Soil physical properties in the long-term field experiment “eternal rye” after 120 years of different fertilization

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Abstract

The effects of differences in the fertilization on soil organic matter and soil physical properties were measured in the long-term field experiment “eternal rye” (Halle, Germany), which has been started in 1878. The trial is one of the oldest agricultural field experiments still continued in recent times.

The unfertilized control in the continuous rye treatment showed the lowest total C content of 1.13 percent in the layer 0-6 cm depth, 1.13 percent in 12-26 cm and 0.49 percent in 32-38 cm. A long term annual mineral fertilization with 60 kg/ha nitrogen, 24 kg/ha phosphorus and 75 kg/ ha potassium increased the total carbon content to 1.33 percent in the first two layers sampled. An annual amount of 12 t/ha of farmyard manure (FYM) increased the total carbon content to 1.63 % in the first two and to 0.78 % in the third layer. These differences in the total carbon content caused profound differences in soil physical properties. The field capacity in all three layers was highest in the FYM-treatment and lowest in the unfertilized treatments, with the mineral fertilizer treatment showing intermediate results. Besides the important macropores larger than 10 µm differed according to the fertilizer treatments. Additionally the pneumatic and hydraulic conductivity was affected by the differences in the long term fertilizer treatments. The conclusion from our results is that for the interpretation of soil functions in long term field experiments changes of soil physical properties have to be considered as an additional explanation for differences in crop yields.

Media summary

Fertilization affects soil organic matter and hence soil physical properties in a long-term field experiment. Favourable structural properties were measured especially in the treatments with organic fertilization.

Key Words

Long-term field experiment, continuous rye, soil structure, soil organic matter

Introduction

A number of long-term field experiments to investigate the effect of different mineral and organic fertilizer treatments on crop yields and crop quality parameters were started in the 19^{th} century. Though the original scientific questions at the start of the experiments have long been answered, some of those experiments are still continued and now provide valuable and often unexpected results for a number of fundamental agronomic and environmental issues. One of those fundamental issues is the effect of husbandry treatments on the organic carbon content of agricultural soils, since increasing CO_2 concentrations in the atmosphere play a major role in the phenomenon of global change. However, the changes in the organic carbon content caused by different husbandry treatments will also affect soil physical properties and consequently modify various soil functions. In order to calculate carbon balances, the crop yields are another important component. Therefore our study was performed to quantify the effect of different fertilizer treatments on soil physical properties in a long-term field experiment.

Methods

Layout of the long-term field experiment “eternal rye”

The field experiment “eternal rye” has been started in 1878 on the experimental site “Julius-K?hn-Feld” of the agricultural faculty of the Martin-Luther-University Halle-Wittenberg, Germany. Originally the field experiment had only continuous rye with different mineral and organic fertilizer treatments to investigate the effect of fertilization on soil fertility. Since the beginning of the experiment the rye yields and changes in the total C content have been recorded. However, the design of the field experiment was fundamentally changed in 1961 due to severe grassy weed infestation in the continuous rye treatments and the unavailability of herbicides to combat those weeds. Since that date a potato-rye rotation and continuous corn were included and only one third of the experiment was still kept in the original design with continuous rye. The results in this paper are based on the plots which have been kept in continuous rye since 1878. The three fertilizer treatments which have been continued since 1878 are an unfertilized control, a farmyard manure (FYM)-treatment with 12 t/ha annually and a treatments with annual mineral fertilization of 60 kg/ha nitrogen, 24?kg/ha phosphorus and 75 kg/ha potassium. Other intermediate treatments which have been established later in the experiment are not reported in this paper. The entire husbandry which is not included in the treatments was adjusted to the seasonal conditions in the specific experimental years. The standard tillage in the field trial was ploughing. Further details of the field experiment “eternal rye” are given in Garz et al. (1999).

Environmental conditions at the experimental site

The experimental site “Julius-K?hn-Feld” is located close to the city of Halle, in the state Saxony-Anhalt, Germany. The region is one of the major crop production areas in Europe. The climate can be described as continental with an average precipitation of 472 mm per year and a maximum rainfall during the summer months June, July and August due to thunder storms. The long-term average temperature is 9.3?? with a clear trend to increasing temperatures in the last decades. The soil can be described as a haplic phaeozem with a content of 69?% sand, 23 % silt and 8 % clay. Given the soil and climatic conditions, water availability during the grain filling period of rye often limits cereal yields.

Measurements

The soil samples were taken in the continuous rye plots in May 2001 in the depth 0-6 cm, 12-26 cm and 32-38 cm to characterize the physical conditions in the uppermost layers of the soil. The specific measurements apart from the total C content comprised of the bulk density (d_B), the penetration resistance (PR) at a matrix potential of -30 kPa, the saturated hydraulic conductivity, and the pneumatic conductivity at -30?kPa, as well as the water retention curve. The porosity was calculated according to Hartge and Horn (1992) based on the bulk density and the particle density. The unsaturated conductivity as a function of water potential was determined at soils samples from the year 2002. The evaporation estimate was based on a method developed by Schindler (1980) and the data of the unsaturated water conductivity were fitted using a SAS makro by Warnstorff and D?rfel (1999).

Results

The measurements of the total C indicate a clear increase from the unfertilized control to the NPK treatments with the highest total C content in the FYM-treatment (Tab 1). The only exception is a slight decrease with little ecological relevance in the deepest layer 32-38 cm. This increase of total C content after such a long period of differentiated fertilizer treatments in the FYM-treatments compared with an unfertilised control and with the NPK-treatment is in accordance with results from similar long-term experiments in different environments (Brown 1994, Jenkinson et al. 1994) and is due to the direct effects of organic matter contribution with FYM as well as an increase in crop residues due to increased yields.

The described differences in the total C content in the different sample depth are the major cause of the soil physical differences described in this paper. The bulk density (d_B) shows an increase in the deeper sample depth with a clear trend of highest bulk densities in the unfertilized control compared with the NPK-treatment. Especially in the soil depth 12-26 cm and 32-38 cm the bulk densities of 1,70 and 1,72, respectively, will already affect root development of rye and consequently plant growth and crop yields. The lowest bulk densities in all three sampled soil depth were measured in the FYM-treatment indicating more favourable growing conditions for the rye. All three parameters porosity, field capacity (FC) and available water content (AWC) are clearly affected by the three fertilizer treatments. Especially the AWC has a tremendous impact on the ecological soil functions. Comparing the unfertilized control with the FYM-treatment in the different soil depths represents differences of 13 to 28 % in available water content. On the particular experimental site, an increase of the total C content of 0,1 percent in the uppermost horizon of the soil caused an increase of the field capacity of 0,7 percent.

Given the conditions at the experimental site, such differences affect crop growth and development in dry seasons.

The macropore volume (MP) shows the largest differences between the unfertilized control and the FYM-treatement in the deepest soil depth sampled. Only 15 volume percent of the total pore space in the unfertilized control are categorized as macropores, whereas 23.5 volume percent macropores were measured in the FYM-treatment. The conductivity parameters are affected by the different fertilizer treatments accordingly.

Table . 1: Physical soil properties in the soil of the long-term field experiment „eternal rye“ Statistics??

Depth	Ct[1]	d_B	Porosity	FC	AWC	MP[2]	K_a[3]	K_s[4]	PR[5]
?	M.-%	g/cm?	Vol.-%	Vol.-%	Vol.-%	Vol.-%	cm/s	cm/d	N/mm?
0-6 cm	?	?	?	?	?	?	?	?	?
Control	1,13	1,58b	39,2b	29,7b	22,5b	21,1a	1,3a	25,3a	0,87a
NPK	1,33	1,45a	44,4a	32,5a	25,5a	24,2a	2,0a	20,5a	0,79a
FYM	1,63	1,43a	44,9a	32,8a	25,7a	25,1a	2,1a	31,1a	0,73a
12-26 cm	?	?	?	?	?	?	?	?	?
Control	1,13	1,70c	34,9c	27,4c	19,6c	14,8b	0,3b	22,8b	1,26a
NPK	1,33	1,61b	38,6b	31,1b	23,1b	18,6a	0,8ab	32,7ab	1,05a
FYM	1,63	1,54a	40,9a	34,8a	27,1a	20,6a	1,0a	70,7a	0,92a
32-38 cm	?	?	?	?	?	?	?	?	?
Control	0,49	1,72c	34,4c	28,8b	21,2b	15,7b	0,3b	29,7a	1,06a
NPK	0,45	1,63b	37,8b	31,8a	24,1a	19,3b	1,0a	28,8a	0,98a

FYM	0,78	1,54a	41,0a	32,7a	25,7a	23,5a	0,5ab	42,2a	0,80a

[1] according to Garz et al. (1999)
[2] macropore volume (< 10 µm)
[3] air permeability (-30 kPa)
[4] saturated hydraulic conductivity
[5] penetration resistance (-30 kPa)

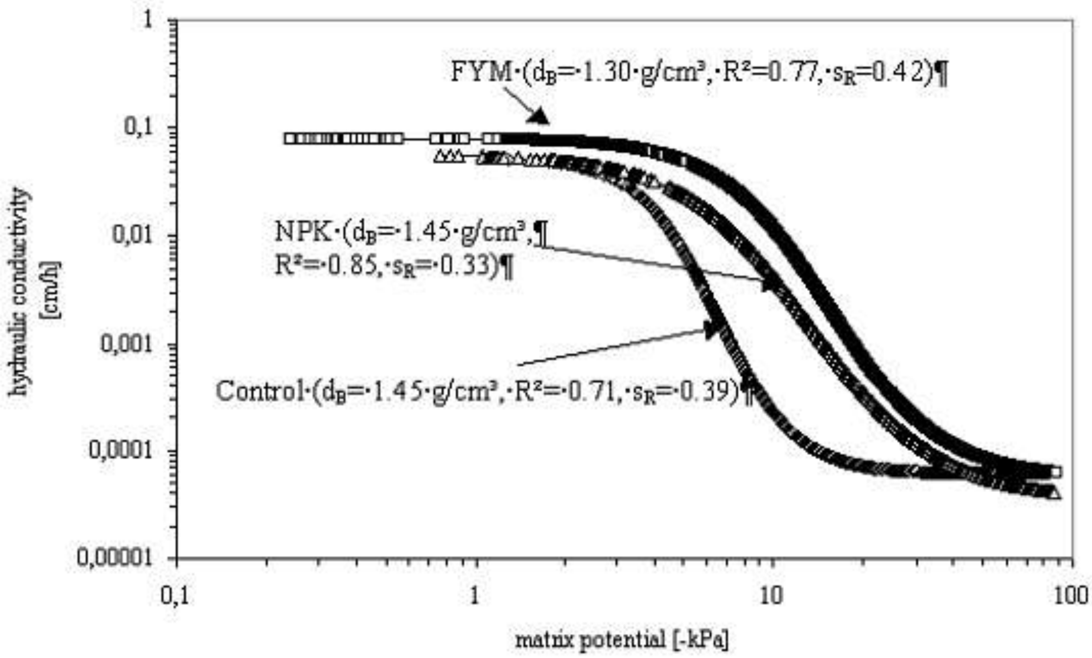

Fig. 1: Hydraulic conductivity in depth 12-18 cm

Especially sensitive to changes in the soil physical conditions is the hydraulic conductivity, which shows a clear increase from the unfertilized control and the NPK-treatments to the FYM-treatment. In contrast, the pneumatic conductivity as a measurement for the continuity of the macropores was not affected by the different fertilizer treatments. The lowest penetration figures were in all sampling depth measured in the FYM-treatment with a trend to relatively larger differences between the unfertilised control and the FYM-treatment in the layers differences 12-26 cm and 32- 38 cm. The hydraulic conductivity k(Ψm) in the range of higher matrix potential is almost completely determined by the soil structure. For that reason, the effects of the long-term differences in the fertilization on the unsaturated conductivity function were determined. The measurements are based on the upper layer of the A-horizon. By doing that it was possible to determine the effect of the total C content and the bulk density on the unsaturated hydraulic conductivity. At higher matrix potential, low SOM content decreased substantially the hydraulic conductivity. In the range of lower matrix potentials (measurements to -63kPa) the influence of the SOM content decreased until the point that no differences in hydraulic conductivity between unfertilized treatment and the FYM treatment were measurable (Fig. 1). The mineral fertilization showed an intermediate response . Compared to the effect of the total C content, the effect of differences in the bulk density on the unsaturated water conductivity were negligible.

Conclusion

Long-term differences in the organic and mineral fertilization have a profound effect on soil physical properties, which, as a consequence will affect yield and quality parameters of crops. These results have to be considered in the interpretation of other long-term field experiment data, since yield response might be caused by a combination of availability of plant nutrients and differences in growing conditions due to differences in soil physical properties. Though information in other long-term experiments is often limited to changes in SOM content, it is very likely that similar soil physical changes occur on other sites of long-term field experiments and affect crop growth and development and soil functions accordingly.

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