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SOIL CHEMICAL INDICATORS OF MEADOW CHERNOZEM UNDER LONG-TERM ORGANIC FARMING: EXPERIENCE FROM UKRAINE

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Abstract

Organic farming as a system of sustainable crop production with maintaining soil fertility has an increasing interest because of its environmental benefits. Here we report changes of soil chemical indicators of virgin Meadow Chernozem after 8-years and 36-years of organic farming in Central Ukraine. We evaluate the effect of biological fertilizers application (manure, crop residues etc.) under reduced tillage (disking to 10-12 cm) on organic carbon and available nutrients content in 0-10 and 15-25 cm soil layers. Long-term organic farming increased N-NO_3 and N-NH_4 content in a soil and contributed to solubilization of phosphorus compounds. The decrease of soil organic carbon by 27% was found after 8-years of organic farming compared to initial content in topsoil; nevertheless biological fertilizers application during 36-years led to gradual replenishment of the soil organic carbon pool.

Key words: *biological fertilizers, soil organic carbon, available nutrients, soluble salts.*

INTRODUCTION

Organic agriculture is a sustainable alternative to conventional (chemical-based) agriculture using environmentally friendly strategies such as the application of biofertilizers and botanical and microbial products as pesticides (Durán-Lara et al., 2020). The global organic market is constantly growing, and this issue is very important for Ukraine as a well-known agricultural country which has a great potential in the production and consumption of organic products (Chyhryn et al., 2017).

Organic farming management relies on developing biological diversity to disrupt habitat for pest organisms, and the purposeful maintenance and replenishment of soil fertility as the main factor of high yields (Singh, 2021). Soil fertility has always been a primary focus and defining issue in organic agricultural systems (Heckman et al., 2009). Soil fertility management in organic farming needs a long-term integrated approach rather than the more short-term solutions to obtain a yield, which are common in conventional agriculture (Watson et al., 2002). The significant impact of long-term practicing of organic agriculture on the status of various soil indicators was proved; organic farming contributes to the conservation of biological diversity (Singh, 2021) and increasing nutrients in the soil (Skrylnyk et al., 2019; Manjunatha et al., 2013) improves soil physical properties (reducing bulk density and increasing porosity and aeration) and chemical properties decreasing acidity (Singh et al., 2020).

Tillage has, and continues to be, widely used for weed control on organic farms globally, in spite of the deleterious impacts that tilling the soil can have on its ecosystem services (Carr, 2017). Many scientists concluded that reduced tillage, including No-till technology is a suitable method for increasing indicators of soil fertility in organic farming systems that may enhance the ecosystem services delivered by organic agriculture and make it more resilient to the effects of climate change (Gadermaier et al., 2012; Zikeli et al., 2017; Singh, 2021).

Organic agriculture with several advantages over the conventional system such as improvement of soil quality and crop quality, can overcome the environmental consequences of intensive farming (Abdelrahman et al., 2020). However, the organic system also has several limitations that must be addressed, and proper management must be evaluated to promote the organic production system.

Nutrient pools in organically farmed soils are also essentially the same as in conventionally managed soils but in the absence of regular fertilizer inputs, nutrient reserves in less-available pools will be of greater significance (Shepherd et al., 2002). Organic production systems rely more on the use of on-farm inputs and less on external inputs, which reduce the input cost (Verma et al., 2020). Maeder et al. (2002) emphasized that enhanced soil fertility and higher biodiversity found in organic plots may render these systems less dependent on external inputs. On organically farmed soils, where the importation of materials to maintain soil fertility is restricted, it is important to achieve a balance between inputs and outputs of nutrients to ensure both short term productivity and long-term sustainability (Watson et al., 2002).

Organic farming systems provide the opportunity to deliver more soil ecosystem services than conventional practices. One such service could be soil organic carbon (SOC) accumulation (Blanco-Canqui, 2017). The Li et al. (2018) study demonstrates that fertilization strategies that include organic manure can increase the pool of stable carbon in the surface soil layer. Meanwhile, Hu et al. (2018), did not detect consistent differences in measured SOC between organically farmed soils and those that are managed conventionally, taking into consideration higher estimated carbon inputs in organic versus conventional systems. It has been shown that soil management under organic farming can enhance SOC, thereby mitigating atmospheric greenhouse gas increases, but until now, quantitative evaluations based on long-term experiments are scarce (Novara et al., 2019).

MATERIALS AND METHODS

The field experiment was conducted at the Private Enterprise «Agroecology» Shyshaky district, Poltava region, Ukraine. Private Enterprise «Agroecology» have been practicing organic farming since 1982 and it is certified as an organic farm in accordance with the requirements of the standards of the EU Council Regulation («EC 834/2007», «EC 889/2008»). The climate of the region is temperate continental with an accumulated temperature of 2500-2900°C and annual precipitation 480-536 mm. The soil - Meadow Chernozem with pH_{KCl} 7.1, bulk density 1.05-1.1 g/cm^3, and humus content 8.0% in topsoil (0-20 cm). At the beginning of the field experiment soil contained 11 mg/kg available nitrogen ($N\text{-}NH_4$ + $N\text{-}NO_3$), 47-52 mg/kg available phosphorus (P_2O_5) and 100-110 mg/kg potassium (K_2O). Crop rotation: winter wheat - sunflower - siderates (buckwheat+vetch, oats, wheat, alfalfa) - winter wheat - maize for silage - barley+esparcet - winter wheat. Crop rotations are designed with regard to maintenance of fertility with a focus on nutrient recycling. Reduced tillage was used (on the depth 10-12 cm). An average of 15-20 t ha^{-1} of cattle manure or compost manure was applied annually. Soil samples were collected after crop rotation from the 0-10 cm and 15-25 cm soil layers.

Organic carbon content was determined by the Tyurin method. Humus content samples of 0.1 g of soil are taken from the samples and after a dichromate oxidation $K_2Cr_2O_7$ with 10 ml the consumed oxidizer (oxidizing agent) is determined by titration with $Fe(NH_4)2(SO_4)6H_2O$ using phenylanthranilic acid as an indicator.

Available nitrogen N ($N\text{-}NH_4$ + $N\text{-}NO_3$) was determined by modification of the method of NSC ISSAR named after O.N. Sokolovsky: nitrogen extraction from the soil using potassium sulfate then nitrates determined photometrically with disulfophenol acid, and ammonium with Nessler's reagent. Available phosphorus and potassium was determined by the Chirikov method, extracting P_2O_5 and K_2O by 0.5M acetic acid with a ratio of soil to a solution 1:25 followed by photometric determination. All measurements were performed in triplicate.

The ions content in water extract from the soil was determined by the following methods: ions of carbonates and bicarbonates – by titration with a solution of sulfuric acid to pH 8.3 (determination of carbonates) and pH 4.4 (determination of bicarbonates); chloride ions – by argentometric method according to Mohr; sulfate ion – by the volumetric method in the

presence of the indicator nitorochromazo; calcium and magnesium ions - by the complexometric method; sodium and potassium ions – by flame photometric method. The exchangeable cations content was estimated by complexometric method.
Analysis of variance was performed using Statistica 10 software.

RESULTS AND DISCUSSIONS

SOC dynamics are regulated by the complex interplay of climatic, edaphic and biotic conditions. The data presented in Figure 1 indicate that C-accumulation in Meadow Chernozem after long-term application of organic fertilizers and siderats under reduced tillage is greater in the 0-10 cm layer than in the 15-25 cm layer. After 8-year organic farming, Corg concentration decreased by 31% in the 0-10 cm soil layer and by 24 % in the 15-25 cm layer compared with the virgin soil. Meanwhile, organic carbon content in soil after 36 years of organic farming decreased by 28% and by 17% compared with the virgin soil in the 0-10 cm and 15-25 cm layers, respectively. SOC is considered as an integral parameter of soil fertility and a source of information for the diagnosis of soil degradation. Long-term organic farming contributes to sustaining organic carbon content in the soil at a fairly high level (3.0-3.4%), but a slight decrease was found compared with virgin soil.

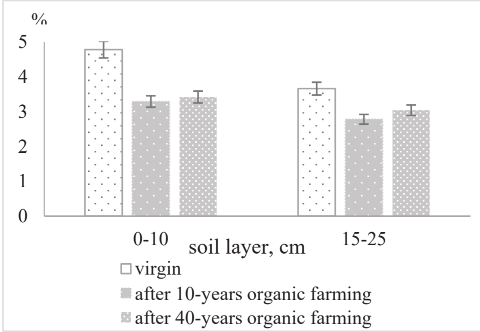

Figure 1. Corg content in the 0-10 cm and 15-25 cm layers of Meadow Chernozem under organic farming

Soil pH or soil reaction is an indication that plays a central role in many soil processes. Soil pH is an important predictor of bacterial community composition and diversity. Soil pH influences chemical properties and biological processes, including solubility, mobility, and availability of nutrients and trace metals. Results showed that organic farming during 36-years led to acidification of soil reaction: pH decreased by 0.4-0.5 units in 0-10 cm and by 1.5-1.7 units in 15-25 cm soil layer (Table 1). At the same time, an increased availability of nutrients in topsoil was observed.

Table 1. Effect of long-term organic farming on soil pH and available nutrients content in the 0-10 and 15-25 cm layers of Meadow Chernozem

Agricultural system	Soil layer, cm	Index				
		pHKCL	mg/kg			
			$N-NH_4$	$N-NO_3$	P_2O_5	K_2O
No treatment (virgin soil)	0-10	5.7	12.0	1.8	67.8	144.6
	15-25	7.0	7.0	0.02	26.9	72.3
8-year organic farming	0-10	5.3	18.6	14.4	77.3	93.4
	15-25	5.5	8.1	6.1	73.9	81.3
36-year organic farming	0-10	5.2	12.5	7.6	93.3	96.4
	15-25	5.3	6.8	2.7	78.7	63.3
$LSD_{0.05}$		0.2	2.6	2.2	7.5	8.8

[1]LSD 0.05 - Least Significant Difference at p=0.05

Nitrogen is a major nutrient, essential for all living organisms. Organic farming systems significantly increased the content of available nitrogen ($N-NH_4$ and $N-NO_3$), especially in the upper soil layer (0-10 cm). Long-term application of organic fertilizers and siderats under reduced tillage caused an accumulation of significant amounts of nitrate nitrogen in Meadow Chernozem. Siderats catch crops promote the sustainability of organic farming by nutrient uptake and transfer to the following main crops. This effect efficiently reduces the risk of nitrate leaching. Our results show that soil under 8-year organic farming is characterized by high NH_4-N content, especially at a depth of 0-10 cm. But after 36 years of organic farming available N ($N-NH_4$ + $N-NO_3$) were greatly reduced by 32-55% with the 8 years of organic farming. The application of organic farming during 36 years led to NH_4-N increasing at a depth 0-10 cm by 0.5-6.6 mg/kg compared with the virgin soil, and at a depth 15-25 cm by 1.1 mg/kg. This may be attributed to the direct addition of these nutrients with organic fertilizers. The improved nitrogen status in the soil following organic fertilization can be explained by the high adsorption capacity of N and increased microbial activity that might have accelerated of mineralization during the growing season (Rutting et al., 2018). Biological nitrogen fixation by legume catch crops is an additional benefit in organic farming.

Phosphorus is the second most limiting nutrient in crop production. Phosphorus is abundant in soil however, the concentration of plant available P in the soil is generally low (Dhillon et al., 2017). The application of manure and compost with siderats under reduced tillage during 36 years led to accumulation of available phosphorus in the soil, presumably by increased the mineralization of organic P by microbial action. The highest P_2O_5 content (77 and 93 mg/kg) were observed in the 0-10 cm soil layer after 8 and 36-years organic farming respectively. While, the highest accumulation of P_2O_5 compared to virgin soil was found in the 15-25 cm layer, which is 2.7 times higher than in the same layer of virgin soil.

Potassium is an essential cation in all organisms that influences crop production and ecosystem stability (Srivastava et al., 2020). Available potassium loss in Meadow Chernozem was observed under long-term organic farming. It was found that K_2O content in 0-10 cm soil layer is by 50 mg/kg[1] less compared to the virgin soil. Even annual application of organic fertilizers (cattle manure or compost manure) during 36 years led to K_2O loss form Meadow Chernozem compared to the virgin soil.

Exchangeable calcium cations (Ca^{2+}) predominated in the studied soil samples: it ranged from 81.4 to 85% of the total cation content (Table 2). The content of Ca^{2+}, which is essential for the structure of the soil and affects the humus accumulation, decreased after transition of virgin soil into arable one under organic farming. On plots of 36-years of organic farming and without treatment, the 0-10 soil layer is depleted in Ca^{2+} compared to 15-25 cm. On a plot that have been engaged in organic farming just for 8 years, this relationship is inverse – the lower soil layer, the less content of exchangeable calcium cations (Ca^{2+} in 15-25 cm soil layer was by 8.6 % less than in the 0-10 cm layer). For magnesium ($Mg^{2+)}$, this difference was even bigger and amounted up to 29.7 %. Total content of exchangeable Ca^{2+} and Mg^{2+} was the greatest in virgin soil, meanwhile on plot of 8-years of organic farming the sum of exchangeable cations was approximately in 2 times less 15-25 cm layer than in virgin soil. The use of land in agricultural production increases the sodium (Na^+) content in the 0-10 cm layer by 0.9-1.5 mmol/kg soil, which is not a significant change. In general, the content and composition of exchangeable cations is most favorable in the soil under 36-years of organic farming.

Table 2. Effect of long-term organic farming on exchangeable cations in the 0-10 and 15-25 cm layers of Meadow Chernozem

Agricultural system	Depth of sampling, cm	Content in soil, mmol kg^{-1}				
		Ca^{2+}	Mg^{2+}	Na^+	K^+	∑ cations
No treatment (virgin soil)	0-10	203.7	30.3	0.9	4.6	239.5
	15-25	331.5	65.5	1.1	2.6	400.7
8-years of organic farming	0-10	184.2	32.3	2.4	3.5	222.4
	15-25	168.3	22.7	1.1	3.3	195.4
36-years of organic farming	0-10	198.7	39.6	1.8	3.8	243.9
	15-25	228.9	32.8	2.4	2.9	267.0
$LSD_{0.05}$		8.2	2.4	0.5	1.5	

[1]LSD 0.05 - Least Significant Difference at p=0.05

For Meadow Chernozems the salt composition is of great importance, since they are formed with the participation of groundwater, which can have different degrees of mineralization. The examined soil samples contained small quantities of water-soluble salts. In virgin soil, salts presented by bicarbonates and chlorides of calcium and magnesium, mainly in the 15-25 cm layer (Table 3).

Table 3. Effect of long-term organic farming on salt composition in the 0-10 and 15-25 cm layers of Meadow Chernozem

Agricultural system	Depth of sampling, cm	pH_{H2O}	Content in water solution, meq/kg							
			HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	$\sum$ eq cations
No treatment (virgin soil)	0-10	6.7	2.8	1.1	1.4	3.5	1.3	0.3	0.2	5.3
	15-25	8.1	7.5	1.5	0.9	5.7	3.5	0.6	0.1	9.9
8-years of organic farming	0-10	6.4	1.5	1.1	2.8	2.4	1.6	1.2	0.2	5.4
	15-25	6.6	1.8	0.4	1.8	1.9	1.4	0.5	0.2	4.0
36-years of organic farming	0-10	6.4	2.0	0.4	2.6	2.6	1.4	0.8	0.2	5.0
	15-25	6.7	2.3	0.9	1.2	1.9	1.4	1.0	0.1	4.4
$LSD_{0.05}$			0.7	0.4	0.8	1.0	0.3	0.2	0.1	

[1]LSD 0.05 - Least Significant Difference at p=0.05

As a result of long-term organic farming the content of bicarbonates and chlorides decreased by 28.6-46.4% (0-10 cm) and by 69.3-79% (in 15-25 cm) compared to the virgin soil. At the same time, the content of sulfate anions (SO_4^{2-}) increased by 2 times, amounting up to 2.6-2.8 meq/kg (0-10 cm) and 1.2-1.8 meq/kg (15-25 cm). The content of the calcium cation (Ca^{2+}) in the soil solution decreased by 25.7-31.4 % in the upper layer and especially strongly in the lower layer (by 66.7%).

CONCLUSIONS

Findings indicate that transition from virgin soil to arable soil with following long-term organic farming with annual application of organic inputs, using siderats and reduced tillage results in significant change of soil chemical indicators, which are critical for long-term fertility maintenance. After 36-year organic farming soil agrochemical characteristics changed as follows: pH decreased by 1.05 units, available nitrogen ($N\text{-}NH_4$ + $N\text{-}NO_3$) increased by 4.4 mg/kg, available phosphorus (P_2O_5) increased by 38.7 mg/kg, meanwhile potassium decreased by 28.6 mg/kg. While Meadow Chernozem under long-term organic farming has larger pools of nutrients compared with the virgin soil, but SOC loss was observed after the transition of virgin soil to arable one with a positive trend of organic carbon accumulation according to the term of organic farming.

The involving of soil into organic farming agricultural system leads to a change in content of exchangeable bases in Meadow Chernozem. The content of exchangeable cations, except Na^+, tends to decrease under long-term organic farming. Organic farming did not induce accumulation of salt in the soil arable layer, but a significant decrease of water-soluble Ca^{2+} and simultaneous increase Na^+ were observed. The composition of the salts of Meadow Chernozem is bicarbonates and chlorides of calcium and magnesium, which has low toxicity to plants. Nevertheless, a necessary measure to preserve soil fertility during the agricultural use of Meadow Chernozem is a regular monitoring of the salts content and absorbed cations.

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