Capstone

The effect of water management on groundwater levels, soil moisture, and CO_2 emission of grassland clay-on- peat soils in Friesland, the Netherlands.

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Abstract

Background: Globally, peatlands are degrading and emitting CO_2. This is because of the global intensification of agricultural practices to feed the increasing global population. However, this is at the expense of the soil's health. Peatlands, in particular, are susceptible to degradation due to lowered water levels, resulting in CO_2 release and land subsidence. However, if well managed, peatland can act as a carbon sink. This research aims to investigate the impact of different water management strategies on groundwater fluctuations, CO_2 emissions, and soil moisture in grassland clay-on-peat soils during the early growing season in Friesland, the Netherlands.

Methods: The research study was conducted on two organic farms in Friesland, focusing on clay-on-peat grassland. The data collection consisted of three rounds in the field in the early spring, with measurements taken at different locations within the fields. Measurements included CO_2 flux, soil moisture, soil organic matter (SOM), groundwater level, soil structure, penetration resistance, vegetation height, and grass-herb percentage. Lab work involved analysing SOM using the Loss on Ignition (LOI) method. A survey was conducted with farmers to gather information on water management practices. Data analysis was performed using statistical tools including Non-metric Multidimensional Scaling (NMDS). The study also considered weather data from the closest weather stations to understand its influence on the variables. Ethical considerations were taken into account, including obtaining permission from landowners and pseudonymizing the data to ensure privacy.

Results: The results did not confirm the hypothesis. There were no clear trends found in the CO_2 emissions, groundwater level, and soil moisture, through the growing season Additionally, several variables that were regressed against the CO_2 flux did not show significant trends. Reasons why the results differ from the hypothesis are due to unanticipated weather conditions and the capacity of the soil to absorb water.

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Introduction

The health of soils is closely related to three different United Nations Sustainable Development Goals (UNSDG) (United Nations, UN, n.d.), namely: zero hunger (2), climate action (13), and life on land (15). A growing world population and an increasing consumption per capita are highly pressuring soil and its natural processes to provide enough food for this rapidly growing demand (FAO & ITPS, 2015; Kopittke, et al., 2019). The challenge is to feed the global population without compromising soil health. Soils are a key component in agriculture, terrestrial ecosystems, and the global climate. Soils are the habitat of about 25% of all living organisms on earth, and more than 40% of terrestrial living organisms are directly associated with soils during their life cycle (FAO et al., 2020).

Healthy soil depends on various factors (e.g., soil structure, organic matter, soil moisture, etc.) and soil in a healthy state has the ability to sustain natural processes and ecosystem services that are necessary for (nutritious) food production. Furthermore, healthy soils have a great potential to mitigate climate change (EASAC, 2018). This is, among others, because soils have the capacity to store and sequester greenhouse gasses (GHGs), regulating the carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the atmosphere (Oertel et al., 2016). These GHGs are contributing to global warming and other aspects of climate change. CO_2 is the major GHG emitted by humans which is equal to about three-quarters of the total GHG emissions (World Resources Institute, 2019). The flux of greenhouse gasses between the atmosphere and soil is particularly active in peatlands (Kopittke et al., 2019). Peatland can contribute to capturing CO_2 from the atmosphere by storing carbon in living and dead biomass. At the same time, peatland can also contribute to emissions into the atmosphere by releasing carbon from plant litter (Baird et al., 2009). Moreover, Peat soils are generally good at holding water, as they are naturally spongy soils with a high carbon content (Kazemian, 2018). The international '4 per 1000' initiative aims to show the crucial role that agricultural soil can play in food security and climate change (4per1000, n.d.). This initiative includes actors on a voluntary basis from both the public and private sectors and the name of the initiative relates to the scenario that if "the top 30 to 40 cm of soil increased by 0.4% per year, the annual increase of CO_2 in the atmosphere would be significantly reduced" (4p1000, n.d., Para 6).

In recent decades, agricultural practices have intensified worldwide to feed the world's growing population, but the negative consequence of soil degradation came with this (Hussain, 2021). Frequent mechanical disturbance of the top layer in agricultural soils has caused an increase in the emission of greenhouse gasses from soil (Van den Akker, Hendriks & Pleijter, 2012). The water management strategies also play a significant role in the release and capture of CO_2 in soils. Peat is particularly susceptible to degradation in the presence of lowered water levels. Deep drainage of peatland causes oxygen to reach the stored carbon through pores that were previously filled with water and thereby releasing CO_2. This type of drainage practice can also result in land subsidence because the peat becomes dried out and the soil is no longer saturated, and the peat is breaking down due to oxidation. Additionally, the capacity of the soil to absorb and hold water is decreasing as soil organic matter (SOM) supports this capacity (Rutgers & Mulder, 2008).

Peat degradation due to agricultural intensification is also seen in the Netherlands. Ditch water levels and therefore groundwater levels have been lowered by about 10 centimeters every ten years (Van den Akker et al., 2012). In the Dutch province Friesland, great amounts of water are led to the sea when it does not suit agriculture and other sectors, as the grassland needs to facilitate heavy agricultural machines and vehicles for modern Western farming, and if the land is too wet, heavy objects can sink into the soil (Vitens, Provinsje Fryslân & Wetterskip Fryslân, 2019). However, in recent years, droughts have become more frequent, severely affecting agricultural practices. In the near future, droughts are also expected to be more frequent during the summer (Knmi, 2021; Spioni et al., 2018). Actions are already taken to raise the groundwater to build resilience against droughts, but there are many implications. Various sectors rely on certain water tables and have different views on how the water should be managed. Whereas agriculture aims for a rather low and stable groundwater level in which the crops can still grow roots, nature organizations prefer a naturally high level of groundwater in which fluctuations can be common (Vitens, Provinsje Fryslân & Wetterskip Fryslân, 2019).

Friesland has about 54.000 ha of peatlands, which is about 16% of the land cover of the province. These peatlands mainly consist of grasslands used for livestock (Provinsje Fryslân, 2015). There is currently no new peat formed in Friesland, and the peat that is currently present is decreasing. The disappearance of peat comes together with CO_2 emissions and land subsidence (Provinsje Fryslân, 2015). Water Levels on peatlands in the province Friesland are relatively low, around 90-120 cm below surface soil (van den Akker et al., 2018). Due to the land subsidence, the ground surface gets closer to the groundwater level which makes the land harder to use. To compensate for this, water level regulations will be adapted, lowering the water level even further, and creating a positive feedback loop (Vitens, Provinsje Fryslân & Wetterskip Fryslân, 2019). The land subsidence is slightly lower for peatlands covered with a clay layer. This clay layer protects the underlying peat from coming into contact with oxygen resulting in peat degradation (Vitens, Provinsje Fryslân & Wetterskip Fryslân, 2019). Almost half of the peatland in Friesland has a layer of clay on top of the peat. The clay layer was deposited on the peatlands during tidal flooding events in the Middle Ages before the barrier dikes were built and the area was regularly inundated by the sea (Provinsje Fryslân, 2015). A clay-layer of 15-40 cm on top of peat is classified as peat land with a thin clay layer. If the clay layer is thicker, but peat is found within 80 cm under the surface, it is classified as clay ground with underlying peat (van den Akker et al., 2018).

The aim of this research is to investigate groundwater fluctuations, soil moisture, and CO_2 emission during the early growing season on grassland clay-on peat soils with different water management strategies. This research will focus on clay-on-peat meadows in the Dutch province Friesland. The research question is formulated as: "How are groundwater fluctuations, CO_2 emissions, and soil moisture on grassland with peat-on-clay soil affected by different groundwater management strategies in the early growing season?" It is hypothesized that groundwater management strategies intensively focussing on increasing the ditch water levels will generally see lower CO_2 emissions, higher groundwater levels, and higher soil moisture. It is expected that these higher groundwater levels and soil moisture will capture the CO_2 better and cause the emissions to be lower. Meadows, where groundwater management strategies do not focus specifically on increasing the water levels, will generally find lower groundwater levels and lower soil moisture resulting in higher CO_2 emissions. For both management strategies, the CO_2 is expected to increase throughout the early growing season due to a decrease in groundwater level and soil moisture.

In the methods, additional information on the study site is provided, the data collection is explained, and the approach of the analysis is given. Afterward, the results are analysed and presented. In the discussion, the results will be explained, compared to the hypothesis, and the limitations will be given. The results will be compared to additional literature and linked back to the background information given in the introduction. Lastly, the paper will be summarized, and takeaways will be presented in the conclusion, with recommendations for further research.

Materials and methods

Study site

The study site of this research is two organic farms in Friesland. Around 54000 ha of Friesland is classified as peatland. Peat is defined as an organic soil that is formed from decomposed plant material (Bakker & Schelling, 1989). The average organic matter in peat in Friesland is about 35.7% (van den Akker et al., 2018). About 44% of the peatland in Friesland is covered by clay. With a clay layer on top of the soil, it can still be considered peat land if the layer of peat is at least 40 cm thick and starts within 80cm depth. In Friesland, 62% of the peatland is used for agriculture, predominantly grassland (Provinsje Fryslân, 2015), which is also the case for the fields researched in this paper. Maintaining the peatlands is important for lowering CO_2 emissions, preventing land subsidence, and providing a habitat for certain flora and fauna species (Provinsje Fryslân, 2015). A rough location of the study site is displayed in Figure 1. At each of these farms, data from three different fields was gathered. All the fields in this study were peat lands covered by a clay layer. The different fields have similar land use intensities. Both sites are managed according to the rules and regulations of organic agriculture. Therefore, artificial fertilizers are not used. Still, two different water management types can be identified at these farms. There are three fields adopting a water management strategy focusing on having a high water table, and three fields adopting a water management strategy focusing on having a moderate water table.

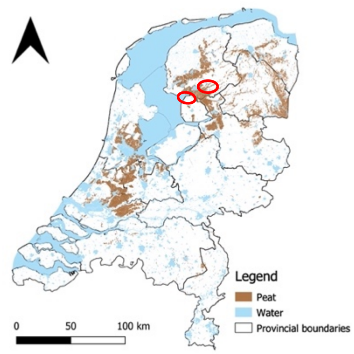

Figure 1: A map of the Netherlands, displaying the peat area in brown. The red circles are roughly the locations used in this study.

Fieldwork measurements

The fieldwork consisted of three rounds in the early spring from the beginning of March until the end of April in order to capture the seasonal trend. In each round, six fields were visited from two different farms (three fields per farm). Between the fieldwork rounds were intervals of at least three weeks and a maximum of four weeks. The first round was at the beginning of March (1st and 3rd), the second round was at the end of March (30th and 31st), and the third round was at the end of April (24th and 25th). Per field, most variables were measured at three different locations: 2 meters from the ditch, 7 meters from the ditch, and mid-field (± 30m from the ditch). These locations were chosen to interpret the potential effect of the ditch on the variables, to get the average values of the fields, and to decrease the uncertainty. All variables except for the CO_2 flux, the SOM, and the ditch water level, were measured at all three locations. In addition, the SOM was only measured in the first round, because this is a rather stable variable. Vegetation height, penetration resistance, and soil moisture were measured three times at each field location. An overview of the measurements can be viewed in the fieldwork sheets in Appendix 1. These sheets were used during the fieldwork. A different sheet was used for the first round and for the last two rounds.

Figure 2: Fieldwork materials used to measure the a) CO2 flux, b) soil moisture, c) SOM, d) soil structure; groundwater level, e) soil penetration resistance.

Figure 2 shows an overview of the material used during the fieldwork. For the CO_2 emission, a closed chamber measurement was conducted. The chamber was put on top of the soil and attached to a Vaisala handheld CO_2 meter GM70 (see Figure 2a). The CO_2 concentration in the chamber was measured in ppm. To ensure the starting value is correct and similar to the atmospheric CO_2 level, the device started measuring right after the box was applied. The CO_2 was measured over a time span of 15 minutes, giving a value for every 30 seconds. The difference between the starting and the end value, as well as the size of the chamber, was used to convert the raw data into the CO_2 emission flux of the soil (µmol m-2 s-1). The soil moisture was measured using an Eijkelkamp Thetaproble ML3 that measures the percentage of the pore space filled with water in the top 10 cm of the soil (see Figure 2b). As soil moisture is extremely variable in time and space, it was measured three times per location. For the SOM, a sample was taken of the top 5 cm of the soil. The upper vegetation was cut off in order to later get the organic compound of specifically the soil. The volume of each sample was the same, using a volumetric ring (100 cm3) displayed in Figure 2c. The groundwater level and soil structure were measured using a hand auger, which can be seen in Figure 2d. The auger was hand drilled into the ground, each time extracting a layer of about 20 cm. The soil that we reached with the auger was placed next to a measuring tape to see the depth of the soil and repeated until we had reached the peat layer and the groundwater level. For the soil structure, we were primarily interested in discovering the thickness of the clay layer that is on top of the peat. For measuring the penetration resistance of the soil surface, the Eijkelkamp handheld penetrometer for toplayers - IB as shown in Figure 2e was used. The end that is pushed into the ground is of the same size as the beak of a black-tailed godwit. It gives an indication of the compaction and/or root mat density of the top 10 cm. There are different springs and cones that can be used depending on the compaction of the soil. The raw data is in cm which was converted to a measure of force (N/cm^2) by dividing the product of the total force from pressing the device (cm) and the force of the spring (N/cm) with the cone-surface (cm^2). The penetration resistance was measured three times at the three different locations as this is a variable that varies considerably in space. The vegetation height was measured three times at a random spot. At each spot the tallest blade of grass that was directly adjacent to the measuring tape was taken for the measure. This was measured in cm. For the grass-herb percentage, the measurement tape was used and randomly placed on the field at a 90-degree angle. An area of 50cm by 50cm was considered. The percentage of grass, herbs, and bare ground was then estimated by counting small 4% squares. Lastly, the ditchwater level was measured relative to the field level using a measuring tape. This level was measured for each field every round. The ditchwater level was measured in cm below the field surface.

Lab work

The measurement of soil organic matter (SOM) is crucial for this research as it consists of carbon based compounds and therefore closely relates to the CO_2 fluxes. The SOM of the samples was measured following the Loss on ignition (LOI) method. This method includes the heating of a soil sample to a certain temperature to allow specific substances to escape. In this case, the samples were heated to burn the organic matter. This was done through a series of carefully controlled steps. First, the samples were dried in the oven at 70°C for about 22 hours. Each dried sample was then divided into three bowls. These bowls were numbered, and their empty weight was recorded. After, the bowls with the soil sample was measured. The bowls were put in the oven and were heated gradually with a ramp from 20 to 500°C for 1 hour, followed by maintaining the temperature at 500°C for 4 hours. All the bowls were weighed again after losing weight from burning the organic material. The percentage of the organic matter was then calculated.

Survey

In order to get an idea of the specific water management strategies that were practiced at the two different farms, a survey was held with the farmers. The questions focussed on gaining a better understanding of the aimed ditch water level and the infiltration practices. Besides that, questions about the costs and benefits of their water management practices were asked. For the full overview of the questionnaire see Appendix 3

Data analysis

For generating and summarizing results, a statistical analysis was conducted using R studio. First, the Non-metric multidimensional scaling (NMDS) statistical tool was used. This tool helps to visualize complex multivariate data in a limited number of dimensions, typically two or three dimensions (Dexter et al., 2018). This method is often used by researchers working in different fields, including ecology. The stress level of the NMDS indicates the fit of the representation (Dexter et al., 2018). The stress levels are classified as followed:

- stress < 0.05 excellent fit
- Stress < 0.1 good fit

- Stress < 0.2 fair fit
- Stress > 0.2 poor fit

After the NMDS was plotted and the stress level retrieved, layers were added to the NDMS to compare groups within the data set. This research questions compares two different water management strategies throughout the growing season. Therefore, a visualization of the different management strategies was added to the representation, as well as three layers representing the rounds. The visualization of this can help to detect differences in the variables between rounds and management strategy. In addition, to decide whether the differences between the groups are significant, a pairwise adonis test was conducted for the different water management styles and for the different rounds.

In order to analyse the data further, the relevant variables were first summarized in boxplots comparing the values between water management strategies and rounds. This includes the CO_2 flux, groundwater level, soil moisture, and ditch water level. A two-way Analysis of Variance (ANOVA) test was done to decide the significance of the relation of the water management strategy and the round with the dependent variable. Another boxplot summarizes the SOM and the difference between water management strategies. Here, a one-way ANOVA was conducted to decide the significance. The SOM was also regressed against the soil moisture using a linear regression model. Afterward, several other linear regression models were plotted, to analyse the relationship between the CO_2 flux and various variables. The CO_2 flux was taken as the response variable and the groundwater level, soil moisture, and clay layer as the explanatory variable. The significance is checked using a one-way ANOVA test. For the ANOVA tests, a P-value lower than or equal to 0.05 is considered to be significant.

The early growing season is strongly defined by the weather. Therefore, the daily maximum temperature and the daily precipitation of the closest weather station with available data were analysed. The data was retrieved from the Royal Netherlands Meteorological Institute (KNMI), which is the national weather service institute of the Netherlands (*KNMI – Daggegevens van het weer in Nederland*., n.d.). The data from the closest KNMI weather station was used. For the high water management fields this was Leeuwarden, and for the medium water management fields, it was Stavoren. For both locations, a graph with the daily maximum temperature over the growing season was presented with a non-linear regression line to understand the average change in temperature. For the precipitation, a line graph was created. In addition, the weather of the week, with the day the data was collected as the last day, was retrieved, and analysed. This was done because the short-term weather can have a significant effect on the variables, such as soil moisture.

Ethical consideration

To ensure ethical practice throughout the research, several steps were taken before, during, and after the research. First of all, permission from landowners of the fields that were researched in this study was ensured. In addition, we chose to pseudonymize the data at the time of collection since the GPS coordinates of the field can potentially link the data back to individuals and because it contains information that, given the present climate, could be regarded as sensitive, such as CO_2 emissions from the soil. Instead of a GPS location, each field was given a number in the dataset. Field IDs and corresponding GPS locations were stored in a separate file on a password-protected computer. Lastly, the results of this research will be shared with the landowners.

Results

Statistical analysis

NMDS analysis

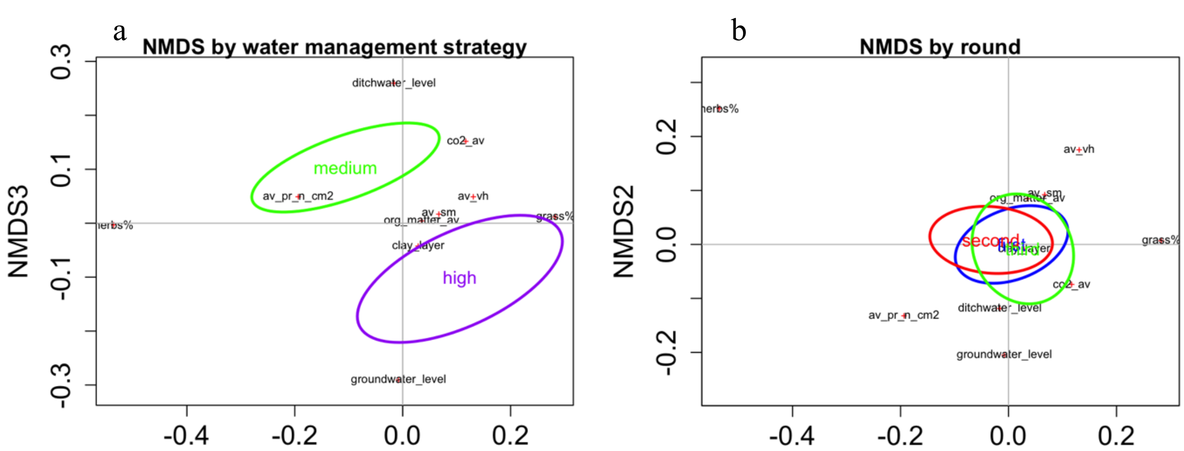

Figure 3: NMDS analysis with (a) an added layer of the water management strategy and (b) an added layer of the different rounds

Table 1: Pairwise adonis - water management strategies

pairs	SumsOfSqs	F.Model	R2	p.value	p.adjusted	Sig
1 medium vs high	0.4221474	18.01731	0.2573265	0.001	0.001	**

Table 2: pairwise adonis - rounds

pairs	SumsOfSqs	F.Model	R2	p.value	p.adjusted	sig
1 first vs second	0.07451788	2.734027	0.07442764	0.051	0.153	
2 first vs third	0.07132403	2.564390	0.07013355	0.058	0.174	
3 second vs third	0.14579416	4.883789	0.12559961	0.004	0.012	.

The NMDS graphs presented above serve as a valuable tool for observing the correlation between various variables. These graphs provide a visual representation of the relationships between the measured variables, offering insights into their interconnectedness. The stress level of the NMDS analysis is 0.106, which indicates a fair fit between the variables (stress < 0.2). The stress level is a measure of how well the data points fit in the graph and indicates the accuracy of the representation. In this case, with a fair fit, the representation is still usable as the stress level is still close to 0.1 (Dexter et al., 2018).

Figure 3a introduces an additional layer to the NMDS graph, specifically representing different management strategies; medium and high. From this it becomes evident that these different strategies yield distinct outcomes, as there is no overlap between them. This finding suggests that the different water management approaches impact the observed results. The layers can be considered significant according to the pairwise adonis test, considering the p-value and the F-value. The outcome of the pairwise adonis test is presented in Table 1. Considering the R-squared, the variation o the data is for 25.7% explained by the management strategy.

In contrast, figure 3b focuses on the different rounds, reflecting the progression of time throughout the growing season. The NMDS looks slightly different than Figure 3a because this graph has taken another dimension. There are three dimensions and figure 3a presents dimension 1 and 3, and figure 3b presents dimension 1 and 2. The three rounds are mainly overlapping, suggesting that the variables remained rather constant throughout this growing season. Only the variability between the second and third round is statistically significant.

Summarising boxplots

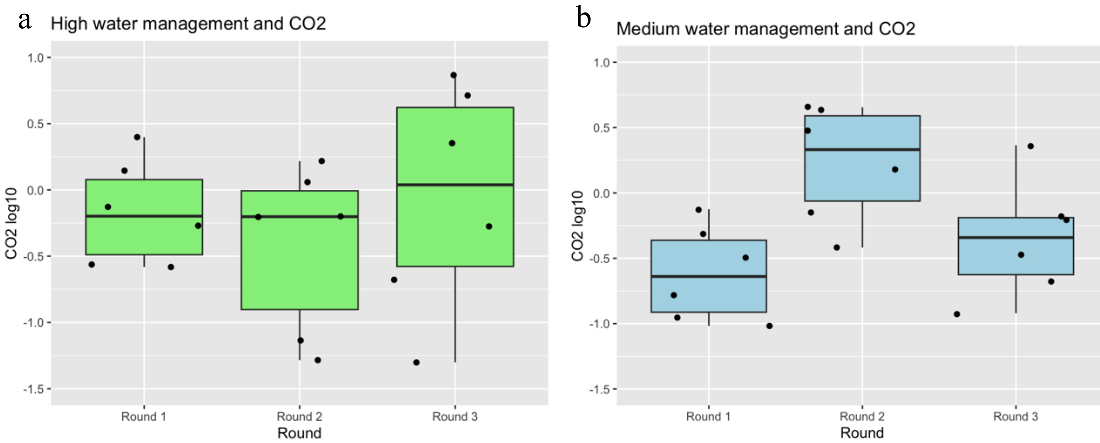

Figure 4: Boxplots summarising the CO_2 flux through the early growing season for a) high water management strategy and b) medium water management strategy.

Figures 4a and b present the log-transformed CO_2 flux (µmol m-2 s-1) by water management type during the growing season. This analysis does not show any clear trend. However, a notable observation is that the CO_2 emissions for the fields with a high water management strategy increased in the last round. Also, this plot has a large standard deviation and the highest measured values in CO_2 flux of the whole dataset. These outliers highly influence this specific boxplot. For the fields where a medium ditch water level is aimed, the CO_2 emissions are clearly higher during the second round. Compared to the other fields, the medium water management fields have lower standard deviation. The rounds (ANOVA: $F=0.776$, $P>0.05$) and the water management strategy (ANOVA: $F=0.023$, $P= 0.88$) do not show a significantly influence the CO_2 flux.

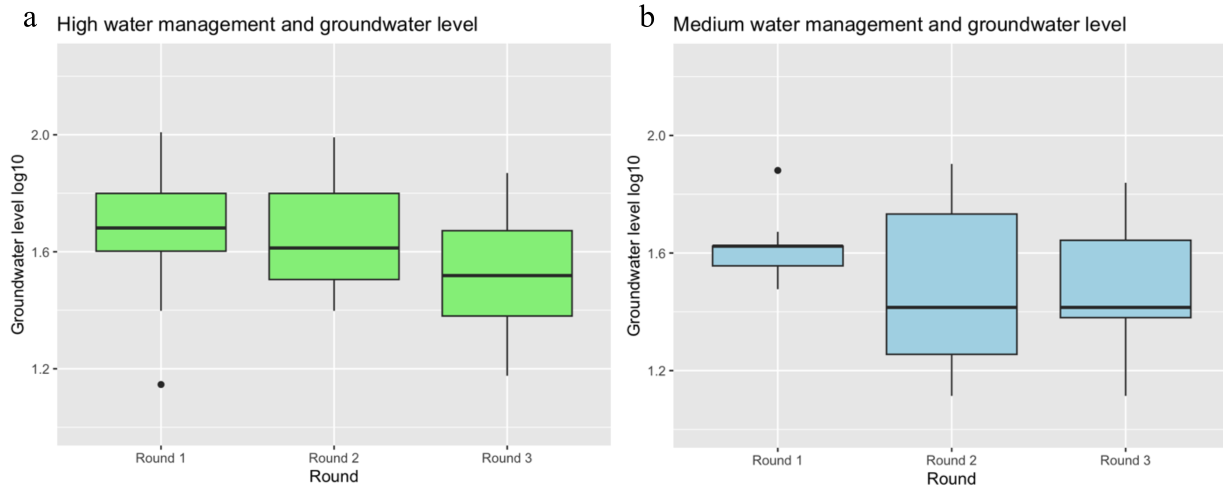

Figure 5:Boxplots summarising the groundwater level through the early growing season for a) high water management strategy and b) medium water management strategy.

The figures above show boxplots of the groundwater level throughout the growing season. The groundwater level that was measured in cm height distance from the field surface is log-transformed. A higher the groundwater level, gives a lower the value, and a lower groundwater level, gives a higher value. For the fields striving for a high water level, it can be seen that the groundwater level slightly increased in time. However, this relation is not significant (ANOVA: F=1.627, P>0.05).

The groundwater levels of the fields where a medium water level is strived for were higher compared to the other fields, but the relationship between the groundwater level and the management type is not significant (ANOVA: F=1.769, P>0.05). There is no trend visible in the groundwater level throughout the early growing season for medium water management fields.

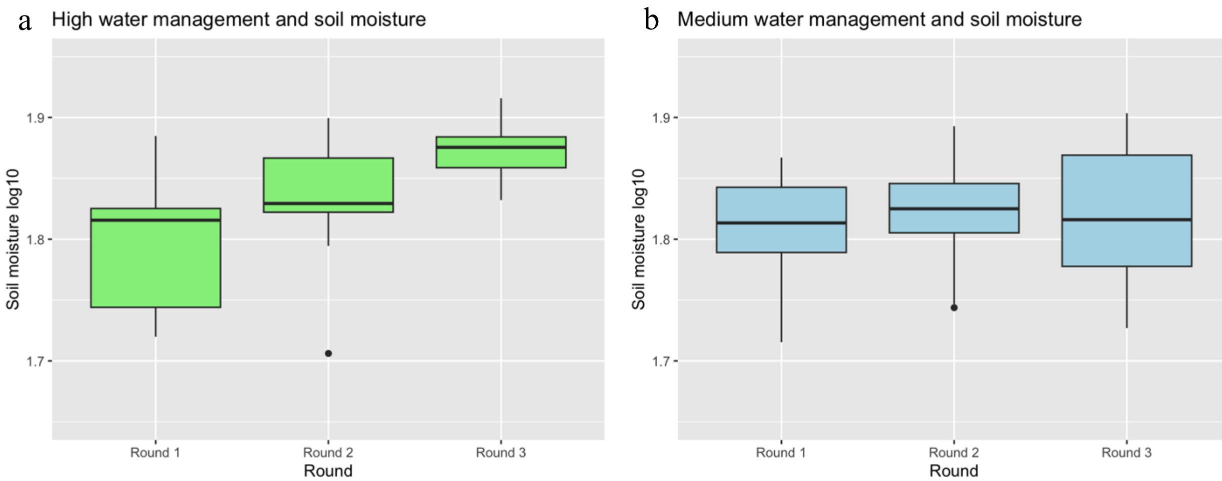

Figure 6: Boxplots summarising the soil moisture through the early growing season for a) high water management strategy and b) medium water management strategy.

The boxplots above summarise the soil moisture of the top 10cm of the fields between the water management strategies and during the rounds. For the fields adopting a medium water level strategy, the soil moisture remained rather stable throughout the growing season. The soil moisture has increased during the growing season for the fields that adopted a high water management strategy. However, this relation between the soil moisture and the rounds is not statistically significant (ANOVA: F=3.058, P>0.05). Comparing the water management strategies to each other, the soil moisture for the medium water management fields is higher during the first round. For the second and third rounds, the values were higher for the high water management fields. The water management strategy does not explain changes in the soil moisture (ANOVA: F=1.549, P>0.05).

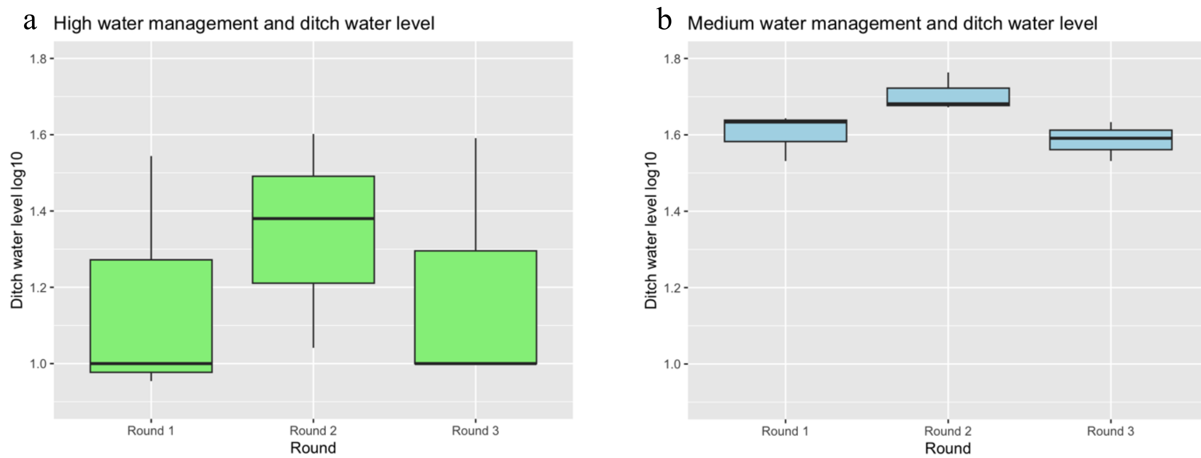

Figure 7: Boxplots summarising the ditch water level through the early growing season for a) high water management strategy and b) medium water management strategy.

Figure 7 shows the ditch water level per round by water management type. The Y-axis is the log transformed ditch water level, which is the distance in height between the field surface and the ditch water surface. Therefore, the higher the value, the lower the ditch water level compared to the field. For the high water management fields, the standard deviation is rather large and it can be seen that during the second round the ditch water level was lower. There is no clear trend through the season. For the medium water management fields, the ditch water level was very stable throughout the season, witch only a small decease in the second round. The standard deviation is very small indicating that the all the different fields have a very similar ditch water level. A two-way ANOVA indicates that the variation of the data is for 53% explained by the management type. This is deemed significant by the p-value (ANOVA: R2=0.529, F=15.72, P<0.001). The rounds do not give a significant relation (ANOVA: F=0.819, P>0.05)

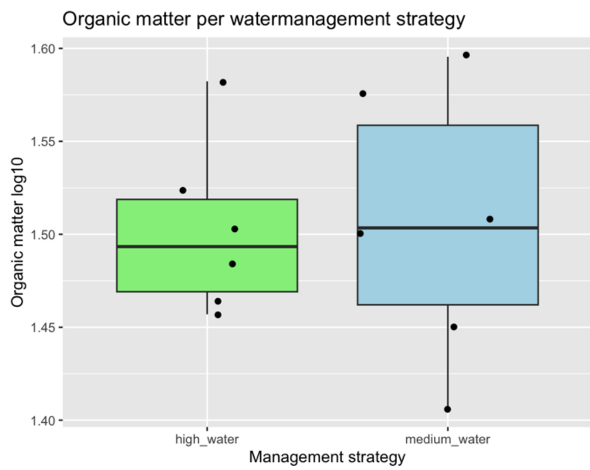

Figure 8: A boxplot summarising the SOM per water management strategy.

A boxplot for each water management type of SOM is presented in Figure 8. There are six data points for each of the strategies as the organic matter was only measured in the first round for two locations per field. The medians lie close to each other. However, it can be seen that the standard deviation for the medium water management type is larger than for the high water management style, as there is more variability in the data points. There is no significant relation between the water management strategy and the soil organic matter (ANOVA: F=0.009, P>0.05).

Regression models

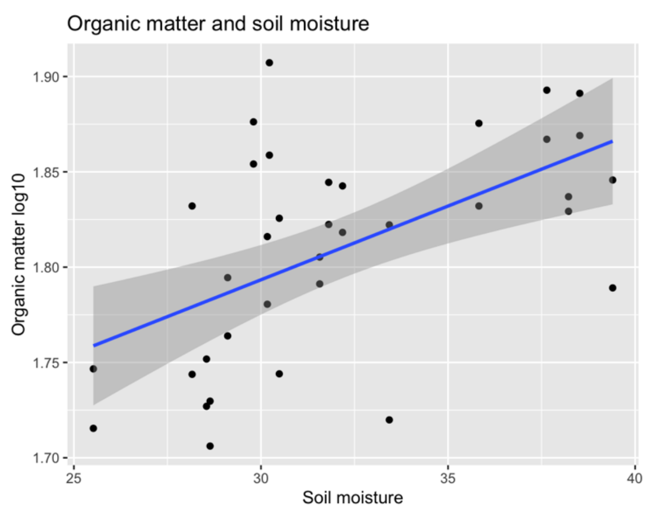

Figure 9: Regression model of SOM and soil moisture

There is a positive and significant trend between the soil organic matter (log-transformed) and the soil moisture (ANOVA: F=15.81, R2=0.317, P < 0.001). The graph therefore suggests that a higher soil organic matter content gives a higher soil moisture value as shown in the regression model (Figure 9). Considering the R-squared, the soil moisture explains 31.7% of the variance in the soil moisture.

The regression model depicted in Figure 10 presents the correlation between CO_2 levels (log10 transformed) and soil moisture. As suggested by the trend line, the graphical representation indicates a positive relation between CO_2 and soil moisture, suggesting that higher soil moisture percentages are related to higher CO_2 fluxes. However, the data points are still rather dispersed, and the relationship is statistically not significant (ANOVA: F=4.093, P>0.05).

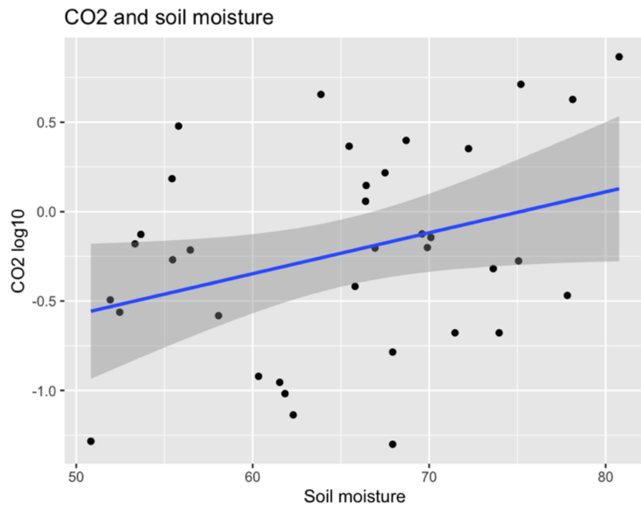

Figure 10: Regression model of CO_2 and soil moisture

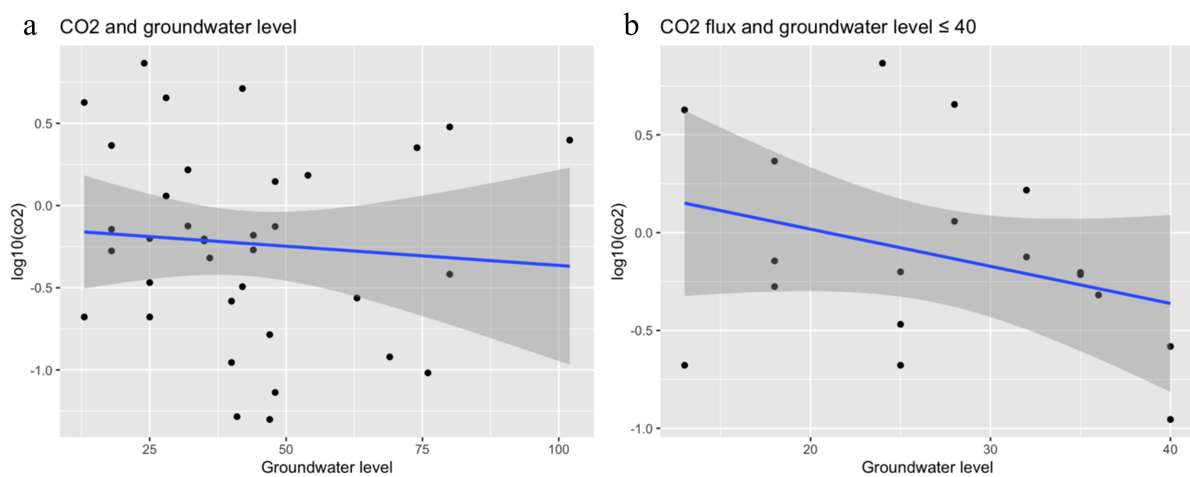

Figure 11: Regression model of CO_2 and groundwater level. Figure 11a includes all groundwater levels and Figure 11b has filtered out the groundwater level values up to 40cm under surface.

The CO_2 flux (log-transformed) and the groundwater level do not show a trend (see Figure 11a). The trendline is close to horizontal. Also, statistically, the correlation is not significant (ANOVA: F= 0.249, P>0.05). Only looking at the groundwater level values that are equal to or lower than 40 cm under the field surface (see Figure 11b), the trendline slightly changes. However, here the relation also is not significant (ANOVA: F=1.905, P>0.05).

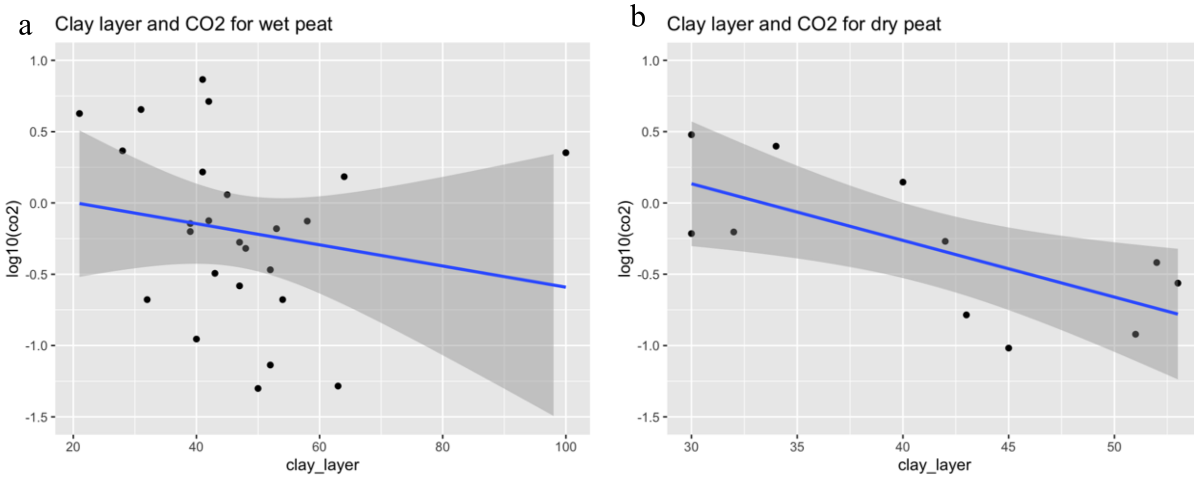

Figure 12: Regression model of the clay layer thickness and CO_2 flux. Figure 12a presents locations where the peat was equal to or lower than the groundwater level. Figure 12b includes only data where the peat was above the groundwater level.

The presented graphs above depict the relationship between CO_2 levels and clay layer thickness. Figure 12a illustrates this relationship in the data where the entire peat layer is underneath or equal to the groundwater level, while Figure 12b represents areas where a portion of the peat layer remained above the groundwater level. There is no clear, nor significant trend in the clay layer and CO_2 flux for wet peat (ANOVA: F= 0.793, P>0.05). For dry peat, there is a significant trend (ANOVA: F=8.114, R2=0.474, P<0.05). This suggests that the variation in CO_2 emissions for these areas is for 47.4% explained by the clay layer thickness. What can also be observed, however, is that the number of data points for this graph is low.

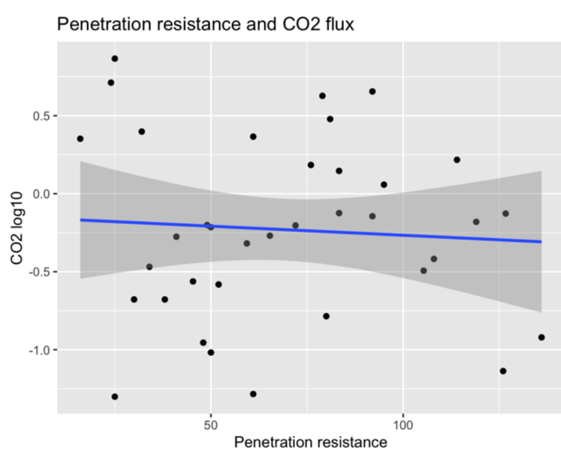

Figure 13: Regression model of the penetration resistance and the CO_2 flux.

Figure 13 shows a regression model of the penetration resistance and the CO_2 flux (log-transformed). The two variables do not show a relationship, as the values are widespread and the trendline is close to horizontal and not significant (ANOVA: F=0.152, P>0.05).

Weather data

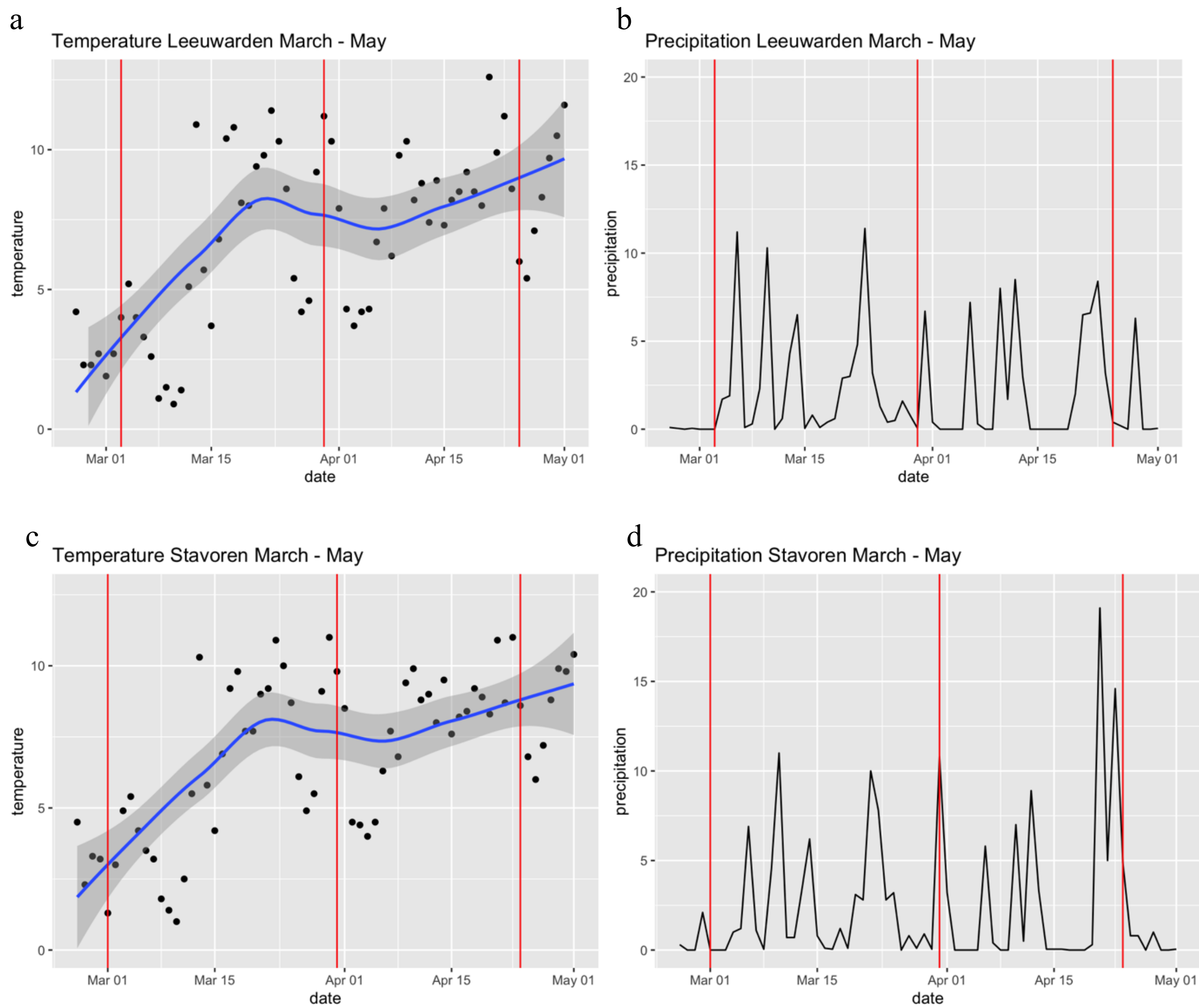

Figure 14: Weather data presented in line graphs. a) daily average temperature Leeuwarden, b) daily precipitation Leeuwarden, c) average daily temperature Stavoren, d) daily precipitation Stavoren

Figure 13 illustrates the average daily temperature and the daily precipitation during the period from March to May 2023 in Leeuwarden and Stavoren. The weather data is retrieved from two KNMI weather station (*KNMI - Daggegevens van het weer in Nederland*, n.d.). The data of weather station Leeuwarden represents the weather of the fields adopting a high water management strategy, and the data of the weather station in Stavoren represents the other fields. The vertical red lines present the dates on which the fieldwork was conducted. The average daily temperature shows for both locations an initial increase of approximately 5 degrees Celsius from March 1st to around March 20th. From the end of March onward, the temperature remained rather stable until at least the beginning of May. The daily precipitation for both locations is mostly similar. One notable difference is the precipitation at the end of April which was higher for the weather station in Stavoren than the weather station in Leeuwarden.

Table 3: Average daily temperature and daily precipitation at the weather stations Stavoren and Leeuwarden.

Location	Date	Temperature °C	Precipitation mm	Location	Date	Temperature °C	Precipitation mm
Leeuwarden	2023/02/27	2.3	0	**Stavoren**	2023/02/25	4.5	0.3
Leeuwarden	2023/02/28	2.7	0.05	**Stavoren**	2023/02/26	2.3	0
Leeuwarden	2023/03/01	1.9	0	**Stavoren**	2023/02/27	3.3	0
Leeuwarden	2023/03/02	2.7	0	**Stavoren**	2023/02/28	3.2	2.1
Leeuwarden	2023/03/03	4	0	**Stavoren**	2023/03/01	1.3	0
Leeuwarden	2023/03/26	5.4	0.4	**Stavoren**	2023/03/27	4.9	0.8
Leeuwarden	2023/03/27	4.2	0.5	**Stavoren**	2023/03/28	5.5	0.1
Leeuwarden	2023/03/28	4.6	1.6	**Stavoren**	2023/03/29	9.1	0.9
Leeuwarden	2023/03/29	9.2	0.8	**Stavoren**	2023/03/30	11	0.05
Leeuwarden	2023/03/30	11.2	0.05	**Stavoren**	2023/03/31	9.8	10.8
Leeuwarden	2023/04/21	12.6	6.5	**Stavoren**	2023/04/20	8.3	0.3
Leeuwarden	2023/04/22	9.9	6.6	**Stavoren**	2023/04/21	10.9	19.1
Leeuwarden	2023/04/23	11.2	8.4	**Stavoren**	2023/04/22	8.7	5
Leeuwarden	2023/04/24	8.6	3.2	**Stavoren**	2023/04/23	11	14.6
Leeuwarden	2023/04/25	6	0.4	**Stavoren**	2023/04/24	8.6	4.9

Above, a table is presented with the average daily temperature and daily precipitation of the days when the data was retrieved and four days before. The first four columns of the table show the values for Leeuwarden (high water management fields), and the last four columns of the table show the values for Stavoren (medium water management fields). The blue row presents the day that the data was collected. The exact dates of the data collection differ between the locations. From the table it can be seen that for both locations the temperature has increased, as the temperature was lowest for the week of the first round, and highest during the week of the last round. Looking at the precipitation, it was slightly higher around the second round compared to the first round, but the daily precipitation was clearly highest during the 5 days up to the last round.

Interview

There were two interviews held with the landowners of the fields. First, questions about the water management strategy were asked. For the high water level management the ditch water level was aimed as high as possible. Realizing, a high water level in the ditch was done by managing a weir. Infiltration of the water into the soil was promoted by foot drains. The ditch water level for these fields was increased since around 2016, after a rather long history of deep drainage. For the medium water management, the strategy was similar, but here the aim was to get the water up to 40 cm under the field surface. The interviews demonstrated that, financially, having a high ditch water level, or increasing the ditch water level is not appealing. There are however several local initiatives and programs that financially support farmers to increase the water table, but it is according to the interviewees still not as financially beneficial as having a lower water table. In addition, managing a higher water table is related to a later start-up in the growing season due to the wet and cold conditions, and makes it challenging to go on the field with farming vehicles. One of the motivations to still increase the water table is to be more resistant to droughts. Other motivations were mostly driven by their intrinsic values regarding nature. For example, promoting more biodiversity and lower CO_2 emissions were mentioned as reasons for having a higher water table. For these farmers, the benefits and disadvantages are balancing each other out. Also, one farmer mentioned that weather influences the growth of the land more than having a high water table. Both farmers believe that managing a higher water table can be adopted on a larger scale.

Discussion

This research focuses on the effect of the water management strategy on the CO_2 flux, the groundwater level, and the soil moisture during the early growing season. The results will now be discussed and compared to the expectations. The results revealed diverse values for the CO_2 flux (Figure 3). For the medium water management fields, the values during the second round were slightly higher than in the other rounds. In the third round, the high-water management fields showed very high CO_2 fluxes compared to the other rounds. A possible explanation for this increase in the last round could be the relief in the field that was caused by grazing cows that were recently in the field. Therefore, it was not possible to put the CO_2 chamber on a flat surface. To still prevent oxygen from coming into the chamber, it was pushed a bit more into the ground filling a part of the chamber with soil and reducing the air volume. This potentially resulted in higher CO_2 readings than the actual values. Therefore, these data points have high uncertainty. There was no trend found in the CO_2 flux through the rounds. This is different from the hypothesis, as an increase in CO_2 emissions was expected during the early growing season. Considering the different water management types, the CO_2 flux was generally higher for the high-water management fields. This also differs from the hypothesis, as it was expected that the CO_2 flux would be higher for the medium water management fields. Throughout the early growing season, the groundwater table was expected to decrease. However, the results show that it remained stable for the medium water management fields and slightly increased for the high water management fields. The groundwater table was on average slightly higher for the medium water management fields, which also goes against the hypothesis. The soil moisture showed an unexpected development during the growing season. It was expected to decrease in time, but instead, there was an increase for high water management fields, and the soil moisture on the medium water management fields remained stable. There was no clear difference in the average values between the water management strategies. In the last round at the high water management fields, there was a lot of surface water. Cows had grazed on the two of the fields and the holes caused by their grazing were filled with water. Consequently, the top 10cm of the soil was wet. However, the groundwater level was often still deeper into the soil. The ditch water was significantly higher for the high water management fields, which is not surprising because the ditch water level is aimed to be as high as possible for these fields. However, there are slight differences between the three fields. Comparing the ditch water level to the groundwater table and the soil moisture gives some interesting insights. For the high water management fields, the ditch water level was higher compared to the other fields. Additionally, the soil moisture increased during the early growing season to values surpassing the values of the other fields. However, the groundwater level was lower for the high water management fields. There is a lot of variation in the groundwater level for both the high and medium water management fields. The two management strategies have no clear difference in soil organic matter. A relation between the SOM and soil moisture was found. A higher SOM supports more water to be absorbed. However, the surface water might have influenced this relation. The soil moisture was expected to influence the CO_2 flux. However, the results do not confirm a relation between soil moisture and CO_2 flux. In addition, a higher groundwater level was expected to decrease the CO_2 flux, but this relation has also not been confirmed by the data. The clay layer was expected to influence the CO_2 flux. A thicker clay layer could potentially keep the CO_2 from being released into the atmosphere. The results show a small decrease in CO_2 flux with a thicker clay layer, based on locations where there was a dry layer of peat. There was no trend found between the CO_2 flux and the penetration resistance. The weather was rather stable during the study which was also different than anticipated. The temperature was expected to increase, while the precipitation would decrease. Instead, the temperature only slightly increased and the precipitation increased through the early growing season.

From these results, it can be said that it is hard to predict the trends of the CO_2 flux, groundwater level, and soil moisture during the growing season based on the water management strategies practiced. As was also said during one of the interviews, the weather highly influences the outcome variables. As there are many variables to consider in this research, there is a lot of uncertainty. The different water management strategies have generally different values but are opposite from what was expected. The medium water management fields have more stability through the growing season. For the high water management fields, it was seen that the water does not infiltrate well into the deeper layers of the soil. Even though these fields have a high ditch water level and surface water, the groundwater level is still rather low. The capacity of the soil to absorb the water is low. The results also do not show clear trends on the influence of the groundwater level and soil moisture on CO_2 emissions.

a

b

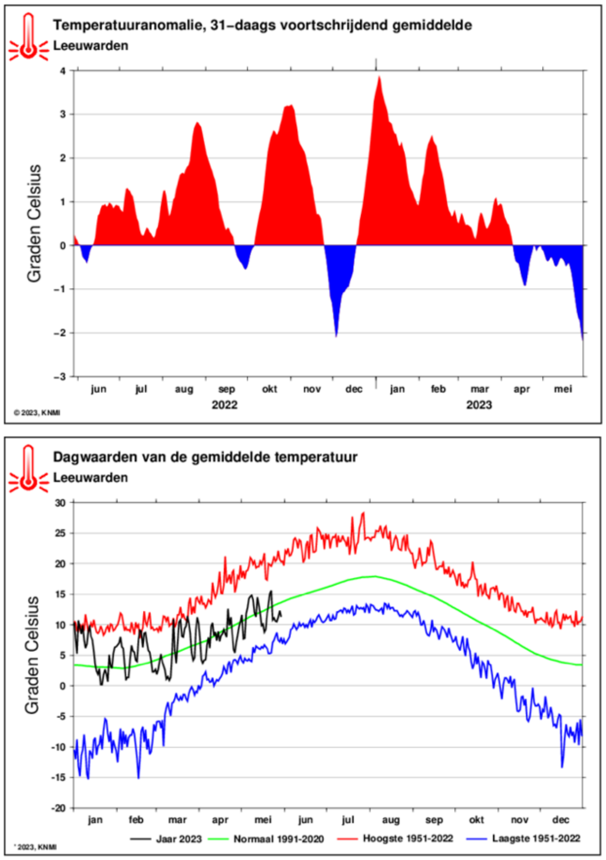

Figure 15: Temperature through the growing season compared to the reference period (1991-2020). Figure 14a shows the anomaly and Figure 14b shows the daily average temperatures.

The results of this study are different from the hypothesized outcome. This is primarily due to the unexpected development of the weather during the growing season. The weather was expected to become warmer and dryer, which is common during the months that the research was conducted in this region. However, instead, the temperature remained rather stable. To illustrate that the weather was different from normal graphs from the KNMI are added (see Figures 15 and 16) (*KNMI - Grafieken van het lopende jaar*, n.d.). These graphs compare the growing season temperatures and precipitation of this year, with the reference period 1991-2020. For Figure 15 the Y-axes show the degrees in Celsius. Figure 15a presents the anomaly of the temperature. Figure 15b the temperature of this year (black line) and compares it to the normal values (green line). The blue line presents the lowest daily values of the reference years and the red line is the highest. In the first three months of the year (2023) it was generally warmer than the reference years. For the months from April until May, the temperatures were lower than average.

Figure 16 shows the precipitation amount of this year, compared to the reference period (1991-2020). The black line presents this year, the green line presents the normal amount of precipitation, and the blue and red lines present the lowest and highest amount of precipitation since 1974. The precipitation was lower than average before the data collection started (January-February), and more precipitation than average was seen in March until the beginning of May, which was during the data collection.

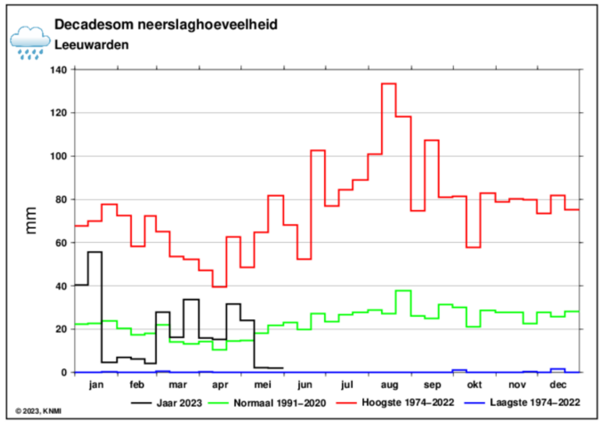

Figure 16: The graph shows the precipitation average compared to the reference period (1991-2020) and the highest and lowest measured value since 1974.

As the weather during the early growing season was different than usual. This has affected the results. The stability and rise seen in the groundwater level is likely to be caused by the increase in rainfall. In addition, the rainfall also caused surface water on the high water management fields which in turn caused the soil moisture of the top 10 cm to increase. As the temperature hardly increased, the soil moisture did not evaporate quickly. It is possible that the weather also played a role in the stability of the CO_2 flux. It was expected to decrease through the early growing season due to a decrease in groundwater level and soil moisture caused by the weather. If the weather would have developed as expected, the CO_2 emissions could have been increasing as oxygen would more easily reach the carbon in the soil.

There is a lot of uncertainty in predicting CO_2 emissions of peatlands, which has also been seen in other studies. There is a relation between the groundwater level and CO_2 flux, but measuring this on a small scale comes with many uncertainties (Tiemeyer et al., 2016). A study conducted by Tiemeyer et al. (2016) showed that the CO_2 flux was dependent on the groundwater level within the fields, but using the complete dataset of multiple fields, there was no clear trend. The small scale of this study could also explain why there were no trends found. Another factor could be the high soil moisture due to the surface water in the last round. The history of the fields should also be considered as this can influence the outcomes. Soil can be water repellent, which is true for various soil types in the Netherlands including peat. If the soil is dry for a longer period, due to dry periods or active deep drainage, the soil starts repelling the water. This can cause surface runoff when there is a lot of rainfall, and it prevents the water from infiltrating into the soil (Dekker & Ritsema, 2000). In addition, theory suggests that dry peat goes hand in hand with higher CO_2 emissions. This can explain the lower groundwater level and higher CO_2 emissions of the high water management fields as these fields know a history of deep drainage. According to Schrier-Uijl et al. (2014), drained land, that acts as a carbon source, can be rewetted, and turned into a carbon sink again. However, this can take up to 15 years. This could possibly explain why, for the high water management fields, the water did not infiltrate well, or rather slowly. These fields are being rewetted for about seven years now, so it might still take several years for turning these fields into carbon sinks. Considering the CO_2 flux, it is therefore suggested to avoid deep drainage and to try to increase the groundwater table. In addition, this would help to avoid further land subsidence, which is a prominent issue in Friesland. However, in recent years, droughts were frequent in the Netherlands, which might have influenced the ability of the soil to absorb the water and can slow down the rewetting process. The agriculturist had to deal with droughts in 2018, 2019, 2020, and 2022 (Van der Wiel, Batelaan & Wanders, 2023; *KNMI - Meerjarige Droogtes in Nederland Waterland?*, 2022). These droughts are likely to have kept the groundwater level from increasing. Two out of the four forecast weather scenarios provided by the KNMI, expect the Netherlands to become dryer (*KNMI – Droogte*, n.d.). Due to climate change, droughts are expected to affect the Netherlands more frequently in especially the summer, and evaporation is expected to increase (Van der Wiel, Batelaan & Wanders, 2023). Also, even though the average precipitation in the summer is expected to decrease, the chance of receiving large amounts of precipitation in a short time is increasing (*KNMI - Droger én natter in Nederland, hoe kan dat?*, 2022). A high water management strategy would support the infiltration of the water into the soil, preventing surface water, evaporation, and runoff. Therefore, increasing the groundwater table would make the agriculturists more resilient to these extremes. However, production is also an important aspect, to feed the growing population. In addition, it should be feasible for farmers financially to increase the groundwater table of their fields.

The data in this study was limited due to time constraints. This research could therefore be significantly improved by expanding the data collection. The study should be conducted over a longer period around the growing season and repeated over several years. In addition, the intervals between data collection rounds can be shorter and more fields should be added. This would probably show stronger trends between variables and through the growing season and would allow one to analyse the effect of the weather.

Conclusion

In conclusion, this study investigated the impact of two different water management strategies on CO_2 emissions, groundwater level, and soil moisture during the early growing season at clay-on-peat grassland meadows in Friesland, the Netherlands. Generally, there was a lack of clear trends throughout the early growing season and hardly any significant differences in the variables between the management strategies. The stable weather conditions during the study period, contrary to the anticipated increase in temperature and decrease in precipitation, highlighted the impact of weather on the results. In addition, the infiltration capacity of the soil seems to play an important role. For the high water management fields, the water did not infiltrate well into the soil. Actively rewetting the field supports the capacity to hold the water, but this is timely, especially for fields with a history of deep drainage. However, eventually, it can lower CO_2 emissions and build resilience against droughts. In this study, there were no clear trends found regarding the effect of the two water management strategies on groundwater fluctuations, CO2 emissions, and soil moisture during the early growing season. For further research, it is suggested to repeat this study over several years and to include more fields. This might allow one to understand the actual effect of the weather and to find trends when the temperature and precipitation changes are different. Also, the development of the soil's capacity to hold water can be further investigated.

References

4p1000. (n.d.). Discover the Initiative: Discover. Retrieved on February 21, 2023, from https://4p1000.org/discover/?lang=en

Baird, A. J., Belyea, L. R., Comas, X., Reeve, A. S., & Slater, L. D. (Eds.). (2009). *Carbon Cycling in Northern Peatlands. Geophysical Monograph Series.* doi:10.1029/gm184

Bakker, H., & Schelling, J. (1989). Systeem van bodemclassificatie voor Nederland: De hogere niveaus. *Pudoc,* 1–217.

Dekker, L. W., & Ritsema, C. J. (2000). Wetting patterns and moisture variability in water repellent Dutch soils. *Journal of Hydrology*, *231–232*, 148–164. https://doi.org/10.1016/S0022-1694(00)00191-8

Dexter, E., Rollwagen-Bollens, G., & Bollens, S. M. (2018). The trouble with stress: A flexible method for the evaluation of nonmetric multidimensional scaling. *Limnology and Oceanography: Methods*, *16*(7), 434–443. https://doi.org/10.1002/lom3.10257

EASAC. (2018). *Opportunities for soil sustainability in Europe*.

Erkens, G., Van der Meulen, M. J., & Middelkoop, H. (2016). Double trouble: subsidence and CO2 respiration due to 1,000 years of Dutch coastal peatlands cultivation. *Hydrogeology Journal*, *24*(3), 551.

FAO, ITPS, GSBI, SCBD, and EC. 2020. *State of knowledge of soil biodiversity - Status, challenges and potentialities, Report 2020.* Rome, FAO. https://doi.org/10.4060/cb1928en

Hussain, S., Hussain, S., Guo, R., Sarwar, M., Ren, X., Krstic, D., Aslam, Z., Zulifqar, U., Rauf, A., Hano, C., & El-Esawi, M. A. (2021). Carbon sequestration to avoid soil degradation: a review on the role of conservation tillage. *Plants (Basel, Switzerland)*, *10*(10). https://doi.org/10.3390/plants10102001

Kazemian, S. (2018). Organic Soils and Peats. Encyclopedia of Engineering Geology. P691-695. https://doi.org/10.1007/978-3-319-73568-9_214

KNMI - Daggegevens van het weer in Nederland. (n.d.). Retrieved June 2, 2023, from https://www.knmi.nl/nederland-nu/klimatologie/daggegevens

KNMI - Droger én natter in Nederland, hoe kan dat? (2022). Retrieved June 3, 2023, from https://www.knmi.nl/over-het-knmi/nieuws/droger-en-natter-in-nederland

KNMI - Droogte. (n.d.). https://www.knmi.nl/kennis-en-datacentrum/uitleg/droogte

KNMI - Grafieken van het lopende jaar. (n.d.). https://www.knmi.nl/nederland-nu/klimatologie/grafieken/jaar

KNMI - Meerjarige droogtes in Nederland waterland? (2022, August 2). KNMI. Retrieved June 3, 2023, from https://www.knmi.nl/over-het-knmi/nieuws/meerjarige-droogtes-in-nederland-waterland

KNMI. (2021). *KNMI 2021: KNMI Klimaatsignaal'21: hoe het klimaat in Nederland snel verandert*, De Bilt, 72 pp.

Kopittke, P. M. et al. (2019). Soil and the intensification of agriculture for global food security. *Environ. Int*. https://doi.org/10.1016/j.envint.2019.105078

Oertel, C., Matschullat, J., Zurba, K., Zimmermann, F., & Erasmi, S. (2016). Greenhouse gas emissions from soils—a review. *Chemie Der Erde - Geochemistry - Interdisciplinary Journal for Chemical Problems of the Geosciences and Geoecology*, *76*(3), 327–352. https://doi.org/10.1016/j.chemer.2016.04.002

Provinsje Fryslân. (2015). Feangreidefisy: In duorsume takomst foar it Fryske Feangreidegebiet. https://www.wetterskipfryslan.nl/documenten/bestuur/waterbeheerplan-2016-2021/2Veenweidevisiejanuari2015.pdf

Rutgers, M. & Mulders, C. (2008). Soil ecosystem profiling in the Netherlands with ten references for biological soil quality. RIVM. https://www.rivm.nl/bibliotheek/rapporten/607604009.pdf

Schrier-Uijl, A. P., Kroon, P. S., Hendriks, D. M. D., Hensen, A., Van Huissteden, J., Berendse, F., & Veenendaal, E. M. (2014). Agricultural peatlands: Towards a greenhouse gas sink – a synthesis of a Dutch landscape study. *Biogeosciences*, *11*(16), 4559–4576. https://doi.org/10.5194/bg-11-4559-2014

Spinoni, J., Vogt, J. V., Naumann, G., Barbosa, P., & Dosio, A. (2018). Will drought events become more frequent and severe in Europe?. *International Journal of Climatology*, *38*(4), 1718-1736.

Tiemeyer, B., Albiac Borraz, E., Augustin, J., Bechtold, M., Beetz, S., Beyer, C., Drösler, M., Ebli, M., Eickenscheidt, T., Fiedler, S., Förster, C., Freibauer, A., Giebels, M., Glatzel, S., Heinichen, J., Hoffmann, M., Höper, H., Jurasinski, G., Leiber-Sauheitl, K., … Zeitz, J. (2016). High emissions of greenhouse gases from grasslands on peat and other organic soils. *Global Change Biology*, *22*(12), 4134–4149. https://doi.org/10.1111/gcb.13303

Van den Akker, J. J. H., Massop, H. T. L., & Rietra, R. P. J. J. (2018). *Potentiële emissiereductie broeikasgassen Fries veenweidegebied: Waterhuishoudkundige en bodembeheermaatregelen om broeikasemissies te beperken*. https://doi.org/10.18174/464675

Van den Akker, J.J.H., Hendriks, R.F.A., Pleijter, M. (2012). CO2 Emissions of Peat Soils in Agricultural use: Calculation and Prevention: *Agrociencia 16(1) 43-50*

Van der Wiel, K., Batelaan, T. J., & Wanders, N. (2023). Large increases of multi-year droughts in north-western Europe in a warmer climate. *Climate Dynamics*, *60*(5–6), 1781–1800. https://doi.org/10.1007/s00382-022-06373-3

Vitens, Provinsje Fryslân & Wetterskip Fryslân. (2019). *Grondwater atlas van Fryslân*. https://www.fryslan.frl/_flysystem/media/Grondwateratlas%20Frysl%C3%A2n%202020.pdf

World Resources Institute. (2019). World Greenhouse Gas Emissions: 2019.

Appendices

Appendix 1: Fieldwork sheets

Fieldsheet (round 1)

Date: Field ID: Ditch water level:

Variable/sample ↓	Location →	2m	7 meter	mid-field
Groundwater level (cm under surface)				
Soil moisture field (%) (check off)		1. 2. 3.	1. 2. 3.	1. 2. 3.
Soil profiles (and photo)				
Soil Organic Matter (SOM) (check off)				
Penetration resistance (cm) Cone = Spring =		1. 2. 3.	1. 2. 3.	1. 2. 3.
Vegetation height (cm)		1. 2. 3.	1. 2. 3.	1. 2. 3.
Percentage grass/herbs (%)				
CO_2 emission (check off)		No measurement		
Grain Size (only if field not sampled before (2022) by research team)				

Fieldsheet (rounds 2 & 3)

Date:

Field ID:

Ditch water level (cm under surface):

Variable/sample ↓	Location →	2m	7 meter	mid-field
Groundwater level (cm under surface)				
Soil profile (and foto)				
Soil moisture field (%) (check off)		1. 2. 3.	1. 2. 3.	1. 2. 3.
Penetration resistance (cm) Cone = Spring =		1. 2. 3.	1. 2. 3.	1. 2. 3.
Vegetation height (cm)		1. 2. 3.	1. 2. 3.	1. 2. 3.
Percentage grass/herbs (%)				
CO_2 emission (check off)		No measurement		

Appendix 2: Lab sheet

Date:

Location:

Samples retrieved on:

Field ID↓	Variable →	Soil Organic Matter Ash weight (%)
Field ID:		1. 2. 3.
Field ID:		1. 2. 3.
Field ID:		1. 2. 3.
Field ID:		1. 2. 3.
Field ID:		1. 2. 3.
Field ID:		1. 2. 3.

Appendix 3: Survey questions

English

- What is the average water level in cm you aim to have relative to the ground level of the field during the growing season?
- What is being done to achieve and maintain this level during the growing season?
- If anything, what is done to support infiltration and water storage of the water on the field?
- So far, do you manage to maintain this water level throughout the growing season? If not, what are the main challenges you face when attempting to achieve/maintain this high water level?
- Do you experience any negative effects of managing the land to maintain high water levels? (for example; reduced yield, soil compaction, or loss in soil fauna?)
- What would you say are the main benefits of high water levels and in your opinion do they outweigh the downsides?
- Do you get any financial support (directly or indirectly) for raising the water levels (for example - Valuta voor Veen (direct) or specific meadow bird subsidies that also require high(er) water levels (indirect))
- Is it financially worth it to maintain high(er) water levels, and do you think this could be implemented on a large scale (in the near future)?

Dutch

- Wat is het gemiddelde waterpeil in cm dat u probeert aan te houden ten opzichte van het land tijdens het groeiseizoen?
- Wat voor maatregelen neemt u om dit waterpeil aan te houden?
- Wat wordt er eventueel gedaan om de infiltratie en wateropslag van het water op het veld te ondersteunen?
- Lukt het u tot dusver om dit waterpeil gedurende het hele groeiseizoen te handhaven? Zo niet, wat zijn de belangrijkste uitdagingen waarmee u wordt geconfronteerd bij uw pogingen om dit hoge waterpeil te bereiken/handhaven?
- Ervaart u negatieve effecten van het beheer van het land om het waterpeil hoog te houden? (bijvoorbeeld; verminderde opbrengst, bodemverdichting, of verlies van bodemfauna?)
- Wat zijn volgens u de belangrijkste voordelen van hoge waterstanden en wegen die volgens u op tegen de nadelen?
- Krijgt u financiële steun (direct of indirect) voor het verhogen van het waterpeil (bijvoorbeeld - Valuta voor Veen (direct) of specifieke weidevogel subsidies die ook een hoog(er) waterpeil vereisen (indirect))?
- Is het financieel de moeite waard om hoge(re) waterstanden te handhaven, en denkt u dat dit op grote schaal (in de nabije toekomst) kan worden toegepast?