Food and Agriculture Organization of the United Nations

VOLUME 4

# RECARBONIZING GLOBAL SOILS

CASE STUDIES

## A technical manual of recommended management practices


## CROPLAND, GRASSLAND, INTEGRATED SYSTEMS AND FARMING APPROACHES

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INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

GLOBAL SOIL PARTNERSHIP

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# 12. Long-term experiment of manure treatments on a sandy soil, Germany

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## 1. Related practices

Organic fertilization (Manure, straw), mineral fertilization

## 2. Description of the case study

The long-term field experiment "V140" (Nährstoffsteigerungsversuch) was established in 1963 at a former uniformly cultivated arable field and is today located at the Leibniz Centre for Agricultural Landscape Research (ZALF) about 50 km east of Berlin in Müncheberg. Since 1963 soil samples were taken, and analyzed for SOC and $N_t$. The samples taken every second year from 1982 to 1994 were archived.

The V140 represents one of the few still active long-term field experiments on sandy soils in Germany. During the running period just small management changes have been done, mostly with respect to the crop rotation and the applied fertilizer combinations and amounts. The recent research focuses mostly on the effect of fertilization on aspects of soil fertility.

The field experiment is located on a relatively flat area of a total of 5 712 m$^2$ which is divided in 8 replicates. Each replicate consists of 21 plots: one plot does receive neither mineral nor organic fertilizer (Control) while the other 20 plots receive fertilization consisting of 5 levels of mineral combined with 4 levels of organic fertilization (Table 47). Overall, the experiment consists of 168 plots of 5 m x 6 m size (Smukalski *et al.*, 1990) (Figure 17). Organic fertilizer was applied every second year in spring before planting sugar beet, potato, or maize, respectively. Mineral fertilizer was applied every year. More details on the soil and crop management were provided by Körschens (1990).

**Table 47.** Fertilizer treatments of V140, Müncheberg

| Treatment | Description | Organic Fertilization | Mineral Fertilization (kg/ha)* | | |
|---|---|---|---|---|---|
| | | *Dry mass (t/ha/yr)* | *N* | *P* | *K* |
| 0 | without | 0 | 0 | 7 | 26 |
| 1.1 | NPK | 0 | 52 | 30 | 122 |
| 1.2 | NPK | 0 | 89 | 35 | 140 |
| 1.3 | NPK | 0 | 118 | 38 | 150 |
| 1.4 | NPK | 0 | 157 | 43 | 171 |
| 1.5 | NPK | 0 | 193 | 48 | 188 |
| 2.1 | NPK+FYM1 | 1.2 | 32 | 26 | 104 |
| 2.2 | NPK+FYM1 | 1.2 | 68 | 30 | 122 |
| 2.3 | NPK+FYM1 | 1.2 | 116 | 36 | 145 |
| 2.4 | NPK+FYM1 | 1.2 | 139 | 39 | 156 |
| 2.5 | NPK+FYM1 | 1.2 | 169 | 42 | 167 |
| 3.1 | NPK+FYM2 | 3.2 | 9 | 24 | 100 |
| 3.2 | NPK+FYM2 | 3.2 | 52 | 30 | 121 |
| 3.3 | NPK+FYM2 | 3.2 | 77 | 31 | 126 |
| 3.4 | NPK+FYM2 | 3.2 | 118 | 37 | 149 |
| 3.5 | NPK+FYM2 | 3.2 | 150 | 42 | 164 |
| 4.1 | NPK+Straw | 2 | 65 | 34 | 123 |
| 4.2 | NPK+Straw | 2 | 101 | 38 | 141 |
| 4.3 | NPK+Straw | 2 | 138 | 43 | 159 |
| 4.4 | NPK+Straw | 2 | 161 | 45 | 163 |
| 4.5 | NPK+Straw | 2 | 191 | 47 | 169 |

*Source: Rogasik et al. (1997)*

*Fertilizer treatments until 1993 in the crop rotation: silage maize (1963), winter rye (1964), potatoes (1965), winter rye (1966), potatoes (1967), spring wheat (1968), sugar beet (1969), spring barley (1970), silage maize (1971), winter rye (1972), potatoes (1973), winter wheat (1974), sugar beet (1975), summer barley (1976), sugar beet (1977), spring barley (1978), sugar beet (1979), spring barley (1980), sugar beet (1981), spring barley (1982), potatoes (1983), winter wheat (1984), sugar beet (1985), spring barley (1986), potatoes (1987), winter wheat (1988), sugar beet (1989), spring barley (1990), potatoes (1991), winter wheat (1992: time of soil sampling), sugar beet (1993)

## 3. Context of the case study

**Geographical location:** 15374 Müncheberg, Germany, 52.516931° N, 14.121930° E

**Pedo-climatic context:** According to the German Guidelines Soil Assessment (Bodenschätzung) the dominating soil types are slightly loamy sand and sand (Sl4D and S4D) with sand contents above 70%. The most common soil sub type is Haplic Luvisol. According to the IPCC, climate is cool temperate moist. The site is characterized by dry periods, particularly during early summer. Weather data for the running period of V140 are available at the homepage of the German Weather Service (DWD) (station number 03376). Data presented here are for soil samples in autumn 1992, a relatively dry year with an annual precipitation of 418 that is 103 mm less than the long-term average.

**Land-use:** field crops: spring barley, potatoes, winter wheat, sugar beet in rotation since 1982 until 1992. After that, flax and peas were added to the crop rotation.

## 4. Possibility of scaling up

It is a context-specific case study.

## 5. Impact on soil organic carbon stocks

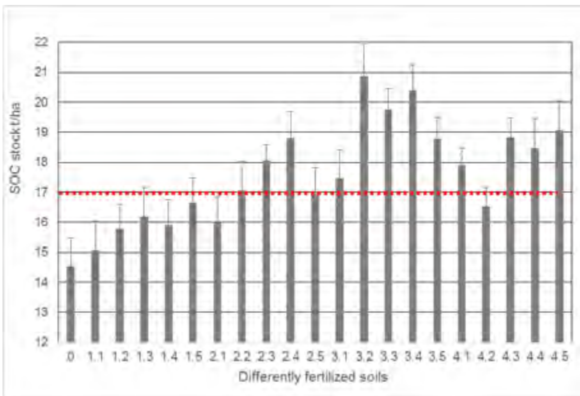
In 1963 the mean SOC stock in the upper 0-20 cm of the soils at the field experiment was 17 t/ha. In autumn 1992, i.e. 29 years later, on average the farmyard manure (FYM) + NPK fertilized soils (treatments 3.1 to 3.5) had the highest SOC stocks (Figure 16a). The FYM fertilized soil (3.2) contained about 21 t/ha, which is about 4 t/ha more than the mean SOC stock of the 1963 samples, while the NPK fertilized soil (1.5) had a SOC stock of 16.2 which is about 0.8 t lower. The differences between the SOC stocks of FYM+NPK fertilized soils (in mean 19.6 t/ha) and that of the unfertilized soil (14.3 t/ha) were up to 3.5-times larger than the measurement error (1.5 t/ha). However, such differences were only found for the treatments 3.2, 3.3 and 3.4 (Figure 16a) and it needs to be noted there are also years in which the differences in SOC contents are less than or equal to the measurement error.

For a more precise comparison the SOC contents of specific plots need to be compared one by one, which has not been done yet. However, due to site heterogeneity with respect to texture and bulk density the SOC stocks vary to a large extent (ranging from 10.1 to 24.4 t/ha) resulting in high standard errors (0.5 up to 1.1 t/ha) for samples from plots that received the same fertilization but originated from different replicates in the experimental field.

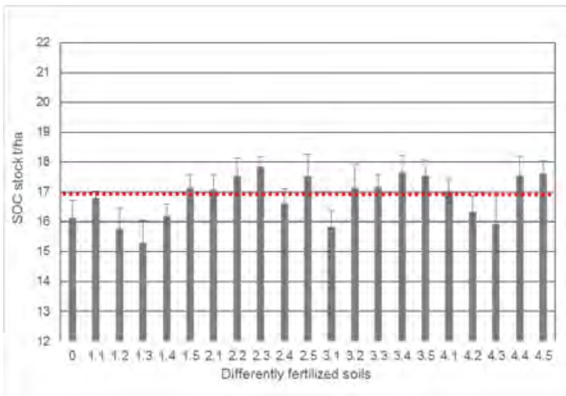
In summary, the combination of mineral fertilizer with a high proportion of manure had the most favorable effect on the amount of SOC in the years under investigation. Pure mineral fertilization (NPK) was the least able to contribute to increasing the SOC stocks on average (Schubert, 2008) which is also described by Smukalski *et al.* (1990) for mean data of a 25-year period. The difference between SOC stocks of the 1992 samples and those of the 1976 samples can be used as an estimate for the SOC sequestration potential of the differently fertilized soils for a 16year period (Figure 16c). These SOC changes within the 16year period between 1976 and 1992 suggest the highest SOC sequestration potential (0.23 tC/ha/yr) for the 3.2 treatment (FYM + N) but a SOC loss for the control (0.11 tC/ha/yr), the 2.1 (0.067 tC/ha/yr) and the 1.4 (0.02 tC/ha/yr) treatment.

SOC stocks varied strongly from year to year: In 1970 there was a large difference in the SOC stocks of the differently fertilized soils which became smaller in 1978, but larger in the following years with the highest difference in 1992. However, in 1994 and 1996 SOC differed to a smaller extent as compared to the 1992 data. Such a constant rate in SOC sequestration or loss per year cannot be stated and we only show the change in SOC stocks for the 1992 samples as compared to those of the 1976 samples (Figure 16c).

a)




b)




c)

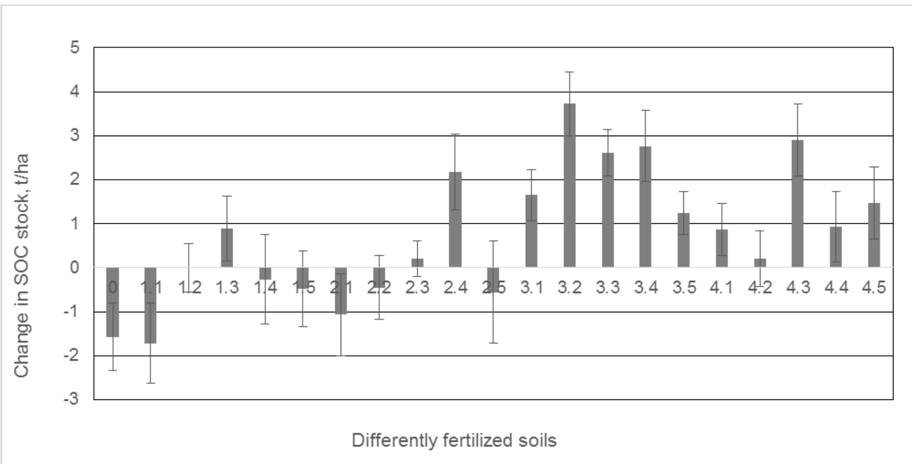



**Figure 16.** SOC stocks in t/ha on 0-20 cm depth of the differently fertilized soils

These soils were sampled in a) 1992 and b) 1976, mean over eight replicates (descriptions of treatments are shown in Table 47; red dotted line indicate the mean SOC content of the soils sampled in 1963) (Schubert, 2008; Smukalski et al., 1990) and c) the change in SOC stock (tC/ha) for a 16-year time period estimated from the differences between data of the 1992 and 1976 samples.

# 6. Other benefits of the practice

## 6.1. Improvement of soil properties

### Physical properties

Bulk density in 1992 varies between 1.29 and 1.74 with a mean of 1.49 g/cm$^3$, which is higher than the bulk density in 1976 that varies between 1.23 and 1.51 with a mean of 1.38 g/cm$^3$.

### Chemical properties

Samples taken in 1992 were analyzed for SOC content and for soil organic matter properties by using FTIR spectroscopy.

In addition to SOC contents the soil samples were analyzed using Fourier Transform infrared (FTIR) spectroscopy to characterize the composition of the soil organic matter with respect to the content of hydrophilic groups (C=O/COC, Ellerbrock and Gerke, 2013). The C=O/COC ratio can be used as an indicator for the hydrophilic character and the potential cation exchange capacity of the soil organic matter (Kaiser, Ellerbock and Gerke, 2008). The higher the C=O/COC ratio the more hydrophilic the soil organic matter becomes. More hydrophilic soil organic matter is able to store higher amounts of water which is related to an increased soil water-holding capacity.

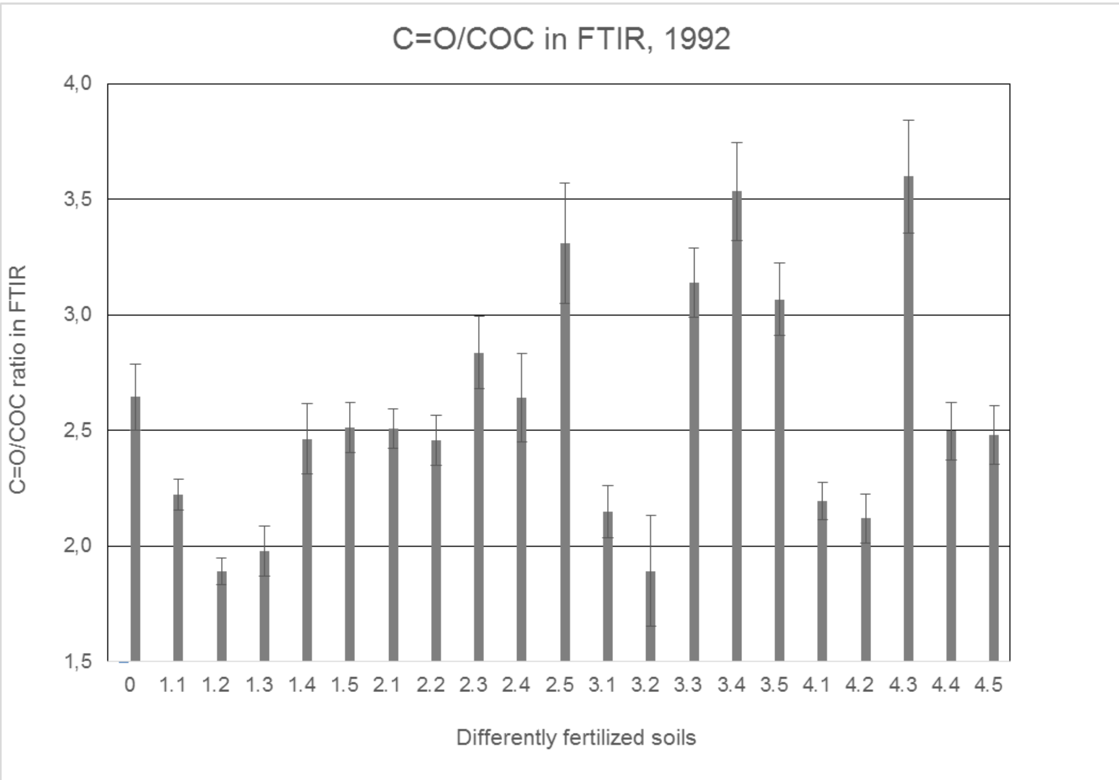



**Figure 17.** The C=O/COC ratios in FTIR spectra of differently fertilized soil sampled in 1992

Mean over eight replicates (descriptions of treatments are shown in Table 47). Error bars represent standard errors.

All soils fertilized with NPK only (Treatment 1) show lower C=O/COC ratios as compared to the control (Figure 17), while the FYM fertilized soils combined with higher amounts of N (Treatments 2, and 3 sub-levels 3 to 5) show higher C=O/COC ratios. For straw application (Treatment 4) such effect is only observed for sub-level 3 (Figure 17). Such change in soil organic matter composition caused by FYM application may result in an increased water-holding capacity of the soils. This may explain why the crop yield on the FYM fertilized soils are in the dry year 1992 higher as compared to that on the mineral fertilized soils (see section 6.3).

However, according to Smukalski *et al.* (1990) liming is needed to reduce a potential decrease in pH caused by organic fertilization and the heterogeneity of the field needs also to be considered since it affects at least the SOC content (see above).

### Biological properties

Properties were not assessed.

## 6.2 Minimization of threats to soil functions

**Table 48.** Soil threats

| Soil threats | |
|---|---|
| **Nutrient imbalance and cycles** | N use by plant was analyzed by Smukalski *et al.* (1990) among others. The Nt levels showed changes corresponding to the organic soil content levels. N intake higher than N deprivation was not sufficient to maintain soil N unless the reproduction of the organic soil content was assured (Smukalski *et al.*, 1990). FYM fertilization enriched the content of lactate-soluble P[3] in soil while an effect on lactate-soluble K was not observable (Smukalski *et al.*, 1990). |
| **Soil water management** | Fertilization with FYM seems to increase the water-holding capacity of the soil because of its effect on soil organic matter composition (higher C=O/COC ratios with FYM fertilized soils). |

## 6.3 Increases in production (e.g. food/fuel/feed/timber)

The plots on which only mineral fertilizer was applied vary in their yields. With a few exceptions, the yields increase with the amount of NPK, i.e. the greatest yields in general for solely mineral fertilized soils were achieved with the fertilizer treatment 1.5 (= highest level of mineral NPK fertilization). However, in 1992 - a very dry year - the combined treatments of mineral and organic fertilization (especially treatments 2.5, 3.4 and 4.5) achieved greater yields than the NPK fertilization (Schubert, 2008).

[3] Lactate soluble cations are potentially soluble in the soil solution such that they are –in general- available for plants.

# 7. Potential drawbacks to the practice

## 7.1 Tradeoffs with other threats to soil functions

**Table 49.** Soil threats

| Soil threats | |
|---|---|
| **Soil erosion** | Although the site is not a hilly site, after rainfall events small changes in elevation may be detectable and a digital elevation model (DEM) of the field experimental areas indicates up to 1 m differences in elevation, leading to potential effects of erosion on the SOC contents (Deumlich *et al.*, 2018). |
| **Soil acidification** | Liming is needed to reduce a potential decrease in pH caused by organic fertilization (Smukalski *et al.*, 1990). |

## 7.2 Increases in greenhouse gas emissions

Possible GHG emissions such as $N_2O$ from manure have not been measured in the frame of this study.

# 8. Recommendations before implementing the practice

According to the results of the Müncheberger long-term field experiment "V140" (Nährstoffsteigerungsversuch), it is recommended to fertilize sandy soils with a combination of FYM and mineral fertilization.

# 9. Potential barriers for adoption

**Table 50.** Potential barriers to adoption

| Barrier | YES/NO | |
|---|---|---|
| Biophysical | Yes | Access to manure may be restricted due to a tendency to stockless arable farms and regional separation of livestock and arable production. |
| Institutional | No | According to the new fertilizer ordinance, in nitrate-contaminated areas from 2021 on it is not allowed to spread FYM between 1st of November and 31st of January (BMEL, 2020). |

# Photo


**Photo 24.** The 168 plots of V140 (Nährstoffsteigerungsversuch), Müncheberg, Germany

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