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Soil organic matter content according to different management system within long-term experiment

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ABSTRACT

Within the long-term field experiments at IOSDV Rakičan, Slovenia, the impact of organic matter management system and mineral nitrogen fertilization on the soil organic matter content was studied in the period 1994-2008. The annual balance of C_{org} was calculated on the basis of the quantity of added organic fertilizers ("Bavarian method", "VDLUFA method"), while the "Swiss method" also consider the quantity of C_{org} in the topsoil in the calculation. The following management systems were selected: system A - no organic matter, system B - farmyard manure ploughing in, system C - straw/catch crop ploughing in. Four different mineral N rates (N0, N1, N2, N3) were evaluated. In 2008 the C_{org} content in topsoil (0-25 cm) was measured according to ISO 10694. Farmyard manure (FYM) fertilization significantly influenced the content of C_{org}, while the straw application did not result in the significant increase of C_{org} content. Mineral nitrogen fertilization did not impact C_{org} content within system A. In system B and system C positive effect of nitrogen fertilization on the C_{org} content was detected. However, statistically significant impact of mineral N on a higher C_{org} content was not determined. All three methods underestimated the actual analysed results, although, we can determine the "Swiss method" as the most precise and appropriate for this site-specific location.

Key words: organic fertilizers, farmyard manure, straw, N fertilizers, C_{org} content, humus balance, humus balance calculation methods

IZVLEČEK

VSEBNOST ORGANSKE SNOVI V TLEH V ODVISNOSTI OD NAČINA GOSPODARJENJA ZNOTRAJ TRAJNEGA POSKUSA

V statičnem poskusu IOSDV Rakičan, Slovenija smo preučevali vpliv gospodarjenja z organskimi gnojili in vpliv gnojenja z mineralnimi dušikom na vsebnost organske snovi v tleh v letih 1994 do 2008. Letna bilanca C_{org} je bila izračunana na podlagi količin dodanih organskih gnojil pri „Bavarski metodi" in „ VDLUFA metodi", medtem ko se je pri „ Švicarski metodi" v izračunih upoštevalo tudi stanje C_{org} v tleh. Vključeni sistemi gospodarjenja so bili: sistem A - gospodarjenje brez organskega gnojenja, sistem B - gnojenje s hlevskim gnojem, sistem C - zaoravanje slame/podorin. Preučevane so bile štiri stopnje gnojenja z mineralnim dušikom: N0, N1, N2 in N3. V letu 2008 je bila izmerjena vsebnost C_{org} v globini od 0 do 25 cm po standardu ISO 10694. Gnojenje s hlevskim gnojem je značilno povečalo vsebnost C_{org}, medtem ko gnojenje s slamo ni imelo takšnega vpliva. V sistemu brez organskih gnojil gnojenje z mineralnim dušikom ni doprineslo k povečanju vsebnosti C_{org}. Kljub pozitivnemu vplivu gnojenja z mineralnim dušikom na vsebnost C_{org} v sistemu B in C, pa vpliv ni bil statistično značilen. Izračuni vseh treh metod podcenijo dejanske rezultate laboratorijskih analiz posameznega vzorca. Še najbolj se omenjenim rezultatom približajo vsebnosti C_{org}, izračunane s „Švicarsko metodo", zato lahko povzamemo, da je slednja najbolj primerna za določitev C_{org} za preučevano lokacijo.

Ključne besede: organska gnojila, hlevski gnoj, slama, mineralni dušik, vsebnost C_{org}, bilanca humusa, metode izračunavanja bilance humusa

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1 INTRODUCTION

Land use and agricultural management practices such as crop rotation, soil tillage and organic amendment, depending on the site-specific conditions can affect soil organic matter (SOM). Changes in the organic carbon (C_{org}) content in soil occur almost exclusively in its decomposable part. The tendency of the decomposable carbon (C_{dec}) changes also depends on its initial level. Application of the same fertilization and cropping system can cause a decrease of the SOM content if its initial level was high, as well as an increase of the SOM if its initial level was low (Körschens, 2002). As the organic substances interact with clay in soil to form complexes and micro-aggregates, which make the organic matter less accessible to decomposers, C_{org} tend to increase and mineralization rate decrease with the clay content (Bosatta and Ăgren, 1997; Körschens, 2004; Diekow et al., 2005). The content of organic carbon (C_{org}) is controlled by changes in management via the annual input of organic matter and the rate at which decays (Jenkinson et al., 1999).

The amount of SOM is generally higher in the fertilized soils than in the unfertilized soils (Ellmer et al., 2000; Hoffmann et al., 2002; Berecz et al., 2004; Goyal et al., 2006). Data from several long-term comparative experiments on the effect of FYM and mineral fertilization prove that FYM increases the organic matter content of the soil to a greater extent than mineral fertilization (Körschens, 1997; Kuzyakov and Domanski, 2000; Berecz et al., 2004; Brodowski et al., 2007; Šimon, 2007). On the other hand organic C stocks had barley changed in response to very considerable changes in management in the experiment by Jenkinson et al. (1999). In case of omitted mineral N fertilization, the humus content in the soil decreased rapidly (Stumpe et al., 2000; Beschow and Merbach, 2004; Winkelmann et al., 2006). Incorporation of harvest residues also increased C_{org} content in soil (Buyanovsky and Wagner, 1998; Triberti et al., 2008). Not only the quantity, also the structure of SOM varies depending on the rate of fertilizer (Ellerbrock et al., 1999; Dorado et al., 2003).

By using methods of calculating the balance of humus we are given an opportunity to control the SOM content in arable soils in order to achieve higher yields and simultaneously avoid environmental pollution. Since the most C_{org} is bound in soil humic matter, the mineralization and humification of plant carbon in soil should be monitored (Filip and Kubát, 2004). There are several humus balance calculation methods and models, however, in many models, humification is not considered as a part of the process of transformation of organic debris into humus, and the role of humus in the kinetics of this process is evidently underestimated (Chertov et al., 2007). Three humus balance calculation methods, which take into account a humification and mineralization rates and are believed to be appropriate for European Central site-conditions are investigated: "Swiss method" determined by Diez and Krauss (1992), the "Bavarian method" determined by Bavarian working group (Anonymous, 1998) and the "VDLUFA method" determined by Körschens et al. (2004).

The aim of our study was to examine, with the application of mentioned methods, the impact of organic and mineral fertilization on the humus content in the soil according to particular crop rotation at ISODV Rakičan location. As the soil analyses were conducted every year since the establishment of the trial, the results calculated by each method could be compared with the analysed results, therefore a most appropriate method for this site-specific condition could be selected.

2 MATERIAL AND METHODS

2.1 Experimental layout

As part of the "International Long-term Experiments for Investigating the Effect of Organic and Inorganic Fertilizers" (IOSDV), field experiment was set up at Rakičan, Slovenia (46°38´N, 14°11´E, Pannonian climate, sandy silt) in 1993. The trial was set up as a permanent experiment related to crop rotation with ten different fertilization combinations as a block trial with three repetitions. First, the trial area was divided into three plots, on which each year crops were sown in the following order: corn, winter wheat, barley. Each plot was further divided into two subplots, on which different systems of fertilization with organic management were studied. Each subplot thus represented five variants differing according to the rate of fertilization with mineral nitrogen in the three repetitions. The basic plot size was 30 m^2 (5 × 6 m). Ten different treatments were included in the investigation:

- management system with no organic fertilizers (system A) and two different mineral rates (N0, N3),
- management system with farmyard manure (FYM) ploughing in (system B) and four different mineral N rates (N0, N1, N2, N3),
- management system with straw ploughing in (system C) and four different mineral N rates (N0, N1, N2, N3).

Fertilizing plan for the nutrition of arable crops is shown in Table 1. Fertilization with phosphor and potassium was uniform for all mineral nitrogen rates (N0=0 N kg/ha, N1=73 N kg/ha, N2=147 N kg/ha, N3= 220 N kg/ha): 75 kg/ha P_2O_5 and 160 kg/ha K_2O. At the harvest time, yield and straw quantities were measured for each plot. After harvesting every year soil samples from each plot were taken at a depth of 0-25 cm.

Table 1: Management systems, mineral N fertilization with regard to the crop, the average amount of mineral N in the three-year crop rotation (N-min$_{aver.}$) at IOSDV Rakičan location

		N-min rates/ Treatment	Maize (kg/ha N)	Wheat (kg /ha N)	Barley/ (kg /ha N)	N-min$_{aver.}$ (kg /ha N)
System A	No organic fertilizers		/	/	/	
		N0 (**AN0**)	0	0	0	0
		N3 (**AN3**)	300	195	165	220
System B	FYM ploughing in (t/ha)		30 t/ha FYM*	/	/	
		N0 (**BN0**)	0	0	0	0
		N1 (**BN1**)	100	65	55	73
		N2 (**BN2**)	200	130	110	147
		N3 (**BN3**)	300	195	165	220
System C	Straw/catch crop ploughing in (t/ha)		Barley straw + fodder radish	Maize straw	Wheat straw	60**
		N0 (**CN0**)	0	0	0	0
		N1 (**CN1**)	100	65	55	73
		N2 (**CN2**)	200	130	110	147
		N3 (**CN3**)	300	195	165	220

* FYM is applied every third year.

** Mineral N is added after barley and before fodder radish is sown, every third.

2.2 Weather and soil conditions

The soil type, soil properties and some climatic characteristics of the experimental site are listed in Table 2 (Tajnšek, 2003). Annual precipitation and the average annual temperature for the period 1994-2008 in comparison with the long-term average precipitation and the long-term average temperature for the period 1960-1990 are shown in Figure 1.

Table 2: Soil properties of the experimental site (Tajnšek, 2003)

Long. East[1]	Lat. North[2]	Prec[3]. (mm)	Temp[4]. (°C)	Soil type (FAO classification)	Clay (<2.0µm) (%)	pH (KCl)	C_{org} (%)	N_{org} (%)	C/N Ratio
14°11′	46°38′	814	9.2	Eutric Fluviosol (ELe)	14.67	7.04	0.926	0.098	9.5

[1]Longitude; [2] Latitude; [3] Precipitation, the long-term average precipitation in the period 1961-1990; [4] Temperature, the long-term average temperature in the period 1961-1990

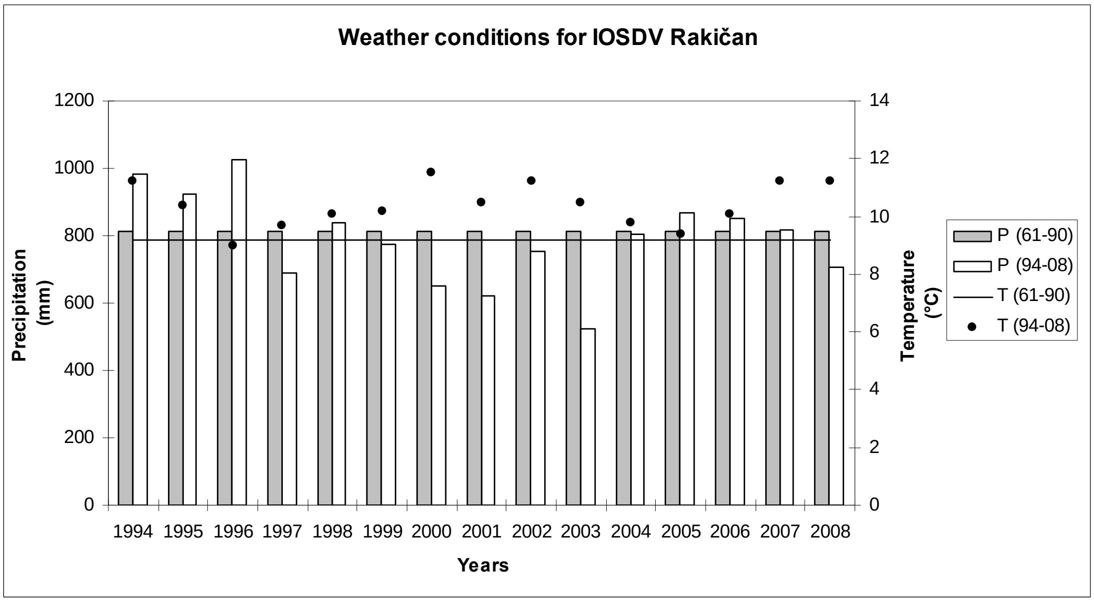

Figure 1: Annual precipitation and the average annual temperature for the period 1994-2008, the long-term average precipitation (1961-1990) and the long-term average temperature (1961-1990) for the IOSDV Rakičan (weather station Murska Sobota) location

2.3 Humus balance calculation methods

In our investigation, there are three methods of calculating the balance of humus involved:

- The method determined by Diez and Krauss (1992) named as the "Swiss method" or “S”. The annual balance is calculated on the basis of the ploughed-in quantity of organic matter (manure, straw, catch crop, harvest residues) with the corresponding humification coefficient, taking into account the quantity of humus in the soil (H) with the appropriate mineralization coefficient. Results are given in the C_{org} value (t/ha), which is calculated on the basis of humus content (t/ha) multiplied by factor 0.58.
- The method determined by Bayerische Landesanstalt für Bodenkultur und Pflanzenbau, Freising-München (Anonymous, 1998) named as the »Bavarian method« or »B«. The humus balance is calculated on the basis of humification rate of individual crop in crop rotation, taking into account the quantity of added organic matter: manure, straw and catch crop. In this method humification factor varies due to soil texture, therefore at IOSDV Rakičan a humification factors for soil type sandy silt (Eutric Fluviosol [ELe]) are chosen. Results are given in the C_{org} value (t/ha), which is calculated on the basis of humus content (dt/ha) multiplied by factor 0.58 (humus content→C_{org}) and by factor 0.1 (dt/ha→t/ha).
- The method determinated by working group Körschens et al. (2004) named as the »VDLUFA method« or »V«. With the “VDLUFA method” an organic matter surplus is calculated by addition of specific humification coefficients using for organic matter depleting crop species and for the organic matter inputs: manure, straw and catch crop. The organic matter decay is represented in the coefficients of depleting and increasing crop species. While for the major intensive forms of agricultural managements the lower values of annual humus balance under specific crop are recommended by DirektZahlVerpfIV (Körschens et al., 2004), we have chosen the lower values for further calculation. Results are given in the C_{org} value (t/ha), which is calculated on the basis of content Humus-C (kg/ha) multiplied by factor 0.001 (kg/ha→t/ha).

2. 4 Chemical analyses

In the year of the establishment of the experiment (1993), as well as in all subsequent years, the soil analyses were conducted at the laboratories UFZ Leipzig-Halle, Germany (Tajnšek, 2003). The C_{org} content was determined according to ISO 10694, 1996-08. In the calculation of humus balance we considered initial value of C_{org} content in 1993.

2.5 Processing of statistical data

Statistical analysis was conducted with the Statgraphics Plus 4.0 program. Before analysis each treatment was tested for homogeneity of treatment variances. If variances were not homogeneous, data was transformed to log (Y) before ANOVA. Multifactor ANOVA was used in order to analyze the effect of different management systems on the humus content in the soil. Differences among treatments were detected by Duncan's Multiple Range Test ($p < 0.05$). Data is presented as untransformed means±SE.

3 RESULTS

3.1 The humus balance in the period 1993-2008

Results showing the C_{org} content of the analysed soil samples at IOSDV Rakičan in the beginning of the trial and the C_{org} content calculated by different methods for the year 2008 are given in Table 3. The initial value of C_{org} in 1993 was 37.27 t/ha C_{org}. FYM fertilization significantly influenced the content of C_{org}, while the straw application did not result in a significant increase of the C_{org} content. Results show that mineral N fertilization had no significant impact within all three management systems.

As demonstrated in Table 3, mineral nitrogen fertilization did not contribute to an increase of the C_{org} content in the management without organic fertilization (system A). Moreover, with the application of the average amount of N in a three-year crop rotation (220 kg/ha N), the C_{org} content resulted in a decrease of 2.3 %, i.e. 0.94 t/ha C_{org}. This is comparable to the results of the experiment by Beschow and Merbach (2004), where a comparison of the highest mineral nitrogen (N) with no-N resulted in a merely 1.2-fold higher value of the C_{org} content in the topsoil. Likewise, in the case of mineral N fertilization, the content of C_{org} was slightly higher (1.4 to 1.5 %) than without any N fertilization (1.3 %) (Stumpe et al., 2000; Triberti et al., 2008).

Table 3: C_{org} content (t/ha) of analysed soil samples in 1993 and 2008, the C_{org} content (t/ha) in 2008, calculated by »Swiss« (S), »Bavarian« (B) and »VDLUFA« (V) methods and the difference between analysed and calculated C_{org} content (t/ha) in 2008 for ten different treatments (IOSDV Rakičan)

Tre.	$C_{org1993}$ (anal.) (t/ha)	$C_{org2008(anal.)}$ (t/ha)	$C_{org2008(cal.)}$ (t/ha)			$C_{org2008(anal.)}$ - $C_{org2008(cal.)}$ (t/ha)		
			»S«	**»B«**	**»V«**	**»S«**	**»B«**	**»V«**
AN0	37.27	41.73± 1.28 a*	37.06±0.02 a	33.28±0.00 a	31.67±0.00 a	4.67	8.45	10.06
AN3		40.79±1.10 a	37.26±0.08 a	33.28±0.00 a	31.67±0.00 a	3.53	7.51	9.12
BN0		46.96±1.36 bcde	38.19±0.02 c	36.76±0.00 b	37.67±0.00 b	8.77	10.20	9.29
BN1		48.97±2.16 de	38.25±0.02 cd	36.76±0.00 b	37.67±0.00 b	10.72	12.21	11.30
BN2		49.37±0.58 e	38.37±0.04 e	36.76±0.00 b	37.67±0.00 b	11.00	12.61	11.70
BN3		47.63±0.75 cde	38.35±0.00 de	36.76±0.00 b	37.67±0.00 b	9.28	10.87	9.96
CN0		40.79±1.68 a	37.90±0.11 b	37.63±0.06 c	37.61±0.08 b	2.89	3.16	3.18
CN1		42.53±1.36 ab	37.92±0.07 b	38.67±0.16 d	39.08±0.23 c	4.61	3.86	3.45
CN2		44.41±1.10 abcd	37.94±0.10 b	39.27±0.18 e	39.91±0.25 d	6.47	5.14	4.50
CN3		43.74±2.11 abc	38.18±0.03 c	39.90±0.03 f	40.80±0.04 e	5.56	3.84	2.94
					$\lvert x_{povp.} \rvert$	6.75	7.79	7.55

*a-f The same letter in the column indicates thet there is no significant difference among treatments (Duncan Multiple Range Test, P<0.05).

In the system with FYM (system B), C_{org} was significantly higher in all the treatments when compared to AN0 and AN3. The application of mineral N increased the C_{org} content; however, the differences were not significant. The C_{org} content increased by 5.23 t/ha (BN0), 7.24 t/ha (BN1), 7.64 t/ha (BN2) and 5.90 t/ha (BN3). The highest amount of mineral N (BN3) combined with 10 t/ha.yr FYM resulted in a slightly lower C_{org} content. Ellmer reported that the total carbon content between 600 and 800 mg/100g can be achieved by organic fertilization (15 t/ha.yr FYM) and with appropriate crop rotation (Ellmer et al., 2000). An average demand for FYM was determined to be 10 t/ha in a year (Körschens et al., 2004).

In the management with ploughing in of straw (system C), there was a decrease of the C_{org} content by 0.94 t/ha in the treatment without mineral N (CN0). Although the C_{org} content increased with higher fertilizer rates of mineral N, a significant impact of N fertilizing could not be confirmed among the treatments. The C_{org} content increased by 0.80 t/ha (CN1), 2.68 t/ha (CN2) and 2.01 t/ha (CN3). In the experiment by Triberti et al. (2008), the SOC stock did not change in unfertilized plot and N fertilized plot, while it increased at a mean rate of 0.16, 0.18 and 0.36 t/ha in a year with the incorporation of residues, slurry and manure.

In both systems (system B, system C), the application of the highest amount of mineral N (BN3, CN3) resulted in a lower C_{org} content.

The contribution of FYM to the maintenance of the C_{org} content is greater than the input of straw. According to AN0, where the C_{org} content amounted to 41.73 t/ha, the C_{org} content in system B increased in the range of 5.23 to 7.64 t/ha C_{org}, i.e. 12.5 % to 18.3 %. In system C, where no mineral N was added (CN0), the C_{org} content decreased by 0.9 t/ha, while in other treatments it increased by 0.80 to 2.68 t/ha C_{org}, i.e. by 1.9 % to 6.4 %.

According to different management system, the same fertilizing rate of mineral N significantly influenced the C_{org} content only in system B. In comparison with AN0, the change of the C_{org} content was higher for 12.5 % in BN0, while in system C the C_{org} content decreased for 2.3 % (CN0). When comparing the treatments with the highest mineral N rate, an increase of the C_{org} content by 16.7 % in BN3 and by 7.2 % in CN3 according to AN3 was confirmed. Compared to the unfertilized plot, the FYM application resulted in a 8.2 % higher total organic carbon content than the equivalent NPK fertilization according to Hoffmann et al. (2006). In the experiment by Berecz et al. (2004), both types of organic manuring (FYM, straw or green manure) resulted in significantly higher C_{org} contents compared to the mineral N fertilization without manuring or incorporation of crop residues.

Application of FYM combined with mineral N resulted in the highest C_{org} content among all the treatments. This is in accordance with the results given by other authors (Filip and Kubát, 2004; Goyal et al., 2006). The increase of the C content in the soil during a 50-year period required a four times (e.g. FYM on loamy soil) to 12 times (e.g. straw fertilization on sandy soil) higher input C, depending on the local conditions and the type of primary organic matter (Körschens et al., 2004).

3.2 Calculated and analysed C_{org} content in 2008

In calculation by “Swiss method”, the C_{org} content increased by application of mineral nitrogen (AN3). The results calculated by “Bavarian method” and “VDLUFA method” within the systems are equal; this was expected as the calculation takes into account the amount of added organic matter which does not differentiate between treatment AN0 and AN3. As it is seen from figure 2, method which most closely approximated the analysed C_{org} content in the system with no organic matter was “Swiss” method. The difference between analysed $C_{org2008}$ content and calculated $C_{org2008}$ content is called deviation from analysed C_{org} content. Deviation from analysed C_{org} content was higher by using “Bavarian” and “ VDLUFA” methods, deviation ranged from 7.51 to 8.45 t/ha C_{org} at “Bavarian” method and from 9.12 to 10.06 t/ha C_{org} at “VDLUFA” method.

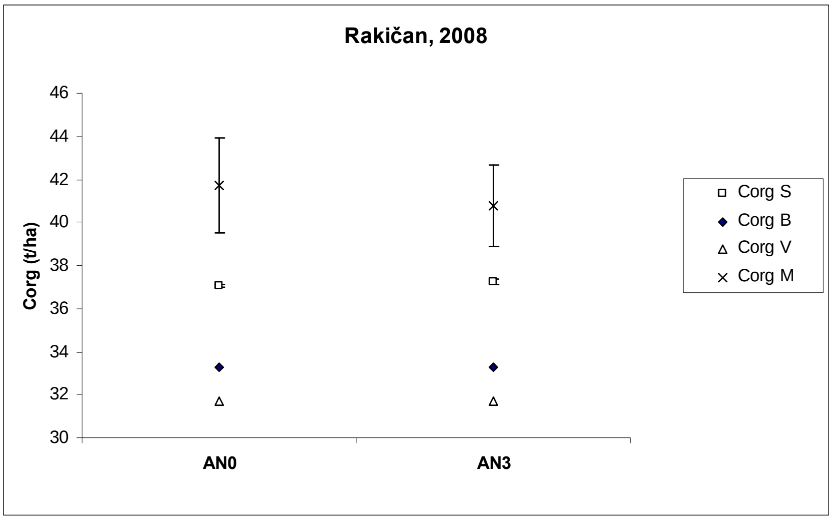

Figure 2: C_{org} content of analysed soil samples (C_{org}M), C_{org} content, calculated by »Swiss« (C_{org}S), »Bavarian« (C_{org}B) and »VDLUFA« (C_{org}V) methods in 2008 for two treatments in management system with no organic fertilizers (IOSDV Rakičan)

The application of mineral nitrogen in system with FYM statistically increased C_{org} content in results calculated by "Swiss" method at BN2 and BN3, while within treatments in "Bavarian" and "VDLUFA" methods there were no differences. Deviation from analysed C_{org} content ranged from 8.77 to 11.00 t/ha C_{org} at "Swiss", from 10.20 to 12.61 t/ha C_{org} at "Bavarian", from 9.29 to 11.70 t/ha C_{org} at "VDLUFA" method. For this system method which most closely approximated the analysed C_{org} content was again "Swiss" method (Figure 3).

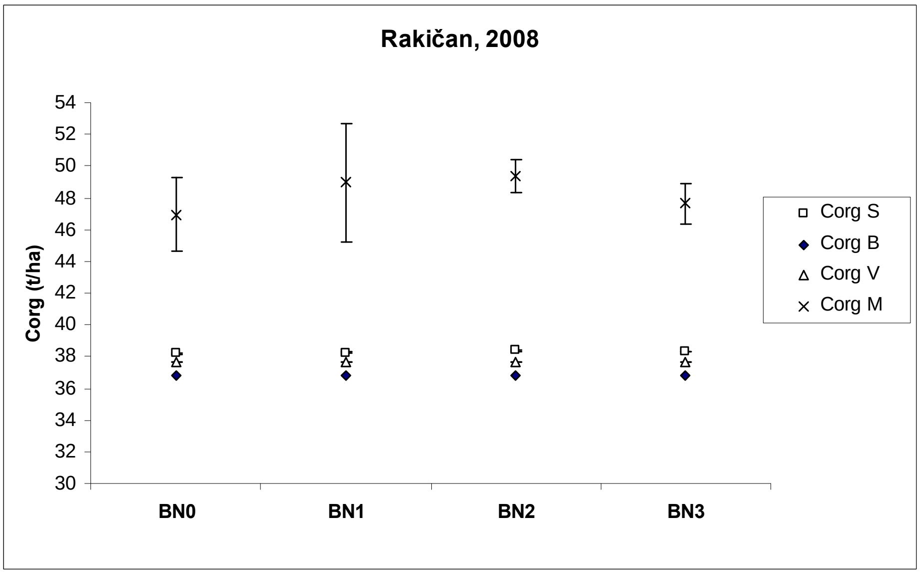

Figure 3: C_{org} content of analysed soil samples (C_{org}M), C_{org} content, calculated by »Swiss« (C_{org}S), »Bavarian« (C_{org}B) and »VDLUFA« (C_{org}V) methods in 2008 for four treatments in management system with FYM ploughing in (IOSDV Rakičan)

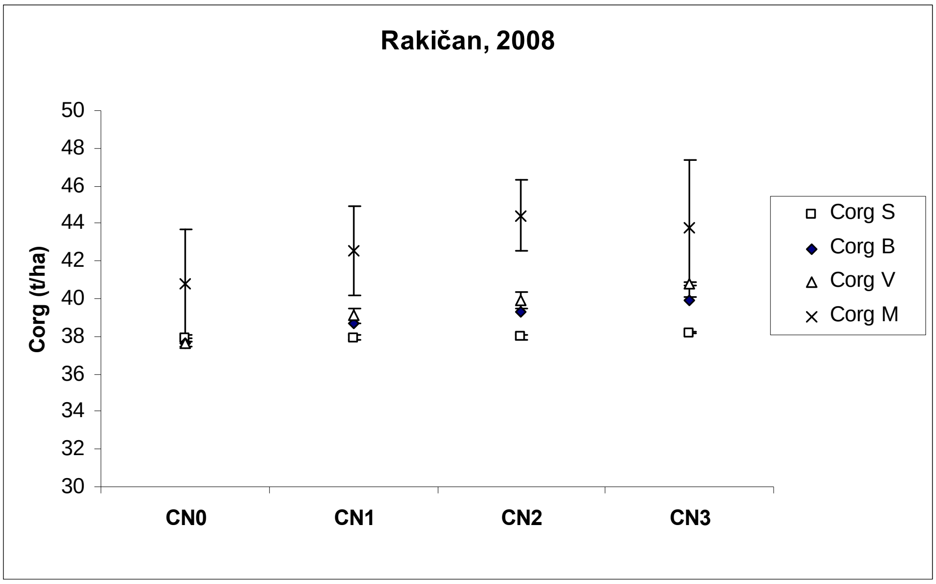

Figure 4**:** C_{org} content of analysed soil samples (C_{org}M), C_{org} content, calculated by »Swiss« (C_{org}S), »Bavarian« (C_{org}B) and »VDLUFA« (C_{org}V) methods in 2008 for four treatments in management system with straw ploughing in (IOSDV Rakičan)

In the system with straw ploughing in application of mineral nitrogen significantly increased the C_{org} content in »Bavarian« and »VDLUFA« method, while in »Swiss« method the impact of mineral nitrogen was notices only in treatment with the highest mineral rate (CN3). In this system the most precise method seemed to be »VDLUFA« method, where the deviation from analysed C_{org} ranged from 2.94 to 4.50 t/ha C_{org} (Figure 4). Using "Swiss" method the mentioned deviation ranged from 2.89 to 6.47 t/ha C_{org}, using "Bavarian" method it was in interval from 3.16 to 5.14 t/ha C_{org}.

4 CONCLUSIONS

After the fifteen-year experiment at IOSDV Rakičan, the application of organic fertilizers (farmyard manure, straw) influenced the C_{org} content. However, the impact was significant only in the system with farmyard manure. Mineral nitrogen fertilization contributed to an increase of the C_{org} content in all three management systems (system A, system B, system C). However, the increase was not significant. With the application of mineral nitrogen in the system with no organic fertilizers the C_{org} content resulted in a decrease of 2.3%, i.e. 0.94 t/ha C_{org}. In the system with farmyard manure ploughing in the C_{org} content increased by 5.23 t/ha (BN0), 7.24 t/ha (BN1), 7.64 t/ha (BN2) and 5.90 t/ha (BN3). In the system with straw ploughing in the C_{org} content increased by 0.80 t/ha (CN1), 2.68 t/ha (CN2) and 2.01 t/ha (CN3). The comparison of C_{org} contents calculated by different humus balance methods in 2008 shows that all three methods underestimated the actual analysed results. "Swiss" method´s results most closely approximated the analysed C_{org} in the systems A and system B, while in the system C the most appropriate method was "VDLUFA". As the average of absolute values of deviations from analysed C_{org} contents was the lowest by using "Swiss" method (6.75 t/ha C_{org}), we can conclude that this method is most appropriate method for this site-specific location.

5 ACKNOWLEDGEMENT

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