IMPACTS OF LONG-TERM FERTILIZATION ON SOIL ORGANIC CARBON AND PHYSICAL PROPERTIES

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Abstract: The present study analyses the effect of differentiated organic-mineral fertilization on soil organic carbon content and selected soil physical properties in one of the oldest long-term fertilization experiments in Germany the Static Nutrient Deficiency Experiment. It represents the sandy soils of the Northeast German Plain formed by glaciers. After 75 years of continued cultivation and sole application of farmyard manure (FYM), soil organic carbon content (SOC) in this treatment was found to be two times higher when compared to the control without manure application. Additional application of mineral N, P and K fertilizer (NPK) resulted in the highest values of SOC. Despite the positive effect of FYM application, fertilization with NPK only also resulted in higher SOC contents. The lowest soil bulk density was found in the FYM+NPK+lime treatment, but also a single application of FYM significantly decreased the bulk density. Accordingly the total porosity was found to increase significantly when FYM was used, especially in combination with the mineral NPK fertilization. This treatment also retained the highest amount of water at all measured tensions (0 to -15000 hPa). The two FYM-treated variants had higher plant-available water contents, as a result of overall larger pore volumes < 50 jum. The saturated hydraulic conductivity (Ks) was characterized by a high variability across samples and the significantly highest in the FYM+NPK+lime treatment when compared to the mineral variants. The treatment solely with FYM was found to have a Ks value in between. The results suggest that long-term fertilization with FYM in combination with NPK has a positive influence on important soil quality parameters crucial for sustainable crop production.

Key words: mineral and organic fertilization, soil bulk density, water retention, pore size distribution, saturated hydraulic conductivity

Introduction

The use of organic fertilizers and especially farmyard manure (FYM) contributes largely to the preservation and partly to the enhancement of soil fertility. As a consequence of long-term application, soil's chemical, biological and physical properties are improved. Since the end of the 19th century, the use of mineral fertilizers for plants has increased due to its better and demand-orientated supply with nutrients. These fertilizers did not show the same positive effects on the soil as organic fertilizers do. Especially the influence on soil physical properties is of marginal relevance. With the application of a combined organic-mineral fertilization, more demand-orientated nutrient supply and at the same time a positive effect on the soil can be achieved. These effects become apparent only after a long time that is only reached in long-term field experiments [6]. In some of those experiments enhancement of soil organic carbon (SOC) [2, 9], reduced soil bulk density [4, 8], increased total porosity [8, 10], enhanced soil water retention [5, 9] and an increased saturated hydraulic conductivity [4] have been determined. In sandy soils with low content of clay and silt these positive effects are of vital importance. In northeastern Germany, a large part of arable land is presented by sandy soils with low fertility. The main drawback of these soils is their low water retention, which is often shown as the yield-limiting factor. As far as the local climate is concerned, an increase of dry periods and as a consequence an insufficient water supply can be observed. To compensate for this disadvantage, the soils have to demonstrate a high buffering capacity. Scattering of precipitation in Thyrow in 2011 is a good example. Until May, the cumulative precipitation was found to be 54 mm below the long-term average. A specific characteristic of 2011 was extremely high precipitation in July (124.5 mm) which was three times higher compared to the long-term average. So the relevance is growing that the soil can buffer not only water deficits but also water surplus. As a result, the physical status of soils causes increasing interest, being the focus of numerous research projects. Soil physical properties mainly depend on its texture and humus content. Whereas the soil texture is unchangeable, the humus content can be influenced in the long run by several agronomic treatments.

Materials and methods

Thyrow experimental station of Humboldt University of Berlin is located 20 km south of Berlin (52°15'8'' N; 13°14'7" E; 44 m a.s.l.) in the Northeast German Plain and on the southern edge of a ground moraine. The soil type is characterized as a Cutanic Albic Luvisol (Abrupt Arenic) consisting of slightly silty sand in the topsoil (sand 83.1%, silt 14.2%, clay 2.7%). Given the low soil fertility, the experimental site is considered marginal for crop production. The average annual temperature is 9.2°C and the mean annual precipitation is 509.8 mm (both given for the period 1981-2010). High variability in annual precipitation often leads to dry periods in spring and summer making the natural yield capability highly weather-depended due to temporary episodes of water deficit.

The Static Nutrient Deficiency Experiment was established in 1937 as the first long-term field trial at that location and has remained largely unchanged since then. With 75 years of continued cultivation the trial is highly valuable for agricultural research. The plots are arranged according to the complete block design with limited randomization with four replicates per plot. Each of 32 single plots measures 7.2 x 10.0 m. Consequently, the trial occupies 2304 m^2. Eight variants of organic-mineral fertilization have been included in this trial. Out of them, five were chosen forthe investigation in 2011 (Table 1).

Variants of organic and mineral fertilization in the Static Nutrient Deficiency Experiment in Thyrow (since 1937)

Variants		
1	no fertilization (control)	*
2	FYM (FYM)	*
3	FYM, NPK and lime (FYM+NPK+lime)	*
4	NPK and lime (NPK+lime)	*
5	NPK (NPK)	*
6	NP and lime (NP-+lime)	
7	NK and lime (N-K+lime)	
8	PK and lime (-PK+lime)	

*** selected for investigations in 2011**

The crop rotation is potato / spring barley / silage maize / spring barley. The annual mineral fertilization of the experiment consists of uniform application of P (24 kg ha^{-1}) and K (100 kg ha^{-1}) whereas the N application is adjusted according to the standing crop; silage maize and potato received 90 kg N ha^{-1} and spring barley 60 kg N ha^{-1}. FYM is applied with 30000 kg ha^{-1} every other year in autumn prior to root crops or fodder plants. Directed on pH value of 5.5, liming is only carried out when needed. Spring barley straw is removed and tillage is done in a conventional manner as well as plant protection measures.

SOC content was measured in dried soil samples with the dry combustion method (vario MAX CNS, Elementar, Hanau, Germany) [3]. Dry bulk density, porosity and pore size distribution, water retention and saturated hydraulic conductivity were measured using soil samples in 100-cm^3 stainless steel cylinders. For determination of dry bulk density the cylinder samples were dried at 105°C for 24 hrs.

The porosity and pore size distribution was calculated based on the water retention, which was measured as the volumetric water content after the equilibrium at different underpressure levels (0, -10, -32, -63, -100, -200, -300, -500, -3000 and -15000 hPa) had been established. The saturated hydraulic conductivity (Ks) was determined with a Dome Permeameter using the constant head method (Dome Permeameter according to Hartge, UGT, Mtincheberg, Germany).

Results

As a result of the unchanged long-term fertilization for 75 years, significant differences in SOC content could be determined. With no fertilization in the control the SOC content was 305 mg 100 g^{-1} soil, which shows an absolute depletion in humus. FYM application had major influence on the SOC content, resulting in a doubled increase when compared to the control (601.4 mg 100 g^{-1} soil). With the combination of FYM and mineral fertilization (FYM+NPK+lime) the highest SOC content of 805.9 mg 100 g^{-1} soil could be determined. This equates to an increase of 264 % compared to the control (Figure 1). The supply of organic fertilizer is therefore essential for the sustainability of SOC content.

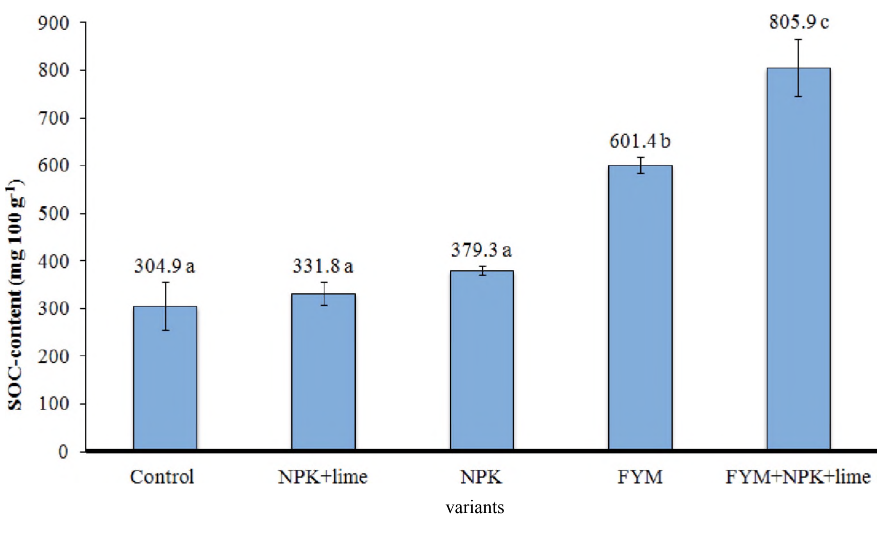

Fig-1. SOC content in the Static Nutrient Deficiency Experiment in Thyrow (2011; Tukey test, p=0.05; different letters indicate a significant difference; error bars = standard deviation)

According to the differentiated SOC contents, significant differences were found in the soil bulk density. Based on the linear relationship (R^2 = -0.96) the soil bulk density decreases significantly by about 0.03 g cm^{-3} per 100 mg of SOC in 100 g of soil. In consequence, there is also a significant difference in dry bulk density on a similar scale as of SOC content. The lowest density could be observed in the control (1.49 g cm^{-3}) whereas the highest density was found in the combined organic and mineral fertilization (1.34 g cm^{-3}) (Figure 2).

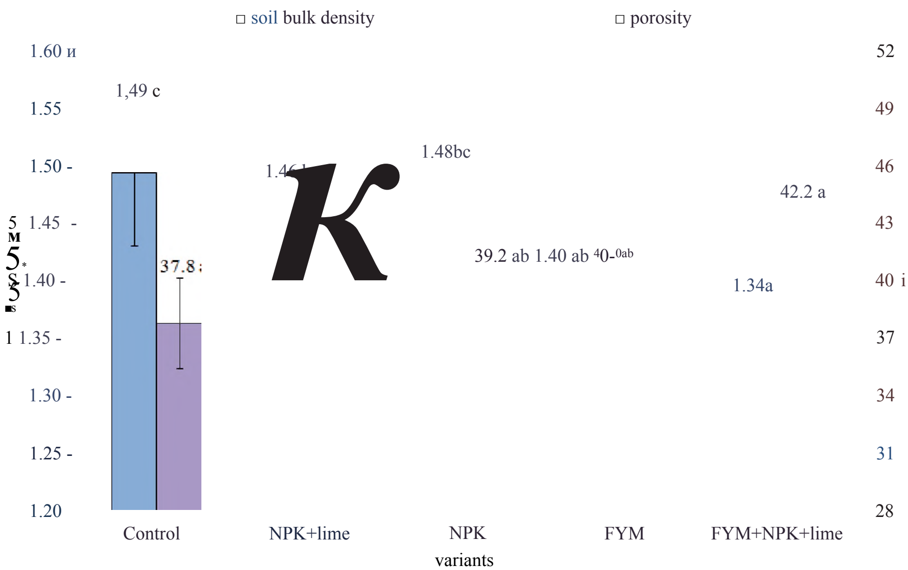

Fig. 2. Soil bulk density and porosity in the Static Nutrient Deficiency Experiment in Thyrow (2011; Tukey-test, p=0.05; different letters indicate a sign, difference; error bars = standard deviation)

The control treatment with the highest bulk density was also found to have the lowest total porosity (37.8 %), whereas FYM+NPK+lime treatment having the lowest bulk density was characterized by the highest porosity (42.2 %). These significant differences resulted in a positive linear regression (R^2 = 0.95) with 0.94% increase in porosity per increase of 100 mg SOC in 100 g of soil. Thus, the ascending trends of total porosity between the treatments were contrary to those of soil bulk density. This complies with the findings of Yang et al. [9].

The total porosity is composed of different proportion of pore size classes. This proportion provides information about how much water can potentially be held against gravity. There were no significant differences in the volume of wide coarse pores with an equivalent pore diameter > 50 μm. Nevertheless, the largest proportion of this pore size class was found in case of combined organic-mineral fertilization (Figure 3).

In contrast to the largest pore class, the tight coarse pores (50-10 μm) and the middle-sized pores (10-0.2 μm), which together represent the useable field capacity showed significant differences. The largest proportion in this range of sizes is being found after application of FYM with a proportion of 16.1% whereas the minimal value can be found as a result of NPK (without lime) fertilization. This difference is mainly caused by a significant difference between these variants in the middle pore size class. In the range

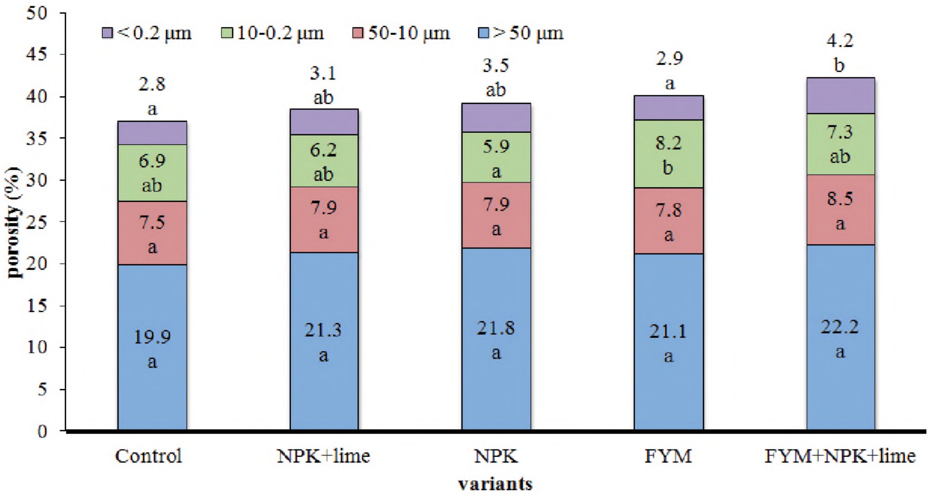

Fig.3. Pore size classes in the Static Nutrient Deficiency Experiment in Thyrow (2011; Tukey-test, p=0.05; different letters indicate a significant difference)

of fine pores (<0.2 µm) where water is not available for plants, the organic and mineral fertilization (4.2%) shows the highest proportion compared to the control with the lowest value of 2.8%.

The water retention curve shows higher water content at many tension levels after FYM application compared to the control. In the range of usable field capacity the water content after long-term organic and mineral fertilization is on average 2% higher compared to the control. Particularly large differences can be found in the range with low suctions. In this range, organic fertilization results on average in 3% increase of water content. The increased ability to hold more water even at low suctions results in higher saturated hydraulic conductivity (Figure 4). This agrees with the findings of J. Lipiec and R. Hatano [7] who concluded that K_s was mainly influenced by the macro pore volume.

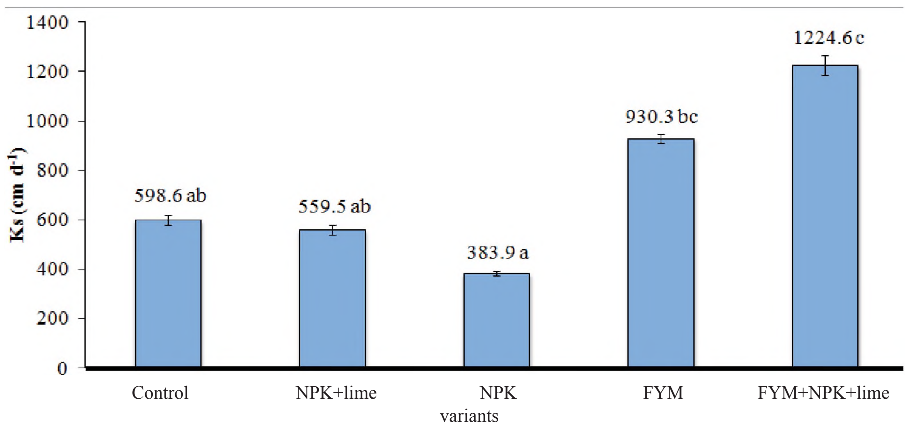

Fig. 4. Saturated hydraulic conductivity in the Static Nutrient Deficiency Experiment in Thyrow (2011; Tukey-test, p=0.05; different letters indicate a significant difference; error bars = standard deviation)

In all variants, the saturated hydraulic conductivity was at extremely high level, according to the German guidelines for soil description [1]. Nevertheless, major scattering of the data was observed. The significant lowest conductivity was found after mineral NPK fertilization without lime (383.9 cm d^{-1}) and the highest - after the combined organic and mineral fertilization (1224.6 cm d^{-1}). The results of the regression analyses showed an increase of Ks with increasing amounts of SOC. Based on the linear regression, the increase in SOC of 100 mg in 100 g of soil would equal an increase of 146 cm d^{-1} (R^2 = 0,87) in K .

Conclusions

After 75 years of differentiated organic and mineral fertilization within the frameworks of the present Static Nutrient Deficiency Experiment, SOC contents of various types options have been established. While sole NPK fertilization showed a small increase in SOC, the fertilization with FYM or the combination of both resulted in a substantial build-up of SOC. In addition, all physical properties were positively influenced by the treatment FYM-containing. These treatments showed a significant reduction in soil bulk density, increase in total porosity, better soil water retention and an improvement in saturated hydraulic conductivity. These chemical and physical properties are largely contributing to soil fertility and buffering capacity, in particular on sandy soils as revealed by the conditions disadvantageous for plant growth in the control treatment. This is mainly due to pronounced improvements in the soil water management or, more precisely, the increase of water holding capacity and higher water conductivity. Taking this into account, the combined application of mineral and organic fertilizers is a better option for soil quality conservation and sustainable crop production than organic or mineral fertilization alone.

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References

1. AG Boden. Bodenkundliche Kartieranleitung. 5th edition. Hannover: Schweizerbart'sche Verlagsbuchhandlung, 2005. 438 p.

2. *CelikL, Gunal H., Budak M., Akpinar C.* Effects of long-term organic and mineral fertilizers on bulk density and penetration resistance in semi-arid Mediterranean soil conditions // Geodenna. 2010. Vol. 160. P. 236-243.

3. *Dumas J.BA.* Precedes de 1'analyse organique //Annales de Cliimie et de Physique. 1831. Vol. 247. P. 198-213.

4. *HatiK. M,, Mandal K.G., MisraA.K., Ghosh P.K., Bandyopadhyav K.K.* Effect of inorganic fertilizer and farmyard manure on soil physical properties, root distribution, and water-use efficiency of soybean in Vertisols of central India // Bioresource Teclmol. 2006. Vol. 97. P. 2182-2188.

5. *Hati K.M., Swarup A., Dwivedi A.K., Misra A.K., Bandyopadhyav K.K.* Changes in soil physical properties and organic carbon status at the topsoil horizon of a Vertisol of central India after 28 years of continuous cropping, fertilization and manuring // Agri. Ecosyst. Environ. 2007. Vol. 119.'P. 127-134.

6. *Korschens M.* Globale und regionale Bedeutung von Dauerfeldversuchen // Archives of Agron. Soil Sci. 2005. Vol. 51. № 2. P. 111-117

7. *LipiecHatano R.* Quantification of compaction effects on soil physical properties and crop growth// Geoderma. 2003. Vol. If6. P. f07-f36.

8. *Rasool R., Kukal S.S., Hira G.S.* Soil physical fertility and crop performance as affected by long term application of FYM and inorganic fertilizers in rice-wheat system // Soil Till. Res. 2007. Vol. 96. P. 64-72.

9. *Yang X., Li P., Zhang S., Sun B., Xinping C.* Long-tenn-fertilization effects on soil organic carbon, physical properties, and wheat yield of a loess soil // J. Plant Nutr. Soil Sci. 2011. Vol. 174. P. 775-784.

10. *Zhang S., Yang X., Wiss M., Grip H., Lovdahl L.* Changes in physical properties of a loess soil in China following two long-term fertilization regimes // Geoderma. 2006. Vol. 136. P. 579-587.

ВЛИЯНИЕ ДЛИТЕЛЬНОГО ПРИМЕНЕНИЯ УДОБРЕНИЙ НА СОДЕРЖАНИЕ ОРГАНИЧЕСКОГО УГЛЕРОДА И ФИЗИЧЕСКИЕ СВОЙСТВА ПОЧВЫ

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Аннотация: в результате 75-летнего применения различных вариантов удобрений установлены существенные различия в содержании почвенного углерода. При внесении только органического удобрения при постоянном культивировании содержание органического углерода в почве удвоилось по сравнению с контролем (без внесения удобрения); при применении органо-минерального удобрения содержание углерода повысилось еще больше. Наряду с положительным влиянием на агрохимические свойства почвы разное содержание углерода обусловило существенные различия в таких агрофизических показателях, как плотность, общая пористость, дифференциальная пористость, водопроницаемость. Эти изменения, в особенности плотность и общая пористость, положительно повлияли на влагонакопление и влагосохранение, что особенно важно в условиях недостаточного или избыточного увлажнения. Тем самым высокое содержание углерода частично компенсирует недостатки физического состояния песчаных почв.

Ключевые слова: органическое вещество почвы, плотность почвы, общая пористость, влагоудержание, водопроницаемость.

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