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Changes in the content of soil organic carbon and total nitrogen in the organic and conventional cropping systems

J. Kuht*, V. Eremeev, E. Loit, M. Alaru, E. Mäeorg, L. Talgre and A. Luik

Estonian University of Life Sciences, Institute of Institute of Agricultural and Environmental Sciences, Kreutzwaldi 5, EE51006 Tartu, Estonia
*Correspondence: jaan.kuht@emu.ee

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Abstract. Maintaining and increasing the stock of soil organic carbon is of vital importance in maintaining the soil fertility. In present research the changes in the content of organic carbon (SOC) and total nitrogen (Ntot) in the soil are investigated. The data is collected from the long-term field experiment, which compares organic and conventional farming systems in a crop rotation (barley undersown with red clover, red clover, winter wheat, pea, potato) during 2014–2018. Based on the 5-year experiment, it was concluded that the cropping systems have a significant effect on the SOC content and a smaller effect on the Ntot content of the soil. The diversification of organic cropping systems with cover crops and composted cattle manure significantly increases the content of organic carbon in the soil. The results of the experiment indicate that the content of organic carbon was significantly lower (by 7.6–12.6%) in conventional systems, where pesticides had been applied and cover crops and manure had not been used, compared to the organic cropping systems. The correlations between the SOC contents of main crops and precrops were statistically more significant in organic farming system, compared to the conventional system. Highest SOC and Ntot values were observed in organic systems with cover crops and composted manure fertilization. Hence, it can be stated that in order to improve the soil fertility and fix more carbon and nitrogen, high amounts of organic material should be applied into the soil and the activity of soil microbes should be a priority. The organic cropping systems have more advantages for sustainable crop production.

Key words: SOC, Ntot, winter cover crops, composted manure, precrops, crop rotation.

INTRODUCTION

Crop cultivation as a conventional and especially as an organic system depends largely on the nutrition status of crops and soil fertility as its base. The latter could be maintained through suitable crop rotation and the use of manure and cover crops (Rasmussen et al., 2006). Lorenz & Lal (2016) point out, that the content of soil organic carbon (SOC) plays an important role in the functioning of the above-ground agro-ecosystems, soil fertility and the productivity of crops, as well as in the quality of the soil and water. Based on the research by Adhikari & Harteminki (2016); Franzluebbers (2010); Lal et al. (2012), the authors came to the conclusion that the soil organic carbon stock also supports other key processes in the soil (water filtration, stability of the soil structure, maintenance of nutrient levels, soil organisms and their energy sources etc.). Major contribution to SOC comes from soil microorganisms, which decompose the plant residues, break down carbon compounds and incorporate these as the part of the soil. Brunetto et al. (2011) point out the importance of soil microorganisms in changing the nutrients into readily available forms for plants. The legumes are the most important source of nitrogen in organic cropping systems (Fuchs et al., 2008) and their cultivation has a positive effect on the yield of the following crops in a rotation (Loes et al., 2006; Böhm, 2007). Winter cover crops, for example, clover undersown to cereal field and red clover grown for green manure, both act as a living mulch layer (Miura & Watanabe, 2002). The year-around field cover has a positive impact on the physical and chemical properties of the soil, by protecting the soil from extreme weather conditions and maintaining the suitable soil moisture. The preservation of SOC and Ntot stock is vital for the development of sustainable agricultural practices and the mitigation of climate changes, through decreasing the emissions of gaseous carbon compounds (Lal, 2004; Singh & Benbi, 2020).

The aim of the present research was to evaluate the effect of farming systems on the content of soil organic carbon and total nitrogen in organic systems with winter cover crops and manure as well as in conventional systems, where chemical plant protection and mineral fertilizers were used. The effects of using precrops in different cropping systems on the content of soil organic carbon has not been studied thoughroughly before. Our study aims to fill that gap by investigating mainly the relationships between precrops and soil organic carbon through 5 years.

MATERIALS AND METHODS

A 5-year crop rotation experiment was established on the field test site of Estonian University of Life Sciences in Eerika. The soil in the experimental area was Stagnic luvisol, according to WRB classification (Deckers et al., 1998), light sandy loam with the humus layer of 20–30 cm (Reintam & Köster, 2006). In present research the data of the crop rotaion period from 2014–2018 is analyzed. The crop rotation was as followed: barley (cv. Anni), undersown with red clover (cv. Varte), red clover (which was ploughed into the soil), winter wheat (cv. Fredis), pea (cv. Starter) and potato (cv. Teele). The crops were grown in 2 farming systems. The conventional system (CON) included chemical plant protection and mineral fertilizers. In conventional system, red clover crop in the rotation used as green manure was the only organic fertilizer. The second farming system was the organic (ORG), where green manures were used as fertilizers, either with the incorporation of red clover biomass, winter cover crops or additionally the application of composted cattle manure. The treatment CON 0 did not recieve any mineral fertilizers, but only chemical plant protection was used. In the treatment CON I the test plots of undersown barley, potato, pea and winter wheat recieved the same amount of phosphorous (P, 25 kg ha^{-1}) and potassium (K, 95 kg ha^{-1}). The rate of nitrogen fertilizers were different: N120 kg ha^{-1} for undersown barley, N150 kg ha^{-1} for potato and N20 kg ha^{-1} for pea. On the red clover plots no fertilizers were applied and no plant protection measures were used. In conventional system after the harvest of potato, pea and winter wheat, glyphosate-containing herbicide Roundup Flex was used for weed control. In 2018, Rodeo FL was used instead. In the plots of barley undersown with red clover and pea, MCPA-750 was used against the weeds. Herbicide Secator OD was applied on the plots of winter wheat and Titus 25 DF was used in case of potato. Against the potato late blight, fungicide Ridomil Gold MZ 68 WG was used 2–4 times depending on the rate of infestation. The potato Colorado beetle was managed with insecticides Fastac and Decis Mega 50EW. There were 3 treatments in organic farming system: ORG 0 only followed the crop rotation; in ORG CC winter cover crops were used (after the harvest of winter wheat the mixture of turnip rape and winter rye was sown, after pea winter turnip rape and after potato winter rye was sown); in ORG CC+M in addition to cover crops mentioned also composted cattle manure was ploughed into the soil in spring (10 t ha^{-1} for cereals and 20 t ha^{-1} for potato). Once a year in mid-April before starting of field operations, soil samples were taken from the depth of 0–25 cm. Eight samples were taken from each plot to obtain the average for each plot. Air-dried soil samples were sieved through a 2 mm sieve.

The content of SOC was measured using the Tjurin method (Vorobyova, 1998), and Ntot content was measured using the Kjeldahl method (van Reeuwijk, 2002) The statistical analysis was performed with software Statistica 13 (Quest Software Inc), using one-way ANOVA. For the differences in the soil microbial hydrolytic activity between crops, Fisher LSD *post-hoc* test ($p < 0.05$) was used. Correlation analysis was used for linear correlation coefficients between variables, and the significance of coefficients was taken as $p < 0.001$, $p < 0.01$, $p < 0.05$, or ns (not significant). The results are expressed as an average of the 5-year experimental period (2014–2018).

RESULTS AND DISCUSSION

The results of the statistical analysis of the data showed that the content of soil organic carbon and total nitrogen were significantly influenced by yearly weather conditions (Y) and farming system (FS) (Table 1). Also, the combined effect of year and farming system (Y x FS) had a statistically significant effect on the content of total nitrogen, but the effect on the SOC was relevant only during 2013–2017.

Table 1. Analysis of variance for the content of soil organic carbon and total nitrogen, depending on year, farming system, crop, and their interactions

Factor	SOC, %		Ntot, %	
	2013–2017	2014–2018	2013–2017	2014–2018
Year (Y)	$F_{4.450} = 7.9$ $p < 0.001$***	$F_{4.450} = 5.7$ $p < 0.001$***	$F_{4.450} = 65.5$ $p < 0.001$***	$F_{4.450} = 45.0$ $p < 0.001$***
Crop (C)	$F_{4.450} = 0.8$ $p = 0.518$	$F_{4.450} = 0.3$ $p = 0.869$	$F_{4.450} = 0.7$ $p = 0.600$	$F_{4.450} = 0.4$ $p = 0.807$
Farming system (FS)	$F_{1.450} = 113.1$ $p < 0.001$***	$F_{1.450} = 123.1$ $p < 0.001$***	$F_{1.450} = 282.5$ $p < 0.001$***	$F_{1.450} = 272.2$, $p < 0.001$***
Y x C	$F_{16.450} = 1.0$ $p = 0.423$	$F_{16.450} = 0.9$ $p = 0.620$	$F_{16.450} = 1.1$ $p = 0.365$	$F_{16.450} = 1.0$ $p = 0.452$
Y x FS	$F_{4.450} = 2.4$ $p = 0.049$*	$F_{4.450} = 2.2$ $p = 0.068$	$F_{4.450} = 37.9$ $p = 0.001$***	$F_{4.450} = 42.7$ $p = 0.001$***
C x FS	$F_{4.450} = 1.6$ $p = 0.161$	$F_{4.450} = 1.6$ $p = 0.162$	$F_{4.450} = 1.5$ $p = 0.197$	$F_{4.450} = 1.9$ $p = 0.103$
Y x C x FS	$F_{16.450} = 0.3$ $p = 0.996$	$F_{16.450} = 0.5$ $p = 0.965$	$F_{16.450} = 0.5$ $p = 0.941$	$F_{16.450} = 0.6$ $p = 0.915$

*significant at 5% level of probability; **significant at 1% level of probability; and ***significant at 0.1% level of probability.

The effect of farming systems on the content of soil organic carbon

Previous studies from the same experimental area (Eremeev et al., 2019; 2020) revealed that undersowing of red clover and organic potato cultivation had positive effect on the content of organic carbon in the soil. Results from the study on the growing spring barley undersown with red clover indicated that in organic systems the soil microbial hydrolytic activity as well as the content of soil organic carbon were increased (Kuht et al., 2019). The dynamics of soil organic carbon (SOC) is explained as the distribution of soil organic matter (SOM) between respective physical, chemical and biological stocks (Banger et al., 2010). Changes in inputs, which regulate the soil microbial activity and mineralization rates, will ultimately be reflected in the SOC content (Gregorich & Janzen, 1996). The soil microbial hydrolytic activity was affected by biochemical conditions during the growing period as well as the previous crop in the rotation, as was seen in the previous results of our experiments (Kuht et al., 2022). It was concluded that the organic treatments with winter cover crops and manure had a significantly positive effect on the soil microbial hydrolytic activity (determined by the methods described by Schnürer & Rosswall (1982).

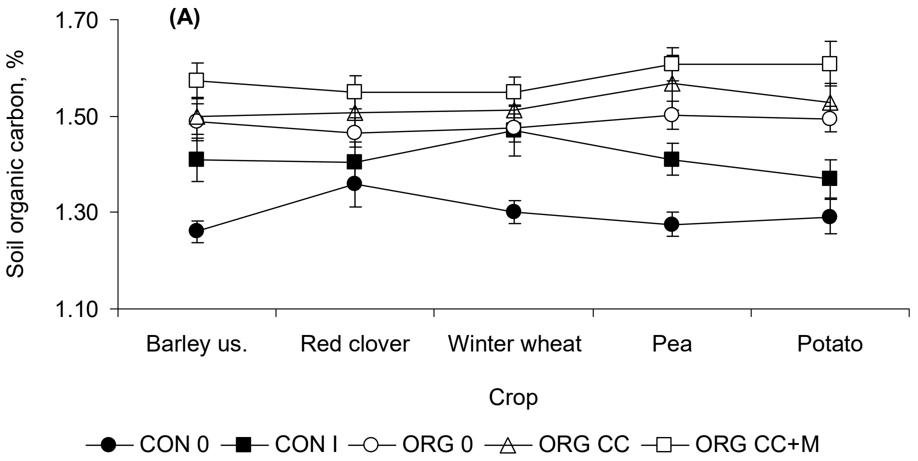

Figure 1. The content of organic carbon in the soil (yearly averages during 2014–2018) The vertical bars indicate the standard deviation between the treatments.

The data on our current crop rotation under study (2014–2018) indicated that The average SOC content in organic systems was higher by 10.3%, compared to conventional system treatments. It was found that in ORG treatments the effect on the SOC content was significantly higher than in conventional treatments, for red clover, winter wheat, pea and potato, by 10.6%, 7.6%, 9.3%, 12.6% and 11.3%, respectively (Fig. 1). Within a farming system a significantly relevant difference in SOC content was seen only after potato cultivation in ORG CC+M, where it was higher by 7.4%, compared to ORG CC treatment. The increased proportion of the soil organic carbon would require significantly larger amounts of organic material applied (Post & Kwon, 2000). Within the conventional cropping systems the SOC content of CON I was higher by 5.4% after winter wheat, that was probably due to the precrop red clover.

The effect of precrops on the SOC

From the perspective of soil fertility parameters, it is important to know how much is the SOC content of crops influenced by the previous crops or the added SOC during the present growing season. Our results indicated that the SOC content in all the ORG and CON system treatments were positively correlated with the SOC content of their respective precrops. (Fig. 2, A–E).

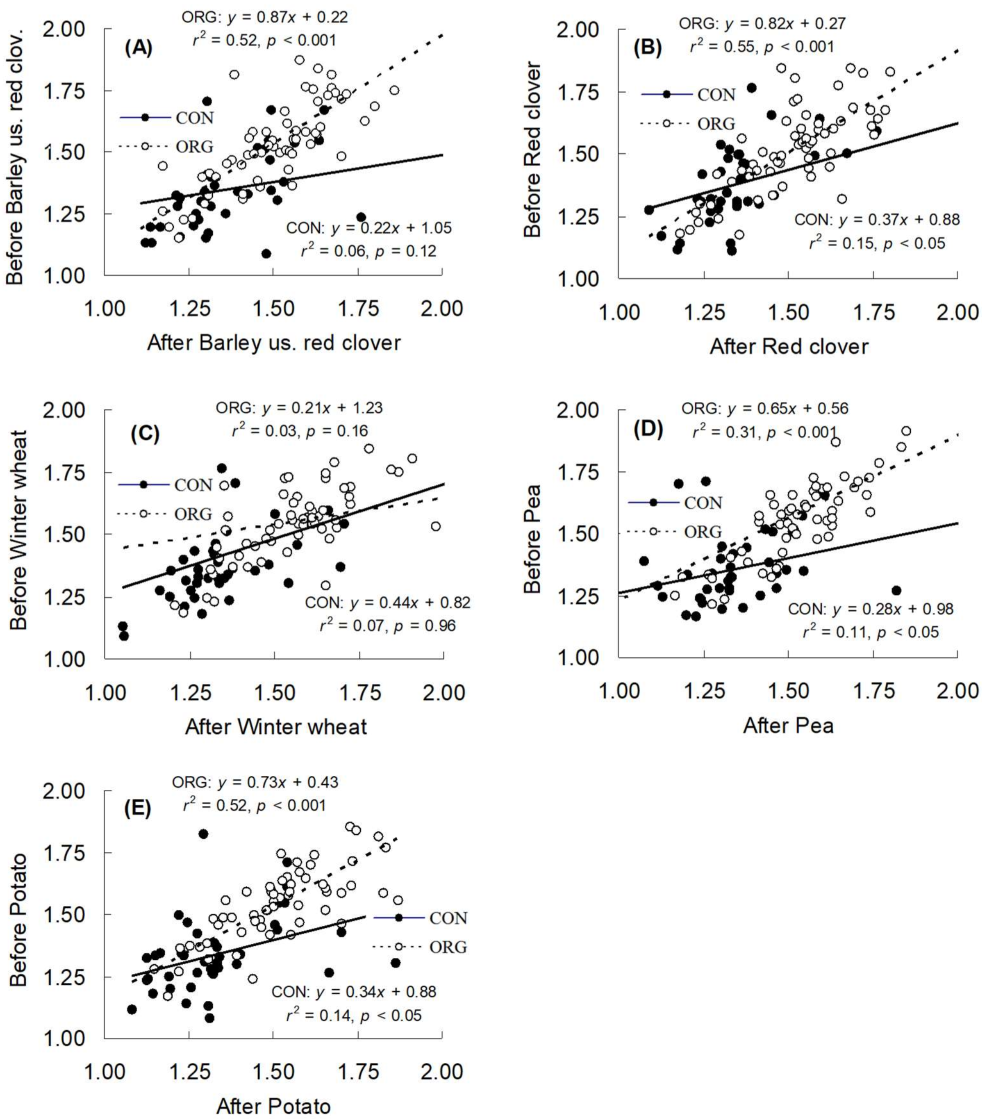

Figure 2. Regression analysis of the concentration of soil organic carbon (SOC, %) of main crop and precrop in conventional and organic systems. (A) – barley undersown with red clover (precrop potato); (B) – red clover (precrop barley undersown with red clover); (C) – winter wheat (precrop red clover); (D) – pea (precrop winter wheat); (E)– potato (precrop pea).

Very strong positive correlation was seen between the SOC content of barley undersown with red clover and its precrop (potato) in ORG system treatments ($r = 0.75$; $p < 0.001$), while in CON treatments the correlation was weak ($r = 0.24$; $p = 0.12$; Fig. 2, A). It was the case, because after the harvest of pea (precrop of potato) in ORG CC and ORG CC+M plots, a mixture of cover crops (winter turnip rape, winter rye) was sown which together with cattle manure contributed to the increase in organic matter and hence the higher SOC content. For increasing the concentration of SOC in the soil, significantly higher amounts of organic matter are needed. Also, its decomposition processes should be enabled directly or indirectly, through favouring the activity of soil organisms with soil management methods (Post & Kwon, 2000). Moreover, the addition of organic matter to the soil stimulates the activity of decomposing bacteria and actinomycetes (Adam & Duncan, 2001).

While comparing the relationships in SOC content of the soils of red clover and its precrop barley (undersown with red clover) in ORG systems, a strong correlation was seen ($r = 0.74$; $p < 0.001$), but in CON system treatments the same correlation was much weaker ($r = 0.39$; $p < 0.05$, Fig. 2, B). It should be taken into account that in ORG system a winter cover crop (winter rye) was sown after the harvest of potato before barley (us). In ORG CC+M treatment, together with green manure also the cattle manure was ploughed into the soil.

The higher organic matter content, due to cover crops and manure, also increased the SOC content in red clover plots, that resulted in higher correlation between the SOC contents of red clover and its precrop in ORG system treatments. In both farming systems the SOC content of previous crop was affected by the amount of organic material from crushed barley straw and the living roots of red clover. Carter & Kunelius (1993) found that barley undersown with red clover increased the root biomass by 6 to 11 times, compared to only growing barley, while also improving the soil structure. According to Skudiene & Tomchuk (2015), the root biomass of the following crop increased up to 6.5 times and the above-ground biomass by 4 times. Our results indicated that after the incorporation of red clover biomass as green manure, the SOC contents following winter wheat were affected by the activity of soil microorganisms during the vegetation period. In conventional system the correlation between the SOC of winter wheat and its precrop was weak ($r = 0.27$; $p = 0.96$; Fig. 2, C). In ORG system the same correlation was even weaker ($r = 0.17$; $p = 0.16$). Therefore it was concluded that the SOC content of winter wheat area was mostly due to the decomposition of organic matter during the same vegetation period and not related to the SOC of the previous crop.

The correlation between the SOC content of pea and its precrop plot was higher in organic treatments, compared to conventional treatments (Fig. 2, D). It was because in CON system plots the SOC content was mainly affected by the plant residues left in the field after the harvest of winter wheat, but in ORG CC and ORG CC+M treatments additionally the organic material from winter cover crops was applied, thereby increasing the effect of a precrop. The straw residues are important sources of organic material in the soil. Tisdale et al. (1985) found that by returning the straw residues to the soil the functional microbial diversity and activity of hydrolytic enzymes will increase.

The relationships between the SOC contents of potato and its precrop (pea) plots were stronger in organic system treatments, compared to CON treatments, $r = 0.72$; $p < 0.001$ and $r = 0.37$ $p < 0.001$ (Fig. 2, E). Results from Qin et al. (2017) indicate that the application of potato-pulse rotation may improve the parameters of soil environment.

The effect of farming systems on the content of total nitrogen

The average soil Ntot content in organic systems was higher by 18.1%, compared to conventional system treatments (Fig. 3). Our current crop rotation data showed that the ORG treatment had higher soil Ntot content by 20.6% for barley (us), 14.4% for red clover, 14.4% for winter wheat, 20.0% for pea, and 21.4% for potato, than in CON.

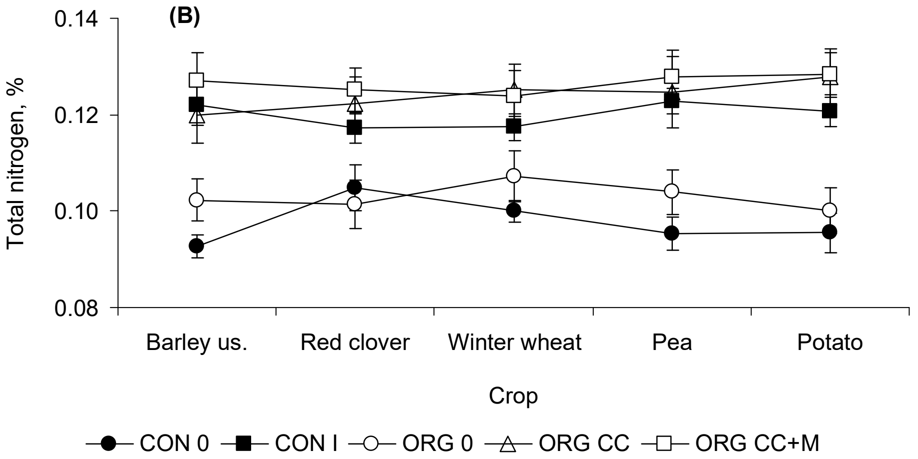

Figure 3. The content of total nitrogen in the soil (yearly averages during 2014–2018) The vertical bars indicate the standard deviation between the treatments.

Based on the Ntot content, as an average of 2014–2018 a clear advantage of ORG farming system over CON was noted, as the Ntot contents were significantly higher in ORG CC and ORG CC+M, compared to CON system treatments.

Compared to CON I treatment the Ntot content values for ORG CC and ORG CC+M were 17.4% and 18.5% higher for barley undersown with red clover, 10.6% and 17.1% higher after red clover, 14.3% and 13.5% higher after winter wheat, respectively. The differences between the Ntot content between the crops were not statistically significant. In ORG CC+M the manure applied in addition to the winter cover crops (ORG CC) did not have a significant effect on the Ntot content of the soil. According to the long-term studies by Paustian et al. (1992), it was found that the quality of the organic compounds has a significant effect on the uptake of nitrogen and the productivity of crops, while they also observed the mineralization and immobilisation of nitrogen. As an exception, a slight increase (by 5.6%) of Ntot content was seen in the plots undersown with red clover. The decrease of Ntot (and also SOC) content in CON system treatments may have been caused by the use of chemical plant protection methods. For example, the use of glyphosate Roundup Flex in our experiment after the harvest of winter wheat could decrease the activity of soil microbes. This has been confirmed by Kremer & Means (2009), who found that in the rhizosphere, glyphosate may have an effect on the biology and ecology of microorganisms and on their interaction with plant roots.

On the contrary to the relationships between the SOC values and the precrops presented in Fig. 2, no significant correlations were found between the content of total nitrogen and precrops.

CONCLUSIONS

Field experiments showed that organic farming systems have a positive effect on the content of soil organic carbon and total nitrogen, compared to conventiona systems. Moreover, the hypothesis on the effect of the precrop on the SOC content, was confirmed. The correlations between the SOC contents of crops and their respective precrops were positively strong in each organic and conventional treatment. The correlations between the SOC contents of crops were statistically more significant ($p < 0.001$) in organic farming system plots, compared to the conventional system treatments. On the contrary, there were no correlations found between the content of total nitrogen and precrops. The relationships between the SOC of various species and precrops presented may serve as the starting point for the improvement of crop rotations and management systems (treatment) and moreover, for assessing the suitability of cover crop species and their effect in relation to precrops. Pea and clover are very useful crops for rotation under sustainable farming systems. Moreover, it can be concluded that organic farming systems have more advantages over conventional systems for sustainable crop production. As it was seen from our results, the organic farming system increases the content of organic carbon and total nitrogen in the soil. Hence, it can be concluded that the winter cover crops as well as the application of composted cattle manure are similarly effective in improving the nitrogen regime of the soil.

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