# Land properties influenced by land use and fertilization

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# 1. Introduction

The fact that the population is exponential rising we need more food or a higher yield compared to hundred years ago. One big point to achieve this is to fertilize the fields to stop the degradation of the soil. . It is not the case, that the humanity has found the perfect way to fertilize their fields. When the farmers fertilize their fields over decades there are unpredictable changes in the soil properties. To keep the yield high and stabilize the soil properties with the least possible amount of fertilizers as possible, long-term field experiments were set up. In this mini-project we measured different land properties influenced by land use and fertilization. The aim is to find out and achieve the best way of fertilizing fields to minimalize the degradation of the soil and get the highest yield.

# 2. Material and Methods

The soil samples were collected from the IOSDV (Internationale Organische Stickstoff Dauerdüngungs Versuchsreihe) long-term fertilization experiment in Tartu. The used experimental plots are shown in Figure 1. The sample N0 was without organic fertilizer and without mineral nitrogen. Sample N120 was without organic fertilizer but with a mineral nitrogen rate of 120 kg N/ha. The samples N120 organic and N0 organic were fertilised with solid farmyard manure in every third year and with mineral nitrogen rates of 0 kg N/ha for the N0 organic or 120 kg N/ha for the N120 organic sample. The source for the sample grassland was permanent grassland next to the experimental plots. All samples were collected from a depth of 0-15 cm.

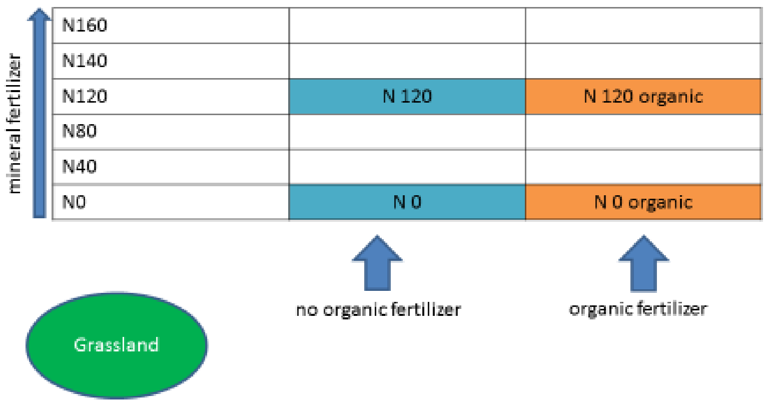


*Figure 1 sketch of the used plots for the soil samples at IOSDV*

Each sample had three replicates. For every replicate out of the field, five specimens were taken while for the replicates out of the grassland ten specimens were taken.

The soil samples were dried overnight. Then, the organic material and small stones were removed before the samples were sieved to homogenise them.

## 2.1 Soil texture fingering test

Water was added to the soil samples to get an even soil. The samples were rolled to get a ball and then, a wire was formed. Afterwards, a ring out of the wire. During the whole process, it was observed when the material broke apart.

2.2 Moisture content by air drying

For each sample, 10 g air-dry soil was weighed into a previously weighed metal can. Overnight, the soil samples were put in an oven at 105 °C. Afterwards, they were removed from the oven and put in a desiccator for at least 30 minutes. Then, the samples were re-weighed.

The water content in the soil samples was calculated with Formula Ⅰ.

$$water\ content\ in\ soil\ sample\ [\%] = 100\ x\ [\frac{m1 - m2}{m1 - m0}] \qquad (I)$$

$m0 = empty\ previously\ dried\ metal\ can$

$m1 = approximately\ 10\ g\ air\ dry\ soil + metal\ can$

$m2 = re - weighed\ dried\ soil + metal\ can$

## 2.3 Soil $pH_{KCl}$

Out of each sample, 5 g air-dried soil was weighed into a 100 mL glass beaker. 12.5 mL 1M KCl solution was added to each beaker using a graduated cylinder. The beakers were placed on to a shaker for 30-60 minutes and the pH was measured by putting the combined electrode about 3 cm deep in the suspensions.

## 2.4 Soil electrical conductivity/salinity

Approximately 5g air-dried soil of each sample was weighed into a 100 mL plastic beaker. With the help of a graduated cylinder, 25 ml distillate water was added to each and the beakers were placed on to the shaker for 30-60 minutes. Afterwards, the suspensions were let to settle for a few minutes before the conductivity cell was immersed in the solutions to measure the electrical conductivity.

## 2.5 P, K, Ca, Mg by Mehlich-3 method

For the measurement of phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) by the Mehlich 3 method, 5 g air-dried soil of each sample was weighed into a 100 mL plastic flask. 50 mL of the prefabricated Mehlich 3 extracting solution was added to each flask. The flasks were placed on the mechanical shaker for 10 minutes (200, 4 cm recipes/minute). Afterwards, the suspensions were filtered through paper filters and the extracts were collected in new 100 mL plastic flaks. The extracts were re-filtrated into 15 mL plastic tubes using syringe filters.

The samples were analysed by the MP-AES (Microwave Plasma-Atomic Emission Spectrometer).

## 2.6 Loss on ignition (LOI)

To determine the soil organic matter, 20 g dried soil of each sample was weighed into a porcelain crucible. The crucibles were placed into the muffle furnace, the temperature was increased to 400 °C. After 24 hours, the crucibles were cooled down and weighed again.

The organic matter content was calculated with Formula II.

$$LOI\ [\%] = \frac{[(Wod - Wi)\ x\ 100]}{Wod} \qquad (II)$$

$Wod = weight\ of\ dried\ sample$

$Wi = weight\ of\ sample\ after\ ignition\ at\ 400\ °C$

$LOI = Loss\ on\ ignition = organic\ matter\ content$

## 2.7 C:N by dry combustion

A small amount of each sample was put into a fully automated machine to get the content of total nitrogen (N) and carbon (C). The machine heated to a temperature of 900 °C.

## 2.8 Dry bulk density

The dry bulk density was measured in cooperation with working group 2. They took the undisturbed soil samples with cylinders and cleaned the cylinders from the outside. All cylinders were put into the oven to dry them at 105 °C for 12 hours. After the drying, the samples were weighed. Afterwards, the cylinders were cleaned and weighed without the soil and the volume of the cylinders was measured.

The oven dry soil weight $p$ was calculated with Formula Ⅲ.

$$p = total\ weight\ (cylinder + soil) - weight\ of\ empty\ cylinder \qquad (III)$$

The dry soil bulk density $D_m$ was calculated according to Formula Ⅳ.

$$D_m \left[\frac{g}{cm^3}\right] = \frac{p}{V} \qquad (IV)$$

$$V = volume\ of\ cylinder\ [cm^3]$$

## 2.9 Calculated soil carbon stock

To calculate the soil carbon stock, it was necessary to first calculate the bulk density for all the samples. This was done according to Formula Ⅴ.

$$calculated\ soil\ bulk\ density\ [\frac{g}{cm^3}] = 1{,}775 - 0{,}173\ x\ LOI^{\frac{1}{2}} \qquad (V)$$

The carbon stock was then calculated with Formula Ⅵ.

$$carbon\ stock\ \left[\frac{t}{ha}\right] = soil\ volume\ x\ calculated\ soil\ bulk\ density\ x\ C\ \% \qquad (VI)$$

$$soil\ volume = depth\ x\ area = 0{,}15\ m\ x\ 10000\ m^2$$

# 3. Results

Table 1 shows the entire results of the experiments. All following results will refer to this table.

*Table 1 All measured values results*

| | P (mg/kg) | Mg (mg/kg) | Ca (mg/kg) | N (%) | C (%) | pH |
|---|---|---|---|---|---|---|
| Grasland 1 | 122 | 130 | 973 | 0,17 | 2,23 | 5,00 |
| Grasland 2 | 108 | 131 | 789 | 0,16 | 2,15 | 4,73 |
| Grasland 3 | 102 | 147 | 1 006 | 0,17 | 2,12 | 4,84 |
| N0/1 | 133 | 149 | 1 332 | 0,08 | 1,25 | 6,39 |
| N0/2 | 128 | 146 | 1 258 | 0,06 | 1,14 | 6,21 |
| N0/3 | 135 | 163 | 1 360 | 0,07 | 1,17 | 6,23 |
| N120/1 | 126 | 112 | 787 | 0,07 | 1,01 | 5,38 |
| N120/2 | 124 | 90 | 738 | 0,07 | 0,99 | 5,11 |
| N120/3 | 161 | 134 | 1 119 | 0,07 | 0,96 | 5,38 |
| N0 org fert/1 | 136 | 167 | 1 294 | 0,07 | 1,10 | 6,28 |
| N0 org fert/2 | 143 | 147 | 1 110 | 0,07 | 1,19 | 6,25 |
| N0 org fert/3 | 141 | 163 | 1 336 | 0,08 | 1,17 | 6,18 |
| N120 org fert/1 | 148 | 121 | 1 036 | 0,08 | 1,11 | 5,85 |
| N120 org fert/2 | 154 | 152 | 1 148 | 0,07 | 1,11 | 6,09 |
| N120 org fert/3 | 123 | 131 | 892 | 0,09 | 1,09 | 6,09 |

| | Conductivity (µS) | Moisture (%) | Bulk density (g/cm3) | Calc. Bulk density (g/cm3) | SOC stock (t/ha) |
|---|---|---|---|---|---|
| Grasland 1 | 58 | 1,19 | | 1,51 | 50,67 |
| Grasland 2 | 45 | 1,51 | | 1,51 | 48,71 |
| Grasland 3 | 43 | 1,60 | | 1,50 | 47,66 |
| N0/1 | 70 | 1,10 | 1,61 | 1,55 | 29,05 |
| N0/2 | 67 | 1,00 | 1,54 | 1,55 | 26,57 |
| N0/3 | 63 | 0,90 | | 1,56 | 27,39 |
| N120/1 | 87 | 1,10 | 1,44 | 1,57 | 23,83 |
| N120/2 | 39 | 1,10 | 1,34 | 1,57 | 23,25 |
| N120/3 | 98 | -19,00 | | 1,58 | 22,81 |
| N0 org fert/1 | 32 | 1,00 | | 1,56 | 25,72 |
| N0 org fert/2 | 60 | 0,90 | | 1,57 | 28,00 |
| N0 org fert/3 | 27 | 1,01 | | 1,56 | 27,38 |
| N120 org fert/1 | 69 | 0,90 | 1,43 | 1,58 | 26,37 |
| N120 org fert/2 | 75 | 1,00 | 1,54 | 1,56 | 26,03 |
| N120 org fert/3 | 90 | 1,10 | | 1,58 | 25,80 |

## 3.1 Soil texture fingering test

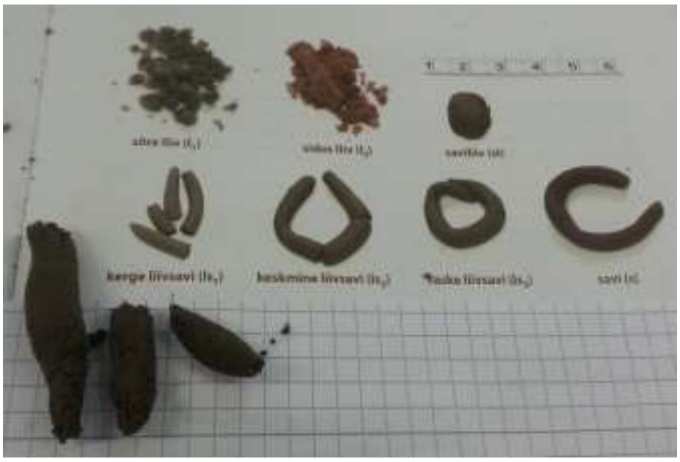

Figure 2 Comparison of sample taken for fingering test with the guideline picture

The soil texture type was determined to be sandy loam with clay content of 10 – 25% according Food and agriculture organization of the United Nations (2006) (Fig. 2). The result was equal for all the samples.

## 3.2 Moisture content by air drying

The measured values are shown in Table 1. They are generally between 0.9 and 1.6 %. The lowest value showed moisture of -19 %.

## 3.3 Soil $pH_{KCl}$

The pH of the grassland soil is 4.86. The field without any fertilizers used, N0, is 6.28 which is also the highest measured pH. The N0 organic is treated with organic fertilizers and has a pH of 6.24. N120 has a pH of 5.29 and the pH of N120 organic is 6.01 (Fig. 3).

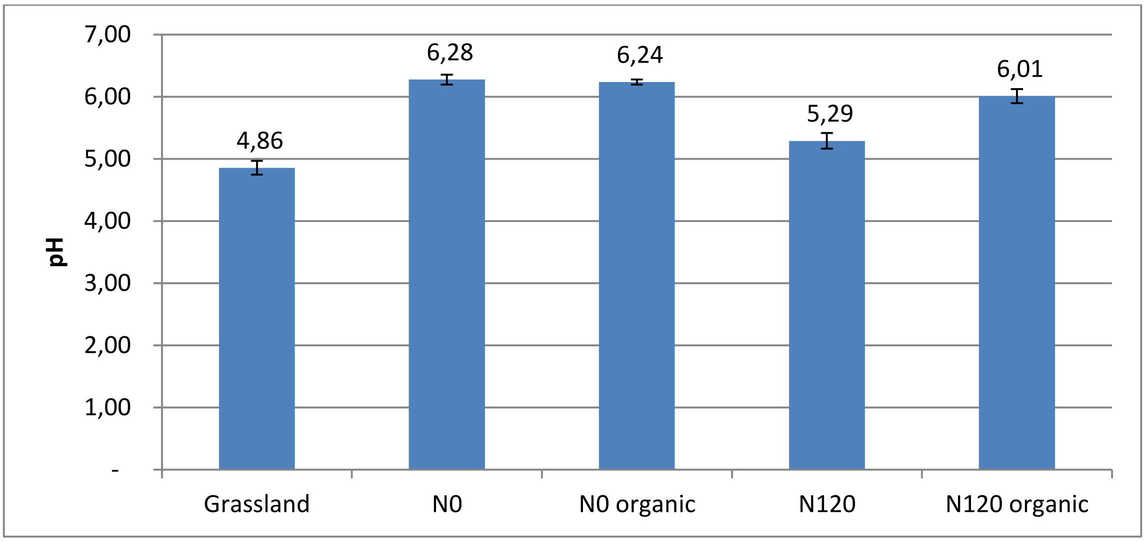


*Figure 3 Soil $pH_{KCl}$ depending on land use and fertilisation. N0: without organic fertilizer and without mineral nitrogen, N0 organic: with orgnic fertilizer every third year (manure) and without mineral nitrogen, N120: without orgnic fertilizer and with 120 kg N/ha, N120 organic: with orgnic fertilizer every third year (manure) and with 120 kg N/ha*

## 3.4 Soil electrical conductivity/salinity

The Figure 4 and the Table 1 show the soil electrical conductivity of the soil solution of the different samples. The N0 organic has the lowest soil electrical conductivity with 39.67 µS and the N120 the highest with 74.67 µS.

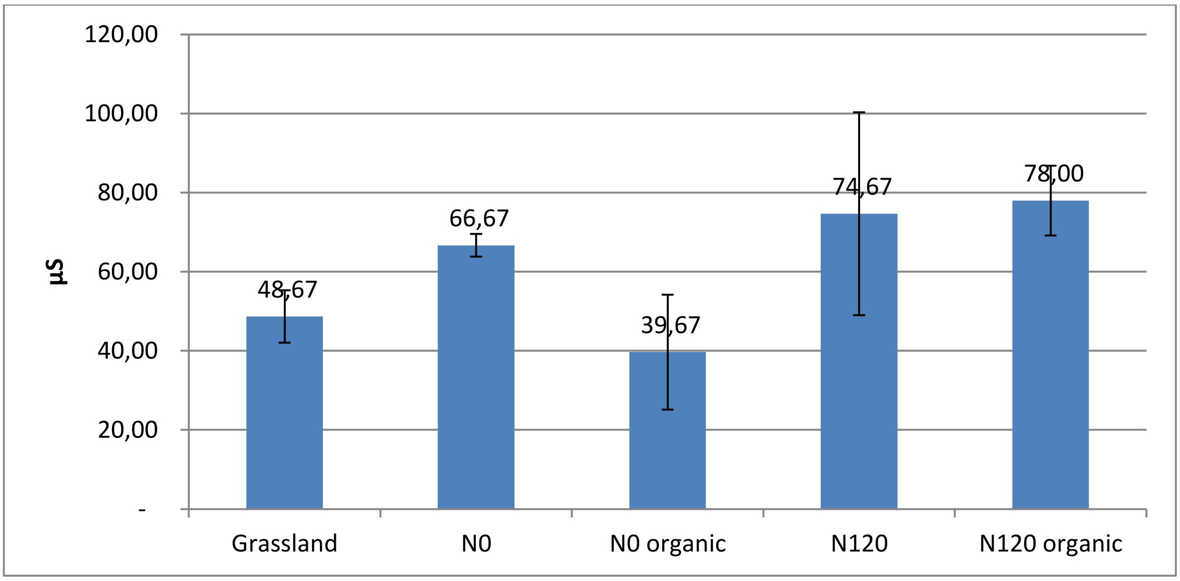


*Figure 4 Electric conductivity of soil solution depending on land use and fertilisation. N0: without organic fertilizer and without mineral nitrogen, N0 organic: with orgnic fertilizer every third year (manure) and without mineral nitrogen, N120: without orgnic fertilizer and with 120 kg N/ha, N120 organic: with orgnic fertilizer every third year (manure) and with 120 kg N/ha*

3.5 P, K, Ca, Mg by Mehlich-3 method

Figure 5 represent the measured amount of macro-nutrients in different fertilized crops, no fertilized crop and grassland.

The received data was compared with reference values and it turned out that phosphorus has a high amount in each case. In-between the different crops there have been no big differences in the Phosphorus amount, what can be seen in figure 1. Just the grassland soil has a little bit less phosphorus than the arable soils, with approximate 110 mg/kg. The highest amount with approximate 145 mg/kg phosphorus can be found in the soil of N120, which has been treated with organic fertilizer.

For magnesium, there is a medium content to the reference values and a high content in the zero fertilized crops, plus in the crops which has been treated with organic fertilizer. The highest amount is almost 160 mg/kg Magnesium in the NO crops with organic fertilizer, and the lowest amount can be found in the N 120 crop with approximate 110 mg/kg.

Potassium reached a higher amount with over 180 mg/kg in grassland, than in the fertilized crops. The lowest amount is shown in the N 120 crop with less than 60 mg/kg of potassium.

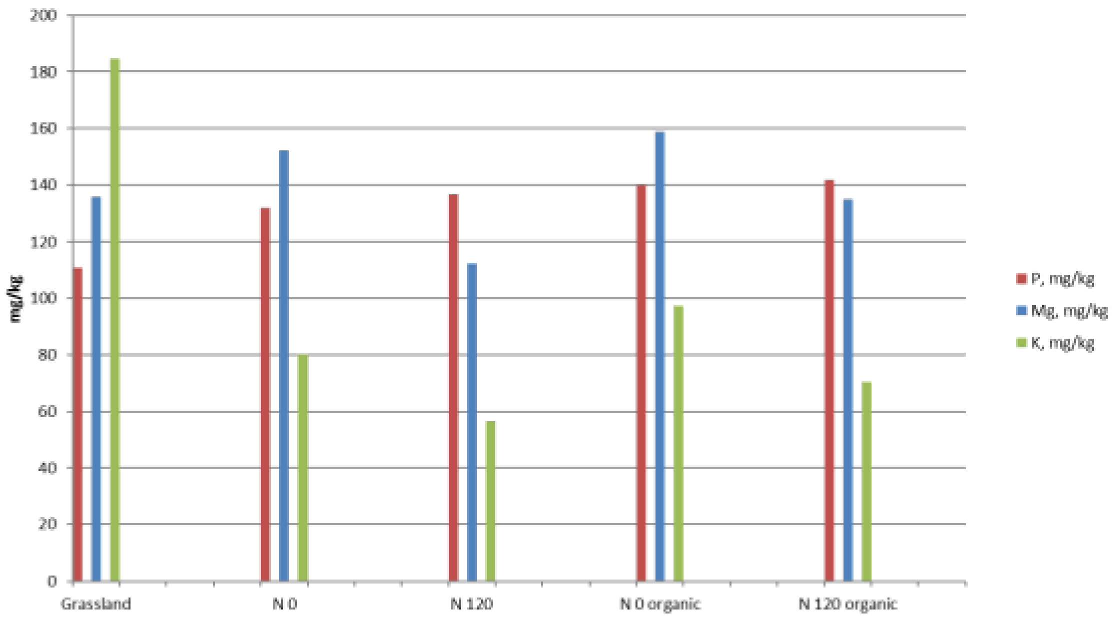


*Figure 5 Measured P, K, Mg by Mehlich-3 method depending on land use and fertilization. N0: without organic fertilizer and without mineral nitrogen, N0 organic: with orgnic fertilizer every third year (manure) and without mineral nitrogen, N120: without orgnic fertilizer and with 120 kg N/ha, N120 organic: with orgnic fertilizer every third year (manure) and with 120 kg N/ha*

Figure 6 shows the measured Calcium amount by the Mehlich-3 method in each arable soil.

There is the highest amount of Calcium in the no fertilized crop (NO) with approximate 1350 mg/kg Calcium. The lowest amount can be found in the crop which has been treated with mineral fertilizer (N 120). It indicates an amount of approximate 900 mg/kg Calcium.

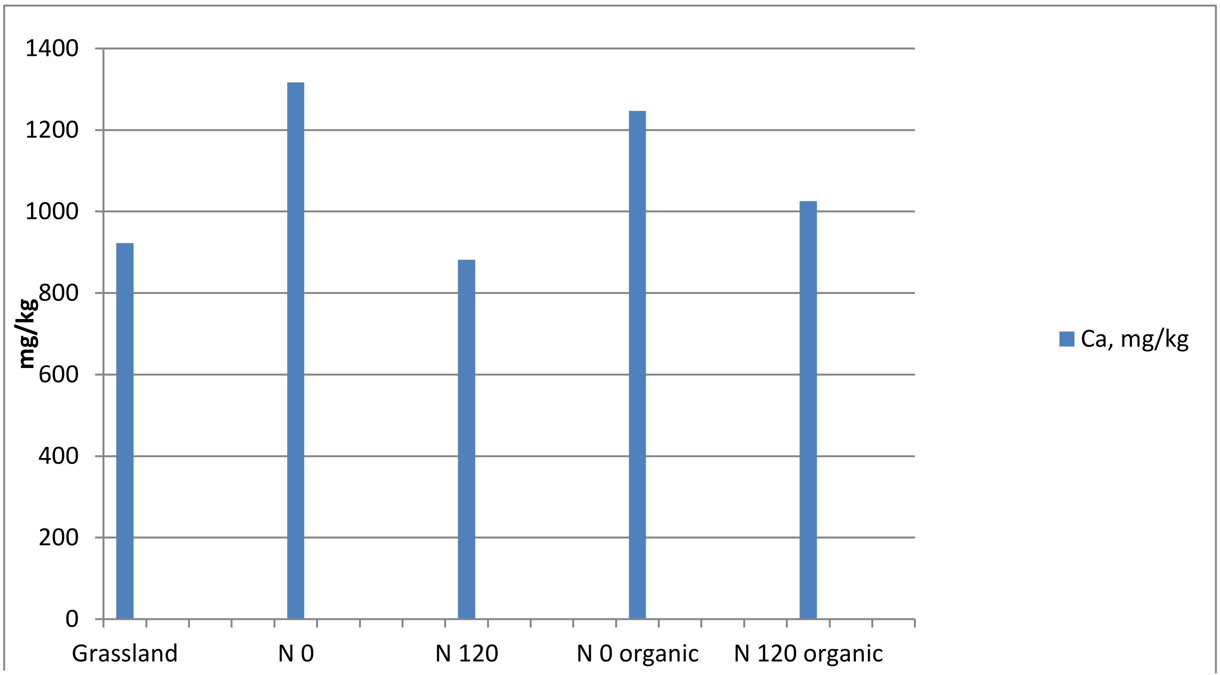

*Figure 6 Measured P, K, Mg by Mehlich-3 method depending on land use and fertilization*

There is a positive correlation between the pH and the phosphorus, what can be seen on figure 7.

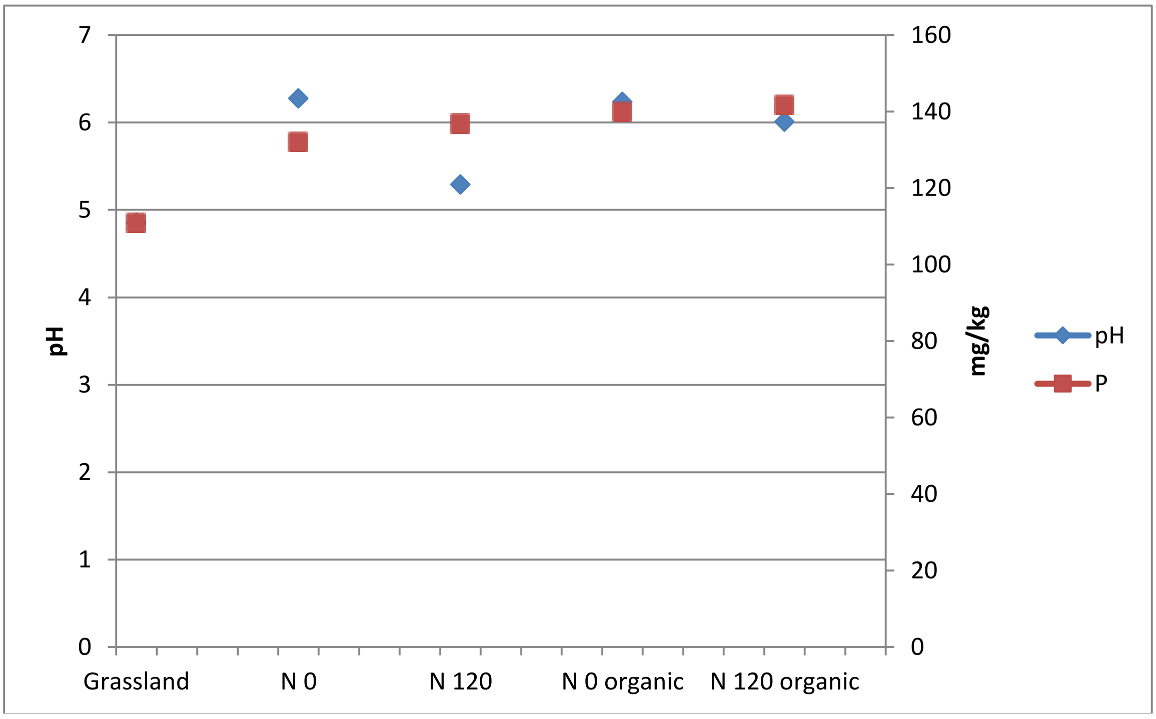

*Figure 7 Phosphorus correlated with pH depending on land use and fertilization*

## 3.6 Loss on ignition (LOI)

The results of loss on ignition show the highest loss in permanent grassland and very similar values in the other fields while the lowest values are measured in the field fertilized with nitrogen (Fig. 8).

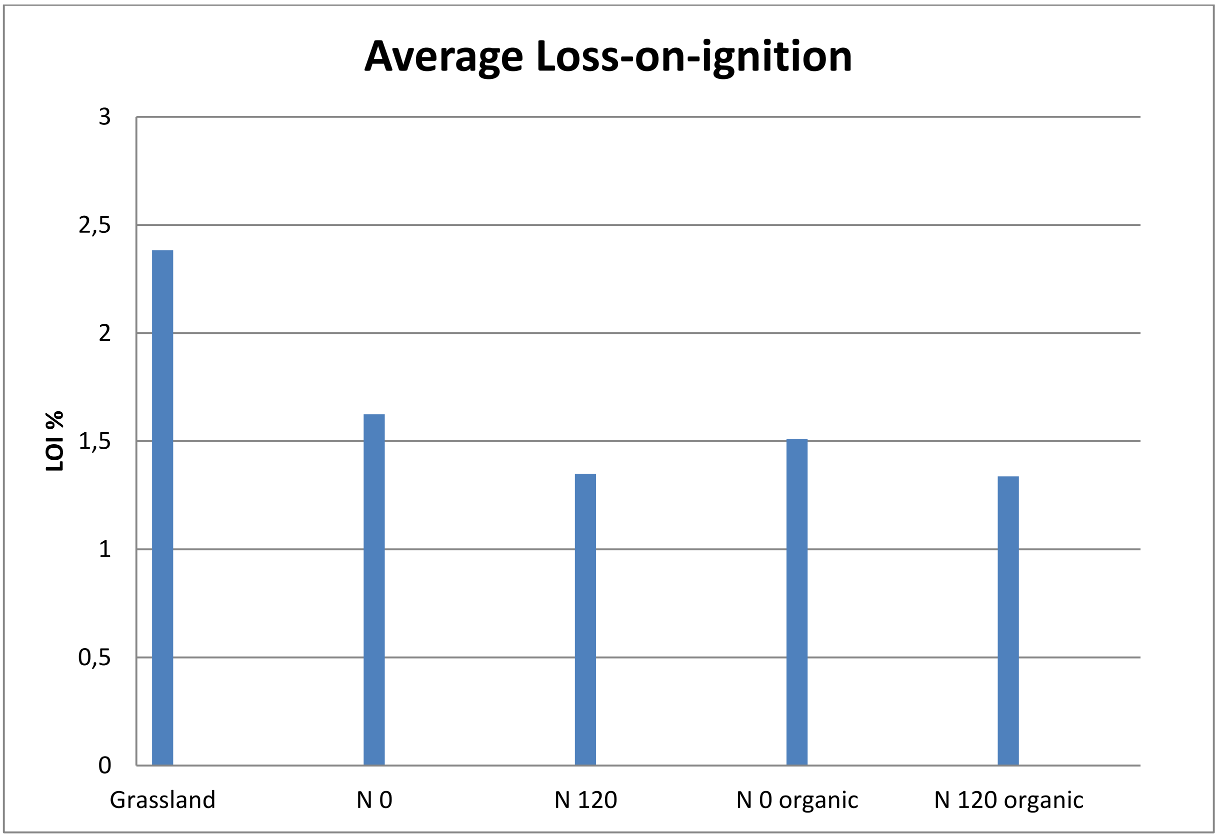


*Figure 8 Average loss on ignition of different experimental field managements.*

## 3.7 C:N by dry combustion

The results show strong positive correlation between C and N percentage in soil samples. The result which is far from the others is the grassland with significantly higher percentage of both carbon and nitrogen (Fig. 9).

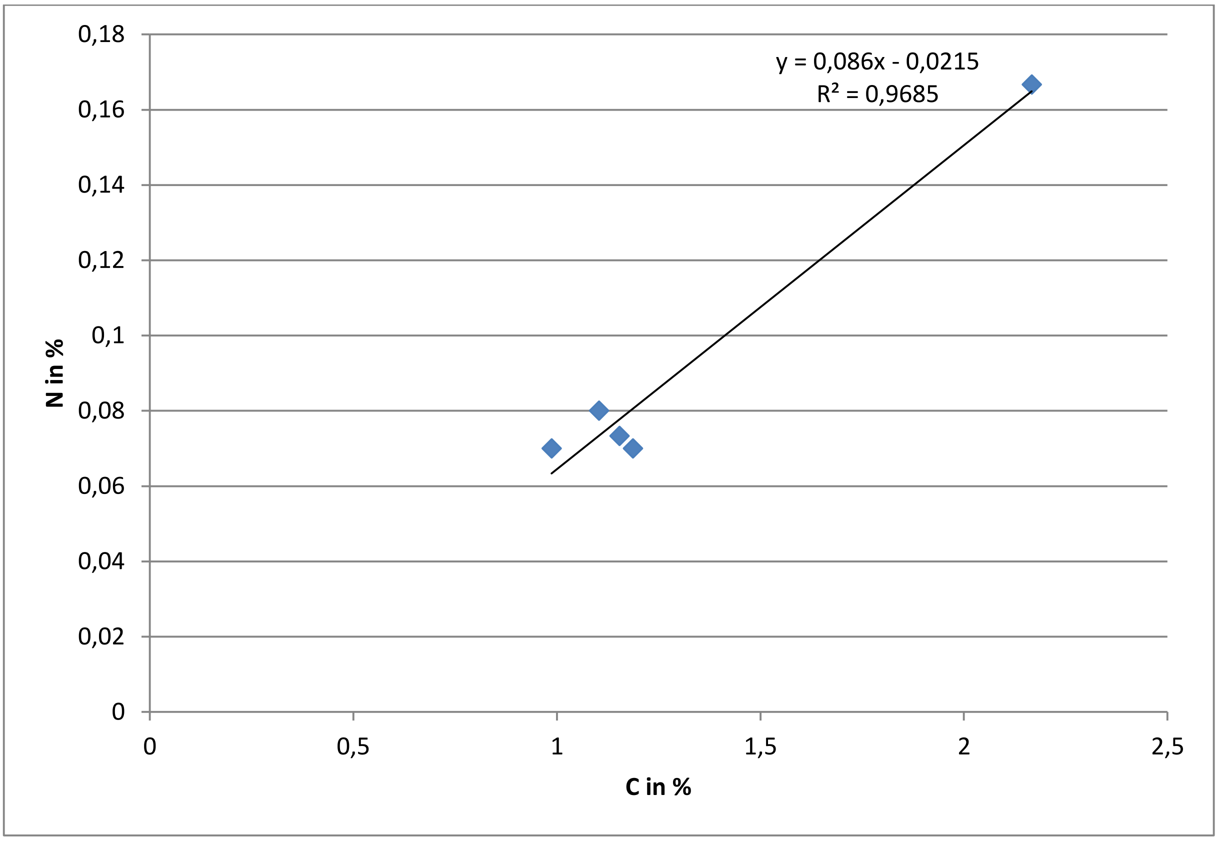


*Figure 9 C:N Correlation in soil samples from different management of field and grassland measured by Dumas dry combustion.*

## 3.8 Dry bulk density

Table 2 is showing the calculated dry bulk density with the equation _ and the average.

*Table 2 Measured dry bulk density and calculated average*

| Sample | Bulk density | Bulk density average |
|---|---|---|
| N0 | 1,61 | |
| N0 | 1,54 | 1,57 |
| N 120 | 1,44 | |
| N120 | 1,34 | 1,39 |
| N 120 organic | 1,43 | |
| N120 organic | 1,54 | 1,48 |

The average was used to create the graph in Figure 10. In Figure 10 the dry bulk density depending on land use and fertilization is shown. The difference between the maximum at N0 and minimum at N 120 is 0.18 g $cm^{-3}$.

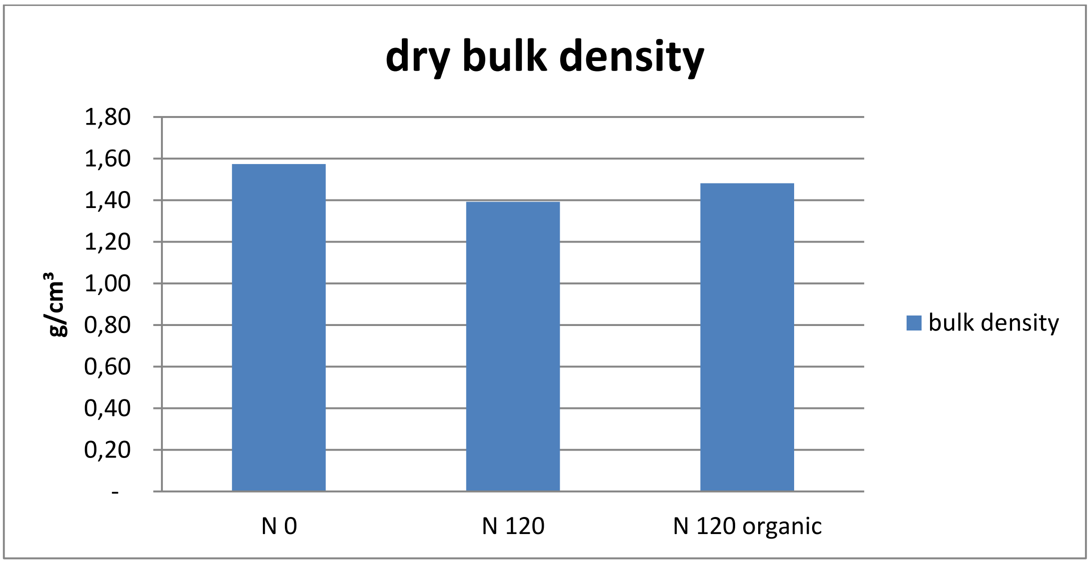


*Figure 10 Measured dry bulk density depending on land use and fertilization*

## 3.9 Calculated soil carbon stock

Because of the little amount of values, the bulk density was calculated with a formula which is shown in the material and method part. The grassland too, because then the different values can be compared.

The calculated average of the soil organic carbon stock depending on land use and fertilization is shown in Figure 11. The soil organic carbon stock is indicated in t $h^{-1}$. There is more carbon stock in the grassland and less in the agricultural fields. Between the agricultural fields is no mentionable difference of the soil organic carbon stock.

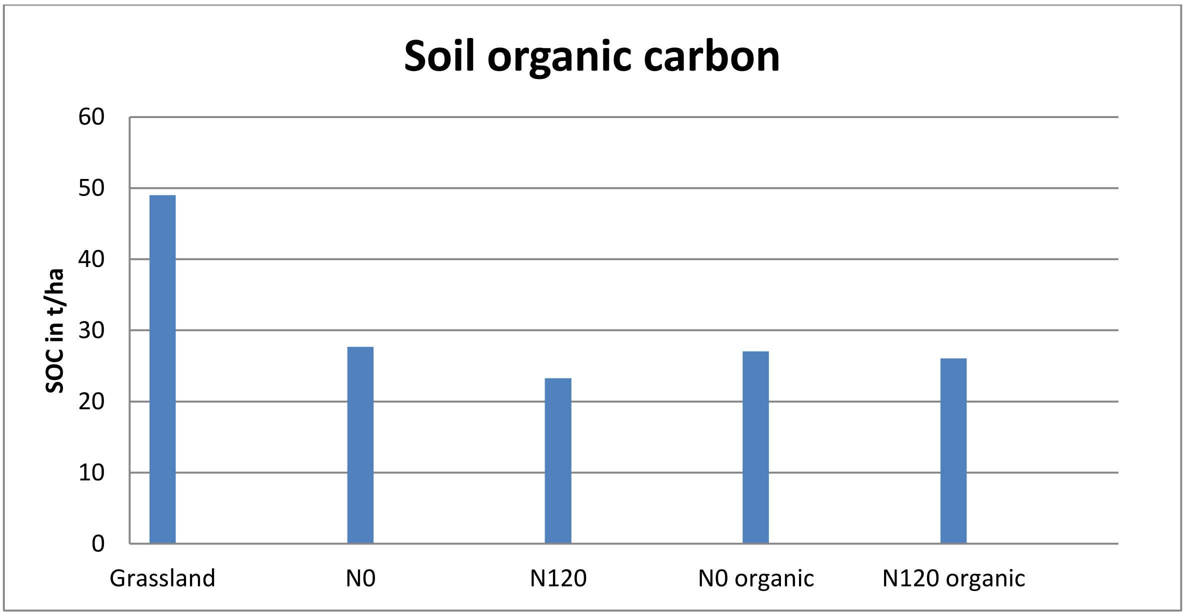


*Figure 11 Calculated soil carbon stock depending on land use and fertilization*

## 3.10 Correlation matrix

The correlation matrix shows strong correlation between all measurements connected to soil carbon. There is quite strong correlation between carbon and nitrogen and also between nitrogen and phosphorus. There is quite strong correlation between phosphorus available and pH too (Tab. 3).

*Table 3 Correlation matrix of all collected data*

| | *P, mg/kg* | *Mg, mg/kg* | *K, mg/kg* | *Ca, mg/kg* | *N%* |
|---|---|---|---|---|---|
| P, mg/kg | 1,00 | | | | |
| Mg, mg/kg | 0,22 | 1,00 | | | |
| K, mg/kg | -0,56 | 0,25 | 1,00 | | |
| Ca, mg/kg | 0,47 | 0,86 | -0,05 | 1,00 | |
| N% | -0,69 | -0,08 | 0,90 | -0,38 | 1,00 |
| C% | -0,68 | 0,03 | 0,92 | -0,26 | 0,97 |
| pH | 0,56 | 0,59 | -0,54 | 0,75 | -0,73 |
| µS | 0,37 | -0,23 | -0,42 | -0,13 | -0,29 |
| % water content in soil sample | -0,52 | 0,05 | 0,17 | -0,07 | 0,19 |
| LOSS ON IGNITION | -0,75 | 0,11 | 0,92 | -0,16 | 0,90 |
| bulk density | 0,27 | 0,94 | 0,82 | 0,91 | 0,04 |

| | *C%* | *pH* | *µS* | *% water content in soil sample* | *LOSS ON IGNITION* | *bulk density* |
|---|---|---|---|---|---|---|
| P, mg/kg | | | | | | |
| Mg, mg/kg | | | | | | |
| K, mg/kg | | | | | | |
| Ca, mg/kg | | | | | | |
| N% | | | | | | |
| C% | 1,00 | | | | | |
| pH | -0,65 | 1,00 | | | | |
| µS | -0,35 | 0,11 | 1,00 | | | |
| % water content in soil sample | 0,25 | 0,13 | -0,48 | 1,00 | | |
| LOSS ON IGNITION | 0,95 | -0,60 | -0,47 | 0,31 | 1,00 | |
| bulk density | 0,88 | 0,93 | 0,51 | 0,00 | 0,70 | 1,00 |

# 4. Discussion

## 4.1 Soil texture by fingering test

The result of the soil texture was similar on the field as on the grassland because soil texture doesn’t change so quickly, thus no changes can be observed after 30 years of experimental agricultural use of this particular site. This result was expected and was described in the guideline of the experimental site (Astover Alar, Estonian University of Life Science, 2017).

## 4.2 Moisture content by air drying

The moisture of the soil according the numbers is quite low comparing to climate conditions in Estonia, where the precipitation is higher than evaporation. All the samples showed quite the same humidity and didn’t show any significant difference between various management types. The lowest humidity value shows unrealistic result and was probably caused by typing error.

## 4.3 Soil $pH_{KCl}$

There are differences between the pH of the grassland and the pH of the fields. The moderate acid pH of the grassland is as expected because of the natural process of acidification and no presence of carbonates in the soil. The pH of the field-samples is higher because of the liming made in year 2000 on the field. If there are no fertilizers added as in the Plot N0 there is no anthropogenic influence on the pH. The higher amount of mineral fertilizers in N120 causes a lower pH than the N0, because the bacteria oxidase the ammonium and they release hydrogen-ion during this process. Organic fertilizers contain calcium and magnesium which neutralizes the pH because they improve soil buffering-capacity. This also could be a reason for the higher pH than in the grassland.

## 4.4 Soil electrical conductivity/salinity

The general trend shown in Figure 3 is that the more fertilizer is used, the higher is the soil electrical conductivity of our samples. That is totally what was expected because when there are some mineral fertilizers added, ions responsible for electrical conductivity are added the same time. The N0 organic sample doesn’t fit in the trend because the soil electrical conductivity is lower than the N0 without any fertilizer used. The high standard deviation of N0 organic shows that the measured result is not very representative. Also the outer standard deviations are high, because of the fluctuations of the values shown by the instrument while measuring.

## 4.5 P, K, Ca, Mg by Mehlich-3 method

The phosphorus concentration is quite high in all arable soils, because it has been fertilized with phosphorus 20 years ago, so an amount can still be found.

As the phosphorus assimilation benefits by the mutualism with mycorrhiza, a lower amount of phosphorus in soil could be expected for grasslands. This might due to a higher density of intact root systems in grassland, so more phosphorus is taken out by the plants. Moreover, the grasslands haven´t been fertilized, why the phosphorus source in the soil decreases over the years. Phosphorus is an important primary macronutrient for plants to build the DNA and to guarantee the membrane development and function. For that reason, fertilization is essential to assure a good yield.

The higher amount of potassium in grassland can be explained by the absent harvest. Thus, there has been no potassium taken out of the grassland over the years. In contrast to that, on the fertilized crops the potatoes have a high demand of potassium, which is taken out more and more by every harvest.

In acidic conditions phosphorus is more available in a free mineral form, thus it can be used by microorganism. When the pH is to low ore to high, phosphorus is fixed for example with iron as a complex, for which reason it is not available any more.

## 4.6 Loss on ignition (LOI)

The highest loss on ignition measured in grassland soil sample shows the highest amount of soil organic matter. The management of mowing only enables soil organic carbon to accumulate in the upper soil layers. Although the other results differences are slightly insignificant, the lowest carbon content should be observed in the nitrogen only fertilized fields because nitrogen addition increase decomposition by saturating the decomposers' need for nitrogen. The organic only fertilized field shows relatively high loss on ignition because organic manure contents high amount of organic carbon which can be quite stable in the soil.

## 4.7 C:N by dry combustion

The strong correlation between C and N amount shows that nitrogen in soil is mainly bound in organic particles.

## 4.8 Dry bulk density

The values are between 1.39 g $cm^{-3}$ and 1.57 g $cm^{-3}$ which is typically, because the density of mineral soils commonly ranges from 1.1 to 1.5 g $cm^{-3}$ in surface horizons [1]. The little deviations can come from samples, which were taken with compaction or crumbling.

The difference between the maximum and minimum from the fields with 0.18 g $cm^{-3}$ is very low. The reason for this is that the used samples are from the same field with the same soil. It's no surprise because the soil changes slowly in the landscape. Maybe there would be a difference when grassland samples are compared. In fact of this, in the grassland should be more carbon than in the other samples.

## 4.9 Calculated soil carbon stock

There is less soil organic carbon stock in the agricultural fields because plants are taking carbon from the atmospheric $CO_2$. The SOC in the grassland is much higher because there are no plants which use a high amount of carbon from the atmospheric $CO_2$ In fact of this the amount of carbon in the soil is higher.  Between the different agricultural fields isn't a significant difference. It doesn't matter which fertilization, the organic carbon left in the soil is always quite the same.

## 4.10 Correlation matrix

The correlation between organic carbon related measurements (loss on ignition, carbon by dry combustion, bulk density, calculated bulk density, total carbon stock) is obvious. The correlation between C:N:P shows that the main source of active N and P in soil is the soil organic matter which contains all these elements.

The correlation between pH and Phosphorus shows that soil phosphorus is available in very pH neutral conditions only because too high (to low) pH cause binding of P into unsolvable complexes. This is why in grassland (where pH is low) the P available is low too.

## 4.11 Comparison

The results of this study are comparable with the results of other analyses on the effect of mineral and organic fertilization on soil. Körschens et al. [2] compared the results of 20 European long-term experiments concerning the impact of fertilization on crop yield, carbon balance, soil organic carbon content and dynamics. In Figure 12, their work is compared to the work at hand. The figure demonstrates the effect of fertilization and clay content on the soil organic carbon content for 18 European long-term experiments and the results for Tartu. From the left to the right side, the clay content of the sites is increasing. The lighter part of the columns shows the soil organic carbon content without fertilization and the darker part shows the content with organic (10 t/ha FYM) and mineral (NPK) fertilization. The results concerning the clay content and the carbon content for Tartu are added in red. The red frame contains the range of the clay content for Tartu according to the fingering test.

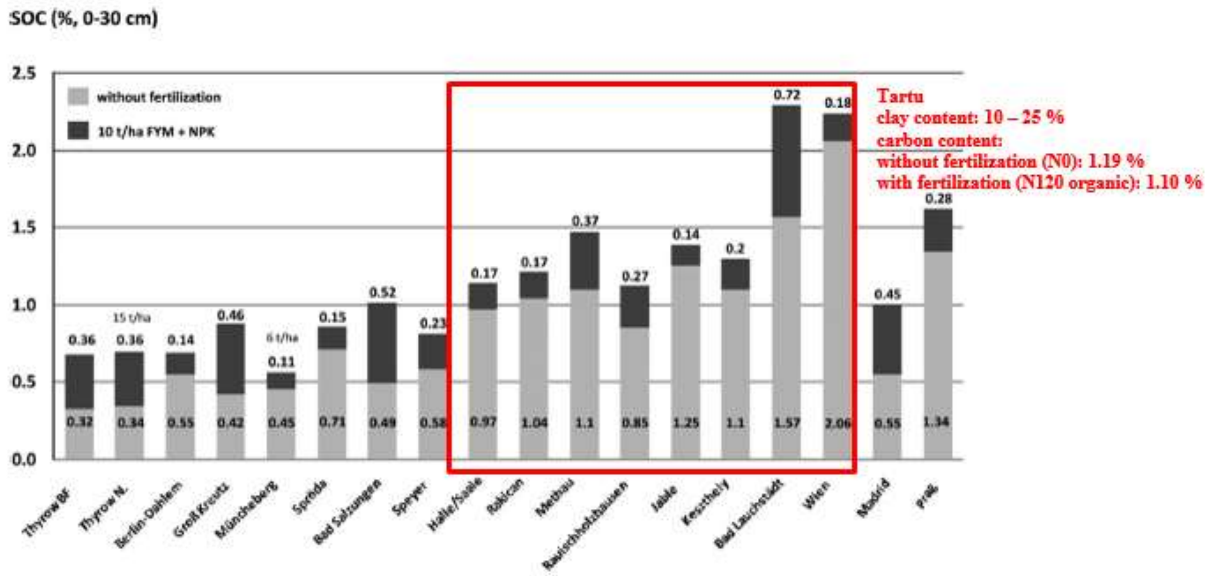


Figure 2. Effect of fertilization on soil organic carbon (SOC) contents in the top soil (0–30 cm) of 18 European long-term experiments – results from the first decade of the twenty-first century. Order of sites corresponding to increasing soil clay content, compare with Table 1.

*Figure 12: Comparison of our measurements with the result of Körschens et al. [1]*

For Tartu, we measured a clay content of 10-25 %. In comparison, Speyer has a clay content of 9 % and Wien a clay content of 25 % [2]. For the treatment without fertilization, Tartu got a result of 1.19 % of carbon, Speyer 0.58 % and Wien 2.06 % of SOC. So the result of Tartu lies in between the results of Speyer and Wien, what is consistent with the expectations. The result for the treatment with mineral and organic fertilizer for Tartu was 1.10 % whereas the result for Speyer was 0.81 % and for Wien 2.24 % SOC. Again, the value of Tartu lies in between the values of Speyer and Wien. However, according to [2], for Speyer and Wien, the carbon content for the treatment with fertilization was higher than for the treatment without fertilization while for Tartu, it was the other way round. To summarize, the values for Tartu are in accordance with the results by Körschens et al. even if the fact that for Tartu the carbon content decreased while using organic and mineral fertilizer is surprising.

# 5. Sources

[1] Thien and Graveel, Laboratory Manual for Soil Science

[2] Martin Körschens et al. (2012) Effect of mineral and organic fertilization on crop yield, nitrogen uptake, carbon and nitrogen balances, as well as soil organic carbon content and dynamics: results from 20 European long-term field experiments of the twenty-first century. Archives of Agronomy and Soil Science, 59:8, 1017-1040