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Proceeding Paper

Carbon Stocks, Sequestration Rate and Efficiency over 50 Years of Increasing Mineral N Fertilization †

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Abstract: Microbially mediated soil organic matter is an extremely sensitive pool that indicates subtle changes in the quality parameters. The calculation of different carbon pools (organic carbon—OC, labile carbon—PMC, light carbon—LFC and microbial carbon—MBC), their sequestration rate (Csr) and efficiency (Cse), as affected by 50 yrs. of mineral fertilization, was carried out. The C sequestration rates between the fertilized plots were not significantly different except for the control plot. The sensitivity index, which indicates the response of soil organic matter to changes in different carbon fractions, demonstrated a strong correlation with the amount of light-fraction organic matter (OM). The use of mineral N over 50 years resulted in increase of soil labile C, but did not result in greater C sequestration efficiency. The results give a deeper insight into the behavior of carbon pools and can serve as a reliable basis for further studies focused on neutral carbon emissions and effective C sequestration.

Keywords: sequestration rate; carbon pools; labile carbon; microorganisms; mineral fertilization; nitrogen

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1. Introduction

Soil organic carbon (SOC) sequestration in agricultural soil is directly affected by anthropogenic activities and climate change; both can alter net primary production (NPP) and organic matter decomposition [1]. Under the same climatic, soil and topographic conditions, the biomass and activity of soil microorganisms are the main conductors of SOM mineralization and CO_2 fluxes. Generally, long-term fertilization adversely affects the soil microbial community [2,3]. Microbially mediated soil organic matter is an extremely sensitive pool that indicates subtle changes in the quality parameters responsible for the soil's ecological and productive functions. However, the accumulation of organic carbon in soil is a slow and reversible process. In contrast, the annual fresh plant litter decomposes during one growing season, thus returning organic carbon into the atmosphere as a carbon dioxide. In Serbia, agricultural production is still largely based on traditional land management. In previous works, we outlined the effect of the long-term application of synthetic fertilizers on various soil properties and parameters [3,4]. In these studies, it was found that increasing the dose of synthetic nitrogen naturally led to an increase in the yield, and thus, also in the biomass of plant residues. The latter found that labile carbon pools also increased. The purpose of this work was to establish how increasing the doses of synthetic nitrogen may or may not contribute to carbon sequestration.

2. Materials and Methods

In a field experiment lasting more than 50 years, four variants of different doses of mineral fertilizers with increasing doses of nitrogen and equal doses of phosphorus and potassium fertilizers were selected and compared with a control that did not receive either synthetic or organic fertilizers. The detailed description of the study site and experimental design can be found in the study by [3]. The soil type was *Eutric Cambisol*, and the area is located in central Serbia (44°24′58″ N and 20°10′34″ E). The plots were arranged in a randomized block design in four replications.

Soil respiration was measured by the alkali trap method under controlled laboratory conditions (temperature—28 °C, and soil moisture—50% WHC) at the following intervals: 3, 9, 16, 30, 44, 62, and 83 days for each treatment in four replications. The potentially mineralizable carbon (PMC) and mineralization rate constant (k) were calculated using the first-order kinetic model (Exponential Rise to Maximum; SPSS Inc.: Chicago, IL, USA; Sigma Plot 14). The microbial biomass carbon (MBC) was determined by the fumigation–incubation method [5]. The light fraction C (LFC) was determined in a CNS atomic analyzer after isolation based on the density separation with a NaI solution [6].

The carbon stocks (Mg/ha) of SOC, LFC, PMC and MBC as well as the carbon sequestration rate C_{SR} (Mg/ha/y) and carbon sequestration efficiency C_{SE} (%) for each fraction of carbon were calculated as described in [7].

3. Results and Discussion

In general, with an increase in the dose of mineral nitrogen, all the studied carbon pools increased accordingly (Table 1). A significant difference was observed between the control and all fertilized treatments, as well as between the lower and higher doses of N. Higher doses of mineral nutrition produce higher plant biomass, both aboveground and belowground [3]. The long-term accumulation of crop residues as an easily available organic substrate resulted in a greater accumulation of labile fractions of SOM under N120 and N150 treatments. Generally, the prolonged use of synthetic fertilizer can adversely affect soil biota [2,3]. However, when soil samples were placed in controlled conditions with optimal moisture and temperature, the microbes began to grow actively. This in turn led to high levels of labile carbon pools. In addition, autumn samples contain significantly more labile fractions of organic matter that return after harvesting.

Table 1. Labile fractions of soil organic matter.

Treatment	Fertilizer	OC, %	LFC mg/kg	PMC, mg/kg	MBC, mg/kg	qCO_2
control	0	0.92 b ± 0.02	332.44 a	913.91 a	188.31 a	3.664 a
N60	$N_{60}P_{51}K_{67}$	0.98 b ± 0.02	589.55 b	1287.95 b	228.66 b	4.562 b
N90	$N_{90}P_{51}K_{67}$	1.08 c ± 0.03	590.69 b	1893.50 c	295.91 c	5.694 c
N120	$N_{120}P_{51}K_{67}$	1.13 c ± 0.03	650.16 c	1840.94 c	342.99 d	4.743 b
N150	$N_{150}P_{51}K_{67}$	1.14 c ± 0.02	680.49 c	2054.64 c	352.14 d	5.331 c
t-test		**	**	***	***	**
		$p < 0.05$	$p < 0.05$	$p < 0.001$	$p < 0.001$	$p < 0.05$

Note: ** Significantly different at $p < 0.01$; *** Significantly different at $p < 0.001$ values followed by the same letter in a column are not significantly different; OC—organic carbon; LFC—light fraction carbon; PMC—potentially mineralizable carbon; MBC—microbial biomass carbon; qCO_2—microbial metabolic quotient.

In contrast to the concentrations of the labile C pools, their reserves did not differ significantly, except for the control and the lowest dose of N (N60) (Table 2). Hence, delta carbon stocks showed the same trend.

Table 2. Carbon stocks in different fractions.

Treatment	Carbon Stock, t/ha				Δ Carbon Stock, t/ha			
	OC	PMC	LFC	MBC	OC	PMC	LFC	MBC
0	1.0585 a	1.1058 a	0.4023 a	0.2279 a				
N60P80K80	1.2110 b	1.5584 a	0.7134 b	0.2767 a	0.1524 a	0.0355 a	0.0247 a	0.0037 a
N90P80K80	1.2639 b	2.2911 b	0.7147 b	0.3581 ab	0.2054 b	0.0959 b	0.0253 a	0.0105 b
N120P80K80	1.2756 b	2.2275 b	0.7867 b	0.4150 b	0.2171 b	0.0924 b	0.0317 ab	0.0154 b
N150P80K80	1.2917 b	2.4861 b	0.8234 b	0.4261 b	0.2332 b	0.1134 b	0.0346 ab	0.0163 b

Note: values followed by the same letter in a column are not significantly different.

Calculations of the rate and efficiency of carbon sequestration for each carbon pools showed that, in general, there was no significant difference between the treatments with increasing doses of mineral N (Table 3) for LFC and MBC, while OC and PMC showed less sequestration efficiency at the lowest dose (N60) of mineral N compared to N120 and N150.

Table 3. Carbon sequestration rate and efficiency.

Treatment	Csr, Mg/ha/yr				Cse, %			
	OC	PMC	LFC	MBC	OC	PMC	LFC	MBC
N60P80K80	0.3049 a	0.0710 a	0.0494 a	0.0075 a	0.07664 a	0.07848 a	0.07934 a	0.07680 a
N90P80K80	0.4109 a	0.1917 b	0.0505 a	0.0210 b	0.05541 ab	0.08088 ab	0.08085 a	0.08080 a
N120P80K80	0.4343 a	0.1848 b	0.0634 a	0.0309 b	0.03822 b	0.08237 b	0.08241 a	0.08252 a
N150P80K80	0.4665 ba	0.2268 b	0.0693 ba	0.0327 b	0.03983 b	0.08216 b	0.08226 a	0.08238 a

Note: Csr—carbon sequestration rate, Mg/ha/year; Cse—carbon sequestration efficiency, %. The same letter within a column signifies no statistical difference.

This study confirmed that long-term field experiments provide a highly reliable basis for setting realistic targets for carbon sequestration in traditionally managed agricultural landscapes. Although the addition of higher doses of mineral nitrogen has increased the concentration of labile carbon pools over 50 years, it has not been able to effectively sequester carbon. This research provides greater insight into the carbon cycle and sequestration potential of a traditional agricultural system that uses only synthetic fertilizers.

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