis. The average soil sample consisted of 5 drillings. Bulk density sampling for each treatment was carried out after harvest by the core method using cylinders of 100 cm^3 volume by Kopecky. Each year, samples were taken from three soil layers (0–60 cm) in three replicates per experimental plot. Data reported for SOC stock and yield were analyzed by the analysis of variance, ANOVA was used to separate treatment means when there was a significant difference at the $P < 0.05$ level. Replication across treatments and effects of year was considered a random effect and cropping systems were considered a fixed effect. In order to analyze temporal interdependencies of soil organic matter regression analysis was conducted. The independent variable (x) was time and SOM content (%) was dependent variable (y).The data were statistically processed by using the program STATISTICA series 12.6.

RESULTS AND DISCUSSION

From the starting point in 1996 the tillage treatments via different level of soil disturbance influenced the potential flux of CO_2 expressed as soil basal respiration of the soil and input output balance of soil C stock.

The average values for eight years significantly indicated higher soil basal respiration in reduced tillage treatments represented by shallow loosening (Fig. 1). Soil basal respiration is defined as rate of respiration in soil, which originates from the mineralization of organic matter (Creamer et al., 2014). In our experiment, reduced tillage create better precondition for basal respiration, which indicated higher potential of biological activity mainly due to the higher content of organic substrate of topsoil.

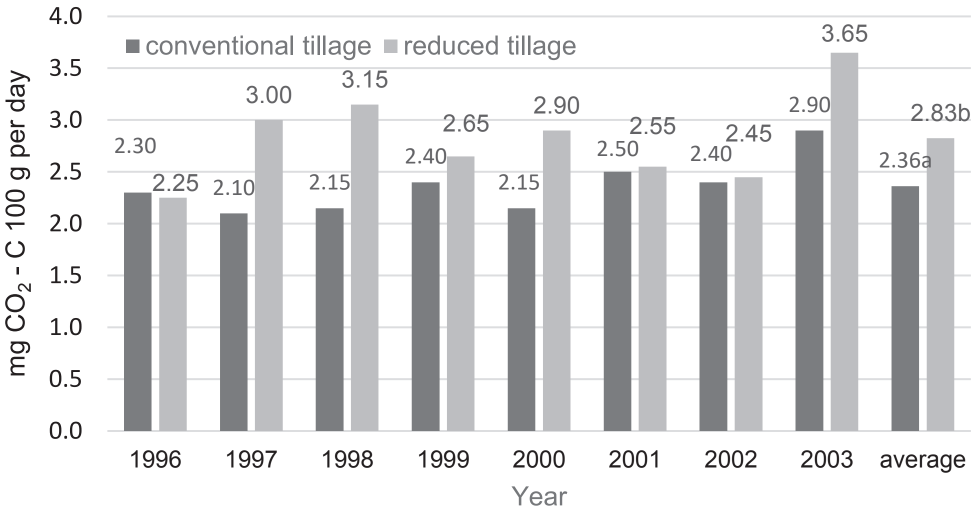

Figure 1. Soil basal respiration in conventional and reduced tillage treatment from 1996–2003, Slovak University of Agriculture in Nitra, Experimental Station Dolná Malanta, the average means at different letter are significant at the $P < 0.5$ probability level.

Mineral fertilizers may support the basal respiration via increasing of roots biomass nutrient availability and strongly correlated with soil organic carbon (Dimassi et al. 2014) but in oure fertilization treatments average soil basal respiration ranged only in narrow interval of 2.52–2.65 mg CO_2–C 100 g per day without statistical differences at the $P < 0.5$ probability level. The reduced tillage has positive influence on soil carbon sequestration with comparison to conventional mouldboard ploughing (Table 2).

Table 2. Soil carbon stock (t ha^{-1}) in each tillage and fertilization treatments. The means between fertilization treatments (small letters) and tillage treatments (capital letters) followed by the same letter are not significant at $P < 0.05$ probability level

Conventional tillage/fertilization treatments	1996–2003	2005–2007	Reduced tillage/fertilization treatments	1996–2003	2005–2007
CT-0	30.9a	29.1a	CT-0	32.2a	31.1a
CT-PH	31.2b	30.2a	CT-PH	32.9a	33.4b
CT-PZ	32.1b	33.4b	CT-PZ	32.6a	33.9b
Conventional tillage	31.4A	30.9A	Reduced tillage	32.5B	32.8B

Both fertilization treatments reached the higher soil C stock with comparison to treatments without any form of fertilization. In control treatment without fertilization 31.4 t ha^{-1} of C in 20 cm soil layer was stored with comparison to 32.5 t ha^{-1} in treatments with forecrop biomass incorporation. After another four year treatment history in 2007 the significant influence of tillage on soil C stock was confirm. Temporal change in SOC can be defined in two ways as an absolute change in stored C which provides an estimate of the actual C exchange between soil and atmosphere or as a net change in storage among treatments (Ellert et al., 2008). Some differences between the treatments with application of mineral fertilizers (PH) or organic and mineral fertilizers (PZ) with control treatments (RT-0) are associated with the decomposition of incorporated plant residues and great amount of biomass production (roots, exudates and post-harvest residues) (Table 2, Figs 2–4).

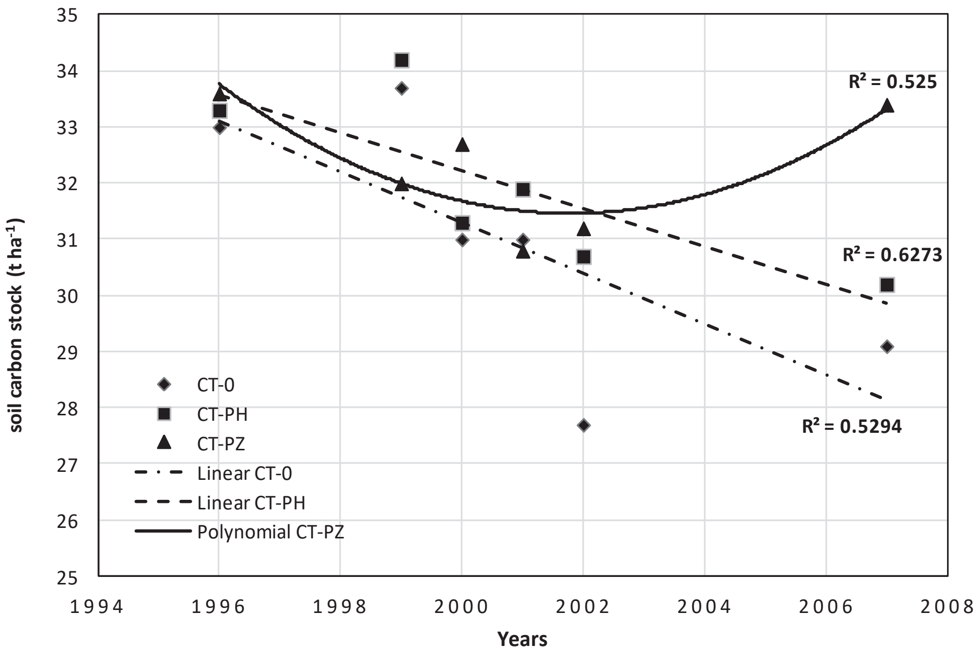

Figure 2. The changes of the soil carbon stock (t ha^{-1}) in the upper soil layer of 20 cm at different fertilization treatments in conventional tillage. SAU Nitra, Experimental station Dolná Malanta, Slovakia.

In treatments with incorporation of aboveground plant material (PZ) average input of aboveground dry matter calculated for whole rotation cycles was 5.15 t ha^{-1}. Non significant differences between treatments with application of mineral fertilizers (PH) and fertilizers plus incorporation of all aboveground plant biomass (PZ) of growing crops indicated that for increase of stocked SOC in the soil profile another input of SOM is needed. Similarly Hernanz et al. (2009) for active sequestration recommended adoption of another measure as crop rotation, tillage treatment and also input of organic matter.

The results of the long–term field trials on chernozem soils showed that properly applied agronomic practices such as crop rotation, fertilization, and tillage are the most appropriate method for preservation of SOC content in soil. The application of N fertilizers resulted in greater aboveground and belowground biomass in the fertilized treatments, which was beneficial for maintaining SOC in the soil but not sufficient for C enrichment, while mouldboard plowing resulted with SOC depletion (Manojlović et al., 2008).

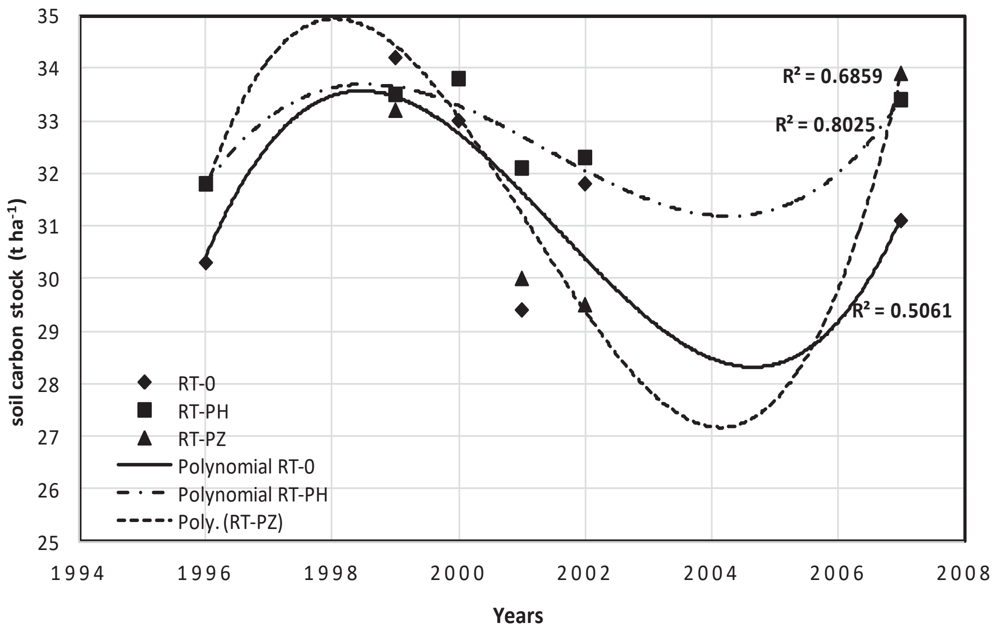

Figure 3. The changes of the soil carbon stock (t ha^{-1}) in the upper soil layer of 20 cm at different fertilization treatments in reduced tillage. SAU Nitra, Experimental station Dolná Malanta, Slovakia.

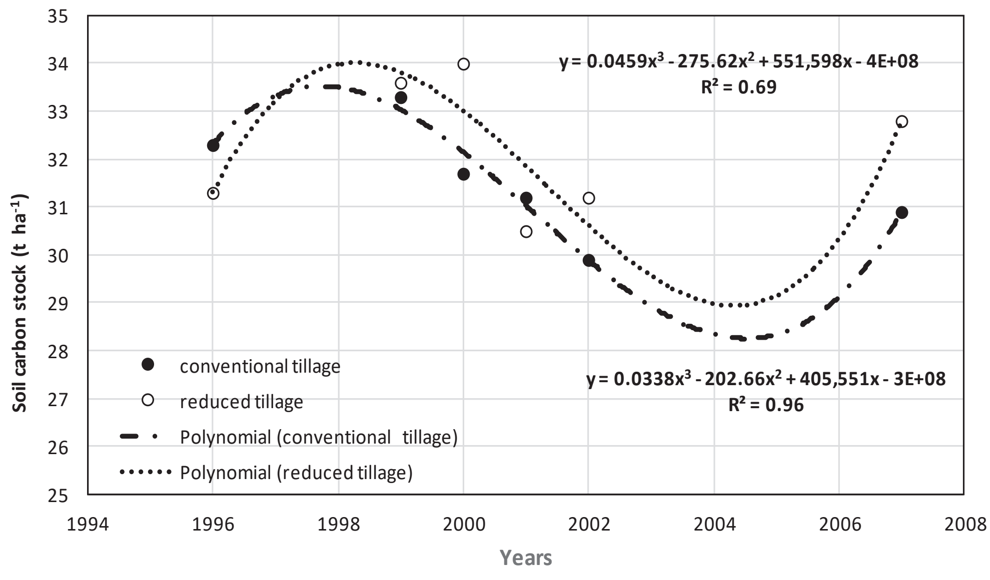

Figure 4. The changes of the soil carbon stock (t ha^{-1}) in the upper soil layer of 20 cm at conventional and reduced tillage treatments. SAU Nitra, Experimental station Dolná Malanta, Slovakia.

Regression coefficients showed significant SOC change over time that can be explained with the quadratic equation. Higher correlation was found at 3–year fertilized rotation whereas 3-year unfertilized rotation can not be explained with quadratic function (Fig. 5). This indicate stabile trend of SOC change with less variation. Generally, for the most cropping system SOC stabilization occurred after 2000 that could be attributed with the improved crop residue management in relation with advanced machinery. The preservation of SOC in wheat monoculture, found in the LTE, coincided with findings reported by Lithourgidis et al. (2006) that under continuous wheat cropping particular soil properties (such as SOC) could be preserved. By contrast, the higher content of SOC at WWF in this study did not correspond with higher yields of winter wheat, which indicates that long–term monoculture is not a sustainable cropping alternative for wheat production (Miloševet al., 2014). Although the soil under permanent wheat monoculture exerts some favorable physical and chemical soil properties, it cannot be recommended for wide adoption as a management option, since significant yield variation could be expected as well as and pathogen proliferation. Defining a clear relationship between the agricultural yields of wheat and the OM is not always possible to determine, because the grain refers to the plot, and the amount of returned C is conditioned by the effect of a number of factors which can have a significant impact on OM (infestation level, rainfall, pest attack, the time of sowing, fertilising etc). The fertilized two–year and 3-year rotations can be considered as potential alternatives for sustaining yield and preserving soil properties with improved cropping technology (Šeremešić et al., 2011).

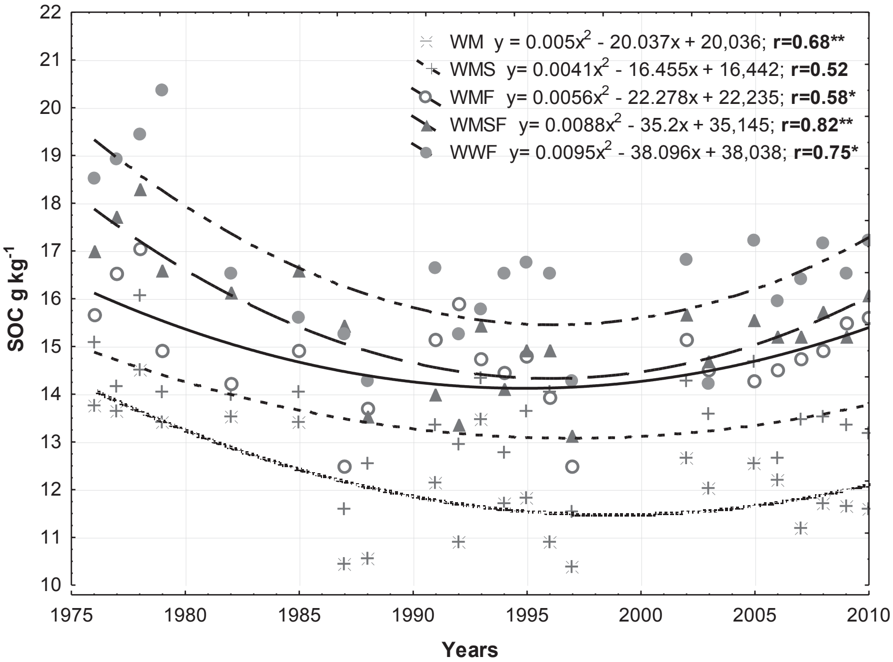

Figure 5. Regression fit of soil organic carbon (SOC) from the LTE experiment (1975–2010). **significant at $P < 0.01$ probability level; *significant at $P < 0.05$ probability level; fertilized 3-year rotation (MSWF); fertilized 2-year rotation (MWF); fertilized wheat monoculture (WWF); unfertilized 3-year rotation (MSW) and unfertilized 2-year rotation (MW).

The average SOC stock for selected cropping systems (0–20 cm) showed significant differences for the analysed period. Significantely higher SOC stock was observed in winter wheat monoculture compared with WMF, WMS and WM (Fig. 6). Significantely lower value was found at the unfertilized 2-year rotation comapred to other systems. Besides that, the unfertilized crop rotation contain 80% of the SOC found at the fertilized rotation. The study conducted at the same long-term experiment showed that additional C input did not increase the SOC pool, suggesting that the invetsigated cropping systems had a limited ability to increase SOC (Šeremešić et al., 2017).

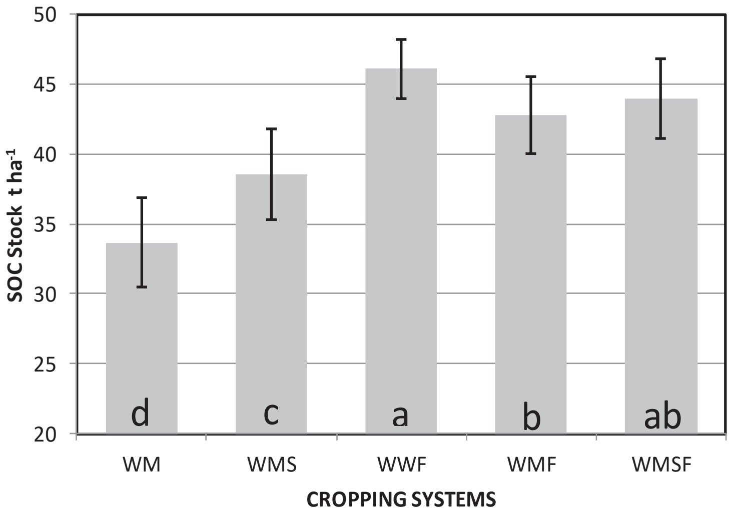

Figure 6. Average soil carbon stock (t ha^{-1}) of different cropping systems in LTE calculated from 1975–2010 (0–20 cm). The column followed by the same letter are not significant at $P < 0.05$ probability level; fertilized 3-year rotation (MSWF), fertilized 2-year rotation (MWF), fertilized wheat monoculture (WWF), unfertilized 3-year rotation (MSW) and unfertilized 2-year rotation (MW).

Further on, explaining the relationship between the crop residues C input and SOC must implicate on the fact that crop are grown in rotation. Therefore, in our study C inputs were accounted as average for the entire rotation. On the basis of the dispersion diagram (Fig. 7) the amount of C in plant residues and SOC content in the soil can be displayed using the regression curve, covering the average values of SOC content on different systems of farming for 2 layer of soil and the amount of C remaining in the plant residues inputs. The values of the coefficient of reggresion shows that their relationship is largely explained and that there is a strong positive correlation between the total average C incorporated with crop residue and SOC content in the soil. For the 0–20 cm soil depth higher regresion was observed.

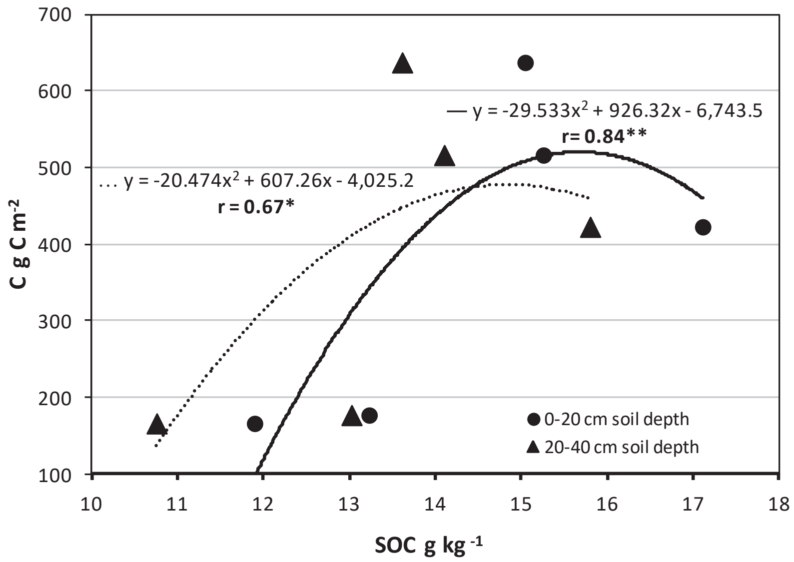

Figure 7. Relationship of C input and soil organic matter (SOC) for different depths.

CONCLUSIONS

The fertilization treatments do not revealed the significant differences in soil basal respiration in an average. Higher soil basal respiration and more CO_2 was realised from reduced-till compared to conventional tillage despite there being increased levels of soil C. The reduced tillage has positive influence on soil C sequestration with comparison to conventional mouldboard ploughing. The NPK treatment was important for increasing crop yields, organic material inputs, and soil C fractions, so it could increase the sustainability of cropping system in the long–term experiments in Slovakia and Serbia. The recommended fresh residues C necessary for SOC maintenance is estimated at approximately 500 g C m^{-2} per year. In addition to that, soil tillage was found to be significantly related to changes in SOC.

ACKNOWLEDGEMENTS. This paper was supported by VEGA project 1/0544/13 'The research of agrienvironmental indicators of sustainability and production capability of agroecosystem by diversification of crop rotation pattern in changing climate' and project No. TR 31073 '*Improvement of maize and sorghum production under stress conditions*', which is supported by the Ministry of Education and Science of the Republic of Serbia.

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