COMPARISON OF THE QUALITY OF RECLAIMED AND NON-RECLAIMED SOIL

WITH EMPHASIS ON THE RECLAMATION OF SOIL QUALITY BY COMPOSTING

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1. ABSTRACT

In this Matura paper the comparison and quality of reclaimed and non-reclaimed soil is discussed. The quality of these soils was compared to each other and to the soil parameters of commercially available potting soil and sand to establish reference values. The reclaimed and non-reclaimed soil samples were sourced from the grounds of the Kantonschule Zug. The process of reclaiming and improving the quality of the soil at the Kantonsschule Zug had been performed by the gardener Mathias Meienberg over the past two years, mainly by adding compost to the soil.

A visual inspection of the areas the samples were extracted from already revealed marked differences between reclaimed and non-reclaimed soil. The reclaimed soil displayed a crumbly soil structure and flourishing flora, while the non-reclaimed soil had a compact and hard texture and reduced vegetation.

The question was now posed as to whether these significant differences were also confirmed by testing certain soil parameters in the laboratory. To address this question, different soil parameters were measured, hoping to obtain consistent results. The parameters investigated included the pH level, the water capacity, the cation-exchange-capacity (CEC), the lime content, the content levels of different ions and the content of organic nitrogen.

The results showed that the reclaimed soil had better values in all aspects when compared to the non-reclaimed soil. The pH value of the reclaimed soil was found to be 7.5-8, which is slightly too alkaline for optimal growth of most plants. The pH of the non-reclaimed soil was 5, which is too acidic for a fertile soil. The water capacity, CEC and lime content all yielded better values for the reclaimed soil when compared to non-reclaimed soil. All the results can be traced back to the incorporation over time of organic matter, and this is also a key reason as to why the reclaimed soil delivered better results than the non-reclaimed soil.

2. INTRODUCTION

2.1 GOAL

With the results of all six experiments it is hoped to show that using compost to improve the soil not only benefits the cultivation of plants but also shows a long-lasting improvement of soil matter. It is expected that the reclaimed soil has better values in all aspects compared to the non-reclaimed soil. However, the non-reclaimed soil should still result in higher and qualitatively better values than the sand, which was used as a control value. It should be possible to confirm that the reason that the reclaimed soil is more beneficial to the growing of plants than the non-reclaimed soil is due to the high amount of organic matter introduced into the soil through the composting process.

If there are any values that aren't yet close to the optimal value for an ideal environment for plant growth and to serve as a beneficial habitat for organisms, improvements should be proposed to improve the soil quality.

2.2 THEORETICAL BACKGROUND

2.2.1 Positive aspects of composting

Healthy and nutritious soil is vital for the cultivation of different plant species. Nowadays, processed organic fertilizers are used to introduce nitrogen and phosphorus back into the soil. (Cruz, 1997) But using compost as an alternative has several benefits, such as the preservation of most of the nitrogen (70-85 %) through organic binding thereby preventing leaching of the nutrients introduced. The increase of important humic substances that revitalize and stabilize the soil and improve the water absorbency and water storage capacity are also beneficial. Compost also enriches the soil and it helps to improve the soil's ability to absorb the nutrients that are delivered. This nutrient retention is improved by increasing the soil's

cation exchange capacity (CEC), which enables the soil to provide important food for the plants. Examples of such nutrients are nitrogen, phosphorus and potassium. (*Compost - Promotes healthier Plant Growth*, no date)

2.2.2 How to compost

Compost is not only highly effective, but it is also economical. Widely available materials can be used to fertilize soil including some that are disposed of as waste by consumers. Such materials include: Fresh green grass clippings, hedge trimmings, leaf litter, fruit and vegetable scraps, food leftovers including meat and bones, coffee grounds, saw dust and wood ashes (as long as the amount does not comprise more than 10 % of the total content) and even organic textiles like jute, flax, linen and cotton. In simple words, there is no organic waste that cannot be composted - it just depends on the right balance ensuring that not too much of a single raw material is used. (Dunst, 2015)

2.2.3 Breakdown process of organic substances

2.2.3.1 Die-off phase

Enzymes of organic matter such as dead animals or browning leaves start the process of hydrolytic decomposition and oxidation of polymer substances. (Walthert et al., 2004)

2.2.3.2 Washout phase

Rainfall starts to wash out water soluble substances like sugars, amino acids and fatty acids from the decomposing matter. These substances provide a good energy and food source for microorganisms, which experience a rapid increase in population. (Walthert et al., 2004)

2.2.3.3 Size reduction phase

The organic matter reduces with the help of primary decomposers (representatives of the macro- and mesofauna). These particles are mixed with the rest of the soil by worms and other organisms. The excreted faeces will be further processed by secondary decomposers

(springtails, mites and more). On the then secreted faecal particles, colonies of different fungi start to form. (Walthert et al., 2004)

2.2.3.4 Microbial phase

The digested particles can now be processed with the help of enzymes in bacteria and fungi. A part of the organic matter mineralizes to the inorganic end products and the rest converts to humus, which are newly formed organic compounds, in a process known as humification. (Walthert et al., 2004)

2.2.4 Humus

Nutritious humus can be broken down into the component nutrients by a separate group of microbes which live in the hair root area of the plant. These nutrients are then available for the plants to absorb. The organisms and plant live in a symbiosis. This means that the organisms exchange the nutrients the plant needs, which are released from the nutrient humus or mineral soil, with carbohydrates provided by the plant, which are used as an energy source by the microorganisms.

The nutrients released during this process are Nitrate-ions (NO_3^-), potassium-ions (P_2O_2), calcium- and magnesium-ions (Ca^{2+} and Mg^{2+}). (Dunst, 2019) Humus is also known as humified organic matter and consists of fulvic acids, humic acids and humin. In early stages of humus development, fulvic acids are produced. The concentration of humic and fulvic acids vary from soil to soil with forest soils having a high amount of fulvic acids and grasslands and agricultural areas containing a higher amount of humic acids. (A. Bot, J. Benites, 2005)

Humus is the central element in the prevention of nutrient loss. Therefore composting can improve humus content and thus be important for a healthy and functioning soil.

Humus is not only important for delivering and storing nutrients for plants, but it also gives soils it’s structure and stabilization. (Dunst, 2019)

2.2.5 Soil components

Soils are a conversion product of mineral and organic substances. The soils are porous systems containing a specific composition of water and air. (Walthert et al., 2004)

2.2.6 Nutrient absorption by plant roots

The roots of plants don't grow towards nutrients, therefore the nutrients must be transported to the plants. In a first step the nutrients must get close to the root's surface before they can be absorbed. The most effective way of doing so is by leaf transpiration. Water is transpired from the leaves which creates a suction at the root surface, thereby attracting the nutritious surface soil solution. 98 % of plant nutrients are moved by this process through the soil to the root membrane, which makes it very effective. When a nutrient dense source enters the soil, such as fertilizer or compost, the nutrients disperse over time creating a more entropically favorable environment. One way of transporting metal ions (iron, manganese, copper, zinc, cobalt and nickel) is with the help of chelate ligands. These chelates can transport nutrients by forming a chelate complex. This chelate complex can then move towards the roots as part of the nutrient movement in water. (Ruehr, no date)

The roots can now take up the nutrients available to them. There is a higher nutrient-ion level inside the root and a lower concentration outside, which makes it energetically unfavorable to diffuse more ions into the root. That is why adenosine triphosphate (ATP) must be used in order to make the process possible. How the process exactly functions is still not clear to scientists. (Ruehr, no date)

2.2.7 Leaching of soil nutrients

Leaching is a process that results in nutrient loss due to rainfall. The water passes through the soil and by doing so it interacts with the materials contained in the ground. These materials such as minerals and ions dissolve in the passing water and move to deeper depths of the soil. Leaching can also be responsible for the transport of materials such as plant materials, fine rocks and microorganisms. (Richardson, 2016)

The process of leaching can be beneficial. Without leaching there would be salt accumulation in the top parts of the soil, which wouldn't be distributed properly, and this could negatively impact plant growth.

However, by flushing out vital nutrients such as nitrate, the soil's pH can drop significantly and become over-acidic. This results in negative effects on plant growth (the root systems become poorly developed) and organisms that live in the soil. Excessive leaching can also lead to groundwater contamination. When nitrate seeps into the groundwater that communities then drink, it can result in serious health hazards. The human body will convert nitrate to nitrite, this then bonds with hemoglobin and results in breathing difficulties due to limited oxygen distribution. Also, pesticides can be leached from the soils into the groundwater, resulting in many health consequences, such as birth defects and cancer. (Dontigney, 2018)

2.3 SOIL IMPROVEMENT AT THE KANTONSSCHULE ZUG

The soil of the school was reclaimed in two phases.

In the first phase, the entire area was first refreshed with compost. This increased the activity of soil organisms. In the spring, when temperatures were ideal, a first surface rototilling was done with grass cuttings.

Small amounts of algae lime and rock flour were incorporated into the soil as revitalizing agents. This prevents the pH from dropping too much.

In the second phase (after about one year), the non-vegetated areas were landscaped. Other surface rotations, together with some compost and coffee grounds were lightly worked in.

After these two phases only alternate mulching and incorporation of mixed organic material (lawn clippings and a small amount of wood

chips) was applied. Coffee grounds from the canteen were also regularly spread over the soil throughout the entire period.

2.4 OBJECTIVES OF THIS PAPER

The hypotheses of this work are that the reclaimed soil is better suited to storing water and exchanging cations. It is also the goal to prove that the lime and the organic nitrogen content is higher compared to the non-reclaimed soil. This should all be attributed to the amount of organic matter introduced into the soil. Due to the lack of fertilizer (here compost), the unprocessed soil has a much lower organic content than that of the processed soil.

3. MATERIALS AND METHODS

In this chapter, the procedures for the different experiments will be detailed. The samples included two soil samples from the grounds of the Kantonsschule Zug, and in addition one sample of purchased garden soil (Coop, oecoplan®, Blühpflanzen- und Balkonerde) and sand (Coop, Qualité & Prix, Spielsand). A total of six experiments were performed to find out more about the chemical components of different soils (reclaimed soil, non-reclaimed soil, potting soil and sand). Both soil samples from the Kantonsschule Zug came from garden areas planted with small woody plants. One of the soils had not been worked for years, the other one had been systematically improved by the gardener of the Kantonsschule Zug, Matthias Meienberg, for two years.

3.1 SOIL EXTRACTION

The soil was extracted from two sites on the property of the Kantonsschule Zug (as seen in figure 1). One sample was previously treated with compost and no measures to improve the soil had been carried out on the other soil sample for at least two years.
The exact locations of the extractions are marked on the map in orange. Number 1 is the spot of the reclaimed soil, and number 2 is the spot of the non-reclaimed soil.

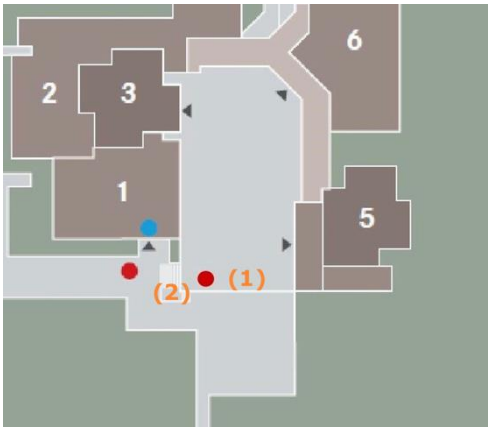


Fig. 1 Extraction spots of soil samples used in the experiments marked as 1 and 2.
source: zg.ch

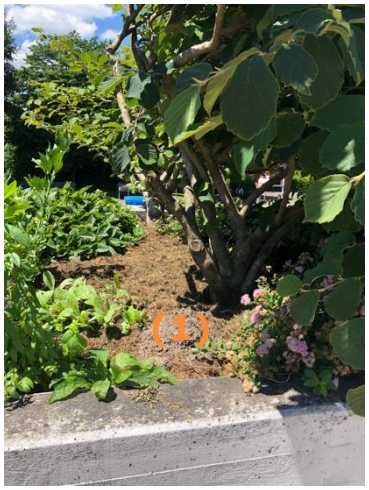


Fig. 2 Extraction place of reclaimed soil

Fig. 3 Extraction place of non-reclaimed soil

Materials:

- Spade
- 2 Buckets

Method:

1. From each soil site, one spade sample with a volume of about 15 cm^3 was taken.
2. The spade was pushed into the ground as deep as possible, resulting in approximately 10-15 cm deep soil samples.
3. For a first analysis of the stratification of the soil, the form of the samples was kept intact.
4. After the soils were analyzed, they were put into the buckets for transportation. The samples were then dried and thoroughly mixed.

3.2 PH-LEVEL

Materials:

- PEHAMETER (Model Hellige)
- Teaspoon

Method:

1. 1 teaspoon of soil sample was put into the divot of the PEHAMETER tray.
2. The soil indicator was added until the soil was fully saturated.
3. The solution was stirred with the spoon and left to rest for 2-3 minutes.
4. Then the tray was pivoted so that the solution could flow through the column and the pH value was read from the color chart.

3.3 WATER CAPACITY

Materials:

- 300 g fresh soil samples
- Crystallizing dish 140 mm
- THERMOCENTER Salvis Lab

Method:

1. The TARE weight of all the crystallizing dishes was written down
2. Soil was put into the crystallizing dish
3. The crystallizing dish was weighed again with the contents
4. The samples were put into the dryer (thermocenter Salvis Lab) at 110 degrees Celsius.
5. The samples were left in dryer over night
6. The samples were weighed and put back into dryer for another 2-5 hours.
7. The samples were weighed again. Those samples where the mass had decreased less than 0.1 g since the previous measurement were considered to be essentially water-free. Other samples were dried for additional 6 hours.
8. The final weight of the samples was written down and compared to the starting weight

3.4 CATION EXCHANGE CAPACITY (CEC)

The cation exchange capacity (CEC) was executed according to an adapted protocol from (Leisinger, 2016 (2)) Experiment 14 (p.15)

Materials: (for 8 samples)

Preparation of samples

- Centrifuge and matching 15 mL centrifuge tubes
- 360 mL $CaCl_2$ solution 1 mol/L
- 360 mL ammonium acetate solution 1 mol/L, pH 7.0
- 360 mL Isopropyl alcohol
- Socorex 10 mL
- 8 volumetric flasks 50 mL

Complexometric titration

- 1 L EDTA standard solution (0.01 M)
  (Fluka EDTA disodium salt dihydrate (372.24 g/mol))
- Buffer solution pH 10.0:
  100 mL 0.2 M ammonium chloride solution is adjusted to pH=10.0 with approx. 15 mL sodium hydroxide solution (1 M)
- Concentrated sodium hydroxide solution
- Dropper pipettes
- Saltshaker containing sodium chloride mixed with a small amount of the metal ion indicator Erio-T
- Magnesium-Titriplex®-Dihydrate (or Magnesium-Complexonate®) with micropolyspoon onto paper napkin
- 50 ml burette with stand
- Magnetic stirrer and magnetic stir bar (suitable for 100 mL beaker)

Method:

Saturation with calcium ions

1. 2.5 g of dried fine soil was weighed into a centrifuge tube. The tube must be large enough for an additional 15 mL of solution.

2. The sample was mixed with 15 mL 1M CaCl2 and shaken for 15 min.
3. Then the solution was centrifuged, the clear supernatant was discarded.
4. Steps 2-3 were performed two more times (total of 3 times).

Washing out the calcium solution

5. The saturated soil material was mixed with 15 mL isopropyl alcohol and shaken for 3 minutes.
6. The suspension was then centrifuged, and the supernatant discarded.
7. Steps 5-6 were performed two more times (total of 3 times).

Extraction of the calcium ions

8. The sample was mixed with 15 mL ammonium acetate (NH_4CH_3COO) (1 M, pH 7.0), shaken for 15 min and centrifuged. The supernatant is collected in a 50 mL volumetric flask.
9. Step 8 was repeated 2 more times (total of 3 times), collecting the supernatant in the same volumetric flask each time.
10. The 50 mL volumetric flask with the supernatant (should be as clear as possible) was filled up to the mark with the ammonium acetate solution. (Seen in figure 4)

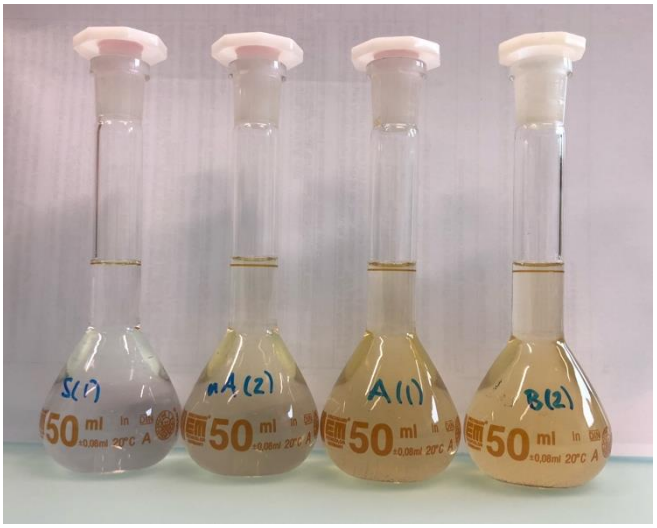


Fig. 4 Final solutions in the volumetric flasks after the process of extracting the calcium ions. Four of the total eight solutions are shown.

Complexometric determination of calcium ions

1. Exactly 10 mL soil solution (corresponding to 0.5 g soil) was transferred to a 100 mL beaker.
2. 5 mL of the prepared pH 10 buffer solution was added to the sample solution using a Socorex pipette. The pH was measured with pH paper and concentrated sodium hydroxide solution was added drop by drop until the pH was around 10 (it must be closer to 10 than 9).
3. Since the sample contains little or no magnesium ions, half a micropolyspoon of magnesium Titriplex® dihydrate was added to the sample solution.
4. The table salt/Erio-T mixture was scattered 1-2 times onto the sample solution until it had a purple coloration with medium color intensity. If the color would have been too weak, the color change would not be clearly visible!
5. The magnetic stirrer was set to medium speed
6. The titration was started with a dropping speed of at most 2 drops per second up to the first appearance of a clear blue tint as seen in figure 5.
7. The amount of EDTA solution needed to capture the calcium ions was written down.

8. If the equivalence point on the drop had been determined exactly, then the titration is complete. Otherwise, the titration would be repeated (main titration), whereby the last mL is titrated particularly slowly and carefully.

Fig. 5 Colour change of the Erio-T indicator from light pink to blue in the process of titrating

3.5 LIME CONTENT

The cation exchange capacity (CEC) was executed according to an adapted protocol from (Leisinger, 2016 (2)) Experiment 15 (p.16)

Materials: (for 8 samples)

- HCl 2 M (Titrisol) with 20 mL full pipet on paper towel
- NaOH 0.1 M (Titrisol!)
- Phenolphthalein in dropper bottle
- Hotplate for heating samples
- Mortar and pestle
- Full pipet 10 mL
- Pipetting aid
- Folded filter paper fitting in funnel
- 8 Erlenmeyer flasks, narrow-necked, 2015 mL
- Mounted 50 mL burette
- 100 mL beaker
- 8 Volumetric flasks
- Funnel

- Magnetic stirrer, stirring magnet

Method:

Preparation of samples

1. About 50 g of dry soil was finely ground with pestle in a mortar
2. Exactly 10.00 g per sample (two samples per kind of soil) were weighed into a narrow-necked Erlenmeyer (250 mL)
3. 20 mL hydrochloric acid (2.0 M, Titrisol) was added using a full pipet
4. The lime was able to react with the acid until no visible foaming occurs
5. The sample was then slightly heated on a hotplate for about 5 min and shaken regularly. Never to be heated to a boiling point, otherwise HCl would escape, and the titration would be inaccurate!
6. After a short cooling, the sample was filtered quantitatively through a funnel and filter paper into a volumetric flask 100 mL (quantitative: all dissolved substances must be transferred to the Erlenmeyer)
7. The volumetric flask 100 mL was filled up to the mark with deionized water and homogenized. (Seen in figure 6)

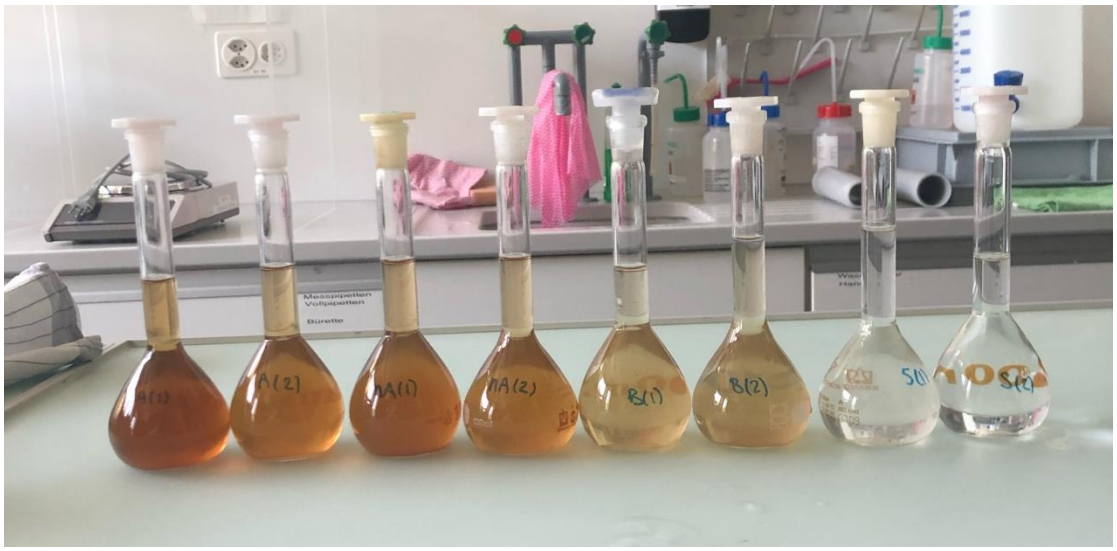


Fig. 6 Prepared solutions in the volumetric flasks after the process of saturating the soil with HCl.

Titration

1. 10 mL of the sample solution (corresponding to 1 g soil) was transferred into a 100 mL beaker using a full pipet
2. About 50 mL of deionized water and 4 drops of phenolphthalein solution were added to the beaker
3. Sodium hydroxide solution with a concentration of 0.1 M (Titrisol!) was then titrated until the color change was visible
4. Before titrating, the outlet tap had to be filled completely with titrant and the amount of titrant used was noted after completing the titration

Pre-titration: Titrant is allowed to run quickly into the sample until the pink color slowly disappears, then a drop rate of approx. 1 drop per second is set until the color fully changes. (As seen in figure 7)

Main titration: Rapid addition of 1-2 mL less titrant than used for the pre-titration. Then titrant is added drop by drop, slowly up to the equivalence point.

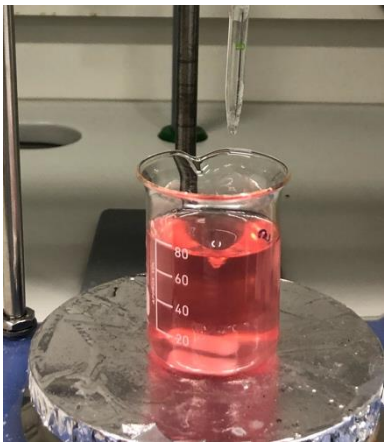


Fig. 7 Colour change of the phenolphthalein indicator to a salmon colour in the process of titrating

3.6 QUICK TESTS DETERMENING DIFFERENT ION-CONCENTRATIONS

Materials:

- Centrifuge and matching 50 mL tubes
- 15 g of dried soil samples
- Quantofix® Nitrite test kit
- Quantofix® Nitrate/Nitrite test kit
- Quantofix® Total iron test kit
- Quantofix® Ammonium test kit
- Quantofix® Kalium/Potassium test kit
- Quantofix® Sulfates test kit
- MERCK® Sulfide test kit

- PASCO® Phosphate test kit
- PASCO® Nitrate test kit
- PASCO® Water Quality Colorimeter and SPARKvue® software

Method:

1. 15 g of dried fine soil were weighed into a centrifuge tube.
2. The tubes were filled up with 45 mL of water (if the tubes are too small, the soil and water should be divided into two batches)
3. The tubes were shaken for 30 min
4. The samples were then centrifuged for 3 min
5. The tests were conducted according to the instruction manual in the test kits
6. The PASCO® phosphate and nitrate test kits were analyzed using the PASCO® Water Quality Colorimeter for measuring and the SPARKvue® software for collecting the data.

3.7 CONTENT OF ORGANIC NITROGEN

The cation exchange capacity (CEC) was executed according to an adapted protocol from (Leisinger, 2016 (1)) Experiment 15 (p.16)

Materials: (for 1 sample, with requirement for 4 samples)

Decomposition

- Kjeldahl tablets with tweezers
- In fume hood: 100 mL Florence flask (heat-resistant, round bottom) with added boiling stones, on stand with suitable heating mantle. A dimroth condenser is attached to the digestion flask (see figure 8).
- In the fume hood: Graduated cylinder and full pipet for measuring the 10 mL of sulfuric acid 98 %
- Volumetric flask 100 mL with funnel (for storing the sample).

Fig. 8 Set up of the heating/cooling mechanism for the decomposition

Steam distillation and titration

- Boric acid solution: 20 g of boric acid (H_3BO_3) was dissolved in in 1 L of water.
- Mixed indicator: 0.1 g methyl red and 0.2 g bromcresol green was dissolved in 250 mL ethanol.
- Sodium hydroxide solution: 33% w/w (100 g NaOH dissolved in 200 mL water) with 20 mL graduated cylinder.
- Hydrochloric acid 0.01 M Titrisol with funnel
- In the fume hood: distillation apparatus with Liebig cooler, Florence flask, two-necked distilling flask, separatory funnel and a thermometer is installed (see figure 9). Enough pumice stones in the Florence flask. The separatory funnel should have a closed tap. The outlets of the cooler have rubber tubing as extension.
- Cotton and aluminum foil for isolation
- 17 mL sodium hydroxide 33% in beaker
- Volumetric flask 200 mL (to dilute distillate to 200 mL).
- Full pipet 50 mL with pipetting aid (for measuring the samples for the steam distillation)
- Full pipet 100 mL (for measuring the sample for titration).
- Burette 50 mL on stand, magnetic stirrer and stirring magnet

- Beaker 200 mL (for titration).
- Magnetic rod for removing the stirring magnets

Fig. 9 Set up of the steam distillation process

Methods:

1. 1 g of dry matter was accurately weighed into a 100mL Kjeldahl or digestion flask. The flask was labeled on the neck (lettering on the flask would be burned in at the high temperatures).
2. Then some boiling stones and a Kieldahl tablet were added.
3. 4 mL of water was added to dry samples and the flask is swirled so that the sample is well moistened.
4. 10 mL of concentrated (98%) sulfuric acid is carefully added, the fume hood must be closed, and heating process was started on the highest setting (heating block to 380°C). When the sample froths too much, the heat was temporarily reduced to avoid boiling over. When the extract has turned white and no more charred particles can be seen, the cooking was continued for another hour. At the end, the solution turned green and clear and hardly boiled anymore. The digestion took about 1.5 hour.

5. The sample was then cooled by letting it rest. Caution was taken as in an uncooled sample the water can cause an explosion.
6. 20 mL of water was added (while exhibiting caution due to the danger of explosion), the sample was left to stand for 30 seconds so that all particles can settle and was then transferred using a funnel into a 100 mL volumetric flask and diluted to 100 mL with deionized water. The sulfuric acid would now have a concentration of 10% or 1.87 mol/L.
7. The steam distillation apparatus was set up. To prevent delays in boiling, a relatively large number of small boiling stones must be placed in the Florence flask.
   If distilled directly, you may get values that are too high, possibly because basic aerosols get into the cooler.
8. The end of the cooler was immersed as deeply as possible in a 100 mL beaker (tall shape) with 20 mL boric acid solution (2 %) and a few drops of mixed indicator was added
9. 50 mL of the entire sample was poured into the attached separatory funnel and transferred into the Florence flask. A few drops of universal indicator were put into the funnel, the funnel is washed with distilled water and that was also added to the flask
10. 17 mL sodium hydroxide solution was added in the same way. If the pH is not yet alkaline (solution colour must be a blue colour), a few mL of sodium hydroxide would be added again in the same way.
11. Heating mantle and Liebig cooler were put into operation (heating mantle: first at the highest level, as soon as it boils very strongly, back to the second highest). It was ensured that the water in the Florence flask is constantly boiling.
12. For better insulation, the Florence flask was wrapped with some cotton and aluminum foil.
13. Steam was introduced into the boric solution until the colour changed from red to green
14. The Erlenmeyer flask was removed, and the solution was saved for the titration. Then the connection between the

Florence flask and the distilling flask was severed and only after doing so the heating mantle and the Liebig cooler was turned off (in this order, otherwise, the distillate would be sucked into the solution in the distilling flask and then further into the Florence flask).

15. The distillate is transferred to a 200 mL volumetric flask (rinsed out, so that all the distillate is transferred) and filled with water to the mark.
16. 100mL of this distillate (corresponding to 0.25 g soil) was measured into a beaker 200 mL for the titration with a full pipet. This was mixed with a few drops of mixed indicator and titrated with 0.01 M HCl from green to colourless until the colour changes to light pink. (As seen in figure 10)
17. The titrant level was noted before and after each titration.

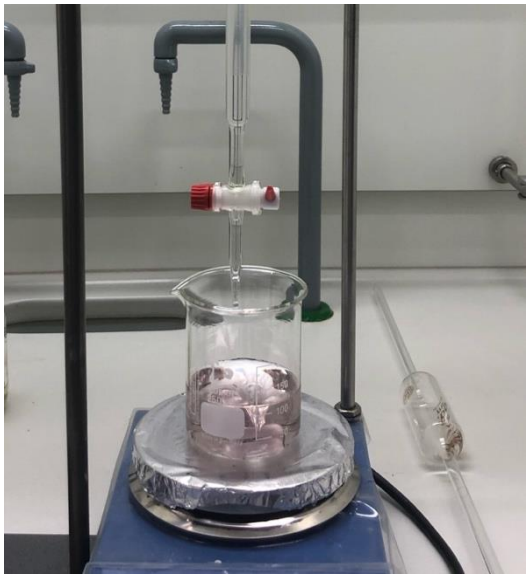


Fig. 10 Colour change of the mixed indicator from green to light pink during the titration.

4. RESULTS AND DISCUSSION

4.1 SOIL EXTRACTION

4.1.1 Results of soil extraction

After the soil was extracted with the spade method, the structure of both soils was clearly visible and could now be compared to each other.

Fig. 11 On the left: Reclaimed soil. On the right: non-reclaimed soil

The first striking difference (seen in figure 11) was the amount of soil that could be extracted which was much greater in the case of the reclaimed soil. More soil could be extracted because the reclaimed soil was less dense than the non-reclaimed soil. Also, the reclaimed soil had a much crumblier structure and a darker colour. A close inspection revealed that the roots in the non-reclaimed soil were much stringier and weaker than the ones in the reclaimed soil.

4.1.2 Discussion about extracted soil

The non-reclaimed soil proved to be much denser, and the reclaimed soil was much airier and crumblier. The reasons for those differences are that the reclaimed soil was loosened up by frequently adding compost to it. Another reason for an increased soil density is that when plant cover is reduced, the bare soil is less effectively protected,

leading to a compacting of the ground caused by rainfall. (Traunfeld, 2020)

Soils that are too dense are inhabited by fewer soil organisms, such as bugs, worms and plants that rework the soil into a better structure and increase aeration, meaning that not all the loosening and improving of the soil has to be done by humans. Such dense environments that are low in organic compounds are rather hostile to soil organisms, as it is harder for oxygen and water to penetrate the soil and less nutrients are available. Because density prevents water from permeating into the soil, it can be said that density and dryness go hand in hand when it comes to the quality of soil. (Anonymous, 2012) Compacted soil is also correlated to a weakening or loss of roots and higher acidity, which will be looked at more closely in the following chapter. (Traunfeld, 2020) The darker color of the reclaimed soil indicates a high organic matter content, while the lighter color of the non-reclaimed soil suggests it is a loamy soil.

4.2 PH-LEVEL OF THE SOILS

4.2.1 Results of measuring the ph-levels

The pH-level of the reclaimed soil is pH=7.5, the level of the non-reclaimed soil is pH=5.0. These values are approximations, as the test kits are not precise.

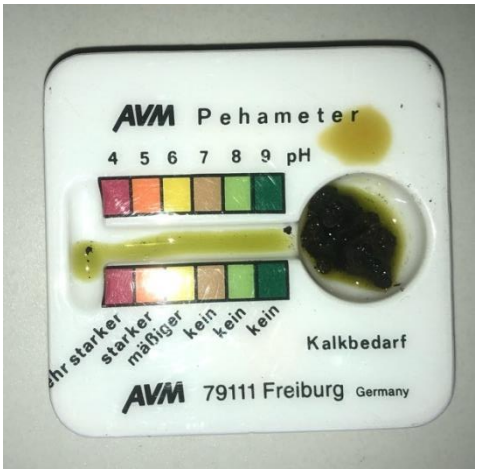


Fig. 12 pH-level of reclaimed soil

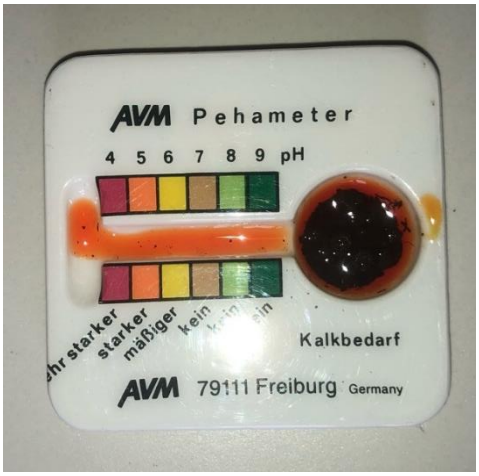


Fig. 13 pH-level of non-reclaimed soil

4.2.2 Discussion about the pH-levels

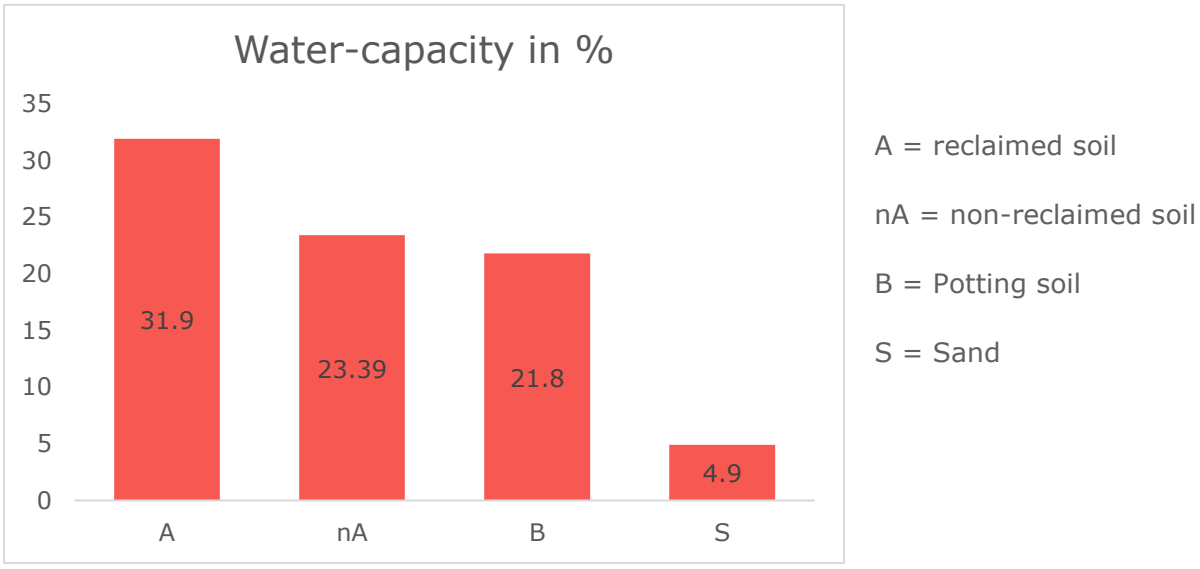
As stated in chapter 3.1.2, denser soil has a higher degree of acidity. A cause for this increased acidity is that high rainfall leads to leaching of the soil's basic elements such as calcium, magnesium, sodium and potassium. (Ball, no date) As a result of the loss of these alkaline cations, the soil gets increasingly more acidic. The non-reclaimed soil has a lower cation exchange capacity (as seen in chapter 4.4), this means that the cations can't bind into the soil structure well enough and can be leached away more easily.

The compost used in the reclaimed soil acts as a buffer and a neutralizer for the soil. It helps the soil to retain key nutrients and decrease nutrient loss from leaching. (*Why Use Compost?*, no date)

4.3 WATER CAPACITY

4.3.1 Results of conducting the water capacities

As seen in table 1, potting soil and sand were also examined for the amount of water contained. The reason for this is that the extra values are used as reference values for the reclaimed and non-reclaimed soil to be compared to. The potting soil is a particularly nutrient rich soil while sand is notoriously nutrient poor.



Tab. 1 Amount of water contained in different soils and sand

The results vary significantly; 4.9 % water retainment for the sand to 31.9 % for the reclaimed soil.

4.3.2 Sources of errors in the water capacity experiment

The main source of error to be observed is that the reclaimed and non-reclaimed soils were retrieved on different days than the potting soil and sand. The humidity and rainfall could have varied. But also, important to note is that the potting soil and sand were stored in bags and had less chance to capture water from their surroundings.

4.3.3 Discussion about the water capacities

The reason for why the reclaimed soil has such a great water storing ability is closely connected with the soil texture. Rather than the water just sitting on top of the soil as is the case with the very dense non-reclaimed soil, it can freely flow through the airy reclaimed soil and saturate it much better.

Potting soil has a high amount of organic matter which is comparable to the amount that the reclaimed soil has, however it can be observed that it still got lower results compared to the reclaimed soil. The reason for that is that the structure of the soil primarily influences the ability to retain water. (De Jong et al., 1983) The difference is that the compost used has a stabilizing affect on the reclaimed soil. Even though potting soil contains a high amount of organic material, it mostly consists of moss and bark. These materials don't contribute as much to an optimum soil texture whereas compost promotes a glue-like affect caused by organisms breaking down the organic matter. Soil accumulations are then formed, which are ideal for retaining water. (Bennaton, 2015)

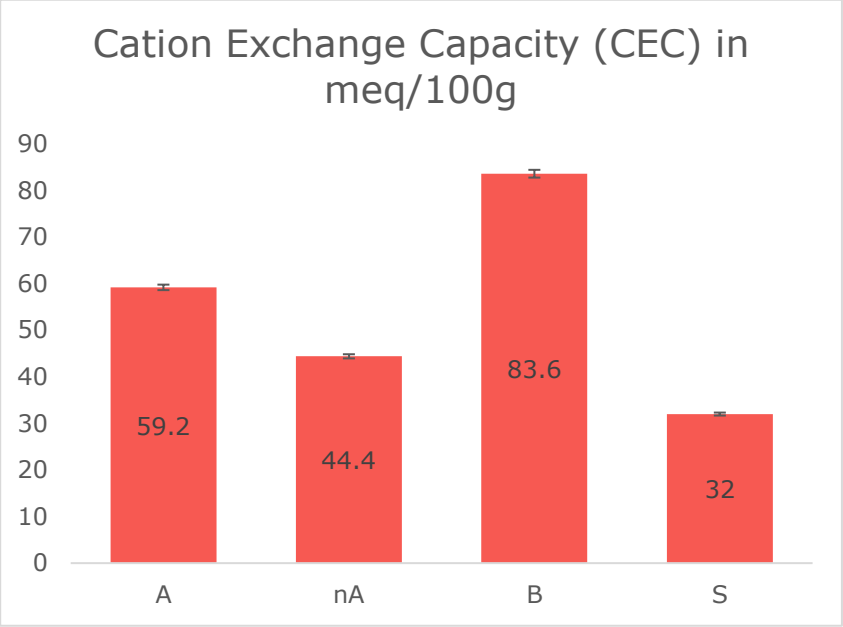
4.4 CATION EXCHANGE CAPACITY (CEC)

4.4.1 Results of determining the CEC

The formula used to calculate the results is listed below.

$$n(Ca^{2+}) = c_T * v_T * 200 * 2$$

- $c_T = 0.01\ mol/L$



Tab. 2 Level of CEC in different soils and sand

The reclaimed soil has a CEC of 59.2 meq/100g. The non-reclaimed soil has a CEC of 44.4 meq/100g. Potting soil has a CEC of 83.6 meq/100g which is almost double of the non-reclaimed soil. Sand has a CEC of 32.0 meq/100g.

4.4.1 Sources of errors in the CEC experiment

The titrant (EDTA) used for the titration could also react with the lime in the soils. Since the sand used had a very high lime content (reacted with hydrochloric acid), it can be assumed that the displayed value of the titration of the sand indicates only the lime content and not the CEC. Therefore, the lime content of sand tested in the following experiment should result in a high value.

4.4.1 Discussion about the CEC

As deduced from table 2, the soils with high soil organic matter (SOM) content also have a high CEC. These two factors are directly influenced by each other. Especially when the SOM content is greater than 20 %, it is proven that if the SOM content rises, so does the CEC. (Essington, 2021) This means that the SOM of potting soil is greater than that of the reclaimed soil and the reclaimed soil then again has a greater SOM content than the non-reclaimed soil. Sand

has little to no SOM, therefore it is correct to assume that the titration indicated just the lime content and not the calcium-ion content that could be captured and then again released by the sand.

Another reason for why the reclaimed soil has a significantly high CEC value is because the CEC is also influenced by the pH level. The more the pH increases and becomes alkaline the greater the number of anions in the soil. (Lines-Kelly, 1993) As measured in chapter 4.2, the reclaimed soil has a pH of 7.5.

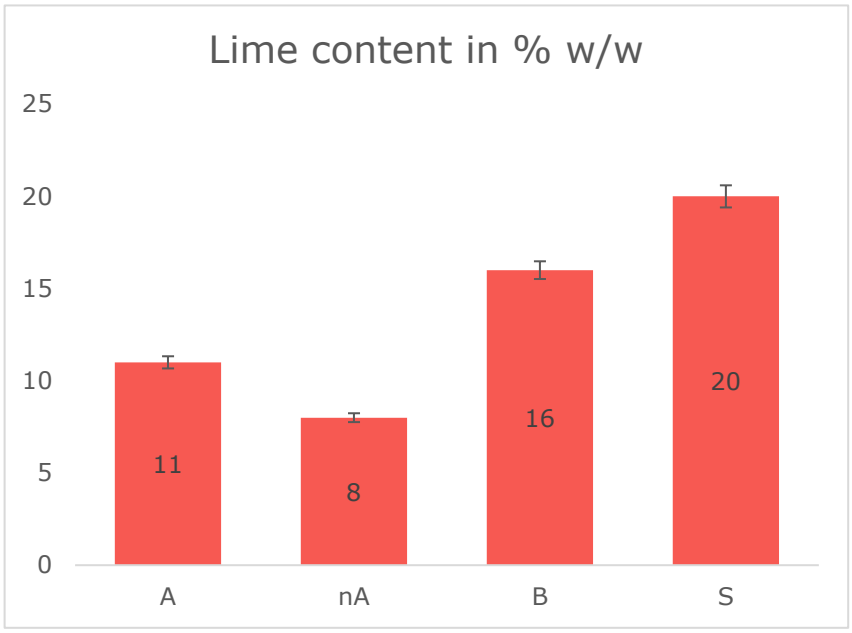
4.5 LIME CONTENT

4.5.1 Results of determining the lime content

The formula used to calculate the results is listed below. V_T was calculated by taking the average of the two variants of every soil sample.

$$\frac{m(carbonates)}{m(soil)} = \frac{n(H_3O^+) - c_T * v_T}{2} * M(CaCO_3)$$

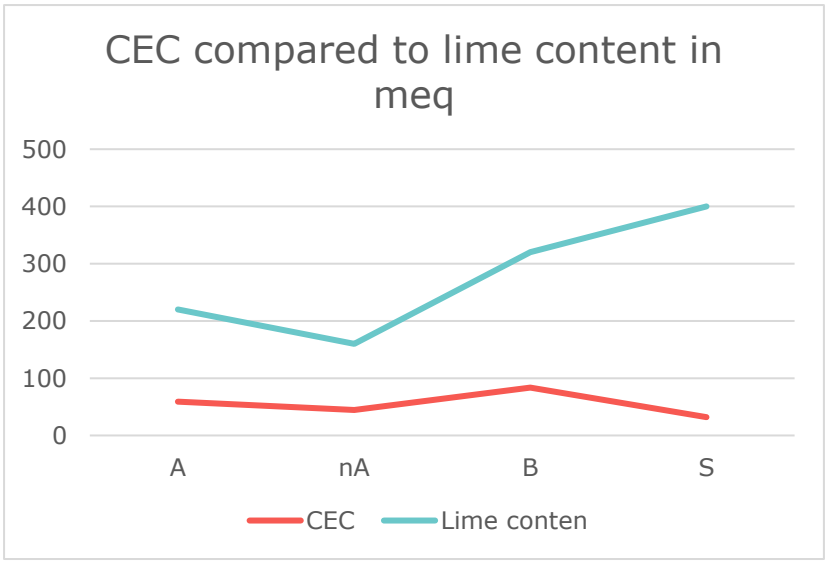
- *m(soil)=1 g*
- *$n(H_3O^+)$=0.004 mol*
- *c_T=0.1 mol/L*
- *$M(CaCO_3)$=100 g/mol*
- *v_T in liters*



Tab. 3 Level of lime content in different soils and sand

The lime content of reclaimed soil is 11 % w/w, the content of non-reclaimed soil is 8 % w/w, the content of the potting soil resulted in 16 % w/w and the content of sand is equal to 20 % w/w.

4.5.2 Discussion about the lime content



Tab. 4 Similarities shown by comparing the CEC to the lime content shown in the unit milliequivalent.

As seen in table 4, the CEC and lime content could not have depended on each other because the values for the lime content are way too high compared to the CEC. This shows that only a few calcium ions were measurable when the CEC experiment was performed. Calcium carbonate is a salt, therefore it is highly unlikely that in the process of analysing the CEC, the calcium-ions could have been separated from the stable coalition with the carbonate-ions. It is also clearly visible in the graph that the sand has a significantly high amount of calcium-ions and a low capacity to store any other ions.

The lime content is correlated to the pH level of the soil as long as the pH level isn't greater than 8.5. The reclaimed soil with a pH of 7.5 has a higher lime content than the non-reclaimed one with a pH of 5. This is because alkaline soils show a richness in base cations, especially Ca (Calcium). This Ca can then react with the CO_2 (carbon dioxide) which is abundant in especially alkaline soils, as there is a tendency for alkaline solutions to be absorbent for CO_2. The Ca will then react with the CO_2 to form $CaCO_3$ (calcite/lime). (Essington, 2021)

When organic matter decomposes it releases CO_2. My assumption is that this high amount of CO_2 produced in the potting soil and reclaimed soil reacts with the available Ca in the soil and can contribute to the $CaCO_3$ production.

Another reason for why the CEC rises is because of the assumed high humus content in reclaimed soil. A high humus content also means an increasing amount of humic acids are present. The dissociation of the phenolic (OH) and the carboxylic (COOH) function groups from the humic acids can create polarized ends which are hydrophilic and hydrophobic. The hydrophilic end of the molecule can form complexes between its anionic part and cationic metals, therefore conserving them in the soil. This causes minerals to be more readably available for plants and provides a higher surface area for chemical reactions to occur.(Ampong et al., 2022)

The potting soil has such a high value for the lime content because it is intentionally manufactured to contain a fixed amount of lime which is most beneficial for cultivating plants.

4.6 QUICK TESTS DETERMENING DIFFERENT ION-CONCENTRATIONS

4.6.1 Results of determining the different ion-concentrations

In the following pictures the results of the quick tests can be seen. For each soil (A=reclaimed soil, nA=non-reclaimed soil, B=potting soil, S=sand) a minimum of two samples were analysed. It should be noted that the solutions were murky, and a tinted brown color on the test strips doesn't indicate a color change of the strips.

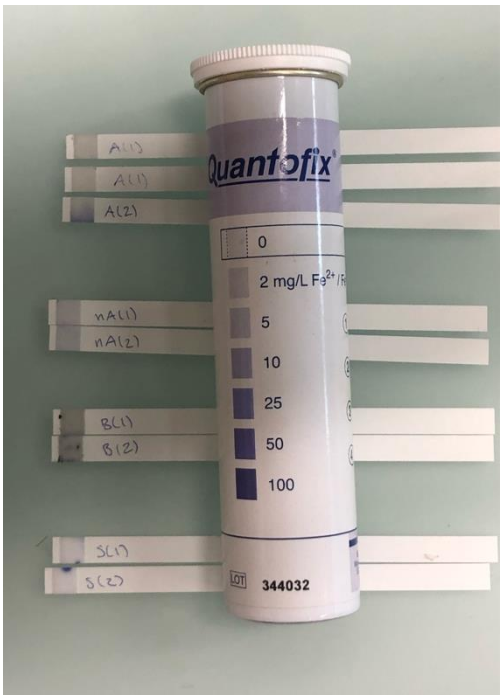


Fig. 14 Total iron (Fe^{2+}/Fe^{3+}) represented on test strip A(2). Slight spotting seen on test strips S(1&2).

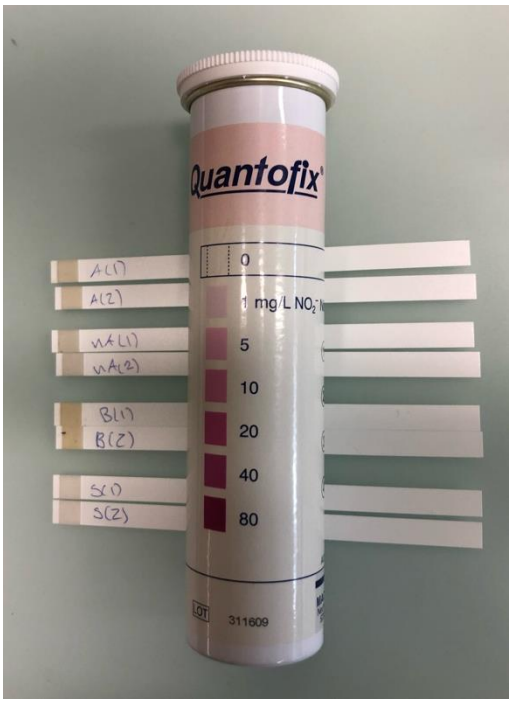


Fig. 15 Nitrite (NO_2^-) not represented on any strips.

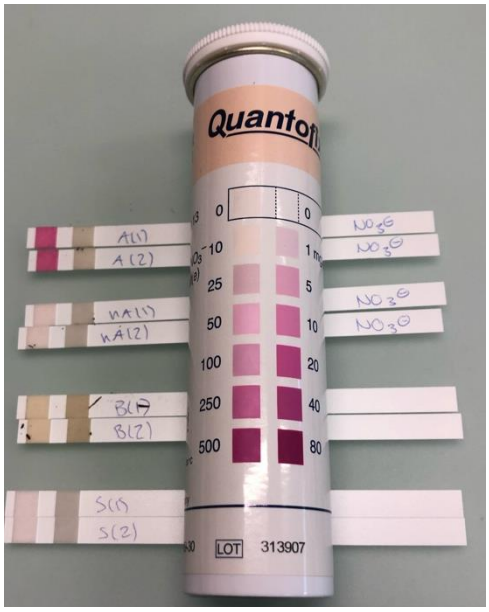


Fig. 16 Nitrate (NO_3^-) represented on strips A(1&2) and lightly on nA(1&2).

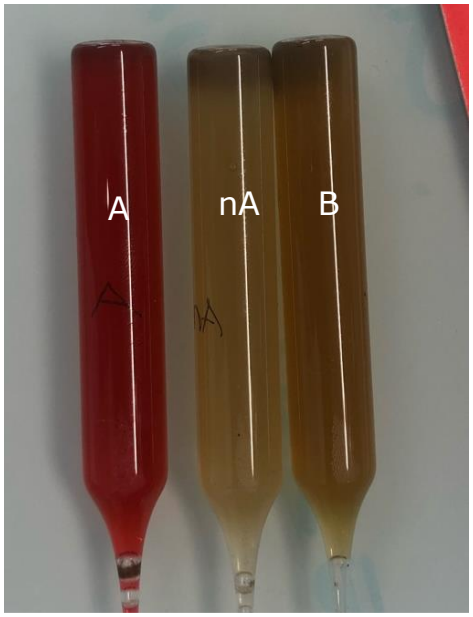


Fig. 17 Nitrate (NO_3^-) represented clearly in tube A.

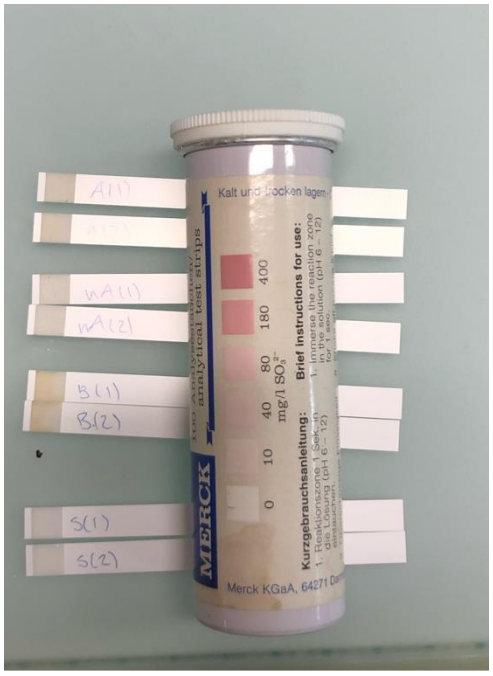


Fig. 18 Sulfite (SO_3^{2-}) not represented on any strips.

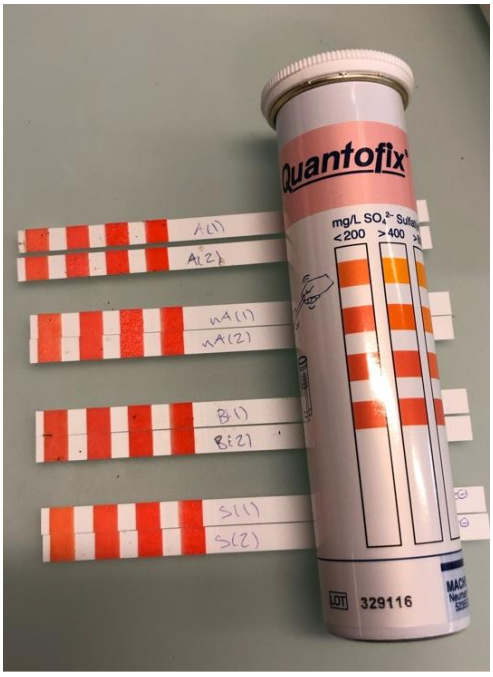


Fig. 19 Sulfate (SO_4^{2-}) lightly represented on strips S(1&2).

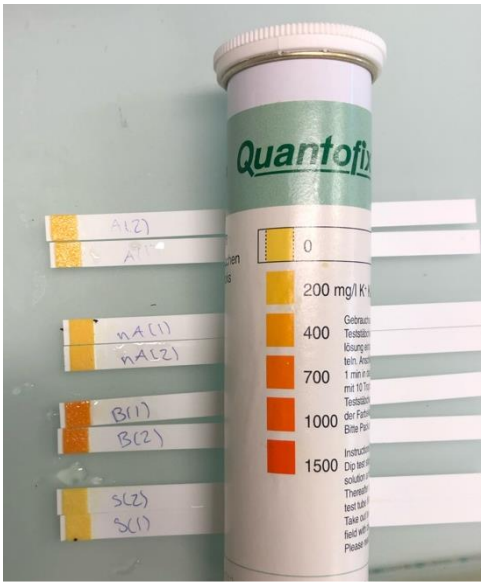


Fig. 20 Potassium (K^+) represented on strips B(1&2).

Fig. 21 Phosphate (PO_4^{3-}) represented clearly in tubes A, nA and B.

The results found in the tests are listed in the table down below.

Tab. 5 All the results shown which were gathered from the quick tests.

	Fe^{2+}/Fe^{3+}	NO_2^-	NO_3^-	SO_3^{2-}	SO_4^{2-}	K^+	PO_4^{3-}
A	10 mg/L		250 mg/L				4.1 mg/L
nA			< 10 mg/L			200 mg/L	3.3 mg/L
B						400 mg/L	3.7 mg/L
S					< 200 mg/L		

The nitrate concentration of the reclaimed soil was converted from mg/L to mmol/100g soil (only the reclaimed soil showed values for nitrate that were significant enough to be compared to other results). This was done so that the value could be compared to the organic nitrogen content value. This can indicate if the soil delivers nutrients

mainly through its organic content (organic nitrogen) or through inorganic ions (nitrate).

$$\frac{n(NO_3^-)}{100g\ soil} = \frac{\frac{v(H_2O) * \frac{c(NO_3^-)}{1000}}{M(NO_3^-)}}{m(soil)} * 100$$

- *$v(H_2O)$ = 45 mL*
- *$c(NO_3^-)$ = 250 mg/L*
- *$M(NO_3^-)$ = 62 g/mol*
- *m(soil) = 15 g*

The value for $n(NO^{3-})$ results in 1.21 mmol per 100 g soil.

4.6.2 Sources of errors occurring with the quick tests

The tests are designed to give a fast but not particularly precise result. The water was also murky, which interfered with the light sensor when measuring the concentrations in the tubes. That is why the concentrations of nitrate from the test tubes were not noted in the table. The concentrations of phosphate could have also varied a lot from the data given, but it gives us a reference point of the relation between the samples and most importantly if there is even any phosphate in the sample that reacted with the test.

A majority of these ions are also tightly bound into molecules and chelate complexes. That is the reason why some test strips only reflected a little amount of ion concentration or none at all.

4.6.2 Discussion about the different ion-concentrations

The reclaimed soil showed the best results in ion concentration compared to all the other soils and the sand. There were two values that were noticeable in the tests for the reclaimed soil, these being the nitrite (strip test and tube test) and phosphate concentrations. Quite significant values were also observed from the potting soil. The potassium and phosphate values stood out from the rest. This indicates that the reclaimed soil and potting soil again performed best in having available ions. That is probably why the CEC of these two soils was also very high compared to the others.

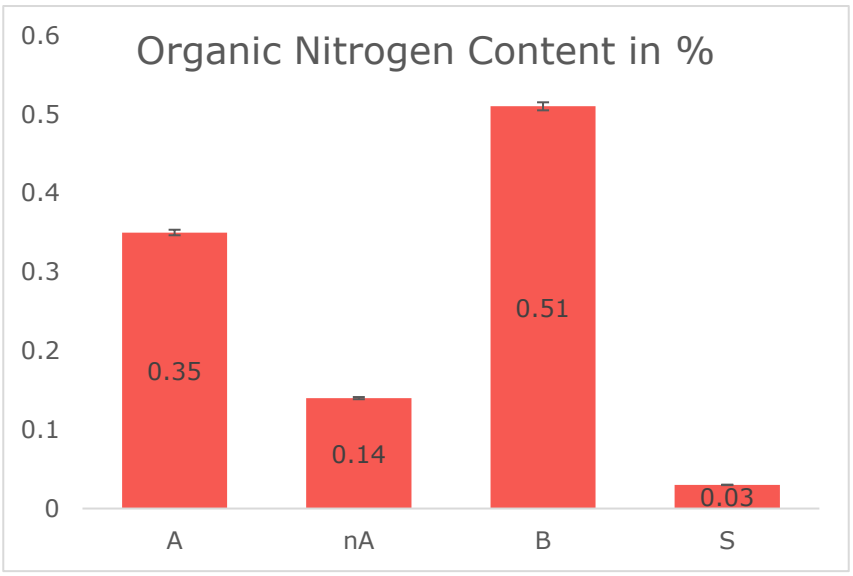
4.7 CONTENT OF ORGANIC NITROGEN

4.7.1 Results of determining the organic nitrogen content

The formula used to calculate the results is listed below. V_T was calculated by taking the average of the two variants of every soil sample.

$$n(N) = \frac{c_T * v_T * 1000 * M(N)}{m(soil)} * 100$$

- *c_T = 0.01 mol/L*
- *M(N) = 14.01 g/mol*
- *m(soil) = 250 mg*
- *v_T in liters*



A = reclaimed soil

nA = non-reclaimed soil

B = Potting soil

S = Sand

Tab. 5 Organic Nitrogen Content in different soils and sand.

The reclaimed soil contains 0.35 % organic nitrogen, the non-reclaimed soil contains 0.14 % organic nitrogen, the potting soil has the greatest amount of organic nitrogen at 0.51 % and sand has the smallest amount at 0.03 %.

The value of the reclaimed soil is converted from % to mmol/100 g soil using the following formula.

$$\frac{n(N)}{100\ g\ soil} = \frac{p(N)}{M(N)} * 1000$$

- *p(N) = 0.35 g*
- *M(N) = 14 g/mol*

The value for n(N) results in 25 mmol per 100 g soil. This is much greater than the previously calculated 1.21 mmol per 100 g soil for nitrate.

4.7.1 Discussion about the organic nitrogen content

In many ecosystems nitrogen is scarce and not readily available for organisms and plants. That is why plant growth is sometimes limited by a lack of nitrogen. The reason for this is that nitrogen (N_2) is very stable and almost identical to the reactive oxygen (O_2). This makes it almost impossible for enzymes to break down the nitrogen safely without also breaking down the highly reactive oxygen molecule. That is why atmospheric nitrogen cannot be directly used by plants. Instead, plants take up nitrogen mainly in the form of nitrate or ammonium ions. (Leisinger, 2016 (2)) Most of these plant-available nitrogen compounds are provided in nature by symbiotic bacteria (Rhizobiaceae) that live in plant roots. They feed on plant carbohydrates and in turn synthesize plant-available compounds from atmospheric nitrogen. (Kaur, 2022)

Decomposing plants and animals also provide the soil with a high amount of nitrogen which can be transformed by bacteria for plants to use. Therefore an increase of soil organic matter directly influences the amount of organic nitrogen in the soil. (Killpack S., Buchholz D., no date)

In conclusion, these results reveal that the soils most suitable for cultivating a high yield of crops, just based on the organic nitrogen content alone, are the reclaimed soil and the potting soil. Also, the comparison with the nitrate concentration shows that the reclaimed soil relies much more on the organic matter for providing nutrients then on inorganic ions. This is good because the organic nitrogen cannot be leached away as easily as nitrate can.

5. CONCLUSION

Now that the individual soil parameters have been discussed, an overall assessment of the soil properties of the different soil samples can be made.

In the test conducted, the reclaimed soil and potting soil proved to be by far the most fertile. Compared to the non-reclaimed soil, the reclaimed soil showed better values in all aspects tested. It's pH lies in a better range for plant growth, the cation exchange capacity is higher, the reclaimed soil can retain more water and it contains higher amount of nitrogen and phosphate nutrients.

As is expected, the examined sand is not suitable for cultivating plants. The sand is simply composed as it lacks clay minerals and organic components. These substances are crucial for soil fertility. However, sand was only used to represent a reference soil with particularly nutrient poor properties. The potting soil on the other hand served as an especially fertile reference soil sample and, not surprisingly, delivered the best results. But the use of potting soil instead of the original garden or agricultural soil would neither be time efficient nor cost effective. In addition, after the potting soil is stocked with cultivated plants for a while, it becomes denser and more and more nutrient deprived and slowly changes into a less valuable soil over time and will have to be reclaimed. For this reason, the reclaimed soil is the most effective soil in the long run.

The reasons for why the potting soil and the reclaimed soil showed the best results can be attributed to the high soil organic matter (SOM) and a higher lime content as compared to the non-reclaimed soil and sand. The SOM turned out to be a key indicator in all the experiments and could explain why the soil treatment had resulted in better values.

Unfortunately, the SOM of the investigated soils has not been determined for this paper. Nevertheless, two indicators show that the organic content of the reclaimed soil was significantly higher than the

organic content of the original soil. Firstly, the reclaimed soil was much darker and showed the brown colour typical for soils rich in humic substances, as mentioned in chapter 4.1.2. Also, the organic nitrogen content of the reclaimed soil was much greater than in the non-reclaimed soil, thus indicating a higher SOM.

Assuring regular compost applications and the addition of rock or lime powder, ideal conditions are created for humus to be developed. This high humus content in turn leads to a high content of humic acids. Humic acids are vital for delivering nutrients from the soil to the plant, as they can build complexes with ionized nutrients (cations), thus stopping them from leaching away. A high content in humic acids can therefore explain the relatively high CEC of the reclaimed soil. Water soluble humic substances are also transported to the depletion zone of the roots (area closest to plant roots where plants deplete nutrients). When the humic acids encounter the roots in the depletion zone, they provide nutrients to the plant. In addition, humic substances can form big numbers of hydrogen bonds and loosely bind ions which in turn interact with water, therefore the SOM not only increases the CEC but also the water holding capacity of the soil. (Meléndrez, 2009; Ampong et al., 2022)

It is important to note that the quality of the soil sample which was reclaimed is continuously being improved, as Mr. Meienberg is still in the process of refining the soil. The process of adding compost must be continued beyond the current point of refinement because the nutrients must be repeatedly replenished in the soil. Because the composting also allows important, long-lasting humus to be produced, refining soil is more effective than switching out potting soil habitually.

In conclusion, the hypothesis that reclaimed soil is a more efficient and cost-effective soil for cultivating plants could be shown not just through observation by the naked eye but could also be proven through the experiments that were performed.

5.1 Possible further improvements for the reclaimed soil

As the reclaimed soil achieved very good values in the experiments, there are not many further improvements that can be made. The only thing that could further benefit the soil is slightly reducing the pH-level. The ideal pH for most plants is around 7. Some examples of the ideal pH-level for different crops are:

Lettuce = pH of 6.0-7.0

Pumpkin = pH 6.0-7.5

Tomatoes = pH 5.5-7.5

Corn = pH 5.5-7.0

Wheat = pH 6.0-7.5

As seen above, the pH of the reclaimed soil is at the upper limit of the most optimal pH-level for most crops. The best and most natural way to make the soil more neutral is to just keep adding compost and the problem will resolve itself over time. Adding peat dust can also achieve the same effect. Information gathered from the additional pamphlet of the AVM-PEHAMETER® kit. (AVM Analysenverfahren, no date)

6. ACKNOWLEDGEMENTS

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