# Management of soil organic carbon in maintaining soil productivity and yield stability of winter wheat

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**ABSTRACT**

The objective of this study was to estimate how soil organic carbon influences winter wheat yield in the South Pannonian Basin. The treatments evaluated were: fertilized 3 year and 2 year crop rotation, fertilized wheat monoculture and unfertilized 3 year and 2 year crop rotation in the 38 years of continuous cropping (1970–2007). These treatments showed a declining trend of soil organic carbon in the 0–30 cm soil layer, respectively. On average, the plow-layer of the treatments lost 10% of soil organic carbon found at the beginning of the investigated period. The plowlayer of the unfertilized treatments reached a possible soil organic carbon threshold (1.16%) after balance on decomposition and formation was observed. We found that soil organic carbon preservation coupled with proper management such as crop rotation and fertilization is important for preserving soil productivity, and when soil organic carbon increases it could benefit winter wheat yield. Obtained results are valuable for developing a sustainable cropping technology for winter wheat and soil conservation.

**Keywords**: SOC; winter wheat yield; South Pannonian Basin; crop residue

Soil organic carbon (SOC) plays an important role as a pool of terrestrial carbon (C) and can be controlled by proper agronomic practices. Therefore, arable soils play a crucial role in C cycling and can be considered as a major reservoir and an important sink for sequestering the atmospheric $CO_2$ (Smith 2004). Patterns of reduced SOC were observed regardless of climate, soil type, or original vegetation. Numerous studies show a decline in SOC content with tillage, insufficient fertilization, and removal and burning of crop residue (Paustian et al. 1997). According to 'Thematic Strategy for Soil Protection', an estimated 45% of European soils have a low SOC content, which poses a threat to all soil functions. Zdruli et al. (2004) estimated that in Southern Europe, 74% of soils contained < 2% organic C in the topsoil (0–30 cm).

For the region of the Southern Pannonian Basin, the threshold of SOC for a significant yield reduction has not been elaborated. It may be assumed, generally, that the critical limit of SOC in the temperate region is 2% (Loveland and Webb 2003). Some authors suggest that the threshold may be less than 1% C in some stable soils, whereas other soils would face structural collapse at such level. Kay and Angers (1999) elucidate that if soil organic carbon levels are less than 1% it would be difficult to attain maximum agricultural yields, regardless of the soil type. Therefore, maintenance of sitespecific SOC content is a prerequisite for sustainable protection of soil function and could be recognized as an important indicator of soil quality and agronomic sustainability of agro-ecosystems (Liu et al. 2005).

Among the factors that control SOM content in arable soils, only crop rotation and management practices (fertilization, tillage or plant protection) can be controlled. The options available for rotation, tillage, fertilization or machinery often have cultural, environmental, or economic restrictions. With these limitations, it could be difficult to predict the magnitude of SOC changes from current practices. The objectives of this investigation were to evaluate SOC content in the topsoil after winter wheat in a longterm experiment and to examine its role in yield increase under continuous cropping with conventional tillage practice in the southern part of the Pannoninan Basin.

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## MATERIAL AND METHODS

A longterm 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'). The experimental site location is on the southern border of the chernozem zone of the Southern Pannonian Basin (SPB) where Vojvodina Province is a major production area. The investigated treatments were presented in Table 1.

Conventional tillage including moldboard plowing, disc harrowing and field cultivating were performed, and harvest residues were plowed under. Winter wheat sowing took place in October with a seeding rate of 250–270 kg/ha, depending on variety, to accomplish 550 germinant grains/$m^2$. During the observed period (1970–2007), the leading wheat varieties grown were: Bačka, Jubilejnaja, NS32, NSrana 1, Evropa 90, Renesansa and Pesma.

Aboveground wheat residue biomass was estimated by using the average yields and multiplying them by harvest index (HI). Grain yields were adjusted to 14% moisture content. HI used in this study is 0.44 for WMSF, 0.46 for WMF, 0.43 for WWF, 0.45 for WMS and 0.48 for WM (Milošev 2000). The C application rate was calculated by multiplying the crop residue with 0.86 and involved an assumption that C content was 44% for wheat straw. The meteorological data for a 38-year period were presented in Table 2.

Samples for the SOC were collected from the topsoil (0–30 cm). Determination of $C_{org}$ (%) concentration in soil samples was done according to Tyurin titrimetric wet combustion method. $C_{org}$ (%) concentration was expressed in the SI unit as g C/kg soil (SOC g/kg). The SOC content in the SPB was estimated from the weighted means of SOC content in the three soil survey. The average SOC (g/kg) SOC stock (t C/ha) was calculated using the following equations:

$$SOC = \frac{\Sigma SOC_i}{i}$$

Where: $\Sigma SOC_i$ – sum of SOC; i – number of analyzed samples .

$$\text{SOC stock (t/ha)} = \frac{\text{SOC (g/kg)}}{1\,000\,000} \times \text{depth (m)} \times$$
$$\times \text{ B (kg/m)} \times 10\,000 \text{ (m/ha)} \times 1000 \text{ (kg/t)}$$

Winter wheat production information was acquired from the Statistical Office of the Republic of Serbia (RZSS 2009). Mean wheat productivity (WP) was obtained by dividing total wheat production by total wheat cropland area for each year. The yield production variability $Y_{pv}$ (%) for each period was calculated by the formula $Y_{pv}$ = yield SD/average yield in analyzed period (Pan et al. 2009). The contribution of unit quantity of SOC

Table 1. Cropping technology of the investigated longterm experiment (LTE)

| Cropping systems | Established | Crop rotation | Fertilization for winter wheat |
|---|---|---|---|
| WWF Fertilized wheat monoculture | 1969/70 | wheat (monoculture) | Mineral fertilization from 1969/70–1986/87 with 100[a] kg/ha N, 80 kg/ha $P_2O_5$ and 50 kg/ha $K_2O$. From 1969/70–1986/87, FYM[b] at 20 t/ha rate every second year. After 1987, no P, K mineral fertilizers or FYM[b], only 100[a] kg/ha N. Crop residues incorporation. |
| WMSF Fertilized three–year crop rotation | 1969/70 | wheat, maize, soybean | Mineral fertilization from 1969/70–1986/87 with 100[a] kg/ha N, 80 kg/ha $P_2O_5$ and 50 kg/ha $K_2O$. From 1969/70–1986/87, FYM[b] at 30 t/ha rate after wheat. After 1987, no P, K mineral fertilizers or FYM, but 100 kg/ha N. Crop residues incorporation. |
| WMF Fertilized two–year crop rotation | 1969/70 | wheat, maize | Mineral fertilization from 1969/70–1986/87 with 100[a] kg/ha N, 80 kg/ha $P_2O_5$ and 50 kg/ha $K_2O$. From 1969/70–1986/87, FYM[b] at 25 t/ha rate after wheat. After 1987, no P, K mineral fertilizers or FYM, only 100[a] kg/ha N. Crop residues incorporation. |
| WMS Unfertilized three–year crop rotation | 1946/47 | wheat, maize, soybean | No mineral fertilization or FYM[b] since 1946/47, crop residues removed until 1969/70. After 1970, crop residues incorporated with plowing. |
| WM Unfertilized two–year crop rotation | 1946/47 | wheat, maize | No mineral fertilization or FYM[b] since 1946/47, crop residues removed until 1969/70. After 1970, crop residues incorporated with plowing. |

[a]100 kg/ha N was applied twice; 50 kg/ha before ploughing in autumn + 50 kg/ha in spring for topdressing; [b]FYM – farmyard cattle manure application

Table 2. Monthly average precipitation and temperatures of the longterm experiment (LTE) and Southern Pannonian growing area Vojvodina (VOJ)

| | Months | | | | | | | | | | | | X–VI | 1970–2007 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | XI | XII | I | II | III | IV | V | VI | VII | VIII | IX | | |
| | average monthly temperature (°C) | | | | | | | | | | | | | |
| LTE | 11.7 | 5.8 | 1.8 | 0.2 | 1.8 | 6.5 | 11.4 | 16.9 | 19.9 | 21.6 | 21.3 | 16.8 | 8.4 | 11.3 |
| VOJ | 11.8 | 6.6 | 1.4 | –1.2 | 0.8 | 5.2 | 11.2 | 16.4 | 19.8 | 21.4 | 21.0 | 17.2 | 8.0 | 11.0 |
| | monthly precipitation (mm) | | | | | | | | | | | | | |
| LTE | 50.9 | 51.0 | 40.8 | 36.4 | 31.9 | 39.8 | 48.6 | 62.3 | 86.4 | 63.9 | 61.1 | 46.6 | 448 | 619.7 |
| VOJ | 33.0 | 57.0 | 62.0 | 41.0 | 42.0 | 35.0 | 49.0 | 64.0 | 77.0 | 62.0 | 50.0 | 39.0 | 460 | 611.0 |

content to productivity increase was estimated by the quotient of difference in crop yield and in SOC content in the soil of the cropping systems with formula P = yield difference/SOC difference (Bauer and Black 1994). Investigated plots (2500 $m^2$) of each treatment were divided into three subplots for sampling and statistical analyses of data. Data reported for SOC and yield were analyzed by the ANOVA, and Duncan's multiple range test was used to separate treatment means at the $P \leq 0.05$ level. Correlation coefficients were calculated between SOC and yield level in order to estimate how SOC could influence winter wheat yield change ($P \leq 0.05$). All analyses were conducted using the statistical software package STATISTICA 8.0.

## RESULTS AND DISCUSSION

According to Molnar (2003) maize-wheat rotation with conventional tillage was a common cropping option for winter wheat production in the agro-ecological area of the SPB. For that reason winter wheat cropping could provide a basis for evaluating the relationship between SOC and yield as it has not undergone a significant change over the past century compared with other crops. Data acquired from the recent soils surveys indicate that the SOC stock declined by 49.5 t C/ha (55%) compared with the SOC stock found in the first soil survey (Table 3). This could be a result of intensified cropping technology, reduced amount of organic and mineral fertilizers, burning and removal of crop residues. The lost SOC of chernozem and chernozem-like soils is verification of a continuing soil deterioration process in the wheat growing area (Birkás 2008).

Wheat yields in the LTE, are spatially and temporally considered as a complex outcome of agroecological conditions, also existing in the SPB. The significantly higher yields of winter wheat in 38 years of continuous cropping were found in the WMSF. In addition to that, on average, the application of fertilizers significantly increased winter wheat yield by a 3580 kg/ha in the WMSF and by 3600 kg/ha in the WMF compared with unfertilized plots (Figure 1). Yield variability, represented with error bars, was more pronounced in the fertilized plots, predominantly in the WWF, as compared to the unfertilized plots. The average yield for Vojvodina Province (4230 kg/ha) was lower compared to the WMF (4630 kg/ha) and WMSF (5050 kg/ha), but higher than the other cropping systems. The observed yield difference (–824 kg/ha and –401 kg/ha, respectively) indicated that wheat production in SPB could be improved by employing proper management practices. Current yields on the unfertilized plots could represent an

Table 3. Changes in winter wheat yield and soil organic carbon (SOC) content in the Southern Pannonian growing area Vojvodina

| Periods | Indicators of wheat yield and SOC | | | | |
|---|---|---|---|---|---|
| | WP (kg/ha) ± SD | $Y_{pv}$ (%) | total area (ha) ± SD | SOC (g/kg) ± SD | SOC stock (t/ha) |
| 1960–1970[a] | 2.644 ± 619 | 23.41 | 413.966 ± 73.378 | 27.55 ± 1.45 | 111.57 |
| 1980–1990[b] | 4.908 ± 413 | 8.14 | 352.012 ± 39.538 | 18.78 ± 2.84 | 76.05 |
| 2002–2007[c] | 3.716 ± 821 | 22.09 | 309.446 ± 35.938 | 15.33 ± 1.18 | 62.08 |

WP – wheat productivity; $Y_{pv}$ – yield production variability; SD – standard deviation; [a]Živković et al. (1972); [b]Bogdanović and Ubavić (1999); [c]Vasin et al. (2008)

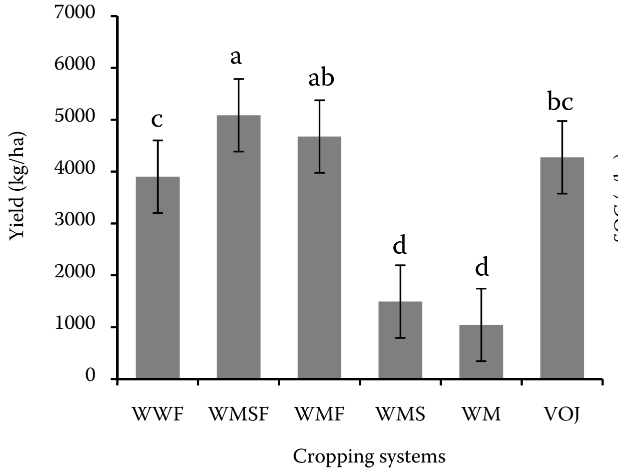


Figure 1. Average grain yield of winter wheat in LTE and Southern Pannonian growing area Vojvodina (VOJ). Values are means of 38 years ± SE. Bars with different letters are significantly different at $P \leq 0.05$

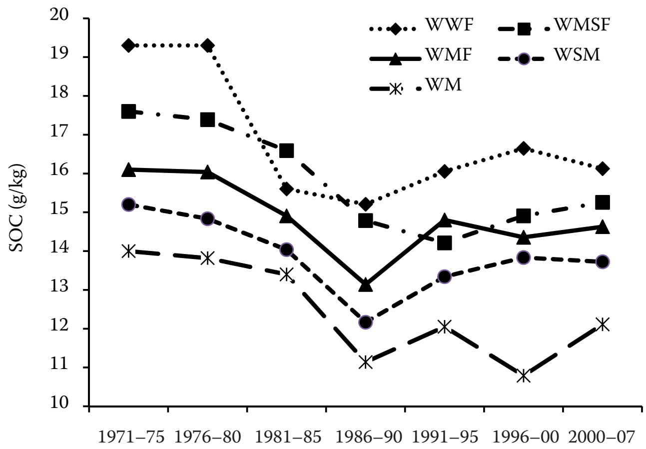


Figure 2. Changes in SOC content for the various cropping systems in the investigated LTE

initial agro-ecological potential of investigated area after 60 years of continuous cropping compared with the fertilized treatments. Wheat yields in the unfertilized treatments (WMS and WM) showed a steep decline after their establishment (1946/47) until 1970–1980 when new balance was established (Milošev 2000). Similar result was observed in long-term trials in the Czech Republic (Černý et al. 2010).

The long-term cropping technology applied at the LTE has led to a reduction of SOC content in average by 10%, and continually decreased soil potential for sustainable wheat production (Figure 2, Table 4). The unfertilized rotation showed a considerable loss of SOC in the 0–30 cm depth when compared with the initial level, likely due deficiency in a photosynthetically fixed C stored in soil. Likewise, soil degradation processes were also observed, due to topsoil attenuation and permanent soil loss and nutrient removal that restricted plant growth. Therefore, we assumed that the loss of SOC and associated processes such as nutrient depletion, structure deterioration, equally with insufficient inputs of fertilizers, pesticides, and intensive technology could irreversibly affect soil productivity of such normally productive soils as chernozem. If the lower limit of SOC securing successful agricultural production is 2% (Loveland and Webb 2003), the investigated site is exposed to a considerable risk of diminishing the production capacity with applied management practice (Figure 2). Depletion of SOC in the topsoil of the unfertilized treatments had led to possible C threshold 1.16% of chernozem soil, since stagnating yield trend indicated that the new equilibrium of SOC decomposition and formation was established at this level of SOC.

At the end of the observed period (2007), considering all the fertilized cropping systems, WWF had the highest and the WMF the lowest SOC content

Table 4. Soil organic carbon (SOC) content, SOC change, annual C input and correlation of winter wheat yields with SOC of the investigated treatments

| Cropping systems | SOC (g/kg) | | | | Plant C input ($g/m^2$/year) ± SD⁺ | Correlations | | |
|---|---|---|---|---|---|---|---|---|
| | 1970–80 | 2000–07 | Δ SOC | change (%) | | equation | $r^2$ | $R^2$ (%) |
| WWF | 17.7$^a$ | 16.3$^a$ | 1.4 | 7.91 | 469.48 ± 78.13 | $y = 218.9x + 418.5$ | 0.54$^{ns}$ | 29 |
| WSMF | 16.9$^{ab}$ | 15.4$^b$ | 1.5 | 8.88 | 592.34 ± 161.67 | $y = 410.0x - 1137.1$ | 0.66* | 43 |
| WMF | 16.3$^b$ | 14.9$^b$ | 1.4 | 8.59 | 555.41 ± 128.72 | $y = 271.1x + 662.3$ | 0.48$^{ns}$ | 23 |
| WSM | 15.2$^c$ | 13.2$^c$ | 2.0 | 13.16 | 178.32 ± 68.83 | $y = -4.3x + 1620.4$ | −0.1$^{ns}$ | 0.01 |
| WM | 13.7$^c$ | 12.1$^c$ | 1.6 | 11.49 | 125.07 ± 46.93 | $y = -14.8x + 1206.5$ | −0.5$^{ns}$ | 0.25 |
| **Average** | 16.0 | 14.4 | 1.6 | 10.00 | 384.12 | | | |

⁺grain excluded; [a-c]values in columns followed by different letters do not differ significantly at $P \leq 0.05$; *$P \leq 0.05$; [ns]not significant

(Figure 2, Table 4). In the fertilized treatments application of N resulted in greater aboveground and belowground biomass, which was beneficial for maintaining SOC in the soil (Manojlović et al. 2008), but not sufficient for C enrichment. The preservation of SOC in WWF, 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. Babulicová (2008) elucidated that fertilization of winter wheat growing in monoculture was more effective than mineral fertilization in crop rotations. By contrast, the higher content of SOC at WWF in this study did not correspond with higher yields of winter wheat, which indicates WWF is not a sustainable cropping alternative for wheat production (Figure 2, Table 4).

Based on the average SOC content at the investigated LTE, the SOC lost ranged from 7.91–13.16% of the observed SOC found in the 1970s/80s (Table 4). Smaller C input was found in the unfertilized rotation which where deficient in photosynthetically fixed C. The WMSF had a higher biomass and potential of C storage (592.34 g/m$^2$/year) compared with other systems and presence of legumes in the WMSF may result in a more efficient conversion of residue C to SOC. Johnson et al. (2006) elaborated that for the Pacific Northwest critical source C input for SOC preservation ranged from 120 to 400 g C/m$^2$. Similar results were presented in Buyanovsky and Wagner (1986) who estimated that accumulated C return to the soil was 372 g/m$^2$. The assumption is that C input for sustaining level of C in soil, regardless to crop rotation, in our agro-ecological area must exceed 550 g/m$^2$/year (approximately 4300 kg/ha of winter wheat grain yield).

To assess the possible yield response to SOC content in soil, data from the LTE experiment were correlated (Table 4). Significant regression was found between SOC and yield at the WMSF ($r^2 = 0.66$; $P \leq 0.05$), while relationship at the other cropping systems was not significant. Positive relationship of SOC and wheat yield was also found in Pan et al. (2009). Observed positive regression at the fertilized plots (WMSF, WMF and WWF) indicated that an increase in SOC could bring up higher yield, however the indirect effects of SOC on other soil properties must also be considered. At the unfertilized treatments, slope and elevation showed no regression between SOC and yield, likely due to prevailing effects of available P and K, water holding capacity, soil compaction etc., on yield. However, even with positive trends, correlated data of the SOC and winter wheat yield cannot fully explain its relationship since their functional association requires an understanding of temporal changes over the observed period.

The SOC stock (DfC) difference of two observed period was in average 4 t C/ha (Table 5). Among the fertilized treatments WWF had in a largest difference (3.5 t C/ha) as a result of the higher initial level of SOC and smaller biomass plowed into the soil each year (Table 4). The smallest difference between SOC stocks was observed in the WMF plot (2.58 t C/ha), as this rotation had a higher amount of plant residue (maize + winter wheat) incorporated with plowing every year, compared with the other treatments (Table 4).

In this study the WMSF, compared with other fertilized systems, showed a smaller yield decline in response to SOC stock change (58 kg/ha). Similar results were presented by Bauer and Black (1994) from a North Dakota experiment in which they found 27 kg/ha reduction in spring wheat yields with each 1 t C/ha loss in SOC within the 0–50 cm depth. According to our results, WMSF rotation could be recommended since productivity of winter wheat in this rotation remains relatively stable over the examined period.

Table 5. Changes of winter wheat yield and soil organic carbon (SOC) stock under different cropping systems in the longterm experiment (LTE)

| Cropping system | Yield (kg/ha) | | DfY (kg/ha) | BD (t/m$^3$) | | SOC stock (t/ha) | | DfC (t/ha) | P (kg/ha) |
|---|---|---|---|---|---|---|---|---|---|
| | 1970–80 | 2000–07 | | 1970–80 | 2000–07 | 1970–80 | 2000–07 | | |
| WWF | 4370 | 2940 | 1430 | 1.30 | 1.34 | 69.0 | 65.5 | 3.50 | 410 |
| WMSF | 5030 | 4840 | 190 | 1.35 | 1.41 | 68.4 | 65.1 | 3.30 | 58 |
| WMF | 4630 | 4200 | 430 | 1.36 | 1.43 | 66.5 | 63.9 | 2.58 | 160 |
| WMS | 1660 | 1530 | 130 | 1.33 | 1.39 | 60.6 | 55.0 | 5.60 | 24 |
| WM | 1160 | 980 | 180 | 1.38 | 1.42 | 56.5 | 51.5 | 5.04 | 36 |
| Average | 3370 | 2900 | 470 | 1.34 | 1.39 | 64.2 | 60.2 | 4.00 | 138 |

DfY – difference in yield; DfC – difference in SOC stock; BD – bulk density; P – productivity

According to the available data, SOC content has declined, regardless of the cropping technology and grown variety (Šeremešić et al. 2007). Similarly to that, physical soil properties, predominantly soil structure and compaction, usually undergo deterioration together with SOC and commonly interact in lower production capacity of soil. Additionally, long-term effects of climate change will affect cropping patterns and likely to have negative yield impacts for major cereals. In the following period, if this negative trend continues SOC content will decline by another 10%, which will ultimately pose a threat to the soil production capacity under the agro-ecological area of SPB. Our hypothesis is that by using proper management practice in the three-year crop rotation the decline of SOC stock could be stopped, and potentially reversed in the agricultural area of the SPB.

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