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Soil Organic Matter of a Sandy Soil Influenced by Agronomy and Climate

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ABSTRACT

Long term field experiments are being conducted at Humboldt University of Berlin (Germany) to obtain information regarding sustainable management of arable land with sandy soils. In Thyrow, a location in the south of Berlin with silty and sandy soil (85 % sand, 12 % silt, 3 % clay, 0.5 % C_{org}, pH 5.5) several experiments have been–carried out since 1937. They include the study of the long-term effects of the agronomic factors of: crop rotation; organic fertilization; mineral fertilization and irrigation on soil and crops.

The results of annual C_{org} measurements make it possible to describe the influence of agronomic management and climate on the development of soil organic matter (SOM). The following ranking of agronomic factors was observed from greatest to lowest influence: Organic fertilization > crop rotation > mineral N-fertilization > irrigation. Organic fertilization with Farm Yard Manure (FYM) increases the content of Organic Carbon by 53 % compared with the control. A crop rotation consisting of cereals only leads to 34 % higher carbon contents than crop rotations including cereals and maize or potatoes respectively. Mineral nitrogen fertilization increases the C_{org} content from between 19 to 32 % but only a minor effect of 2 to 8 % was detected with irrigation treatments. At the Nutrient Deficiency Experiment Thyrow, contents of SOM have been analysed since 1965. In general, the results show a decreasing level of SOM contents with all treatments of fertilization. Over a period of 40 years the organic carbon content lost 10 to 13 % while the average air temperature rose by 1.2 °C.

Key words: Sandy soil, long-term experiments, soil organic matter, climatic change

INTRODUCTION

Soil organic matter is the most important basis for the soil fertility. It is also a sensitive indicator of different kinds of external influences on the ecosystem soil. In order to study the development of SOM contents in different soils, long-term field experiments are necessary (Körschens 2002). In sandy soils SOM shows a greater dynamic than in better-buffered soils. At the Humboldt University of Berlin (Germany) a number of long-term field experiments are being conducted to investigate the effects of agronomic factors on soil, crops and the environment. The agronomic questions include aspects of crop rotation, soil tillage, organic and mineral fertilization as well as irrigation. The results of the investigations allow a ranking of the importance of the different agronomic factors for the reproduction of soil fertility.

MATERIALS and METHODS

The experiments are being conducted in a region strongly influenced by the last ice age, approximately 15000 years ago. In this region about 70 % of the soil is typically sandy. Long-term experiments are being carried out at the experimental station Thyrow, 25 km south of Berlin (Ellmer et al. 2000).

The soil is sand that is low in silt with 83 % sand, 14 % silt and only 3 % clay. There is a low usable field capacity and the soil fertility status is also low (Ellmer and Baumecker 2005). The climatic conditions are limited by mean precipitations (Tab. 1).

Table 1. Site characteristics of Thyrow

Parameter	**Data**
Usable field capacity	11 mm dm^{-1}
pH value	5,4 … 5,8
C_{org}	5500 … 6000 mg kg^{-1}
P	56 … 80 mg kg^{-1}
K	60 … 90 mg kg^{-1}
Mean precipitation	495 mm
Mean air temperature	8,9 °C

This paper will present the current results from the long-term experiments in the agronomic factors of crop rotation, organic fertilization, mineral N-fertilization and irrigation.

Crop Rotation

In 1976 the Static Crop Rotation Experiment was established. The aim of this experiment is to investigate the effects of increasing the concentrations of cereals in the rotation on the soil status and the yield development. In three different crop rotations the cereal concentration increases from 50 %, 75 % up to 100 % (Tab. 2).

Table 2. Treatments of the Static Crop Rotation Experiment Thyrow (1976)

Cereals concentration in crop rotation		
50 % cereals	**75 % cereals**	**100 % cereals**
Potatoes	Silage maize	Oats
Winter rye	Spring barley	Winter rye
Silage maize	Winter rye	Winter barley
Spring barley	Winter rye	Spring barley

Organic and Mineral Fertilization

The important international trial The Static Nutrient Deficiency Experiment, which was established in 1937, is being carried out at Thyrow. Here the effects of organic fertilization using FYM as well as mineral fertilization, are being investigated (Tab. 3).

Table 3. Selected treatments of the Static Nutrient Deficiency Experiment Thyrow (1937)

Number	Treatments
1	Control (unfertilised)
2	FYM (15 t ha^{-1} a^{-1})
3	FYM + NPK + Lime
4	NPK + Lime

Along with a permanent unfertilised treatment there is a variant with 30 t ha^{-1} FYM in every second year. The third treatment includes additional mineral fertilization with 60 (spring barley) or 90 kg ha^{-1} N (potatoes, silage maize), 24 kg ha^{-1} P and 100 kg ha^{-1} K. The fourth treatment is the exclusive mineral fertilization.

Mineral N Fertilization

The effect of mineral N fertilization can be quantified in the Static Soil Fertility Experiment which was established in 1938. In this experiment, different treatments of organic fertilization are investigated with and without mineral N fertilization, in that case 120 kg ha^{-1} (Tab. 4).

Table 4. Selected treatments of Static Soil Fertility Experiment Thyrow (1938)

Number	Treatments
1	PK
2	PK + 120 kg ha^{-1} N
3	FYM + PK
4	FYM + PK + 120 kg ha^{-1} N

Irrigation

The only long-term experiment in Germany involving irrigation is at Thyrow and this was established in 1969. This experiment is investigating the effects of permanent additional water supply on soil and crops. It is also investigating the influence of mineral fertilization in combination with irrigation on potatoes, field grass, winter rye, winter barley and oil seed crops. (Tab. 5).

Table 5. Selected treatments of the Static Fertilization and Irrigation Experiment (1969)

Unirrigated	Irrigated
0 kg ha^{-1} N	0 kg ha^{-1} N
120 kg ha^{-1} N	120 kg ha^{-1} N

In all of the above experiments the soil organic carbon content was analysed annually in autumn to a depth of 0 – 20 cm. Analyses were carried out by the method of wet burning after Springer and Klee (1955). The long-term dataset makes it possible to analyse the development of soil organic matter content over more than 40 years in relation to environmental and agronomic conditions.

Meteorological standard data are permanently collected with an automatically working measurement station nearby the experimental field.

RESULTS and DISCUSSION

Long-term agricultural field experiments are living laboratories providing opportunities for experimentation in which the effects of manipulation may be separated from other variables (Southwood 1994, Merbach and Deubel 2007). The results from long-term investigation at Humboldt-University of Berlin into soil organic carbon show that agronomic factors as well as climatic inputs are important for the increase and decrease in development.

Agronomic Effects on Soil Organic Carbon

Soil organic matter is the basis for soil formation and soil functions (Körschens et al. 1997). In the long-term experiments different effects of crop rotation, organic manure, mineral nitrogen fertilization as well as irrigation were measured.

Pure cereal cultivation from the point of view of agronomy is problematical, because at first the yields decrease. However, this cropping system is favourable for the soil organic carbon content. Without root crops or maize in the crop rotation the C_{org} content increases because of the higher amount of cereal crop and root residues (Fig. 1).

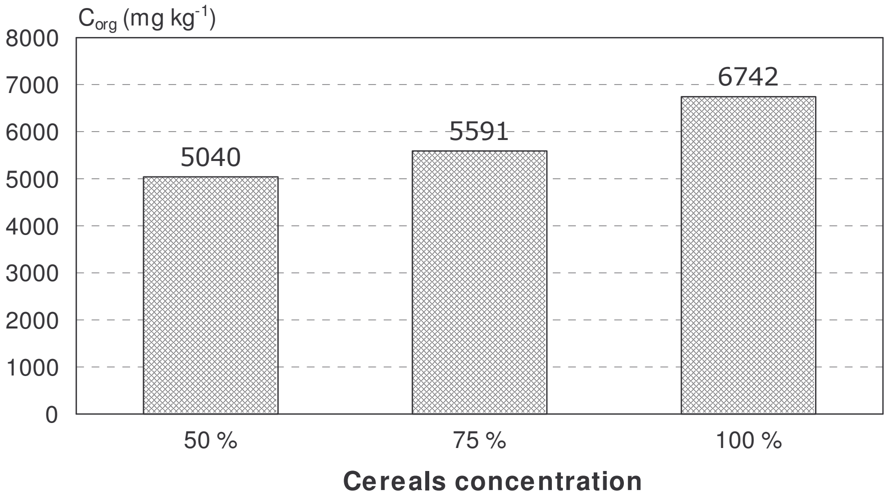

Figure 1. C_{org} content of the soil in different crop rotations with 50 %, 75 % and 100 % cereals; average 2002 - 2006

After thirty years of experimentation the C_{org} content in total cereal rotation is one third higher than in the rotation with half of the concentration.

The effects of organic manure are higher than with crop rotations. With no fertilization the SOM content shows a very low level of less than 0.37 %. Mineral fertilization with NPK and lime results in an increase of only 12 %. With organic fertilization the C_{org} content is 53 % higher than in the control treatment. In the combination treatment of mineral and organic fertilization we find the highest SOM content with 0.67 % C_{org} on average, 81 % more than in the control treatment (Fig. 2).

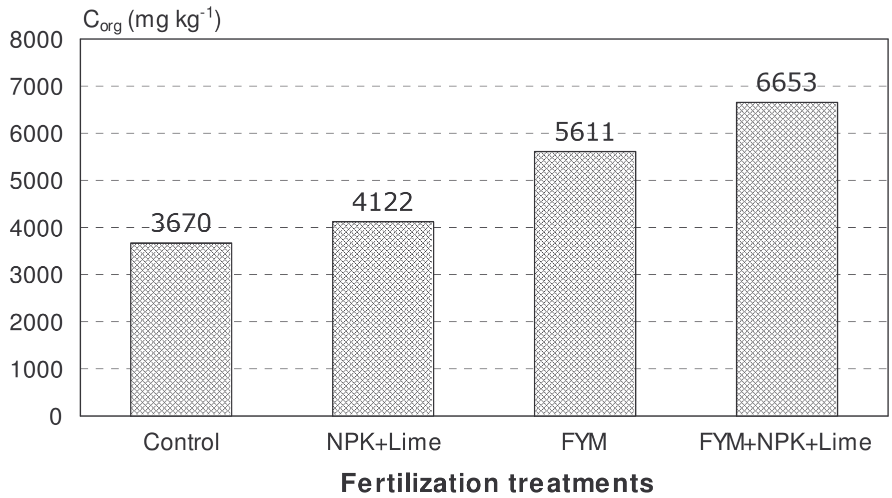

Figure 2. C_{org} content of the soil as result of different fertilization; average 2002 - 2006

These results show that for the sufficient reproduction of soil organic matter in sandy soils organic fertilization is necessary. Similar results were obtained by Zimmer et al. (2005) in a long-term experiment in sandy soil (*Albic Luvisol*) at experimental station Groß Kreuz, near Berlin. FYM fertilization (42 t ha^{-1} every third year) increased the soil organic carbon content in that case from 4370 mg kg^{-1} to 6000 mg kg^{-1}; an increase of 37 %. Under the climatic and soil conditions of Estonia, Teesalu et al. (2006) also found a significant increase in soil organic carbon content after long-term FYM fertilization in relation to mineral treatment.

With sandy soil the mineral nitrogen fertilization has a significant effect on the level of soil organic matter. In the treatment without manure 120 kg ha^{-1} mineral N resulted in an increased C_{org} content of 1031 mg kg^{-1} (+32 %). FYM without mineral N increases the C_{org} content to 5415 mg kg^{-1} (+69 %). At this level the additional mineral N fertilization has an effect of 1051 mg 1000 g^{-1}, 102 % more than in the control (Fig. 3).

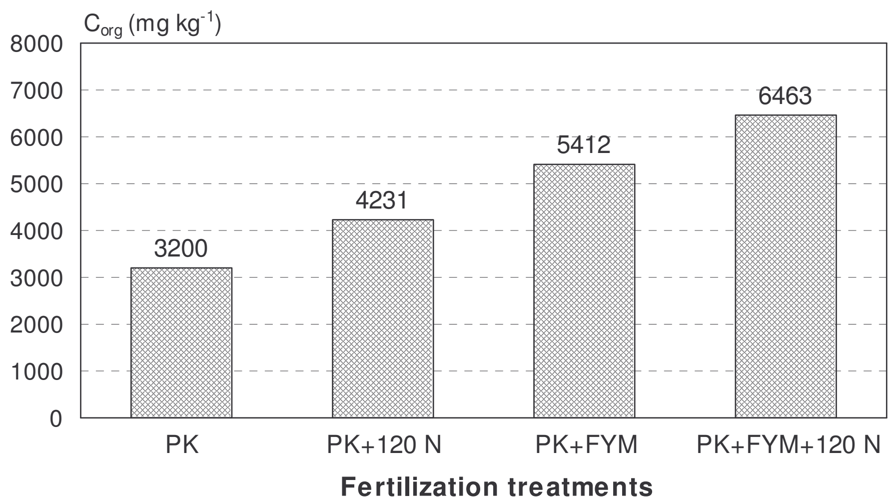

Figure 3. C_{org} content of the soil as result of different organic and mineral N fertilization; average 2002 - 2006

The increasing effect of mineral N on the C_{org} content is on the higher level of SOM content more distinct than on the lower level. Similar results were reported by Antil and Singh (2007), who, after 10 years of fertilization with 150 t ha^{-1} FYM and 150 kg ha^{-1} mineral nitrogen achieved an increase of organic C from 0.38 % up to 0,99 %.

In the long-term experiment, results show that the influence of irrigation on soil organic matter is extremely low (Fig. 4). Without mineral N a 7% increase of C_{org} content and the treatment with 120 kg ha^{-1} mineral N fertilization produced a 2% increase. Compared with this the N fertilization increased the C_{org} content by 17 % without irrigation and by 12 % with irrigation.

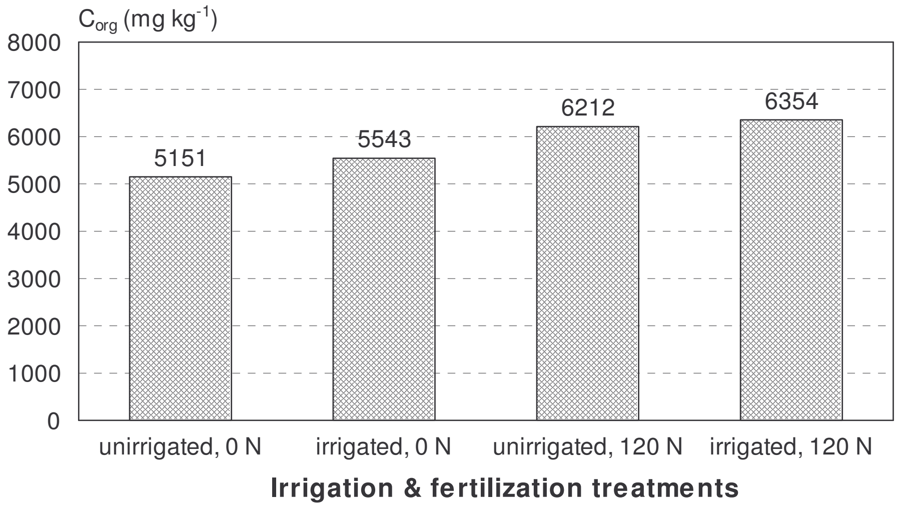

Figure 4. C_{org} content of the soil as result of irrigation and N fertilization; average 2002 – 2006

Based on the results of these four long-term experiments it is possible to deduce a ranking of agronomic factors influencing the soil organic matter content in sandy soil:
Organic fertilization (+53 %) > Crop rotation (+34 %) > Mineral N fertilization (+19 … 32 %) > Irrigation (+2 … 8 %).

Effects of Climate on Soil Organic Carbon

After four decades of experimentation the dataset can now be used to evaluate external influences on the development of SOM (Ellmer 2008). A look at the air temperature at this site shows two phenomena:

- Great variations in the mean temperature between the years with a maximum of 3.1 °C (1996 vs. 2000). The greatest variations were observed in the last decade.
- A trend of increasing mean air temperature. A simple linear regression shows an increase of 1.2 °C over the four decades (Fig. 5).

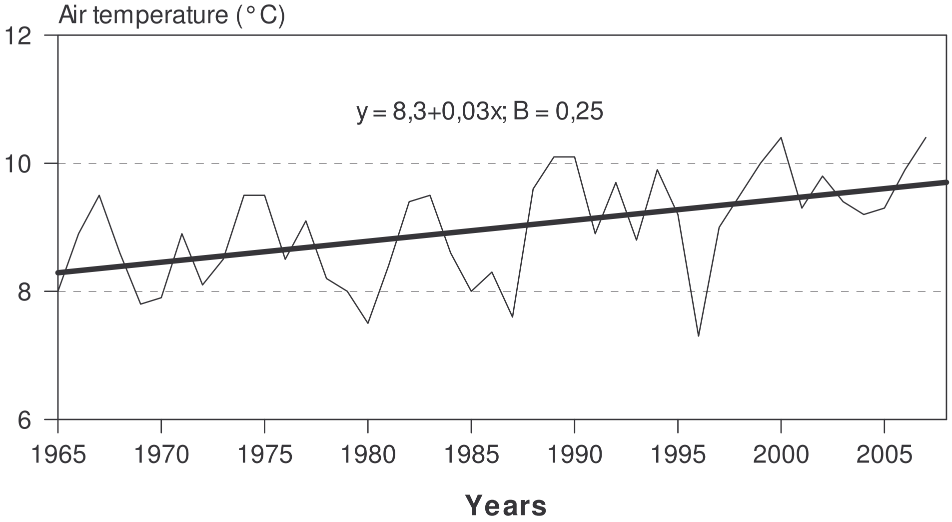

Figure 5. Development of mean air temperature at experimental station Thyrow; 1965 - 2006

More important for the dynamic of SOM is the soil temperature. It shows a similar picture:

- The variation between the years is slightly lower (maximum 2.9 °C)
- The linear trend also increased by 0.8 °C over four decades (Fig. 6).

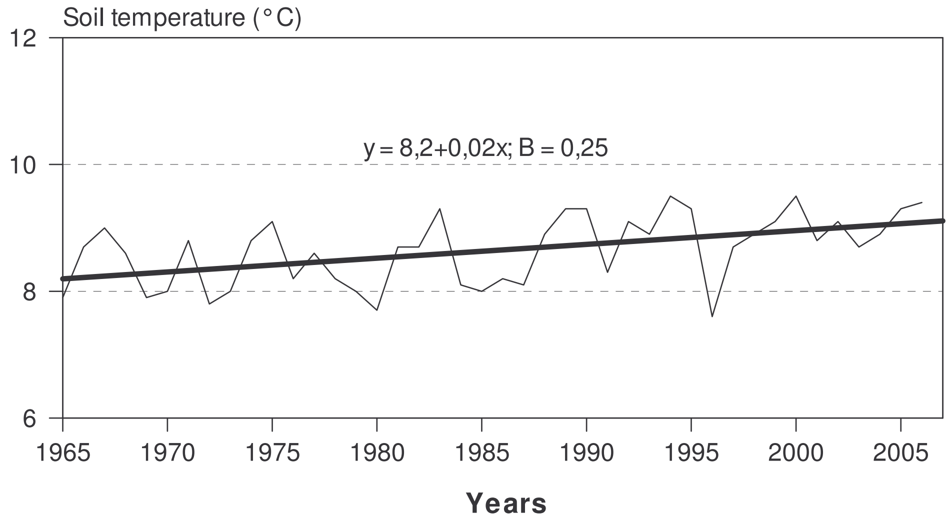

Figure 6. Development of soil temperature (10 – 20 cm) at experimental station Thyrow; 1965 - 2006

The climatic development with increasing air and soil temperatures is to be seen in connection with the development of soil organic carbon contents. In the Static Nutrient Deficiency Experiment this can be shown at two selected different treatments – mineral fertilization (NPK+lime) and organic-mineral fertilization (FYM+NPK+lime) (Fig. 7).

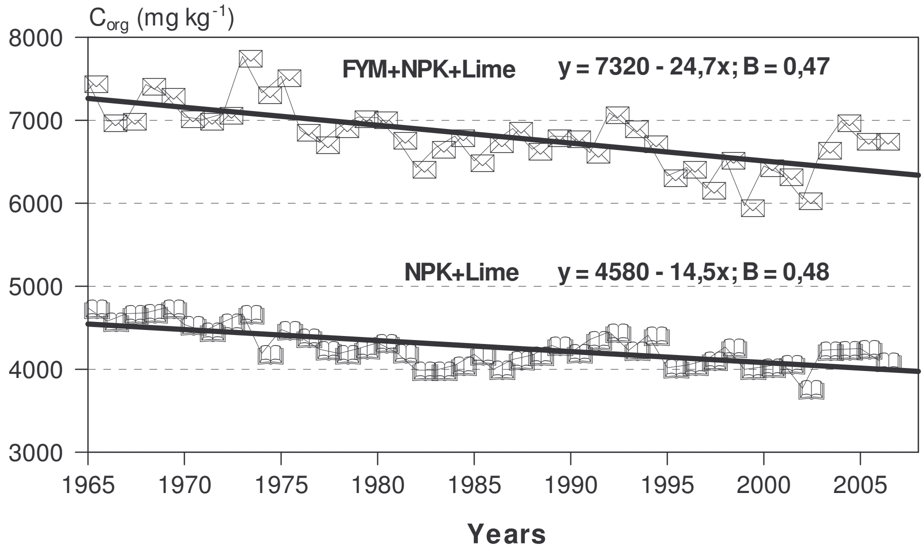

Figure 7. Development of C_{org} content in the soil in two selected treatments of the Nutrient Deficiency Experiment Thyrow

The treatment with organic and mineral fertilization over four decades results in a decreasing trend with an annual loss of about 25 mg kg^{-1} C_{org}. Over the entire period, a total loss of about 700 mg kg^{-1} was quantified. This amounts to 10 % of SOM compared to the status at the beginning of the measurements. With the other non organic fertilised treatments the results are similar. At a lower level of SOM the total loss amounts to 13 % of the initial value. Similar results were reported by Giram et al. (2007). In their long-term experiment founded in 1832 at „Magruder plots" at Oklahoma/USA they reported losses in the soil organic matter of more than 50% of the starting values. Christensen (1997) reported the same phenomena from the Askov long-term field experiments in Denmark.

These results show that soil organic carbon content is a very sensitive matter in the soil ecosystem. Its long-term development is influenced by the climatic conditions. At the investigated sandy soil it causes a negative effect on the sink function of soil for carbon. However, humus stocks and their dynamics are of special importance in connection with current environmentally relevant problems: As a sink for or a source of emissions of atmospheric carbon dioxide, which is a cause of the greenhouse effect (Reuter et al. 2007, Stevens et al. 2006).

CONCLUSIONS

1. As the most important basis of soil fertility the soil organic carbon content on sandy soils shows a distinct dynamic development over the time.
2. In arable farming organic fertilization and crop rotation have the largest effects on soil organic carbon. Mineral N fertilization is of secondary importantance and the effect of irrigation is only marginal.

3. Climatic changes have a significant influence on the organic carbon content of sandy soil. A mean increase in air temperature of 1 °C causes a decrease of carbon content of between 0.05 and 0.1 %.

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