Research Article

THE EFFECT OF DIFFERENT DOSES OF N FERTILIZATION ON THE PARAMETERS OF SOIL ORGANIC MATTER AND SOIL SORPTION COMPLEX

Vladimír Šimanský[1], Peter Kováčik[2], Jerzy Jonczak[3]

[1] Department of Soil Science, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia, e-mail: Vladimir.Simansky@uniag.sk

[2] Department of Agrochemistry and Plant Nutrition, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia

[3] Department of Soil Environment Sciences, Warsaw University of Life Sciences – SGGW, Poland

ABSTRACT

Mineral N fertilizer application may have an effect on soil organic matter and other soil parameters. Therefore, we studied the effects of different doses of N fertilization on soil organic matter and chemical properties of Haplic Luvisol in the locality of Dolná Malanta (Slovakia) during 2014–2016. Soil samples were collected from the plots exposed to the following treatments: 1. N0 – no N fertilization as control during 2014–2016, 2. N40 – N fertilizer at the rate of 40 kg N ha^{-1} in 2014 and 2016, 3. N80 – N fertilizer at the rate of 80 kg N ha^{-1} in 2014 and 2016, 4. N160 – N fertilizer at the rate of 160 kg N ha^{-1} in 2015, and 5. N240 – N fertilizer at the rate of 240 kg N ha^{-1} in 2015. The results showed that in N80 the soil organic carbon (SOC) content increased by 32% in comparison to N0. The addition of 80 kg ha^{-1} of N significantly decreased the humic substances (HS) content in the soil by 16% compared to N0. The higher doses of N fertilization 80 rather than 40 kg ha^{-1} as well as 240 rather than 160 kg ha^{-1} significantly decreased humus stability. The addition of N fertilization decreased the average values of soil pH. Values of hydrolytic acidity (Ha) increased by 41% and 46% in N40 and N80, respectively than N0, but on the other hand, this one decreased by 36% and 27% in N160 and N240, respectively in comparison to N0. Positive statistically significant correlations were determined between soil pH and SOC in N40 and N80 treatments. The increase of soil pH was connected with higher humus quality in N160 and N240. Negative correlations between humic acids (HA) and sum of basic cations (SBC) and cation exchange capacity (CEC) were observed in N80 < N160 < N240 treatments. Higher values of fulvic acids corresponded with lesser CEC in N80 and N160 treatments. In N160, with increased humus quality, CEC significantly decreased. The same effect was observed in N240. In addition, in N240, we also observed that with increased HA:FA ratio SBC and base saturation significantly decreased.

Keywords: nitrogen, fertilization, Luvisol, soil organic matter, hydrolytic acidity, cation exchange capacity.

INTRODUCTION

Fertilizer inputs are used primarily to increase crop yields. Nevertheless, fertilization may also accelerate SOC decomposition (Luo et al. 2015). On the other hand, there is published information regarding the positive effects of chemical fertilizers on the increase of SOC [Subbian et al. 2000], which ameliorates the physical soil conditions. Soil properties such as: pH, texture and native soil organic matter (SOM) are main drivers that also influence the abundance and diversity of microorganisms in soil after application of organic amendments and fertilizers [Zornoza

et al. 2016]. From a long-term view, the application of only NPK fertilizers to soil has a negative impact, which means that this alternative, from the view of sustainable farming, is not suitable for the future [Šimanský 2015]. N fertilizer is of great importance in crop production. Mineral N fertilizer application may also enhance the CO_2 efflux [Sainju et al. 2008] and effected SOC pools [Li et al. 2013]. Soil nitrogen concentration and its availability are generally associated with the SOC, because N increases production and therefore SOC, and SOC can serve as an N reservoir [Kaur et al. 2008]. Adequate N application could not only enhance production and N stocks, but as a result also increase soil microbial abundance or functionality, potentially feeding back to facilitate suitable conditions for root growth of plants. On the other hand, the degradation of soil structure and subsequent decline of crop yield could occur, especially in the intensively cultivated soils [Shisanya et al. 2009, Pelster et al. 2011]. Therefore, one of the main aims of scientists is the search for an efficient N strategy, to strike a balance between potential benefits and risks of N fertilization [Chandel et al. 2010].

On the basis of the above, the prediction of potential fertilization on C balance, as well as other characteristics of the soil, is complicated [Cusack et al. 2011, Schmidt et al. 2011]. Therefore, the objectives of the study were (1.) to quantify the extent to which doses of N fertilization influence soil organic matter and chemical properties of Haplic Luvisol, (2.) to determine the relationships between parameters of soil organic matter and chemical properties of Haplic Luvisol with dependence on dose of N fertilization.

MATERIAL AND METHODS

Study area

Nitra-Malanta is located in the lower part of Selenec Creek basin with its tributaries and it belongs to the central part of Nitra River basin. It is located east of Nitra, on the Žitavská upland. The annual average temperature and precipitation are 9.8 °C and 573mm, respectively. The study area (lat. 48°19′00′′; lon. 18°09′00′′) is very important for Slovak University of Agriculture because there are a few experiments. The experimental area is flat, with a slight incline southwards. The geological substratum consists of little previous rocks with high quantities of fine materials. Young Neogene deposits are composed of various clays, loams, sand and gravels, on which loess was deposited in the Pleistocene Epoch. The soil type is classified as a loamy Haplic Luvisol [WRB 2006]. Before initiating the experiment (spring 2014), soil samples (0–20cm) were collected from a plot. The initial soil analysis showed that the experimental soil had a pH_{KCl} of 5.71, soil organic carbon content of 9.13 g kg^{-1} and soil was silt loam with content of clay 25.2 %.

Experimental design

The experiment was laid out in a randomized block design (with 4 replications) having spring barley (*Hordeum vulgare* L.), maize (*Zea mays* L.) and spring wheat (*Triticum aestivum* L.) crop rotation in 2014, 2015 and 2016, respectively. The experiment consisted of the following treatments: 1. N0 – no N fertilization as control during 2014–2016, 2. N40 – N fertilizer at the rate of 40 kg N ha^{-1} in 2014 and 2016, 3. N80 – N fertilizer at the rate of 80 kg N ha^{-1} in 2014 and 2016, 4. N160 – N fertilizer at the rate of 160 kg N ha^{-1} in 2015, and 5. N240 – N fertilizer at the rate of 240 kg N ha^{-1} in 2015. Applied N fertilizer was ammonium nitrate with 27 % of N during experiment.

Soils sampling and analysis

For each treatment, soil samples were collected in 0–20cm depth monthly from March to July in 2014, from April to September in 2015 and from April to July 2016. For each plot, soil samples were collected at 3 points, then mixed, and sieved through a 2mm screen to remove the roots and other residues. Soil organic carbon content (SOC) was estimated by the Tyurin wet oxidation method. The reagent mixture used in 0.07 M H_2SO_4 and $K_2Cr_2O_7$, with titration using 0.01M Mohr's salt [Dziadowiec and Gonet 1999]. The quantification of the humic substances (HS), humic acids (HA) and fulvic acids (FA) was calculated by the method described by Belchikova and Kononova [Dziadowiec and Gonet 1999]. The method is based on the extraction and separation of the alkali soluble (HA and FA) by 0.1 M NaOH, and separation of HA from FA using of 1 N HCl. Based on the contents of HA and FA, HA:FA ratios were calculated. The absorbance of

HS and HA was measured at 465 and 650nm (using a Jenway Model 6400 spectrophotometer) to calculate the colour quotients of humic substances (Q_{HS}) and humic acids (Q_{HA}). We determined also soil pH_{H2O} potentiometrically (1:2.5 – soil:distiled water) and sorptive parameters such as: hydrolytic acidity (Ha), sum of basic cations (SBC), cation exchange capacity (CEC), and base saturation (Bs) [Hanes 1999].

Statistical analysis

The statistical evaluation of the data was performed according to the Statgraphics Centurion XV.I software (Statpoint Technologies, Inc., Warrenton, VA). The changes of the soil organic matter and sorptive parameters of soil were evaluated by using a Kruskal–Wallis test. The correlation analysis to determine the relationships between soil sorptive parameters and quantity and quality of soil organic matter was used. Significant correlation coefficients were tested on P < 0.05.

RESULTS AND DISCUSSION

Soil organic matter

The primary effect of fertilization is that it improves the nutrient management with increasing plant productivity. Enough nutrients in the soil will provide the optimum condition for the increase in over and underground biomass, resulting in the increase in SOC [Subbian et al. 2000]. Used fertilizers can also improve residue quality and quantity, but this does not necessarily increase the SOC pool [Halvorson et al. 2002]. Furthermore, as stated by Munkholm et al. [2002], under some conditions, fertilizers may also decrease SOC concentration. In the long-term, inorganic fertilization alone proved unable to increase SOC concentration [Triberti et al. 2008, Chandel et al. 2010]. In our case, the SOC in N0, N40, N80, N160 and N240 were 12.4, 13.5, 16.3, 12.2 and 12.1 g kg^{-1} respectively. The results of the Kruskal-Wallis test in the most cases did not show statistically significant differences between the SOC due to N fertilization except treatments with application of 80 kg N ha^{-1} (Fig. 1a). In N80, the SOC increased by 32% in comparison to N0. When crop residues are incorporated, N fertilization can improve SOC content indirectly, by increasing crop biomass production [Hati et al. 2006]. Figures 1 b, c, d summarize the application effect of nitrogen fertilization on the soil organic matter parameters. The rates and forms of N addition have also affected the chemical structure of humic substances [Cheng et al. 2017]. In our case, the addition of 80 kg ha^{-1} of N significantly decreased the humic substances content in the soil by 16% compared to N0. At the same time, the addition of 40 and 80 kg ha^{-1} of N significantly decreased the humic acids content in the soil. The Kruskal-Wallis test showed no significant differences between N treatments for content of fulvic acids. Zalba and Quiroga [1999] determined a higher content of fulvic acids was caused by fertilization and it affected the narrowing ratio of HA:FA. Application of fertilization to the soil can increase mineralization [Jagadamma et al. 2007] and this negatively affects the stability of organic substances and overall quality of SOM [Zalba and Quiroga 1999]. In our research, the humus quality based on HA:FA ratio significantly decreased in the following order: N0 > N80 > N40 = N160 > N240 (Fig.1e). The higher doses of N fertilization 80 rather than 40 kg ha^{-1} as well as 240 rather than 160 kg ha^{-1} were significantly decreased in humus stability (Figs. 1f and g). The higher the dose there can be enhanced mineralization and resulted in unstable organic compounds. In the N fertilization treatments, some organic substances such as: O-alkyl C and carboxyl C may also further promote microbial growth and consequently increase the decomposition of recalcitrant organic C [Li et al. 2015].

Soil pH and sorptive parameters of soil

The addition of N fertilization decreased the average values of soil pH, but statistically significant effects were observed between N0 and N40 as well as between N0 and N80 (Fig. 2a). The soil sorptive parameters with dependence on N fertilization evaluated by the Kruskal-Wallis test is shown in Figures 2 b, c, d, e. Different N fertilization had statistically significant influence on all sorptive parameters of soil except cation exchange capacity (CEC). Values of hydrolytic acidity (Ha) increased by 41% and 46% in N40 and N80 respectively than N0. But on the other hand, it decreased by 36% and 27% in N160 and N240 respectively in comparison to N0 treatment. This may be due to the cultivation of different plants
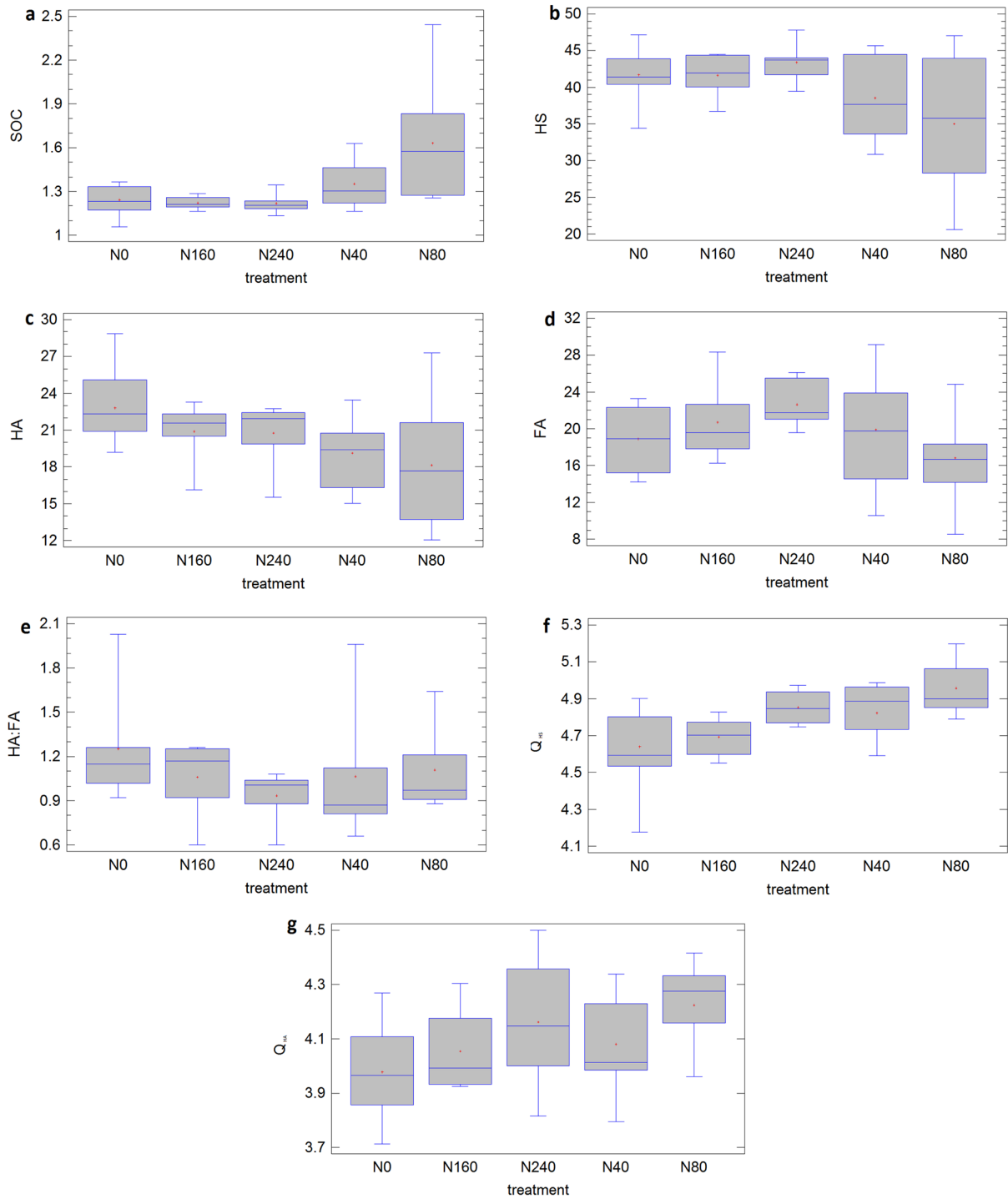
Figure 1. Parameters of soil organic matter: a) soil organic carbon, b) humic substances, c) humic acids,
d) fulvic acids, e) humic acids to fulvic acids ratio, f) colour quotient of humic substances,
g) colour quotient of humic acids

with different nutritional requirements and doses of N. During the barley farming system, the acidification process was observed in comparison to the cultivation of maize, which led to a lower soil pH and an increase in Ha (Figs. 2 a, b). Corn is a crop that has higher demands for nutrients, and particularly N [Fecenko and Ložek 2000], and the

residues are alkaline in nature, which can increase the pH of the soil [Purakayastha et al. 2015]. As N fertilizer, we used ammonium nitrate which included both NH_4^+ and NO_3^- forms. Acidification or alkaline effects could also be linked with N intake from the soil into the plant. Barley probably absorbs more NH_4^+ with a resulting acidity
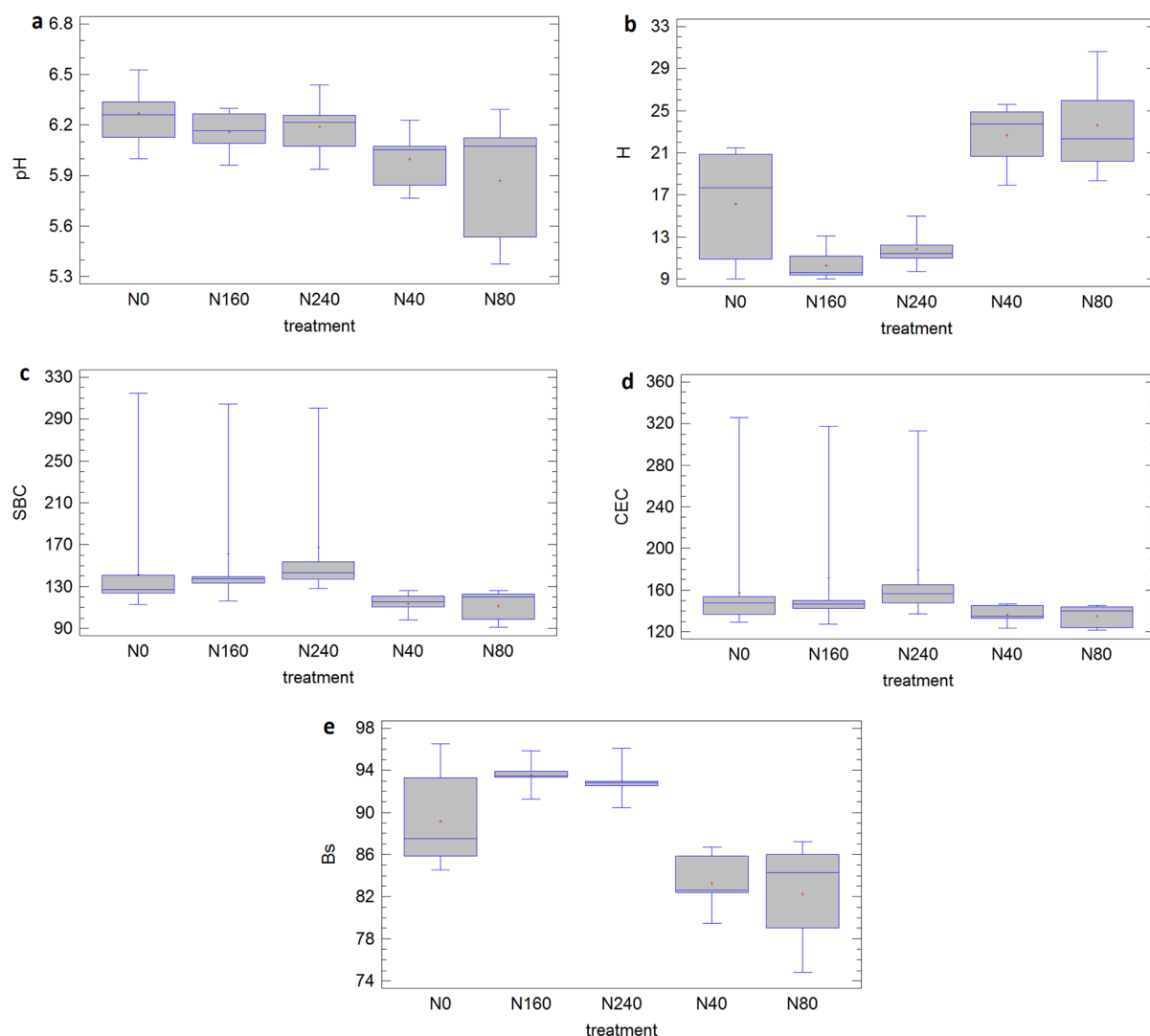
Figure 2. Soil pH and soil sorptive parameters: a) soil pH, b) hydrolytic acidity, c) sum of basic cations, d) cation exchange capacity, e) base saturation

effect whereas corn absorbs NO_3^- with a resulting alkaline effect [Fecenko and Ložek 2000]. Results show that if the hydrolytic acidity increased other sorptive parameters decreased with higher doses of N fertilization. On the other hand, if values of Ha decreased, the sum of basic cations (SBC), CEC and base saturation increased with higher doses of N fertilization (Figs. 2 c, d, e). As is mentioned above, after the application of N the soil pH was changed (Fig. 2 a), which effected electrolyte concentrations in the soil [Neff et al. 2002] with following refection in the soil sorptive parameters [Šimanský and Tobiašová 2010]. In our study, the decrease of soil pH resulted in decrease of base saturation in N treatments and this effect was more intensive with higher doses of N fertilization, which is consistent with the findings of Chodak et al. [2015].

Correlations between soil sorptive parameters and soil organic matter with dependence on N fertilization

Positive statistically significant correlations were determined between soil pH and SOC in N40 and N80 treatments. In these treatments of N fertilization (N40, N80) and in addition in N160 treatment we found negative correlations between pH and HS. The increase of soil pH was connected with higher humus quality in N160 and N240. SOM performs a variety of functions and one of the most important is its sorption capacity [Stevenson 1994, Szombathová 2010]. Therefore, the correlations between soil organic matter and sorptive parameters of soil were calculated under different N fertilization. In control treatment no significant correlations were observed, except

Q_{HS} and Bs. Here it was noted that lower humus stability decreased base saturation. We also detected an important correlation between soil sorptive parameters and soil organic matter with dependence on N fertilization. A high negative correlation between HS and CEC (-0.823**) as well as with Bs (-0.676*) were determined in N80. At the same time we determined a positive correlation between SOC and SBC (0.669*) and CEC (0.702*) in N80. Negative correlations between HA and SBC and CEC were observed, however, the higher dose of N fertilization in N80, N160 and N240 treatments (N80 < N160 < N240) was connected with stronger correlation relationships (Table 1). As presented by Jagadamma et al. [2007] fertilization increases mineralization and this negatively affects the stability of organic substances and overall quality of SOM [Šimanský and Tobiašová 2012] with effects on sorptive parameters [Šimanský and Polláková 2014]. Higher values of fulvo acids corresponded with lesser CEC in N80 and N160 treatments. In N160, with increased humus quality (HA:FA ratio), CEC (r = -0.813*) significantly decreased. In N240 except the same result as in N160 between HA:FA and CEC (r = -0.940**), we observed also that with increased HA:FA ratio SBC (r = -0.941**) and Bs (r = -0.816*) significantly decreased.

CONCLUSION

Our results indicate that the higher doses of N fertilization 80 rather than 40 kg ha^{-1} as well as 240 rather than 160 kg ha^{-1} significantly decreased humus stability. However, the humus quality was not significantly affected. The addition of N fertilization decreased average values of soil pH, but statistically significant effects were observed between N0 and N40 as well as between N0 and N80. In our study, the decrease of soil pH resulted in a decrease of base saturation in N treatments and this effect was more intensive with higher dose of N fertilization.

The intensity of fertilization affected changes in quantity and quality of SOM. Therefore, it is very important to pay attention to the quantity and quality of organic matter and sorptive parameters mainly under intensive N fertilization. In the long-term, the application of only N fertilization is not appropriate. We recommend the application of other nutrients and the best way to do so is with a combination of mineral and organic fertilizers and in amounts which are adequate for the plants as well as for healthy soil life and fertility.

Table 1. Correlations between SOM parameters and sorptive parameters with dependence on N fertilization

	Ha	SBC	CEC	Bs	pH$_{H2O}$
N0					
SOC	n.s.	n.s.	n.s.	n.s.	n.s.
HS	n.s.	n.s.	n.s.	n.s.	n.s.
HA	n.s.	n.s.	n.s.	n.s.	n.s.
FA	n.s.	n.s.	n.s.	n.s.	n.s.
HA:FA	n.s.	n.s.	n.s.	n.s.	n.s.
Q_{HS}	n.s.	n.s.	n.s.	-0.516*	n.s.
Q_{HA}	n.s.	n.s.	n.s.	n.s.	n.s.
N40					
SOC	n.s.	n.s.	n.s.	n.s.	0.771*
HS	n.s.	n.s.	n.s.	n.s.	-0.771*
HA	n.s.	n.s.	n.s.	n.s.	n.s.
FA	n.s.	n.s.	n.s.	n.s.	n.s.
HA:FA	n.s.	n.s.	n.s.	n.s.	n.s.
Q_{HS}	n.s.	n.s.	n.s.	n.s.	n.s.
Q_{HA}	n.s.	n.s.	n.s.	n.s.	n.s.
N80					
SOC	n.s.	0.669*	0.702*	n.s.	0.711*
HS	n.s.	-0.785*	-0.823**	-0.676*	-0.794*
HA	0.708*	-0.794*	-0.776*	-0.757*	-0.786*
FA	n.s.	n.s.	-0.726*	n.s.	n.s.
HA:FA	n.s.	n.s.	n.s.	n.s.	n.s.
Q_{HS}	n.s.	n.s.	n.s.	n.s.	n.s.
Q_{HA}	n.s.	n.s.	n.s.	n.s.	n.s.
N160					
SOC	n.s.	n.s.	n.s.	n.s.	n.s.
HS	n.s.	n.s.	n.s.	n.s.	-0.904*
HA	-0.927**	-0.895*	-0.899*	n.s.	n.s.
FA	0.892*	n.s.	n.s.	n.s.	-0.969**
HA:FA	-0.956**	n.s.	-0.813*	n.s.	0.926**
Q_{HS}	n.s.	n.s.	n.s.	n.s.	n.s.
Q_{HA}	n.s.	n.s.	n.s.	n.s.	n.s.
N240					
SOC	n.s.	n.s.	n.s.	n.s.	n.s.
HS	n.s.	n.s.	n.s.	n.s.	n.s.
HA	n.s.	-0.935**	-0.943**	n.s.	n.s.
FA	n.s.	n.s.	n.s.	n.s.	n.s.
HA:FA	n.s.	-0.941**	-0.940**	-0.816*	0.818*
Q_{HS}	n.s.	n.s.	n.s.	n.s.	n.s.
Q_{HA}	n.s.	n.s.	n.s.	n.s.	n.s.

**$P \leq 0.01$, *$P \leq 0.05$, n.s. – non-significant.

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