End report DK2A

Targeted regulation of fertilisers to obtain sustainable intensification.

Investigating the potential for natural break-down of pollutants in the subsurface groundwater.

Central Denmark Region

Horsens Kommune

AARHUS UNIVERSITY

Content

1. Summary

Problem

Agriculture and the open land has a vital part to play in climate adaptation. A healthy vegetation can decrease higher temperatures and provide food. The buffer ability of the soil can retain water and thereby prevent flooding in low lying areas downstream. The buffer ability of the soil to retain water, and thereby give good conditions for the plants, depends on several factors such as texture (amount of clay and sand), structure (single particles or crumb structure), content of humus and the depth where the drainage in the soil are placed. Many of these factors the farmers can change by the way he cultivates the soil.

In Denmark predictions on future climate are foreseeing a rise in temperature of approximately 3 ºC, dryer summers and increasing precipitation during wintertime. The predicted change can cause lower yields due to water shortage during summertime, and groundwater flooding and increased leaching of nutrients during wintertime. Thus the goal in a climate adaptation perspective must be to capture the nutrients before they leave the field and use the buffer capacity of the soil to retain water.

Pilot area

The Lillerupgaard pilot area are intensively farmed fields. In many climate adaptation studies the approach would be to initiate intense geological investigations, set up geological and hydrogeological models. Finally a computer driven model would point out vulnerable areas where actions should be taken. In this study a dialogue driven process has been chosen. The farmer Martin Mogensen brings in his local knowledge and knowledge about farming in practice. The region and the municipality brings knowledge about administrative tools and state of the surrounding environment. Finally Aarhus University has introduced state of the art investigation techniques. Together we have developed the project and exchanged knowledge.

A number of new and traditional techniques have been tested and used in the project:

- Geophysical mapping with Ground Conductivity Meter and t-TEM
- A prototype of a magnetometer that can map tile-drain pipes
- Drill holes for geological description
- Drain water samples
- Drain water flow measurements
- Chemical analysis of the drain water
- Precipitation measurements
- N-min sampling
- Yield measurements

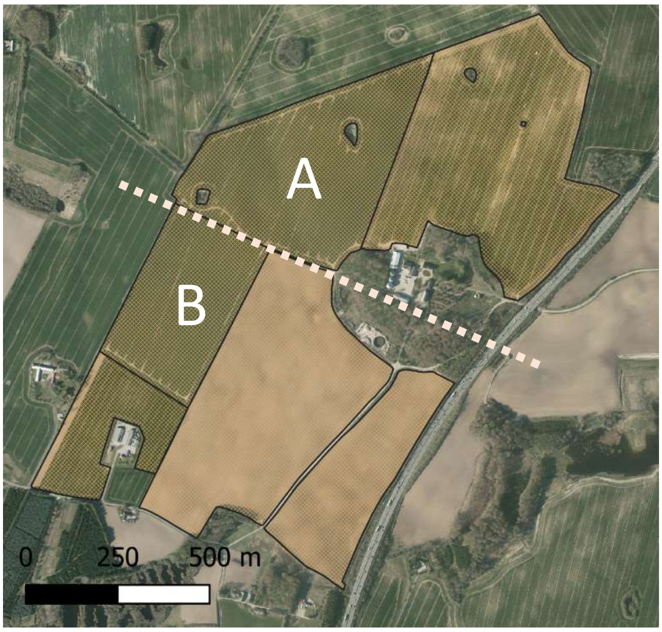


Figure 1. Pilot area Lillerupgaard, field area A and field area B

Results

The most important results of the investigations are the in-depth knowledge about how the different parts of the fields interact with the surrounding environment. E.g. at the most intensive investigated field it is clear that almost no groundwater is generated in this particular area due to the underlying fat clay (field area A in figure 1). The field interacts with the surroundings via the drain with an almost instant increase in flow and leaching during winter rain. Thus this field has a strong potential in climate adaptation perspective to retain water (buffercapacity) reducing the risk of flooding in downstream areas. The leached nitrogene from this field is neutralised in the newly formed Gedved Lake, and therefore does not contribute to the leaching of nitrogene to Horsens Fjord.

The field (field area B in figure 1) south of field area A is situated in a more flat area and the geologic composition is different. In this area groundwater is generated, accordingly other considerations are necessary and different measures have to be taken. In-depth knowledge makes it possible to recommend diverse measures for different parts of the fields.

A reduced investigation program could be the following:

1. GCM geophysical investigations with a penetration depth of about 5 meters. The top 5 meters are of special interest for the farmer to evaluate draught resistance and quality of the soil, because a traditional crop will typically have roots that reach into approx. 2 meters depth.
2. t-TEM with a penetration depth of about 100 meters can describe the interaction with the underlying groundwater
3. Evaluation of flow variations in drain can give an impression of the interaction with streams in the area.

The climate challenge.

Summer

Models for a future climate (www.cliwat.eu) for the pilot area in Denmark indicates a 15% decrease in summer precipitation in year 2100 and a 2.8 C temperature increase. This summer scenario indicates an increased evaporation and risk of water shortage. The climate change will not have an effect on leaching during the summer period as the evaporation is higher than the precipitation and no groundwater/drainwater is generated. An increase in organic matter in the soil will however give the soil better buffer capacity to retain water and nutrients from the winter period. Increased organic content will also have a good effect on preventing surface run-off from heavy rain-showers.

Winter

Winter temperatures are likewise foreseen to increase approximately 3 ^{o}C and winter precipitation to increase about 40 % (www.cliwat.eu).

The temperature rise will have the effect that mineralization of N from organic matter will continue for a longer period and with higher intensity during the winter. This can give problems in controlling the N-mineralization if the organic content in the soil is raised at a time where the plants have stopped their growth and the mineralized N will instead leach out of the soil.

Winter precipitation is forecasted to rise with 43% and at the test field, where we have noticed that leaching is relative constant throughout the season where groundwater/drain water is formed, we can roughly estimate that leaching will rise from 40 kgN/ha to 57kgN/ha (assuming that there is a linear correlation between leaching and lake precipitation).

The target of TOPSOIL is to reduce this rise in leaching by 20%, so that the rise will be approximately 11 kgN/ha lower.

At the particular test field, this rise will however be of less importance to the environment, while the drain via a stream will pass through the re-established Gedved Lake that is supposed to neutralise a part of the leached nitrogen. Thus the additional leaching from the test fields, will not affect the recipient Horsens Fjord.

In the dialogue with the farmer Martin Mogensen new instruments was pointed out in order to reduce the leaching from the test field, which then could be applied to other fields at the farm, which are positioned so that the leaching of N affects a vulnerable recipient.

Subject	Advantages	New Management Option
Surface water	Drains control the majority of the water flow. Knowledge of drain location is critical when measures to reduce nitrate are prioritised.	Registration of placement of drains are needed.
Ground water	T-tem mapping gives knowledge of infiltration areas.	Knowledge-based dialogue between farmer and authority improves choice and effective placement of measures.
Soil quality	GCM mapping maps distribution of clay content in soils. Increasing organic content and reducing soil compaction makes soil robust to climate fluctuations.	Good soil is easy to manage and give better yields.
Buffer capacity	1) Soil quality relates to buffer capacity. Organic rich soils holds more water. 2) Root depth may be increased if drainage depth is increased. Buffer capacity is increased and crops will be more drought resistant. 3) Reduced tillage may result in deeper and more "open" soil structure	1) Organic matter must be incorporated in soils resulting in better soil structure and possibility for early seeding. 2) Increase of drainage depth. 3) Increase the infiltration depth at heavy rain.

Spatial planning:	New and more accurate knowledge on the subsoil zones with extra attention for runoff, drainage and infiltration can be used to redistribute fields.	1) By redistribution individual fields will perform evenly. Fields on vulnerable areas can be managed accordingly. 2) Nitrate vulnerable areas should be planted early in the autumn to reduce nitrate leaching.
New innovative solutions/research for climate resilient farming	The above mentioned management options can improve climate resilience to a certain point	Research for new climate resilient crops or new techniques to use e.g. grass from permanent grassland to feed the livestock (here the pigs) are needed if the intensive production is to be maintained.

Table 1. Instruments discussed with the farmer

The farmer Martin Mogensen is already practicing some of these management options. In Denmark there is a general consensus about the range of effect of some of these measures https://pure.au.dk/portal/files/84646400/Virkemiddelkatalog_web.pdf

Accordingly the range of the effect of some of the above mentioned instruments are:

Instrument	**Effect on leaching kgN/ha**
More organic matter in soil/early seeding	5-8
Reduced tillage	10
Redistribution of fields with same properties/GPS guided fertilizing	1-2
Increased drainage depth resulting in better uptake of water and nutrients	?
New innovative solutions such as production of proteins feeding the pigs from permanent grass. The grass field must then be cultivated as an part of crop rotation, where it is possible to rearrange the field every 5 years, in order to get a better yield	20
Increased knowledge on how the individual parts of the field interacts with the surrounding environments	Large (should leaching be avoided at the field (if groundwater is formed) or outside the fields eg. in constructed wetlands)

Table 2. Instruments for improving the soil conditions

The reduction target for the TOPSOIL project is about 11 kgN/ha. The farmer Martin Mogensen has all ready introduced some of the management instruments above. However it should – by the new better understanding of the interaction of the fields with the surrounding environment – be possible to reach the TOPSOIL target of a reduction of anticipated increased leaching.

2. Problem & background

The Water Framework Directive came into force on December 22nd 2000. The EU Water Framework Directive establishes the framework for the protection of streams and lakes, transition waters (estuaries, lagoons, etc.), coastal waters and groundwater in all EU countries.

The Water Management Plans are the fundamental basis for the management of water in Denmark. All water bodies must achieve good ecological status. The effort is put into practice in three Water plan periods: 2009-2015, 2015-2021, 2021-2027.

The current plan is "Water Management Plan 2015-2021". Denmark is divided in four superior water districts. Each district consists of several minor water areas. Goals for environmental conditions are defined and measures to achieve the objective are described in the plans. Denmark must achieve a reduction of agricultural nitrogen leaching to the aquatic environment towards 2021 according to the requirements.

The pilot area is situated in the Horsens Fjord catchment area. In order to achieve a good condition in the aquatic environment of the fjord according to the Water Area Management Plan, **leaching of nitrogen must be reduced by approximately 420 tonnes of nitrogen per year**. About half of this reduction must be achieved before 2021, and the other half is to be achieved in the third water plan period (2021-2027).

During the time of the Top Soil project, the Danish regulation of agriculture has changed due to the Danish Governments Food and Agricultural Package. Previously, regulation was based on uniform requirements for improvement. Currently, a geographic targeted regulation (Geotargeted Regulation) is applied in relation to local environmental status and local growing conditions. One objective of the targeted approach is individual responsible farms achieving environmental improvements.

As an impact of the changed regulation, the Danish farmers were allowed to increase allocation of fertiliser to ensure optimal crop growth instead of adding the amount of nitrogen that would secure a minimum of leaching. Thereby farmers were enabled to secure the most economical way to cultivate the land, conditioned by the use of necessary nuisance collection tools.

The rate of nitrogen leaching depends on different factors. Farmer's operation of the soil and the plants he grows is a factor that determines a part of the leaching (F). Other environmental factors have an impact on leaching. These factors, the farmer has no influence on (E) and they can ultimately have a decisive impact on the farmer's harvest. Below, some of the factors are listed:

- Fertilisation (F).
  - It is substantial whether commercial fertiliser or livestock manure is used. The organically bound N part in livestock manure must be mineralized prior to plant absorption. Part of the mineralisation takes place in the autumn when precipitation increases, as a result there will be a greater leaching from livestock manure.
  - It is important how the fertiliser is applied on the field (on the surface or incorporated), and also where the fertiliser is placed in relation to the plants.
- Soil cultivation or not (F)
  - E.g. uncultivated fields leach 2-12 kg nitrogen per hectare, while cultivated areas leach 15-100 kg nitrogen per hectare to the surface waters. The farmer may choose to refrain from cultivating fields located in peri-urban areas to vulnerable recipients.
  - Autumn growth. The greater the nitrogen uptake from plants can be in autumn, the less leaching of nitrogen to the aquatic environment.
  - The amount of organic matter (humus) in the top soil. Humus content in soil are very important to the earth's physical properties. It promotes the formation of aggregates in the soil and improves soil structure and water-holding capacity. Under extreme weather conditions, with heavy rains or prolonged periods of drought, an arable land with a high humus content, all else being equal, will be better able to withstand the adverse climate impacts.
- Top soil types, precipitation, temperature and drainage (E+F).
  - Nitrogen leaching is twice as high on sandy soil as on clay soil. This is due to the fact that the soil's root zone capacity for water is approx. 60 mm on sandy soil and up to about 200 mm on clay soil – therefore sandy soil is "flushed" several times during the winter - as opposed to clay soil, which may only be flushed 1-2 times. This is reasoned by that the root zone capacity is usually used up during harvest on both soil types. Thus there is a coincidence of increased precipitation and sandy soil in the western part of Denmark.
  - Drainage and surface run-off. In order to be able to cultivate the clay soils, it may be necessary to drain the land. By heavy rainfall, added fertiliser is lead away through drains or via superficial runoff.

It is important that farmers do understand how and when the different factors needs to be taken in consideration, and that the farmer has the necessary knowledge about his soil to make the right decisions.

The specific characteristics of this project in relation to other more research-based projects are that development proposals must be co-created along with the farmer, the agricultural advisor, the administrators (Horsens Municipality, Central Denmark Region) and the researchers (Aarhus University, Hydrogeophysics Group and GEUS). All must bring their knowledge into play in a joint dialogue and development.

Agriculture in Denmark is changing and farms are enlarged which means that local knowledge possessed by the smaller farmer disappears. In this project it is investigated whether local knowledge can be recreated, through geophysical surveys and digitised registration. If so, local knowledge of the soil's properties can be included in future field planning.

The project examines how to implement increased geological and hydro-geological knowledge to reduce leaching of nitrate but still maintain or even improve mark dividends. The aim is an improved understanding and basis for decision-making as well as awareness of knowledge gaps. It is evaluated whether improved knowledge of the topsoil field conditions can change the farmers field management.

3. Objectives

The overall objective of the project is to investigate whether increasing the fertiliser allocation on less vulnerable soils and reducing the allocation of fertilisers to vulnerable soils, can enable the farmer to achieve greater yields while reducing the overall leaching of nitrogen into surface water and groundwater. The studies include both the current climate and a future climate with increased rainfall during wintertime and a higher frequency of dry summers. In addition to leaching it will be discussed how the investigated fields can act as buffers retaining water by heavy rainfall and more drought resilient during dry periods.

In the TopSoil project it is generally decided to have some qualitative and quantitative objectives in mind. Thus, in this subproject there is a qualitative objective of achieving a 20% reduction in the leaching of nitrogen into the aquatic environment in a future climate. Likewise an increase of the soils buffer capacity to retain water of 20 % is set as a target. It all has to be seen in a perspective of a coming climate change where:

- precipitation in the season when groundwater is formed (late autumn to early spring) will increase up to 43 % in 2100 followed by an increase in temperature that will prolong the period where N is mineralized from organic matter
- a higher risk of very dry summers as experienced in the summer 2018
- a higher risk of heavy rainfalls during summer, where the earth ability to hold back and store water is of importance

The main instruments will be listed and described in a new management plan developed in dialogue between farmer, researcher and administration.

Primary purposes is

- to help bring nutrients into the fields to the greatest possible benefit for the farmer while at the same time minimizing the damage to the aquatic environment
- to reduce nitrate leaching from selected fields to surface water and groundwater by up to 20%
- to describe how climate change (increased precipitation) affect soil management and nutrient loss
- that administration, research and agriculture in close interaction work to develop, select and describe methods for achieving the stated purposes

Secondary purposes

- Test and understand geophysical mapping methods like GCM and tTEM and evaluate their use in relation to the overall objective and in relation to daily farm practice (e.g. are the methods so cost effective that it is possible to implement them in practice).
- Test if the magnetometer method is suitable for mapping drainage pipes of clay.

4. Pilot area and Agricultural application

The farm

The pilot area is located in Jutland in Denmark, on the property Lillerupgaard, which is located on Lillerupvej 4, 8751 Gedved in Horsens Municipality. The landowner is Go Gris represented by Martin Mogensen. He has operated the farm since 2006. Throughout the ages, there has been cattle and pigs on the farm, livestock production on the farm ceased in 1980.

The property consist of approximately 186 ha land, of which 156 ha are in operation while 30 ha is forestry. The areas are supplied with fertiliser and livestock manure from livestock production, from the general partnership GO Gris. Go Gris is owned by five farmers, who in total operate seven properties with pig production. Approximately 650 ha are cultivated in the partnership.

Figure 2. Lillerupgaard in the summer of 2013 (http://www.go-gris.dk/).

Regarding the yield of the year 2018 Go-Gris states (on their webpage):
..“The year goes into history because of the unusually dry weather. In terms of yields, it has been a rough process with low yields. On the positive side, it has been an easy harvest, and therefore there has been considerable savings on drying costs, overtime pay and since there is not much straw produced in Denmark, the straw was sold at a favourable price. Overall, it has not been to bad”.

Figure 3. Harvest on Lillerupgaard summer of 2018 (http://www.go-gris.dk/).

Conditions in the area

Subsoil
There is groundwater abstraction in the area. Figure 4 shows the assessed vulnerability, the location of the catchment areas and the well protection zones.

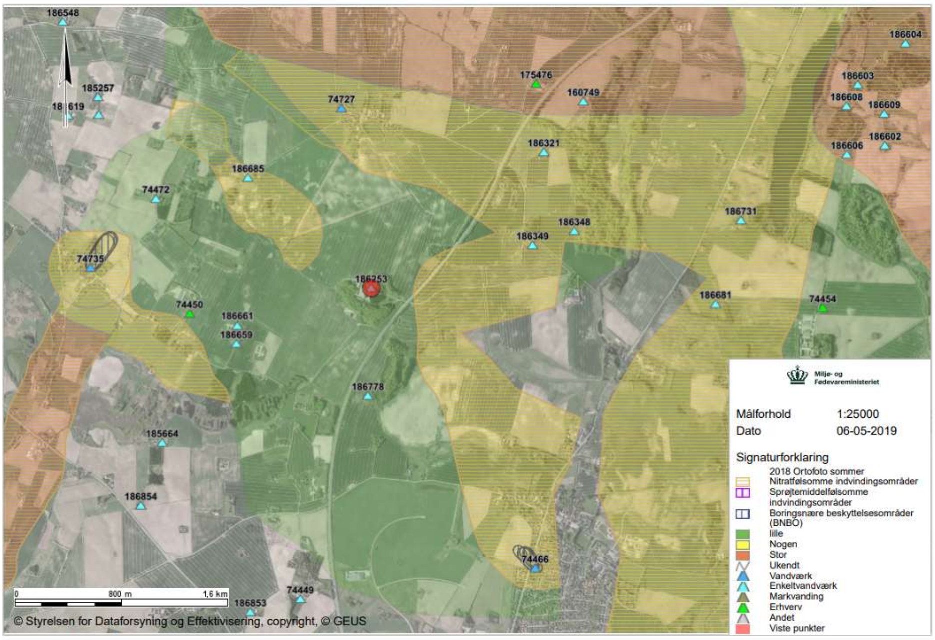


Figure 4. The map shows groundwater vulnerability near Lillerupgård, Lillerupvej 4 (marked with a red dot). Red areas are at high risk of loosing nitrogen, yellow is medium risk and green is low risk of groundwater leaching.

Surface

The pilot area is located in the hinterland of Horsens Fjord. It is situated within an ID-15 catchment area (figure 5). According to the Water Area Plans this ID-15 catchment must reduce leaching of nutrients up to 6.5 kg N/ha of agricultural area/year, at full implementation of the targeted regulation in 2021. The current need for catch crops in the hinterland was set at 6,7% in 2019. The 6.7% is expected to increase in year 2020 to 13% and in year 2021 up to 20%.

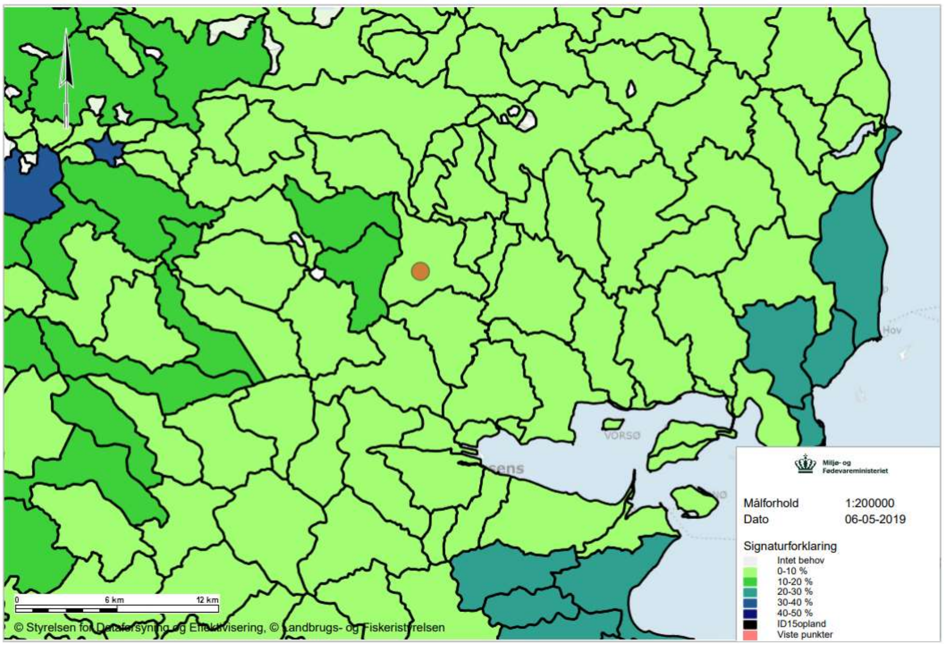


Figure 5. The location of Lillerupgaard 4, within the ID15 catchment area, requiring 0-10% after-harvest crops. Denmark is divided into about 3.000 ID15 catchment areas. Each area is approx. 15 km² and has a specific environmental vulnerability according to the receiving recipient. Accordingly, each ID15 area has different N-reduction goals.

In the Food and Agriculture Package (Danish political agreement of December 2015), it was decided to finance collective initiatives to reduce nitrogen emissions such as Constructed wetlands. The collective efforts are an essential prerequisite for the Food and Agriculture Package, as it became possible for landowners to increase the allocation of fertiliser. All landowners in a coastal watercourse will benefit from the nitrogen reducing effect of the constructed wetlands. According to an analysis made by the Ministry of the Environment and Food the constructed wetlands must be placed on the appropriate and/or potentially suitable areas to ensure that the constructed wetlands will have a good effect and lie in a coastal watershed with a nitrogen reduction requirement. See the designation map in figure 6.

On the property there are areas which, according to the Danish Agency for Agriculture, have a nitrogen reducing effect over 300 kg N/ha constructed wetlands (figure 6). This means that it is possible to place constructed wetlands on the property, if possible.

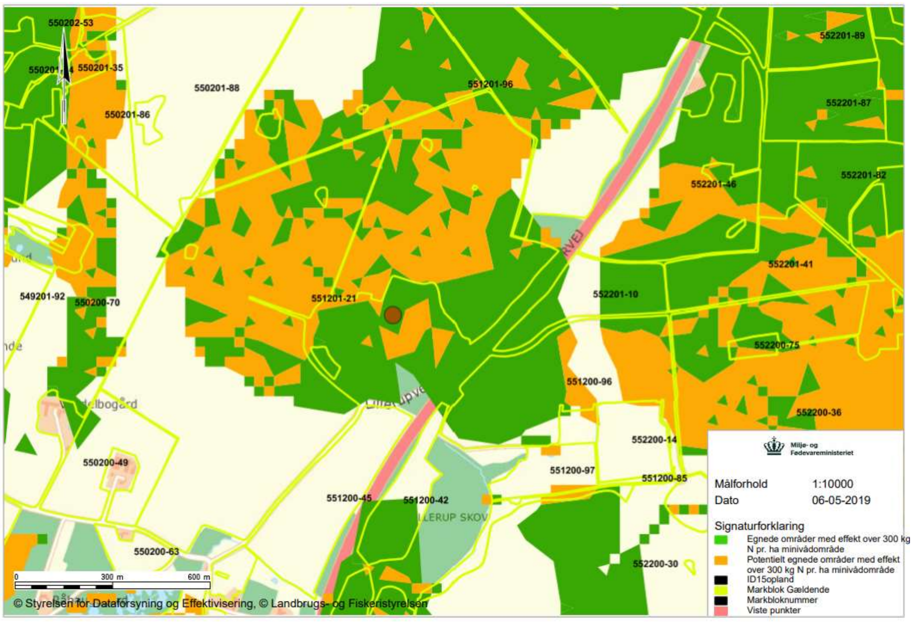


Figure 6 The designation map shows the location of Lillerupgaard (red dot), where constructed wetlands can be placed. Green means high potential for N removal and orange indicates a possible potential.

During the project period, an Intelligent Buffer Zone (IBZ) was established at Lillerupgaard, as part of the NIFA project "Intelligent buffer zones" (IBZ). The location of the plant is shown in figure 7. The plant is approx. 500 m^2. It is assumed that the effect of an Intelligent Buffer Zone is at least at the same level as a constructed wetland.

An IBZ can be constructed as a traditional edge zone and function by disrupting the field drains and lead the water into a constructed trench. The water seeps through the buffer zone from the trench, and trees and plants absorb the nutrients in the drainage water. In the IBZ there is a turnover and restraint of sediment and nutrients, as well as a conversion of nitrate-N to free N. The plant was monitored from January 2018 until January 2019. The measurements showed that the plant mostly receives groundwater and not surface water as expected. The IBZ received 45 kg N from the field. The overall N retention efficiency for IBZ in the measurement period was 55%.

Figure 7 The map (left) shows the location of the IBZ (blue arrow) at Lillerupgaard 4 and (right) the location of drains and IBZ (red arrow).

Gedved Lake
The project area Lillerupgård is located in the hinterland of Gedved Lake, which is a new 30 ha great lake, which was completed in May 2019 (in the TopSoil project period).

The Danish Government has established the lake as a wetland, which contributes to Denmark fulfilling its obligations under the EU Water Framework Directive. The overall purpose is to reduce the supply of nitrogen to the aquatic environment (e.g. also from fields at Lillerupgaard) and thereby improve the water quality in Horsens Fjord. The project also complements the municipality's climate efforts, by acting as a buffer for major precipitation incidents.

The lake is approx. 30 ha with an average depth of 2.4 m. An area of approx. 42 ha are taken out of rotation. It is expected that the lake will result in an annual N-reduction of 7.5 tons N / year with an N-efficiency of 178 kg N / ha / year.

Description of the farmer and the way he manage his soil

The farmer, Martin Mogensen, has had the farm since 2006, where he bought it in free trade. The former owner was an organic plant breeder. When Martin took over there was a fairly large amount of weed in the soil.

Martin must be characterized as a frontrunner among farmers, and he has had the following focus points in the field operations.

1. *The level of organic matter in the soil has been elevated*.

Martin has worked hard to raise the amount of organic matter in the topsoil. The aim is to get a better soil structure, that will secure a good and safe establishment of new crops. The instruments have been incorporation of straw in the soil and strategic use of cover crops. In the first years, when the stables and the sturgeon on the farm was heated by straw boilers, some of the straw was removed from the field for heating purposes. When the farmed established a biogas plant more straw was incorporated in the soil, but now a days a more pragmatic programme is followed. In dry years where the price of straw is high (which coincides with years of low yield) straw is sold, and in years with low prices on straw, the straw is incorporated in the soil.
There is a turn over of crops over the years in order to have a low pressure from weed.

2. *Drain*.

Drains are repaired on a running basis. While repairing single malfunctioning points the original drain depth of 60-70 cm is maintained. But if possible the drain depth is increased to 90 cm in order to give a more convenient soil, - and at the same time the root-depth will be increased and plants draught resilience is enhanced.

3. *Seeding*.

In general it is aimed to seed as early as possible, as the clay rich soil is vulnerable to heavy rain in the autumn.

4. *Density of crops*.

In general the goal is to have 250 living plants pr. m^2, reflecting a balance between quality of the harvested grain, water demand and fertiliser at hand for the field. At the lower parts of the test field with better soil-quality approximately 90 % of the sown grains will establish a living plant. At the higher parts of the test-field with more varied soil quality only about 70 % of the sown grain will establish living plants. As a kind of precision farming the sowing machine is adjusted to deliver more grains pr. m^2 in the parts of the field with more poor soil. A good knowledge of the different conditions (organic content of the soil, clay content, water demand) in the field is the basis for good farming practice in this respect.

5. *GPS guided farming*.

GPS guided farming is mainly used to keep the heavy machinery on the same tracks in the field in order to minimize compaction of the soil from heavy machinery.

6. *Low till farming*.

As an experiment low-till farming is used if the conditions are good. However only a few periods a year are suitable for low-till farming, which is a problem when the farm has to culture as large an area as 600 ha. Traditional ploughing is thus considered a more safe way of establishing the crops.

5. ***Soil types (JB types) on the fields***

The soil type on the fields has some years ago been analysed through soil samples. A sample has been taken out for every hectare. The results are shown in Figure 8. Three different soil types are found throughout the fields; JB5, JB6 and JB7**.** Table 3 describes the soil types found on the fields.

JB number	Texture	% Clay (less than 0,002 mm)	% Silt: (0,002-0,02 mm)	% Fine sand (0,02-0,2 mm)	% Sand, (0,2-2 mm)	% Humus
JB-5-6	**Fine/coarse sandy claysoil**	**10-15**	**0-30**	**0-40** **40-90**	**55-90**	**Less than 10**
JB-7	Claysoil	15-25	0-35		40-85	Less than 10
JB-8	Solid claysoil	25-45	0-45		10-75	Less than 10
JB-9	Very solid claysoil	45-100	0-50		0-55	Less than 10
JB-10	Siltsoil	0-50	20-100		0-80	Less than 10
JB-11	Humus					More than 10

Table 3: Soil types.

In general in the pilot area there is soil type 6 on all fields, but locally soil types JB7 and JB5 are found.

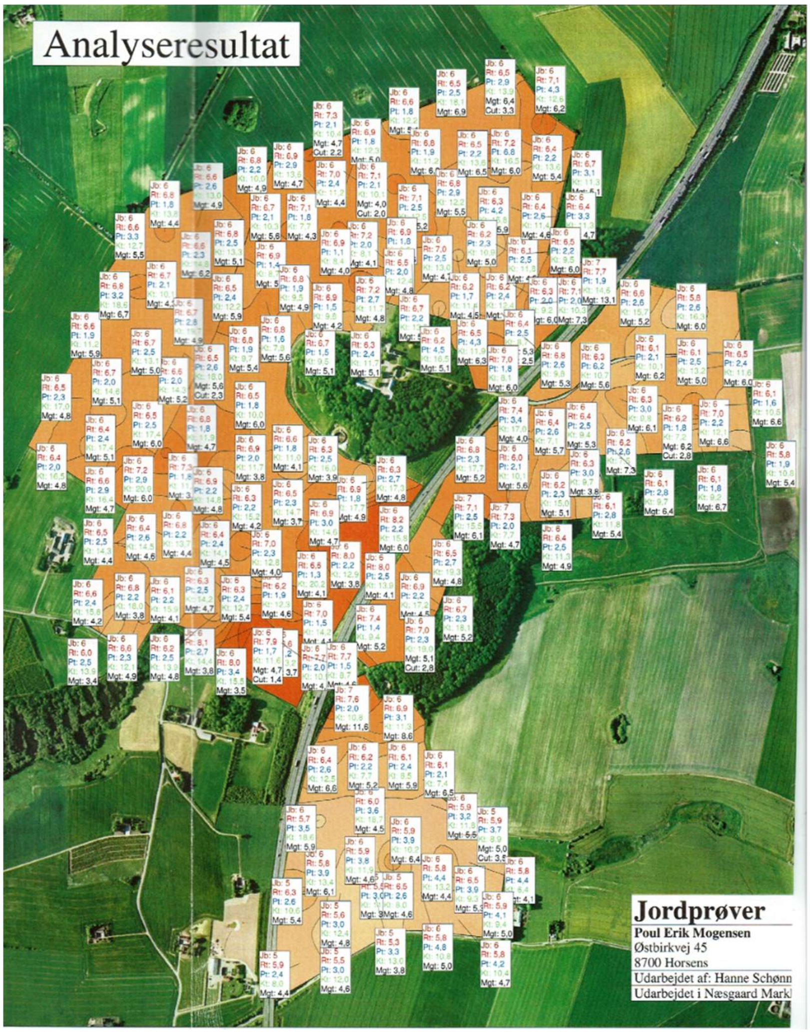


Figure 8: Soil types/JB types found on the fields.

6. Topographical setting

The topographical setting will have a large impact on water run-off from the areas. There are large topographical variations found within the fields as shown in figure 9. In the northern part the elevation of the field reaches 110 meters above sea level, whereas in the southern part of the fields, the elevation is less than 40 meters above sea level. On the northwestern part of the fields (figure 9) the inclination often reaches 8% or more.

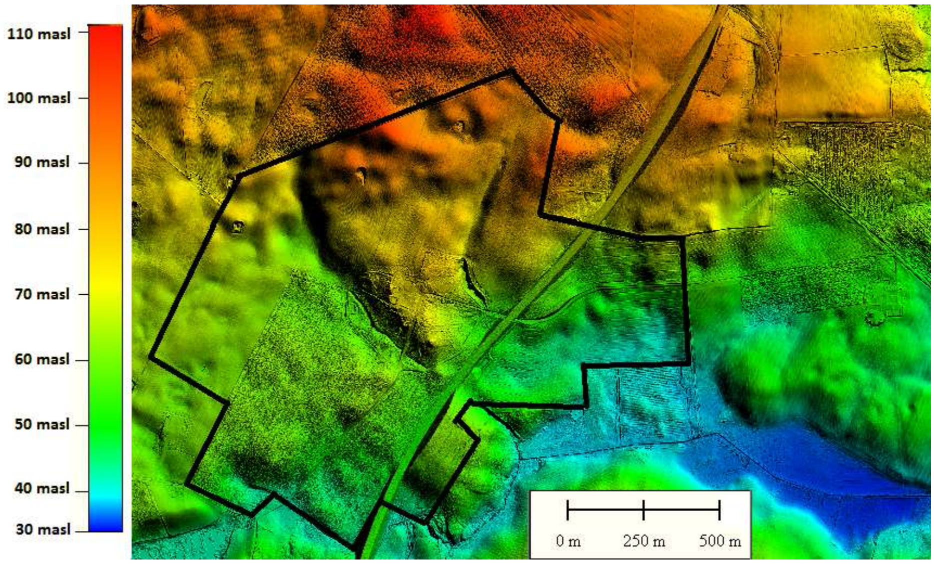


Figure 9: Topographical setting. The elevation varies from more than 110 meters above sea level to 40 meters above sea level within the 271 hectares study area.

7. Groundwater and vulnerability

The pilot area is located in a large-scale hilly moraine landscape. Tertiary plastic clay/marl (Søvindmarl) is found relatively close to terrain, and together with mica clay and mica sand it represents the sole of the quaternary layers. Public waterworks extract drinking water from the quaternary deposits consisting mainly of melt water sand and clay till. North and east are minor areas, within the survey area, where the protective covering clay layers are scattered and therefore the area is characterised as a vulnerable area of groundwater abstraction (figure 10). Otherwise, the survey area is characterised as non-vulnerable. The water type in the area is dominated by reduced (oxygen free) water and in general, this indicates less vulnerable conditions.

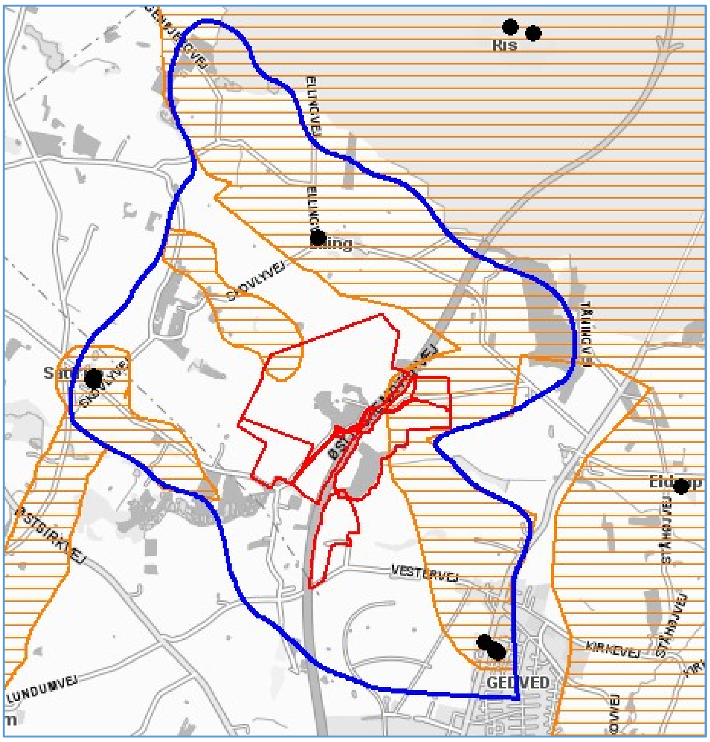


Figure 10: Pilot area

Red: Survey site – pilot area
Blue: Abstraction area
Black dots: Water abstraction wells
Orange: Vulnerable abstraction area

8. Ground conductivity meter mapping

Revealing soil structures in the upper 5 meters of the ground

The entire area was mapped with a geophysical instrument called DUALEM421s in September 2017. DUALEM42s is a ground conductivity meter, which is especially designed for mapping the uppermost 5 meters of the soil, and is even capable of mapping layers as thin as the plough layer. The results of the mapping has been documented in the report GCM mapping Gedved, Report number 23-06-2017, June 2017. The line spacing was 10-15 m and a total of 117.179 measurements were performed corresponding to 117 line km of data. The GCM results displays a lot of resistivity variations in the shallow soil, which can be related to soil structures, see figure 11. A number of hand drillings have been performed in connection with the GCM survey in order to relate the resistivity contrast from the GCM measurements to soil types (JB). A good match was found between the hand-drilling results and the geophysical results.

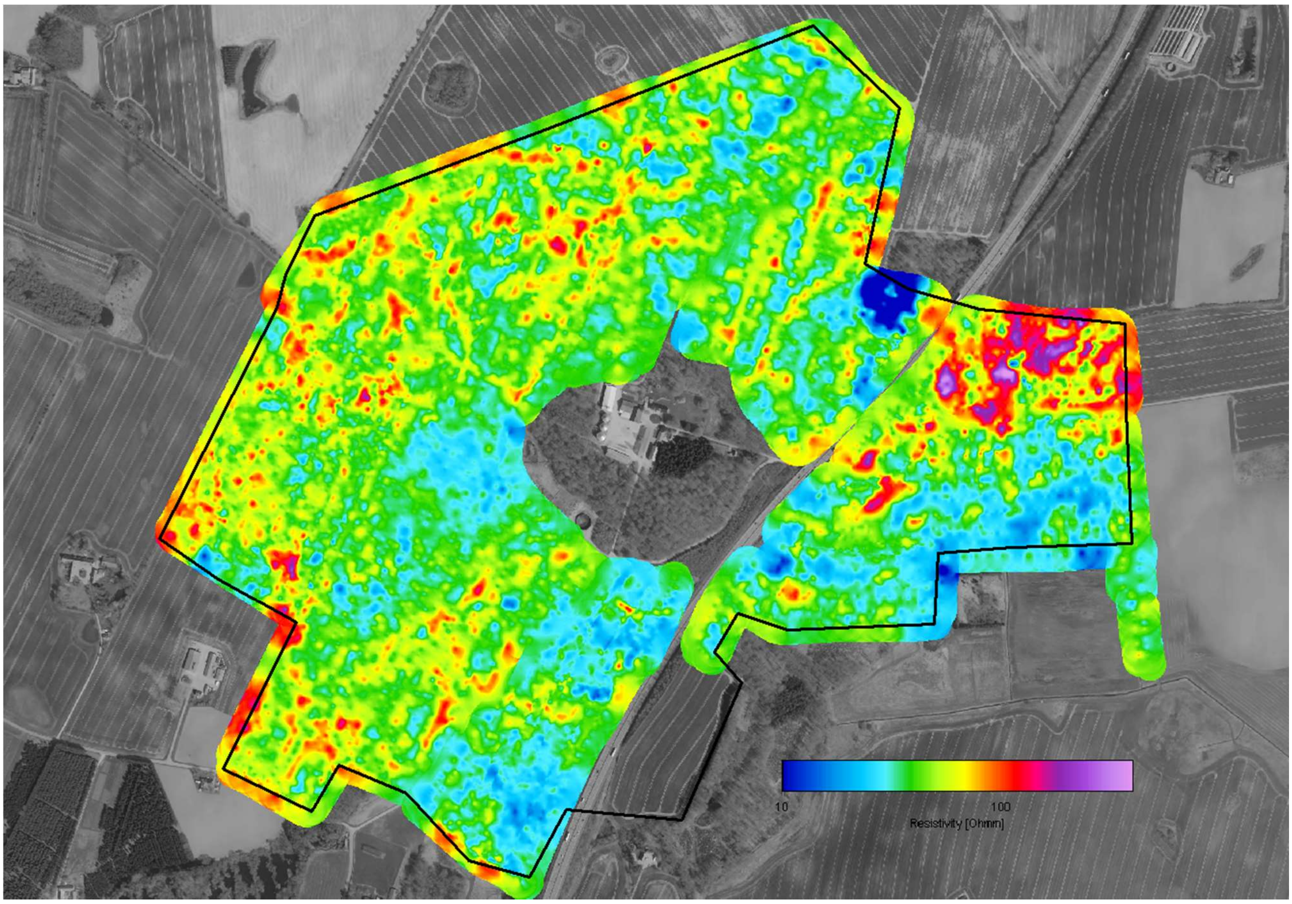


Figure 11: GCM results from a depth of 0.5 to 1 meter. A lot of structures is visible in the maps which can be related to sand and clay content of the soil. A detailed mapping like this will – in time –have a potential to form a basis for precision farming, where allocation of fertilisers are adjusted to soil type. At present it is the view of the farmer that it is not possible to differentiate allocation of fertiliser for areas of a size less than 1000 m2. Red and violet colours indicates sandy soil and blue colours indicate clay-rich areas.

9. Drainage network

There is an extensive drainage network on the fields. The drain pipes are tile drains that were dug into the soil by manual labour in the late 1900's. The tile drains were dug to a depth of 0.6-0.7 meters in the clay-rich soil. The network of drains has been carefully documented on layout plans, as seen in the Figure 12. The farmer still maintains this drainage network. However, it is still difficult to locate drains since the layout plans are not always accurate, and are most likely an ideal plan for the drainage network, resulting in hours of digging with heavy machinery in order to locate the drains, when repairs are needed.

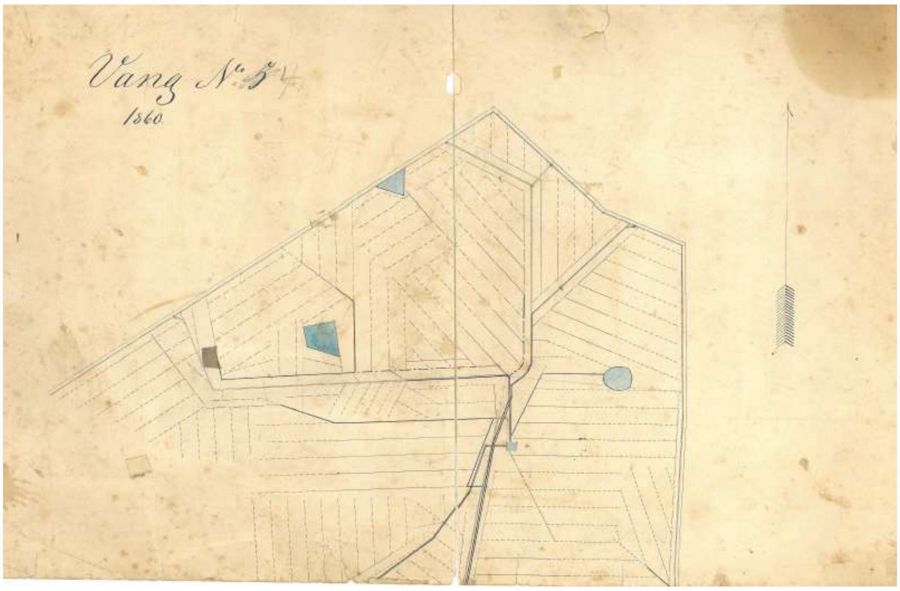


Figure 12: Layout plan for the tile drain network on the most northern field of the study area.

10. Digitization of drainage network layout plans

The layout plans of the tile drain network from the late 1900's has been geo referenced and digitalized. The result is shown in Figure 13. Thick lines symbolizes main drains, which typically had a diameter of 10-20 centimetres. Thin lines symbolizes side-drains with a diameter less than 10 centimetres. The network was often dense and complex as seen in the Figure 12. The fields without shown drains in figure 13 are also drained. The layout plans have simply been lost or not created at all.

Figure 13: Drainage network on the fields. Fields with no shown drains are also drained but the plans are lost.

11. Gradient magnetometer measurements

Understanding the tile drain network

In the project, we aim to map the tile drainage network by means of geophysical methods. First test measurement, with a prototype instrument with only one sensor, has been carried out. They were successful, so now we are in the process of developing a larger system. We aim to have the system fully operational in 2019- 2020, - thus a major test of the system cannot be performed within the TOPSOIL project period. The system is called tMag which stands for towed-Mag. The tMag system is a towed array of vector magnetic gradiometers. Figure 14 shows a prototype of the tMag system. Designed for hydrogeological and archaeological applications, the array consists of 8 fluxgate vector magnetic gradiometer instruments, comprising 48 total magnetic sensors. This ultra-high-resolution instrument records data at 200 Hz, resulting in a sample from each sensor every 2.5 centimetres along-line, with a lateral sensor spacing of 50 cm resulting in a total width of the system of 4 m. This allows for the mapping of nearly 50-70 hectares per day on farm fields at an effective line spacing of 50cm. The system is easily deployed by a two-person field crew and consists of an ATV which tows the array on a sledge.

The system is designed to detect tile drains, but would also work for detecting archaeological structures, drums, cables and other man-made items. The tile drains can be detected by tMag because of the way the tiles were burned, producing a net magnetization. Tile drains are typically around 10-20 cm in diameter, setting high requirements to the lateral resolution of the measurements in order to be detected. Mapping the tile drains is of special importance, since the majority of the nitrate transport is in the drains. As seen in the Lillerupgaard case, the amounts of nitrate transport is very high, and hence a detailed mapping of the drain network is crucial in order to get a full overview of the nitrate transport on field scale. When one understands the water and nitrate flow fully, remediation can be managed in an efficient approach. Here the knowledge of the location of the main drains, and their outflow location to the nature is naturally as crucial as knowing the hydrogeological setting. Mapping and understanding the drain network is believed to be the key to understanding and reducing the nitrate load on farms fields.

Figure 14: A prototype of the tMag system.

12. tTEM measurements

Mapping geological structures to 70 meters depth in 3D

In connection with the project, the HydroGEophysics Group, Aarhus University, has developed a new geophysical instrument capable of mapping geological structures in 3D. The instrument is called towTEM or tTEM. tTEM is a ground-based transient electromagnetic data acquisition system capable of mapping the soil structures to earth depths in the range from 0 – 70 m. The system is quick to deploy and is easily managed by a field crew of two people. It consists of an ATV towing the transmitter and receiver coils. To make it robust on even harsh farm fields the coils are mounted on sledges with runners. Typical driving speeds are 3-5 m/s, providing a measurement for every 3-5 meters. Distances between mapping lines are 10 – 20 m resulting in a full 3D map of the subsurface. The system is applicable for the mapping of raw materials (identification of sand, gravel and limestone), pollution mapping (tracking the hydrogeological setting around landfills and detecting leachate), and vulnerability mapping (estimating clay thickness which acts as a protective cover for our groundwater reservoirs).

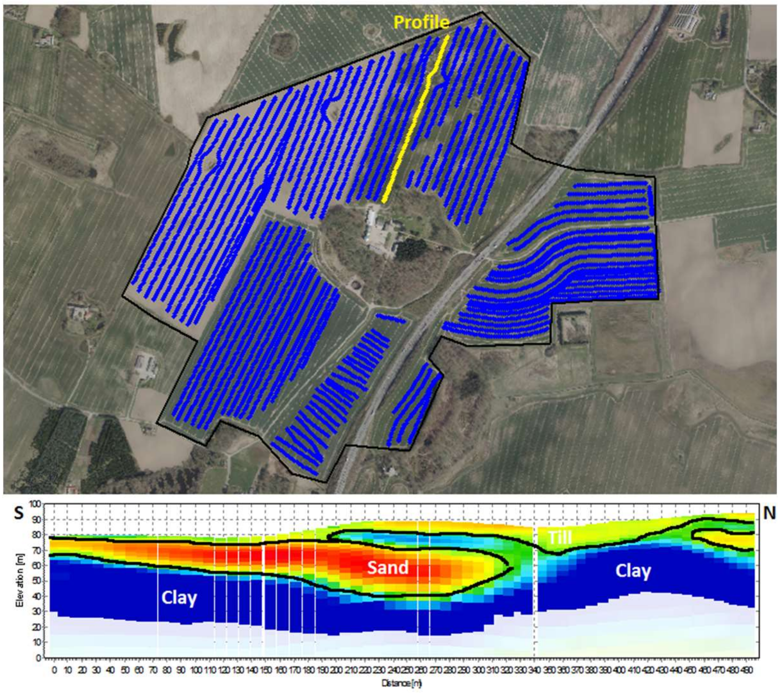


Figure 15: tTEM data coverage and a profile section showing the complex geological setting on the fields.

A mapping has been conducted at the fields in the study area. The line spacing corresponds to the spraying tracks, which is roughly 15-20 meters. Along the lines, there are 10 meters between the measurements, resulting in a 3D resolution of the geology. In total more than 119 line km of data has been collected during two days of surveying. Figure 15 shows the data coverage with the tTEM instrument, and a profile revealing a very complex geology with dipping clay layers, interbedded sand layers, and thick clay deposits. The results are described in more details in the following section.

13. Geological model

Geological frame

The area is situated on the northern flank of the Ringkøbing-Funen Ridge, probably on top of a salt structure. Deep movements have caused the formation of two major faults running parallel with the north and south shores of Horsens Fiord, respectively, and thereby forming a depression in the chalk surface. The chalk surface is situated at depths ranging from 400 to 150 m below sea level.

The area is characterised by several deeply cut buried tunnel valleys which traverse the area and they comprise a complex network of cross-cutting structures. These valleys occur in several generations. At several locations, the valleys reach more than 100 m down into the Palaeogene layers. The valleys are of considerable importance to the area's water quality and its protection (Møller, R.R. & Jørgensen, F. 2011: Geologisk model ved Egebjerg. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2011/37. 95 pp.).

The terrain of the surrounding region has considerable level variations and large-scale structures such as end moraine hills, areas characterised by glacial tectonics, signs of ice-shoved hills, dead-ice landscapes and glacial lake deposits. The signs of glaciotectonic deformation is confirmed by the presence of rafts in several boreholes. It is therefore expected that the setting is deformed.

The pre-Quaternary section includes Bryozo chalk from Danian, impermeable clay and marl from the Eocene in the form of Røsnæs clay, Lillebælt clay and Søvind marl, and mica-rich clay, silt and sand contained by Oligocene and Miocene deposits. The boundary between Palaeogene and Neogene is in the area typically seen as an erosion discordance and the Oligocene/Miocene layer is upwards getting increasingly more silty and sandy. The silty parts are rich in organic matter, giving the layers a characteristic dark colour. The typical thickness of the Paleogene section ranges from 50 to 200 m. The lower part of the Miocene section consists of the Vejle Fjord Formation and the upper part the Arnum Formation.

The Quaternary section consists of clay till of varying thickness at all levels. Meltwater sand and gravel are often seen in the buried tunnel valleys. Glaciolacustrine clay is also found in the area – typically within the buried tunnel valleys.

Interpretation of tTEM

A 3D grid of the tTEM data have been gridded in GeoScene3D. It has 1 m depth discretization and 10 m horizontal discretization. Combined with borehole information, this grid is used as background for geological interpretation.

Four investigation boreholes were drilled in the pilot area in order to validate the geophysical data and to collect water samples and hydraulic head measurements. The boreholes were made by auger drilling reaching approximately 30 m depth.

The geological interpretation of the pilot area is shown in Figure 16 and Figure 17. In both figures a map is showing the resistivity at the level of 10 m above sea level. This corresponds to depths of 30 to 80 m. Two main types of geology are seen on the map: Buried valleys with resistivities between 30 and 150 ohm (red, yellow and green colours) and Tertiary clay with resistivities below 40 ohmm (blue colours). There are two deep buried valleys in the area, one cutting through the area with an orientation of NW-SE and another with the orientation NE-SW.

In each figure, a cross section displays the vertical section through the area. Three of the four boreholes are displayed on these cross sections. In the cross section in Figure 16, it is seen that the NW-SE trending buried valley cuts down into the tertiary clay. The valley is filled with coarse meltwater sediments in the deeper part followed by a layer of clay till and glaciolacustrine clay. The upper part is dominated by a mixture of clay till and meltwater sand. In the close-up section, it is seen that there is a good agreement between the borehole data and the tTEM data: as expected, the sandy section shows high resistivities and the clay sections show medium to low resistivities. The thin grey line on the cross section marks the depth of investigation (DOI). Below this line the tTEM data is of limited confidence.

The other cross section (in Figure 17) passes two other boreholes. These two boreholes show a deeper part that is dominated by Tertiary mica silt and mica sand. The geology in these two boreholes are very much alike, also in the upper parts where they are dominated by clay till. Both boreholes are drilled at locations where thrusted parts of mica silt and sand reaches the top of the deformed section. Interpretations of the structural setting are outlined on the cross section. The thrust faults dip towards the East or Southeast.

Also the two boreholes in this cross section show a good agreement with the tTEM data: relatively high resistivities for the mica silt and sand, whereas the clay till in the upper part has a medium level of resistivity. The NE-SW trending buried valley is clearly seen with medium to high resistivities in right part of the cross section.

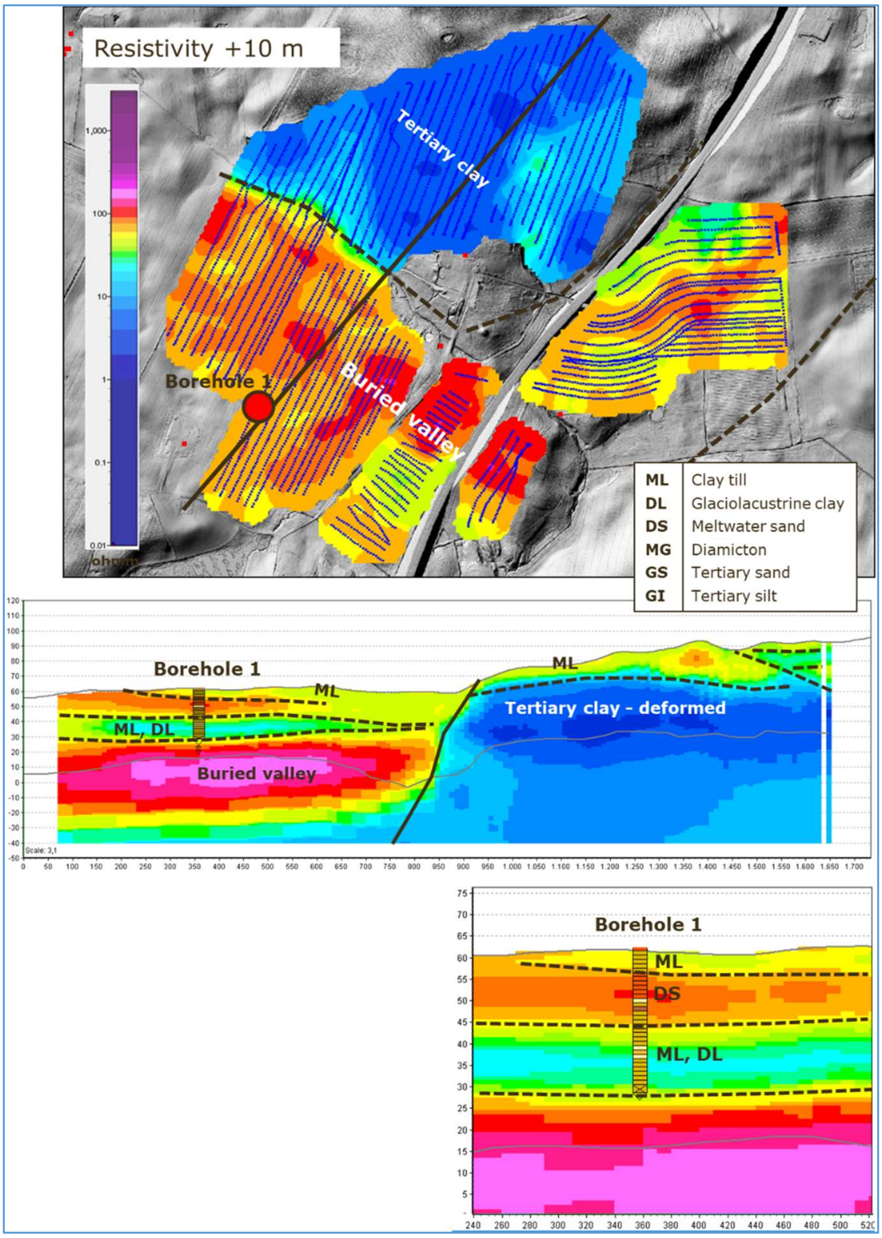


Figure 16. Geological interpretation of tTEM data and comparison with the investigation drillings. Upper: Map of tTEM resistivity at 10 m above sea level. Interpretation of buried tunnel valleys indicated with dashed black lines. Location of cross section indicated with thick black line. tTEM data are shown with blue lines/dots. Middle: Cross section with geological interpretations. The thin grey line marks the depth of investigation. Lower: Close up of the section around the borehole.

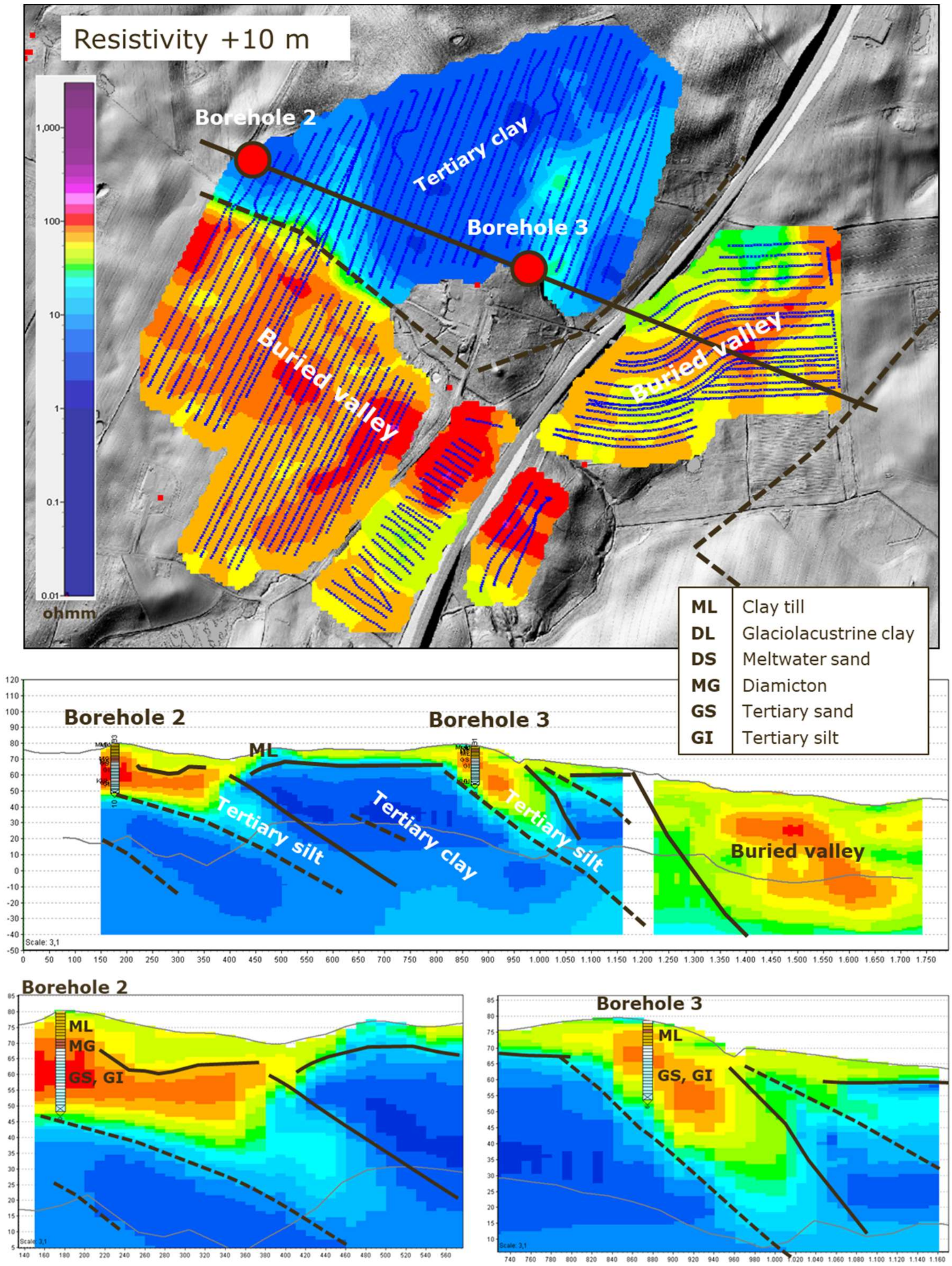


Figure 17. Geological interpretation of tTEM data and comparison with the investigation drillings. Upper: Map of tTEM resistivity at 10 m above sea level. Interpretation of buried tunnel valleys indicated with dashed black lines. Location of cross section indicated with thick black line. tTEM data are shown with blue lines/dots. Middle: Cross section with geological interpretations. The thin grey line marks the depth of investigation. Lower: Close ups of the section around the boreholes.

14. Soil content of mineralized nitrogen (N-min)

N-min tests can give a good estimate of a fields nitrogen content, thereby the next crop's nitrogen requirements can be calculated.

In the autumn and winter 2017/18, N-min analyses were performed on 4 sites in the field at 4 different times. The purpose was to investigate if there were significant differences between the content of the N-min on sites and see the change of content over time. The measurements were made in 3 depths: 0-25 cm, 25-50 cm and 50-75 cm. The field crop was winter barley sown at the 5th of September 2017.

Figure 18: Location of benchmarks for analyses of Nmin.
Nmin is an expression of how much Nitrogen is mineralised and exposed to leaching.

In Denmark, there is always a surplus of rain in the winter period, which gives potential for leaching of nitrate from the plants root zone to drainage and groundwater. Therefore, it is interesting to measure the amount of nitrate and ammonium present in the soil in the autumn, when evaporation is low and the soil volume in the root zone can no longer absorb the precipitation. In this situation nitrate start leaching, which normally happens from October-November.

Location of benchmarks are shown in figure 18. The measurements (figure 19) in general show that N-min in the soil peaks in the early autumn (September). As the drainage flow increases during October, the content of N-min in the upper layer of the soil (0-25 cm) decrease while the content of N-min of the deeper layers (25-75 cm) increase slightly. The measurements in January show that the content in all 3 depths is reduced relative to the September and November measurements. There will also be an amount of N-min uptake in the winter barley from September to November, if the barley has been sown early. It is expected that the amount of N-min in the soil in November will no longer be absorbed by the plants but will be exposed to leaching.

Figure 20 shows that the average N-min content falls from 27 kg N-min/ha to 6 kg N-min/ha from September to January and 19 kg N-min/ha to 6 kg N min/ha from November to January. Therefore 13 kg N/ha N-min has probably been leached out in the period of November to January from the depth of 0-75 cm.

To get an idea of the content of the root zone on clay soil (0-100 cm) multiplication with 1.3 is required to include ammonium as the measurement is on nitrogen – so the loss in the root zone is on average 17 kg N-min / ha. The N is lost to either drain (surfacewater) or groundwater.

Sample point P2 is located in a valley where surface flow is expected from the surrounding areas in situations with large precipitation events. It is also in this place, the largest loss of N-min is found, deduced by the January results where the level of P2 is not much higher than other sampling points.

The analyses from March show a significant increase in the content of N-min for all sampling points, compared to January, which is believed to be due to the fact, that 21 kg N/ha has been allocated to the crop on the 5th of February as 100 kg/ha sulfuric acid ammonia. The largest increase occurs in P2, presumably due to surface runoff to the site.

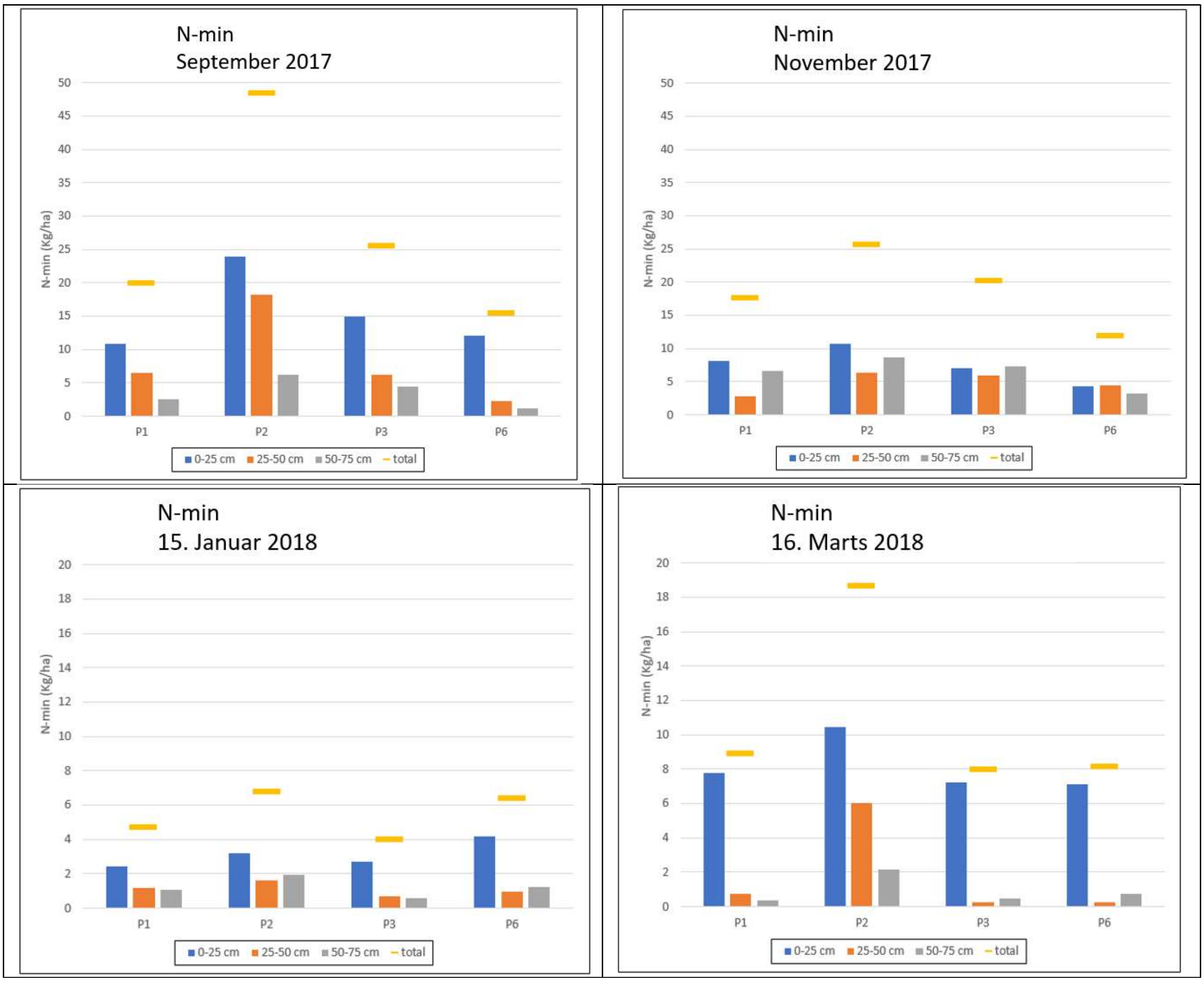


Figure 19.: Content of N-min at 4 sites in 3 depths and at 4 times. The crop was fertilized at 5. February with 21 kg N/ha.

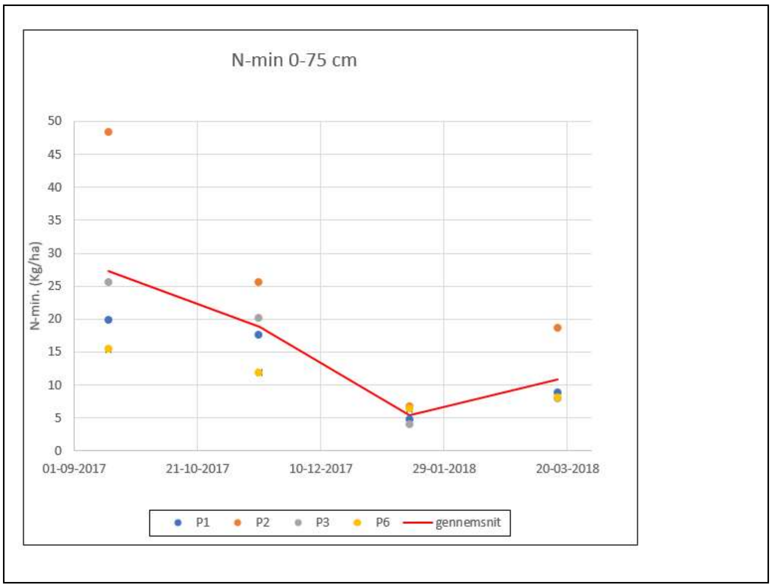


Figure 20. Average content of N-min at the 4 sample times.

15. Cropsat

Biomass maps are generated via satellite photos from the Sentinel Satellites. Biomass maps can be used to assess the current state of plants and whether there is a need to add more nitrogen to an area.

A vegetation index is based on reflected light as more vegetation growth will affect the ratio of infrared light reflected and visible light absorbed. A vigorous crop will reflect much infrared light while its chlorophyll will absorb visible light. Calibrated results can then be used to estimate vegetation growth and overall biomass. The vegetation index map is displayed in yellow and green colours – a yellow colour equals a low biomass index 0 and a green colour equals a massive biomass index 1. Map pixels vary between 10-30 meters.

Denmark is passed by the Sentinel-2 satellite every 4th day, a vegetation index is not produced on cloudy days. The web application CropSAT is developed by DataVäxt AB. CropSAT.dk is provided by the agriculture organisation SEGES and the Danish Nature and Business Authority. Via CropSAT.dk the farmer is able to download biomass maps and monitor crops. CropSAT.dk enables creation of graduated allocation maps for fertiliser or biocides based on the biomass maps. E.g. in relation to allocating nitrogen, areas with a low biomass indicates one of two:

1) The crop may consume more nitrogen
2) The crop is unable to consume nitrogen due to water shortage
Thus biomass maps must be used along with the knowledge of soil conditions and water availability.

Biomass indexes 2017 and 2018 at early spring, at peak and at harvest are shown below. In 2017 the crop is Wheat (European, Winter) and in 2018 the crop is Barley (European, Winter).

Figure 21: Biomass 24/3-2017 – biomass in early spring 2017

Figure 22: Biomass 9/7-2017 – biomass index at its peak 2017

Figure 23: Biomass 23/8-2017 – biomass at harvest 2017

Figure 24: Biomass 19/3-2018 - biomass index in early spring 2018

Figure 25: Biomass 30/5-2018 – biomass index at its peak 2018

Figure 26: Biomass 27/6-2018 – biomass index is affected by water shortage

CropSAT.dk is not used at Lillerupgaard. The farmer states that for now precision farming on Lillerupgaard only makes sense on areas of at least 1000 m^2.Since much of the manure comes from livestock, it is difficult to dose the allocation. Layering in the slurry injection tank when allocating fertiliser from livestock manure makes it impossible to control the exact amount. Fertiliser from biogas is more uniform than manure directly from the slurry tank, and therefore changing to this can make it possible in the future. Furthermore a sensor measuring the nitrogen content in the nozzle of the slurry injection tank could improve precision allocation.

16. Yield measurements

A combine harvester with a yield monitor provides data for the creation of a yield map that displays the spatial variability within the field. The yield monitor is one of the precision agriculture tools that increase the farmer's field knowledge. Yield maps are utilised for making decisions on best management practices in terms of comparing crop varieties, fertiliser types and application rates as well as pesticide application. A yield map makes it easy to point out problem areas within the field and enables a targeted action plan for the specified areas.

The yield monitor measure the harvested grain mass flow, moisture content and speed to determine the yield. The monitor is coupled with a GPS to record the spatially variability across the field. The yield monitor is not exact and may have misreading's due to an uneven crop, a wedge shaped field or slopes. Furthermore the current harvest conditions must be taken into account when yield maps are examined as weather conditions and weeds also affects measurements. Also when the harvester is turning it measures a combination of an area that has been harvested and an area with unharvested crops. These areas are seen as red areas along the fringe of the field.

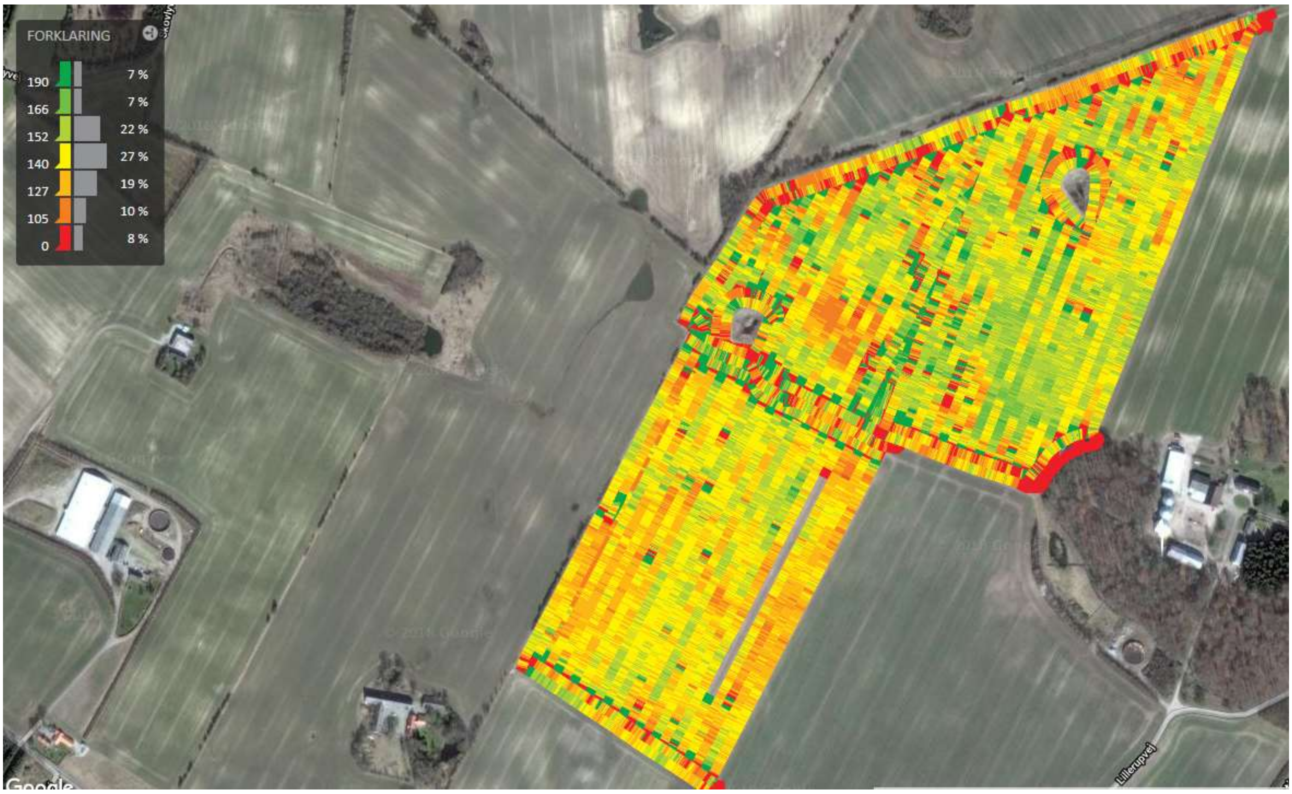


Figure 27: Yield measurements harvested 24/8-2017 – Wheat (European, Winter) dry yield in hkg/ha.

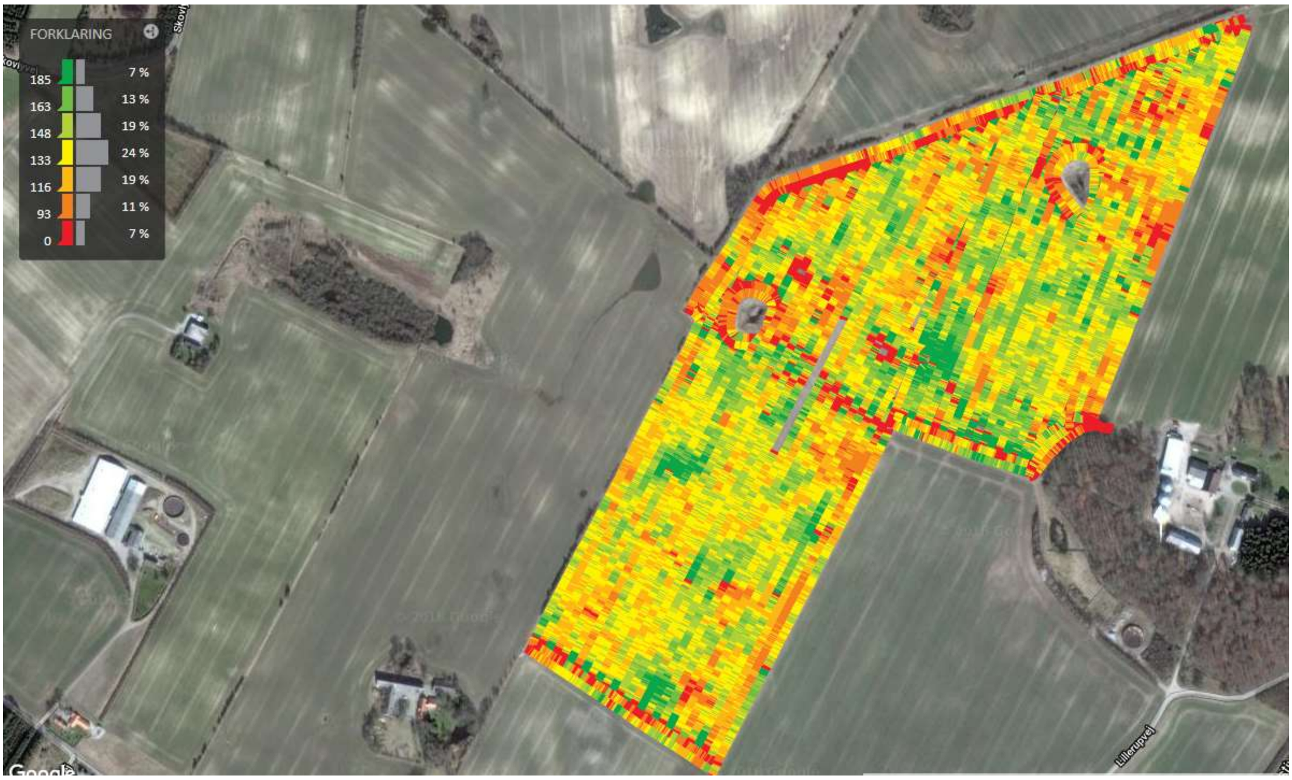
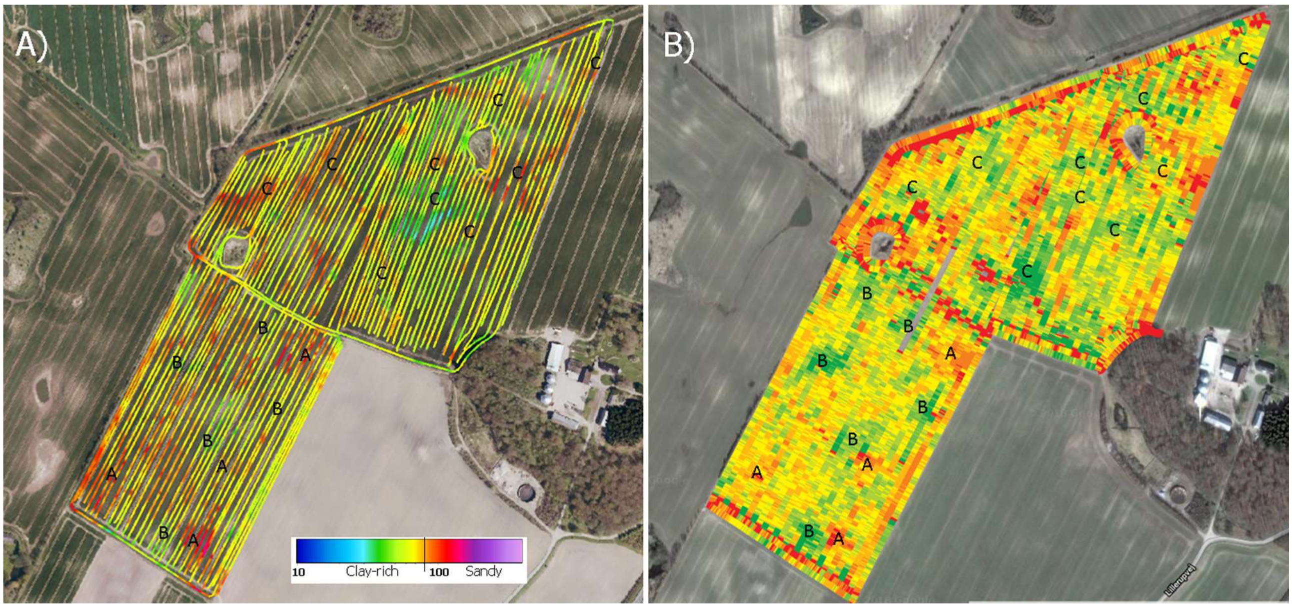


Figure28: Yield measurements harvested 28/6-2018 – Barley (European, Winter) dry yield in hkg/ha

Comparison of yield measurements 2017 (figure 27) and 2018 (figure 28) illustrates that the overall level of yield is similar but the distribution of the yield within the field differs. In 2018 areas of high yield are distinct and somewhat defined whereas high yield pixels in 2017 are blurred. This may be due to a severe drought period in late spring and early summer 2018 entailing water shortage. Crop conditions have been favourable in clay rich soil most capable of retaining water. Furthermore the unusual warm spring and early summer resulted in an early developed crop and therefore early harvest in late June.

The yield from 2018 has been compared to the GCM resistivity results from the first meter of the soil. The results is displayed in Figure 29. The plot in a) shows the resistivity values from the GCM. The blue to yellow colours indicate soil with a clay content. Orange to red values indicate sandy soil. Based on the GCM results it is clear that there are distinct areas with larger sand or clay content. For the southern field the resistive/sandy soil zones has been highlighted with the marker A, and the more conductive/clay-rich zones has been highlighted with the marker B. By comparing the zones with the yield map it seems there is a trend that the A zones results in a lower yield as compared to the B zones. The clay rich soil in the southern field have most likely retained the water more easily and hence the crops were not that affected by the drought period. In the northern field, the pattern is the other way around. Zones with high resistivity indicating sandy soil has been highlighted with a C. By comparing with the yield map it is evident that the sandy soil zones have produced a higher yield as compared to the clay rich zones. This pattern is probably due to several factors.

The geological setting on the two adjacent fields are quite different as seen in the tTEM results. On the southern field, there is a thin shallow till layer with underlying sand sediments. In the A zones there is thus almost only permeable sediments and any precipitation would quickly flow into the aquifers, and hence the soil is not good at retaining water and consequently more pronounced to be affected by drought. In the B zones, where we have more clay content, the soil would be better at retaining the water, and hence the yield is increased. On the northern field the sediments are generally quite clay rich as seen in the tTEM results. This is valid until more than 50 m depth at some locations. Furthermore, there is a large topographic gradient, so any rainwater would quickly run-off or end in the drains. Here it seems that it is an advantage to have a higher sand content in the upper 1 meter of the ground, since the sand layer is on top of a thick clay layer, and hence any precipitation would be available for the plants and not simply run-off.



Figur29. a) GCM resistivity results from the 1st m of the soil. b) Yield results from 2018.

17. Drain measurements

Following the leaching from day to day

The water flow and content of Nitrate and Phosphorus has been followed in the drain water. The field drains shown in figure 12, and 13. Flow measurements and water samples have been collected every month in the summertime and every 2 weeks during wintertime in the period from 6/6-2016 to 19/8-2019. The water samples for the entire period have been analysed for nitrate and dissolved phosphor (total P). For a part of the period nitrate analyses was supplemented by analyses for N as this parameter is more often used by biologists and farm consultants. Geologists are in favour of using nitrate as a N indicator. However comparing the two values shows good compliance.

Results from the samples are shown in table 4 and figure 30.

Date	Waterflow l/min	Nitrate (mg/l) Calculated (total N x 4,42)	Nitrate (mg/l) Measured directly in sample	Total P mg/l
6/6	27	21		0,025
4/7	24	19		0,031
11/8	14	19		0,033
7/9	12	19		0,020
21/9	7	18		0,029
4/10	16	29		0,041
25/10	365	66		0,099
11/11	164	62		0,046
23/11	425	88		0,069
8/12	86	62		0,022
20/12	75	66	65	0,023
2017				
5/1	163	88	84	0,027
19/1	134	71	66	0,034
2/2	67	66	67	0,020
20/2	102	80	78	0,026
2/3	446	80	81	0,062
16/3	110	71	67	0,018
30/3	105	66	61	0,025
12/4	41	53	54	0,020
26/4	20	49	49	0,030
11/5	15	44	44	0,019

24/5	5	37	36	0,022
7/6	1	37	36	0,024
28/6	1	34	34	0,026
24/7	0,25	31	30	0,12
23/8	0,15	30	29	0,084
7/9	0,26	37	34	0,62
21/9	29	62	60	0,028
4/10	50	66	67	0,034
17/10	155	66	59	0,034
1/11	147	57	61	0,021
16/11	117	57	63	0,014
1/12	256	66	69	<0,01
11/12	240	62	Not analysed	0,014
2018				
3/1	>450	49	44	0,72
11/1	176	62	60	0,015
26/1	>450	62	60	0,018
8/2	164	57	59	0,013
22/2	289	58	57	0,011
9/3	78	57	50	<0,01
22/3	119	53	47	0,086
5/4	196	53	50	0,055
20/4	34	49	47	0,015
2/5	36	43	43	0,027
17/5	1	33	33	0,044
1/6	0,1	29	29	0,013
29/6	0			
24/8	0			
21/9	0			
12/10	0			
1/11	0			
30/11	0,17			
14/12	18		70	
Date	Waterflow l/min	Nitrate (mg/l) Calculated (total N x 4,42)	Nitrate (mg/l) Measured directly in sample	Total P mg/l
2019				
10/1	44	75	88	0,011
25/1	38	75	82	<0,01
7/2	286	89	98	<0,01
21/2	81		81	
8/3	555	62	69	0,07
22/3	200	57	62	0,022
4/4	38	48	53	0,014
12/4	9	53	49	<0,01
1/5	0,51	49	43	<0,01
4/6	0			
27/6	0			
19/8	0,15		28	

Table 4 - . Results from water samples (drain).

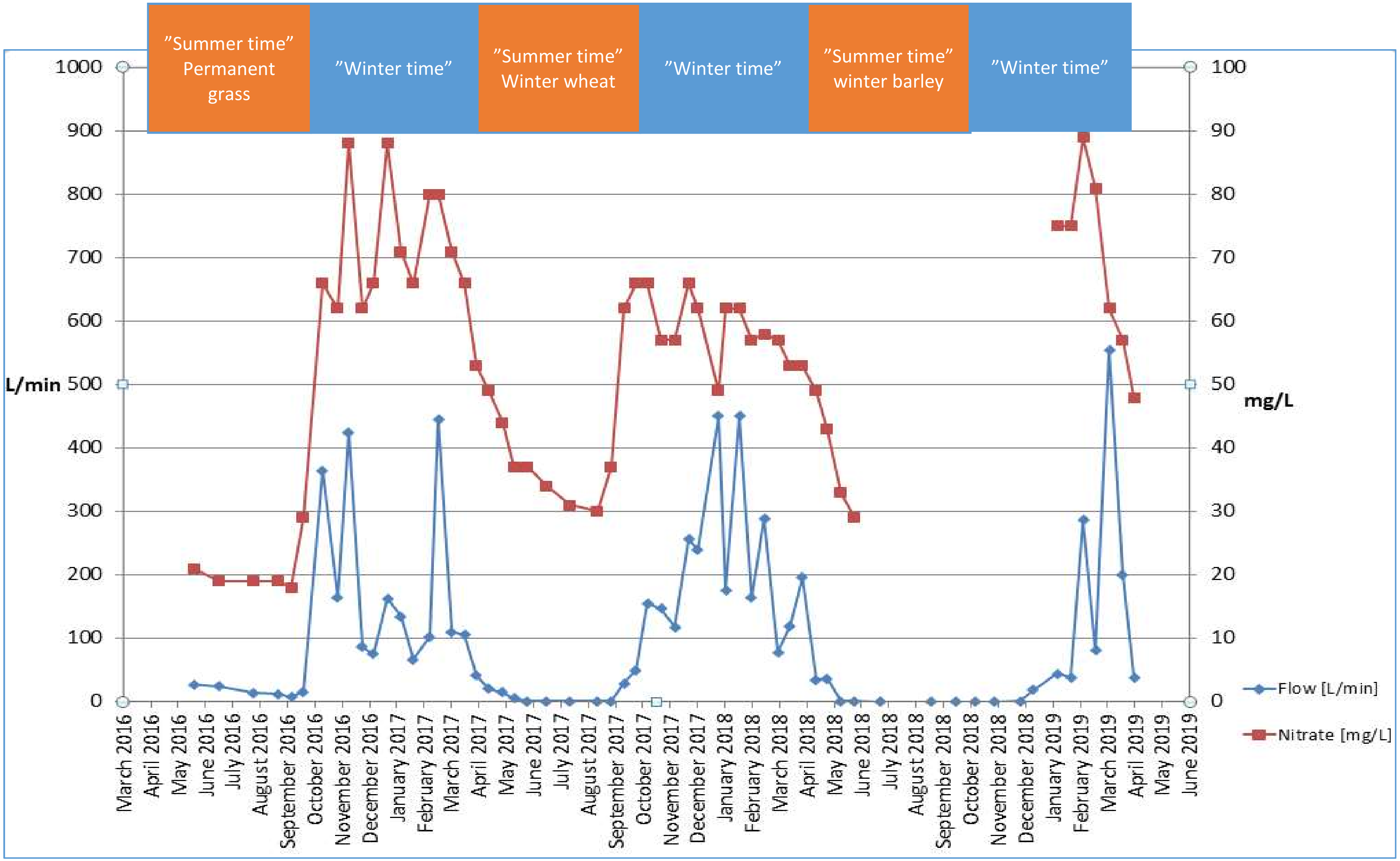


Figure 30. Comparison of water flow, nitrate-content and activity in the field

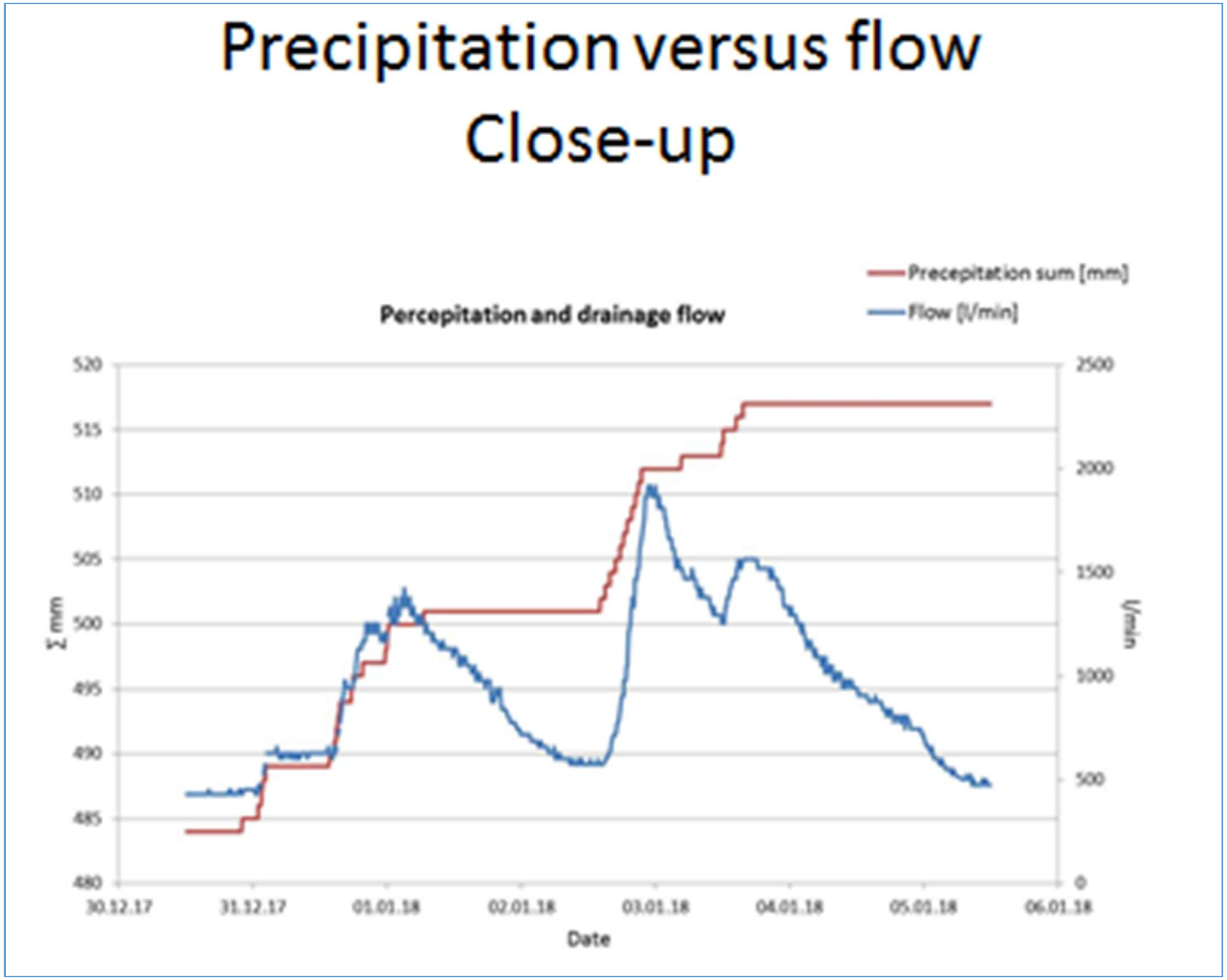


Figure 31. In this close up showing results from our online precipitation/flow measurements, the red line is accumulated precipitation and the blue line is drain flow. In 24 hours from 31/12 to 1/1 precipitation is about 15 mm resulting in an almost immediate rise in flow to about 1.200 l/min. Fairly fast the flow ceases to about 500 l/min until 3/1-2018 where a new rain-event results in a new flow peak of about 2.000 l/min. The drain thus demonstrates a very fast response to rain in the wintertime.

It is vital to point out at that every field has its own characteristics. As shown by the detailed geological/geophysical modelling, the characteristic of this field is that it is underlain by a fat clay that in combination with the steep slope hinders the formation of groundwater here. All nutrients leaves the field by the drains. In the other field investigated to the south in a more flat area, groundwater is generated and only smaller amounts of water is leaving via drain. The upper part of the test field is relatively poor soil while the lower parts are rich in organic matter and have better water retention.

Water flow.

During the **summertime** while the crops are growing and the evaporation is high and the topsoil dry, the water-retention is very good. Even the most heavy rain events is not reflected in flow in the drain. Neither has surface runoff been observed during intensive rain. There are no erosive tracks of surface run-off in the field. According to the farmer, Martin Mogensen, the good ability to withhold summer rain in the field and the lack of erosion is the results of the focus on incorporating organic matter in the soil. Neighbour fields cultured by other farmers in the area with a strategy of removing organic matter from the fields are much more prone to erosion.

The **wintertime** is the period that defines the amount of nitrogen leached from the field either to groundwater or surface water via the drain. In 2016 and 2017 the formation of groundwater (here in this case flow in the drain) started in the middle of October. Groundwater (flow in drain) is formed in the coming 6 months until mid April, where evaporation from the plants take over and flow in the drain ceases. During the wintertime when the unsaturated zone is filled, the fields ability to withhold water is very poor. Within a few hours after a heavy rain event (figure 31) the flow in the drain rises to almost extreme levels, measured up to 2.000 l/min. This shows that we have an enormous potential to store and buffer extreme rain events in the soil either for use for the plants during the growing season or to prevent flooding of areas, cities or installations downstream.

A special situation occurred in the summer 2018. The summer was extraordinarily warm and dry for a long period, hence demonstrating how many summers could be in a future climate. The relative dry conditions continued during the autumn and early winter and we had to wait until mid January before the first groundwater was formed. In this way the period with formation of groundwater was reduced significantly to about half of the normal. According to predictions of future climate this winter was not "the new normal". In 2100 winter precipitation is predicted to increase with about 40 % and summer precipitation to decrease with 15 %.

All in all the measurements of precipitation and drain flow clearly shows a high potential and need for strengthening the buffer capacity of the soil by enhancing the organic content of the soil in order to hold water and nutrients in the soil, minimize soil erosion and allowing early seeding. Along with this CO_2 will be captured in the soil.

The farmer Martin Mogensen is already far a long this track.

Leaching.

Nitrate in the drain water is in the level of 20 - 30 mg NO3/l during the summertime, but the flow is either close to zero or very low. Thus the accumulated leaching during summertime is of negligible importance.

In wintertime the level of nitrate in the drain water is high at the level of 60-90 mg NO_3/l. It is remarkable that the NO_3-level remains at this high level throughout the entire season of leaching. It is also remarkable that during extreme flow-events with a flow of more than 1,5 m^3/min in the drain, the nitrate content stays at the high level. Thus it can be concluded at this field, that the amount of precipitation during the wintertime is guiding the amount of leaching from the field.

With different methods it is attempted to calculate the entire leaching from the field during the winter 2017/2018:

- A calculation from Anders Vest Christiansen (Aarhus University) based on analytic values and the flow on the sample date indicates a seasonal leaching of 12,5 kg N/ha. This calculation is only for surface water and is furthermore not able to incorporate the peak flows, where a large part of the leaching happens. Thus this calculation must be considered too low.
- A calculation based on the N_{min} measurements of soil-samples indicates a leaching of ca. 17.5 kg N/ha (as described in Chapter 14).
- FarmN calculations (a standard farm tool) indicates a level of 40-45 kgN/ha.

The following calculations of the challenge in a future climate will be based on a level of 40 kgN/ha as this number is generally accepted by administrators and farmers. This is the total amount of nitrogen flushed from the root zone (calculated on the average annual precipitation) of the field to either groundwater or surface water.

18. The climate challenge

Modelling shows increased leaching in future climate and need for buffer capacity to store water and nutrients.

Modelling future climate is a scientific discipline in itself and the different climate models do to a certain degree point in different directions. All models of future climate in Denmark do however agree that the temperature will rise, summer precipitation will be lower and winter precipitation will be higher. In order to be able to model the future challenge for farming the following modelling and discussion takes the departure in a climate scenario agreed on in the CLIWAT project (www.cliwat.eu). The discussions below are however robust in the way that different climate scenarios will only change the resulting numbers but not the trends, that we have to deal with.

Summer

Models for a future climate (www.cliwat.eu) in the study area indicates that the summer precipitation will decrease about 15 % in 2100 and temperatures will rise about 2.8 ^{o}C. This summer scenario indicates an increased evaporation and need for water. The climate change will not have an effect on leaching during the summer period as the evaporation is higher than the precipitation and no groundwater/drain water is formed. An increase in organic matter in the soil will however give the soil better buffer capacity to hold water and nutrients during the winter period. Increased organic content will also have a good effect on preventing surface run-off from heavy rain-showers.

Winter

Winter temperatures are foreseen to rise about 3.1 ^{o}C and winter precipitation about 43 % (www.cliwat.eu). The temperature rise will have the effect that mineralization of N from organic matter will continue for a longer period and with higher intensity during the winter. This can give problems in controlling the N-mineralization if the organic content is raised.

Winter precipitation is forecasted to rise with 43% and at the test field, where we have noticed that leaching is relative constant throughout the season where groundwater/drain water is formed, we can estimate that leaching will rise from 40 kgN/ha to 57kgN/ha.

The target of TOPSOIL is to reduce the future leaching by 20%, equal to 11 kgN/ha so that the future level will be approximately 46 kgN/ha. At the particular test field, this rise will however be of less importance to the environment, while the drain via a stream will pass through the re-established Gedved Lake that is supposed to neutralize the Nitrogen.

In the dialogue with the farmer Martin Mogensen new management options in order to reduce the leaching from the test field was discussed and listed. However the most important results of the investigations are the in-depth knowledge about how the different parts of the fields (field area A and field area B in figure 1) interact with the surrounding environment. E.g. at the most intensive investigated field it is clear that almost no groundwater is formed in this particular area due to the underlying fat clay. The field (field area A in figure 1) interacts with the surroundings via the drain with an almost instant increase in flow and leaching during winter rain. Thus this field has a strong potential in climate adaptation perspective to withhold water (buffer capacity) reducing the risk of flooding in downstream areas. The leached nitrogene from this field is neutralized in the new Gedved Lake, so that it will not contribute to the leaching of nitrogene to Horsens Fjord. The field (field area B in figure 1) south of field area Ain in in a more flat area and of a different nature and here groundwater is formed, so that other considerations have to be taken.

The new knowledge on the area helps to foster a number of advantages in new management approaches listed in table 5.

Subject	Advantages	New Management Option
Surface water	Drains control the majority of the water flow. Knowledge of location is critical when measures to reduce nitrate are prioritised.	Registration of drains is needed.
Ground water	T-tem mapping gives knowledge of infiltration areas.	Knowledge-based dialogue between farmer and authority improves choice and effective placement of measures.

Soil quality	GCM mapping maps distribution of clay content in soils. Increasing organic content and reducing soil compaction makes soil robust to climate fluctuations.	Good soil is easy to manage and give better yields.
Buffer capacity	1) Soil quality relates to buffer capacity. Organic rich soils holds more water. 2) Root depth may be increased if drainage depth is increased. Buffer capacity is increased and crops will be more drought resistant. 3) Reduced tillage may result in deeper and more "open" soil structure	1) Organic matter must be incorporated in soils resulting in better soil structure and possibility for early sowing. 2) Increase of drainage depth. 3) Increase the infiltration depth at heavy rain.
Spatial planning:	New and more accurate knowledge on the subsoil zones with extra attention for runoff, drainage and infiltration can be used to redistribute fields.	1) By redistribution individual fields will perform evenly. Fields on vulnerable areas can be managed accordingly. 2) Nitrate vulnerable areas should be planted early to reduce nitrate leaching.
New innovative solutions/research for climate resilient farming	The above mentioned management options can improve climate resilience to a certain point	Research for new climate resilient crops or new techniques to use e.g. grass from permanent grassland to feed the livestock (here the pigs) are needed if the intensive production shall be maintained.

Table 5. New management options

The farmer Martin Mogensen already practice some of these management options. In Denmark there is a general consensus about the range of effect of some of these instruments (http://pure.au.dk/portal/files/84646400/Virkemiddelkatalog_web.pdf).

Accordingly the effect of some of the above mentioned instruments are in the range of:

Instrument	**Effect on leaching kgN/ha**
More organic matter in soil/early seeding	5-8
Reduced tillage	10
Reorganisation of fields with same properties/GPS guided fertilizing	1-2
Increased drainage depth resulting in better uptake of water and nutrients	?
New innovative solutions such as production of proteins feeding the pigs from permanent grass	20?
Increased knowledge on how the individual parts of the field interacts with the surrounding environments	Large (should leaching be avoided at the field (if groundwater is formed) or outside the fields in constructed wetlands)

Table 6. New management options, effect on leaching

The reduction target for the TOPSOIL project is about 11 kg N/ha. The farmer Martin Mogensen has already introduced some of the instruments above. However, it should – by the new better understanding of the interaction of the fields with the surrounding environment – be possible to reach the TOPSOIL target of a reduction of anticipated increased leaching.

19. Appendix.

DK2A – Pilot: Lillerupgaard management plan

For all TOPSOIL pilotareas a brief management plan is describing the major findings. The idea is **to reflect und summarize** the strategical impacts on and learnings for groundwater management of the pilot. The new management plan builds on the investigations described in the TOPSOIL pilots' catalogue, and is structured along guiding questions. The plans of all pilots will be an important input for the TOPSOIL end report.

1. What is the Objective of the pilot?

The objective is to investigate whether increasing the fertiliser allocation on less vulnerable soils and reducing the allocation of fertilisers to vulnerable soils, can enable the farmer to achieve greater yields while reducing the overall leaching of nitrogen into surface water and groundwater. Futhermore it is an objective to investigate how the soil can interact as a buffer component holding water for dry periods and retaining water in wet periods.

2. Studied

TOPSOIL Challenges.

Flooding

Soil conditions

Break down capacity

3. Context of current management.

To meet the targets in the Water Frame Directive, plans are made for the aquatic environment.

The latest plan is called Water Plan 2. According to Water Plan 2, leaching to Horsens Fjord must be reduced by approx. 420 tonnes of nitrogen per year in order to achieve a good condition in the aquatic environment of the fjord. About half of this reduction should be achieved before 2021 and the other half are planned to be achieved in the third water plan period. The reduction targets are based on the current climate conditions.

4. What is the expected impact of climate change?

- Less precipitation in summertime, increasing precipitation in winter time.
- Up to 40 % increase in winter precipitation is forecasted in 2100 (www.cliwate.eu). Investigations in this pilot and geological setting indicates that levels of leaching nitrate are at a constant level during the entire season of leaching. The combination of higher winter precipitation with a constant level of N in the leaching water is increasing the need for reductions in the leaching to Horsens fjord.
- Warmer and dryer summers with a changed precipitation pattern (more intense rain with a larger tendency to surface run-off) leading to reduction in crop yields.

5. What are the main management questions at the start of the project?

- One of the instruments to reduce nitrate leaching could be targeted fertiliser allocation on the cultivation surface which requires detailed identification of vulnerable areas within the fields. Will new mapping methods (t-tem) be adequate?
- Will new mapping methods in combination with the farmer's knowledge give a better understanding on how water is retained in the soil, whether the drainsystem can be used in buffering the water, and locate where groundwater is formed and finally locate where there is a more direct run-off from the field?
- Will new understanding develop, when the farmer and his advisor meets the new knowledge from the scientific /administrative level and vice versa in a mutual dialogue during the investigations, instead of using the traditional approach where a groundwater model defines vulnerable areas that are transformed into planning maps?

6. Which knowledge has been missing to find the climate resilient solution (at the start of the TOPSOIL project)?

Detailed knowledge of the geological setting within the fields.

Detailed knowledge of drainage impact.

Calculation of the effect of climate change.

Knowledge of practical farming at the administrative level

7. Steps taken to get to the missing knowledge / solve the problem.

Technical field investigations:

Geophysical mapping with Ground Conductivity Meter and T-tem

Drill holes for geological description

Drain water samples

Drain water flow measurements

Chemical analysis of the drainwater

Precipitation measurements

N-min sampling

Yield measurements

Analysing data: Geophysical data has been analysed by the Aarhus University and transferred into a geological model.

Using models: To calculate the effect of climate change and the impact of drainage in a simple model calculations estimating waterbalances and leaching from individual fields has been applied.

Measures taken: Farmer had used the new knowledge to innovate on farming practice.

Involvement stakeholders: See stakeholder involvement strategy.

8. Solutions found to solve the main management questions

Weather conditions prior and post seeding has a major impact on crop establishment as well as on nitrate leaching. Targeted fertiliser allocation will not achieve substantial reduction in nitrate leaching. If water retention in topsoil may be prolonged nitrate leaching may be reduced. Water retention in soil depends on content of organic material in soil and the deep soil structure.

However the main result are the new understanding on how individual parts of the field interact with the surrounding environment. Where groundwater is generated caution should be taken on the surface, is there a problem with groundwater flooding? Where are the interaction with the surroundings dominated by drain, - is there a potential to store and buffer water and how should the drain water be treated in miniwetlands?

9. New management and advantages

	Advantages	New Management Option
Surface water	Drains control the majority of the water flow. Knowledge of location is critical when measures to reduce nitrate is prioritised.	Registration of drains is needed.
Ground water	T-tem mapping gives knowledge of infiltration areas.	Knowledge-based dialogue between farmer and authority improves choice and effective placement of measures.
Soil quality	GCM mapping maps distribution of clay content in soils. Increasing organic content and reducing soil compaction makes soil robust to climate fluctuations.	Good soil is easy to manage and give better yields.
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Spatial planning:	New and more accurate knowledge on the subsoil zones with extra attention for runoff, drainage and infiltration can be used to redistribute fields.	1) By redistribution individual fields they will perform evenly. Fields on vulnerable areas can be managed accordingly. 2)Nitrate vulnerable areas should be planted early to reduce nitrate leaching.
New innovative solutions/research for climate resilient farming	The above mentioned management options can improve climate resilience to a certain point	Research for new climate resilient crops or new techniques to use e.g. grass from permanent grassland to feed the livestock (here the pigs) are needed if the intensive production shall be maintained.

10. Benefits transnational exchange Topsoil:

t-TEM mapping has proven as a relevant and strong tool for top soil mapping and vulnerability mapping. The method provides high 3D resolution of the shallow subsurface and is relevant on field scale.

Measures to improve agricultural practice in a more climate safe direction has been exchanged with the other partners

11. Measure of pilot's success with results 'indicator

Indicator (goals)	Baseline of Indicator (value at start of pilot)	Reached water quality goal (include target value and mark red for not reached and green for reached target
Water Quality: 20 % reduction in flux of water from drains and recharge in a future climate by innovative management	Leaching is calculated to 54 kgN/ha in 2100	20 % reduction is proven possible by a mix of instruments.
Water Quantity: To improve by 20 % the soils ability to hold excess water for a longer period and likewise retain water for dry periods	Baseline is an evaluation of the soils ability to hold a heavy rainfall during wintertime in hours (estimated to 24-48 hours).	Deeper drainage, increased organic matter and better soil structures will facilitate the increased buffer capacity. Exact effect can not be calculated.

12. Consequences for implementation of Water Frame Directive

Currently the focus in respect of the Water Frame Directive is to reduce the amount of N discharged to Horsens Fjord seen in the context of the current climate . Seen in the light of the future increased winter precipitation and loss of N from the fields focus should be on continued research on the interactions with the surrounding environment.