New agri-environmental measures to retain nutrients relevant within the buffer zone

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Summary

This report is the result of an internship at SEGES where a literature study has been requested to investigate new environmental edge of field measures to retain nutrients (N and P). The work has been conducted within the frames of the BufferTech project. BufferTech is a project with multiple collaborating institutions, among them SEGES and Aarhus University, Department of Agroecology. The literature study investigate the following problem formulation: *What are the relevant measures within the buffer zone to retain nutrients, including cutting-edge research, based on international literature?*

The international literature has revealed interesting agri-environmental measures, which are evaluated to be feasible and relevant in a Danish context. One of these are denitrifying bioreactor that show promising results, but there are big challenges related to finding the right dimensions and design to ensure high efficiency and avoiding detrimental side effects. The newest measure found in the international literature is Algae Turf Scrubbers where drainage water is circulated over rubber raceways by solar power to grow algae. The algae are a potential source of organic fertilizer. As a result of this report I make a proposal of a possible combination of environmental measures.

The internship has been a good learning experience, and I have expanded my professional network significantly. I can highly recommend having an internship at SEGES provided that the frames of expectations from both parties are well established.

Key words: nutrient retention, environmental measures, nitrogen, phosphorus, bioreactor, denitrification, algae turf scrubbers, soil amendment, controlled drainage.

Abreviations

Al-WTR: Aluminum based waste water residuals.
ATS: Algae Turf Scrubbers
BufferTech: Project for development of targeted environmental management of diffuse nutrient losses from agricultural production (www.buffertech.dk).
IBZ: Integrated Buffer Zones, relates to the environmental measure depicted in figure 1, developed in the BufferTech project.
NLES: Modelling tool for nitrogen losses.

Introduction

As a member of the EU, Denmark has an obligation to fulfill the Water Frame Directive to ensure a good ecological status in all natural water bodies (EC, 2014). Furthermore Denmark has national water plans and is currently in the process of developing the 2. generation water plans with the emphasis on targeted environmental measures (Eriksen et al., 2014).

The history of the buffer zones regulation has been turbulent, and the implementation has been heavily criticized. The establishment of the BufferTech project (with SEGES as one of the main collaborators) is a direct consequence of this as well as working towards more targeted and differentiated environmental regulations. The focus of BufferTech is to identify in more detail the nutrient losses from agricultural production in order to make targeted and site specific mitigation plans. The environmental measure proposed in this project is the Integrated Buffer Zones (IBZ) and will be described in more detail later on.

This report is made as a part of my internship at SEGES, and is a result of the request by the business partner to investigate the possibilities of expanding the potential of the buffer zone to retain nutrients (nitrogen and phosphorus) from surface waters suitable for Danish conditions. During the preliminary meetings with my supervisor from Aarhus University, Department of Agroecology (Tommy Dalgaard) and SEGES (Irene A. Wiborg) the following problem formulation was developed: *What are the relevant measures within the buffer zone to retain nutrients, including cutting-edge research, based on international literature.*

The scope of the internship report was to make an overview over the international literature on practical experiences of relevant measures in the buffer zone and to find a suitable method for this task. The conclusion of the report includes a recommendation to SEGES of the process of choosing relevant measures and new possible combinations of measures that can enhance the potential of the IBZ. In the catalogue of environmental measures gathered by Eriksen et al. (2014) there are disclosures of ongoing research on several of the newer environmental measures in Denmark, such as constructed wetlands with and without filter matrixes and controlled drainage (Eriksen et al., 2014) and this document will be used as the main reference on reporting the effect of these measures.

The purpose of the internship has also been to follow the daily work at SEGES, I have attended several meetings (some not directly related to BufferTech) and made an extensive summary of a meeting with the BufferTech stakeholder group. A summary of the internship report will be made into a small article published on Landbrugs Info. Furthermore, as a result of an evaluation meeting initiated by Rasmus Pedersen (AU coordinator), where Irene A. Wiborg and also Anette Højgaard Andersen (Concern HR & Organization developer) attended, several ideas were formulated on how to strengthen the collaboration of Aarhus University, Department of Agroecology and SEGES.

Method, process and learning outcome

The motivation for conducting a review can be categorized by the following statements: 1. Compilation of knowledge that makes new connections and therefore new knowledge. 2. Collection of the newest knowledge. 3. Knowledge made applicable. 4. The paradigm of a field has been changed (Aagaard Christensen, A 2015, personal communication, 23 September). In this literature study the focus has been on finding new knowledge in terms of new environmental measures to restrict nutrients entering the surface waters, and also how the knowledge is made applicable.

This literature study has been conducted based on personal contact with employees at SEGES and other resource persons either in my own network, at the University or persons I have been referred to. In the beginning, much time was spent trying to get an overview of what was already common knowledge to the SEGES employee and where the uncertainties ley. It was also a challenge finding out how to organize the references, the search strategy and the content. During my search, I was introduced by Aagaard Christensen (2015, personal communication, 23 September), to a method to conduct a systematic review in the field of Environmental Management (Pullin and Stewart, 2006).

The purpose of this method is to make an overview of all relevant articles, a method that makes sure that nothing is overlooked, and so is not entirely applicable to my research question, but some of the approach was helpful.

My task of finding new measures has been somewhat expanded by a concrete request from Flemming Gertz (employee at SEGES), that there is a need for specific knowledge about the effect of trees on infiltration and nutrient uptake, specifically in alder, an endemic species along Danish water courses and used in the BufferTech pilot areas. I have, late in the process, only come across one measure that can be characterized as a new measure, the Algae Turf Scrubbers, but the focus of the section on environmental measures is on bioreactors. This is because of the very promising results in nitrate removal and the surprisingly large amount of literature on this area. Measures that are described in the catalogue of environmental measures (Eriksen et al., 2014) are only briefly mentioned.

The time did not allow me to critically go through all the articles that were found through the method of conducting a systematic review and to include them in the analysis, but the compilation of articles I have made from this search strategy will be highly relevant for further work within this field.

Because the aim of the study and the research strategy was not absolutely clear from the beginning, this has had obvious repercussions. There has been confusion weather I was to create an overview of documented effects on all possible measures that potentially could be placed in a buffer zone, but when looking at the initial problem formulation, this was abandoned, and the focus of this work is on the new measures found and their relevance. It took a while to find any new measures, which was said almost to be an impossible task by both Frank Bondgaard (SEGES) and Flemming Gertz (SEGES). One of the biggest contributors in finding new measures was the input of Frank Bondgaard. He has recently conducted a search for new measures by using the picture function in Google, his focus thus being on the practical implementation of the measures. He has also pointed me toward the Finnish hydrologist Sirkka Tattari who mentions chemical amendment of wetlands and algae production in drainage ditches in a conference presentation (Tattari, 2012). Flemming Gertz has pointed me to the Swedish researcher Peter Feuerbach, who has combined controlled drainage and the concept of integrated buffer zones. Research Professor at Aarhus University Brian Kronvang informed me via email correspondence about a project yet to be established investigating biological amendment of buffer zone soil (Kronvang, B 2015, personal communication, 21 September). Furthermore, researcher Hans Martin Hanslin at the Norwegian Institute for Bio Economics (NIBIO) helped me in finding an approach in my searching for articles about the issue of increasing infiltration by alder roots (Hanslin 2015, personal communications, 20 September) and Associate Professor at the University of Southern Denmark Henning Jensen has helped me finding literature about soil amended with water treatment residuals (Jensen 2015 personal communications, 9 October).

During this process I have learned more about how the Web of Science search engine works, and as a result my strategy was iteratively revised. With the introduction to a more systematic method I also became more aware of how to select literature, on what basis, and what made it relevant for my task. I have learned the importance of having a focused research question in order to conduct a systematic search and to be able to be consistent in selecting the relevant articles.

In order to extract all relevant information from conversations with interesting people and the meetings I have attended I have continuously evaluated how it relates to the project I am working on, made notes on my learning process and also how this has affected my further process. The interface between different people's various field of work and content of the meeting has been obvious because the BufferTech project includes so many different aspects within the agri-environmental area. It has been a time-consuming process, but at the same time some matters can be resolved very quickly due to the resource people being at close proximity. As I was investigating the idea of adding algae production to sedimentation ponds, the feasibility was quickly questioned by both Frank Bondgaard and Flemming Gertz. Nevertheless it was mentioned by Sirkka Tattari at a conference (Tattari, 2012) and later on I have discovered the project with algae by Kangas and Mulbry (2014) and water plants grown in drainage ditches (Pallesen, 2015).

The buffer zone as an environmental measure

Farmers and policy makes have demanded to know more exactly the effect of buffer zones. Several attempts have been made to predict this, which is highly complex, site specific and dependent on many factors (Schoumans et al. (2014); Dorioz et al. (2006)). The aim of the BufferTech project is not to find a general effect of buffer zones, but rather how to optimize the effect of a specific placement and design of the Integrated Buffer Zone (IBZ). The development of the design is based on extensive research of particularly the mechanisms governed by hydrology and nutrient dynamics.

Two kinds of buffer zones are described and the effect analyzed in the catalogue for environmental measures (Eriksen et al., 2014); buffer zones with a fixed width, and locally adapted buffer zones that represent the design developed in the BufferTech project (IBZ). In the unmanaged buffer zone with a fixed width, there is no active N removal, only the decreased emission that comes from not fertilizing the area. But there is not enough data to document the N leaching from the buffer zone, although some NLES modeling have been done. There are no requirements of biomass removal but there is still estimated a net retention of P of 2 – 20 tons P/year even if the buffer zone is not harvested (Eriksen et al., 2014). According to Habibiandehkordi et al. (2015) sub-surface transport in a vegetated buffer strip removed 90% of inflowing P concentration, though a slight but significant increase in the release of the soluble fraction of P in surface run-off was recorded.

Broad and locally adapted buffer zones are analyzed both according to P removal and N removal: This measure covers a buffer zone with varying width, removal of plant material and trees may be planted to stabilize the stream banks. To estimate the P effect in correlation to the width a conjunction of the slope and clay content has been made by Dorioz et al. (2006). These results together with data on soil P content and erosion risk can be used to place these buffer zones. Planting of trees along buffer zone helps stabilizing the stream bank and thereby reduce P losses by prevention erosion. Whereas planting of trees and grasses is recommended as a means to increase infiltration, it is thereby primarily seen as measure to retain P through reduced surface runoff. The inclusion of still water in ponds with collected drainage water target N removal through denitrifying processes. These ponds can also retain particulate and dissolved P by sedimentation and plant assimilation. Assuming the right dimensions for sedimentation and retention time for denitrification, the IBZ targets both N and P retention. When the water table is elevated, the risk is that P can be released from the saturated buffer zone. This happens when the soil has a concentration of soluble P that is higher than the Soil Equilibrium P concentration (EPC_0), which is the equilibrium between sorbtion and desorption (Hoffmann et al., 2009). A sufficient slope is required to prevent water levels in the fields from rising too much (Kronvang et al., 2014)

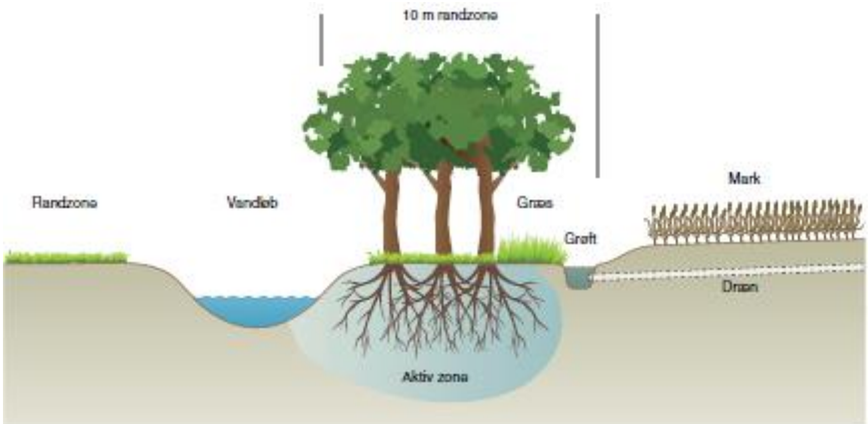


Figure 1. Schematic overview of the design of the IBZ (Kronvang et al., 2014).

Preliminary results from integrated buffer zones

On September 30th the first preliminary results from the pilot area of Fillerup was presented. The average nitrate removal from April 14th to June 17th was 32 %, calculated as the percentage of the difference between inlet concentration and the outlet concentration. The IBZ in Fillerup also show positive results in regards to total P removal the average of four measurements during the same time period show a removal of 50 – 60 %. The potential of nitrate removal of the IBZ was compared to some of the most effective wetlands, and this shows that an IBZ can potentially be twice as effective (the pilot area of Fillerup was compared to Karlsmosen) (Jensen, 2015).

Production of algae and water plants in drainage water

To grow algae in order to remove nutrients from water is not a new idea. Already 20 years ago similar technology has been used to clean waste water and manure effluent (Kangas and Mulbry, 2014). What is innovative is to take the technology off grid by using solar power and out in the field margin as Kangas and Mulbry (2014) have done. They have placed a 1 m x 50 m raceway made of rubber as the growing area in a 2 % slope. A solar power driven pump circulates water from a drainage ditch over the raceway. The biomass that the algae produce is harvested once a week with a regular broom, and can potentially be used as a slow-release organic fertilizer. The results from such devises fluctuate, but removes on average 125 mg N /m^2/day and 25 mg P/m^2/day (Kangas and Mulbry, 2014). They have shown that the higher the nutrient concentration in the overflowing water, the higher the nutrient concentration will be in the algae, and hence more effective removal

There is also an ongoing project at AgroTech in Denmark where water plants are grown in drainage ditches to remove nutrients and use the biomass as protein fodder (Pallesen, 2015). Preliminary results will be published in November, but the project manager Bodil E. Pallesen is very optimistic that the project will show positive results. The nutrient retention per hectare water surface is expected to be 880 kg N and 22 kg P.

Soil amendments

The effect of aluminum-based water treatment residuals (Al-WTR) and ochre (applied at 20 t/ha) on surface and sub-surface P losses were tested in a laboratory experiment by Habibiandehkordi et al. (2015). Vegetated buffer strips enhance infiltration through preferential flow (through root channels, cracks etc.) and matrix flow and thereby particulate P can be retained whereas soluble P may be released. This experiment shows that ochre and Al-WTR treated soil can reduced losses of soluble P by 15 - 16% and 61 – 61% respectively. The effect of ochre decreased rapidly over time, whereas the effect of Al-WTR was more consistent. The treatments also had a significant effect on total P and particulate P (Habibiandehkordi et al., 2015).

One of the main mechanisms for P to be retained is through interactions with soil particles, therefore contact time is an important factor and the importance of vegetation to slow the speed of water carrying particulate and soluble P is related to this aspect. Habibiandehkordi et al. (2015) found that a higher P concentration requires higher contact time. Contrary to Habibiandehkordi et al. (2015), Wagner et al. (2008) found no significant effect of treatment with WTR. This was attributed to lack of contact time between WTR and P in runoff. This was field trial opposed to the former and might show a more realistic picture of the potential of WTR.

Through email correspondence Brian Kronvang mentioned biological amendment/ bioaugmentation of the microbial community in the buffer zone soil, but no details were mentioned (2015, personal communication, 21 September). There have been studies showing positive results of inoculation of soil with bacteria- and fungal cultures to prevent soil borne deceases, but the effect has decreased over time and the effect of crop rotation was more persistent (Larkin, 2008). This suggests that the best way to ensure high rates of denitrification activity in the soil might be by ensuring a high diversity of plants in the buffer strip. Schipper et al. (2010) also mentions that inoculation with denitrifying bacteria was not necessary.

Trials of soil amendment with waste products have also been suggested in BufferTech, but initial trials show that the ochre sludge used is already P enriched and will thus not result in P adsorption. Other products will presumably be tested during the course of the project (Jensen, H 2015personal communication, 9 October).

Bioreactors, denitrification walls and ditches

In this paper, bioreactor is used as a collective term for all measures that uses primarily woodchip to facilitate denitrification in removal of nitrate from water. A common denominator is that they are covered with soil, contrary to constructed wetlands with filter matrices in Denmark, and usually the bioreactors are lined to prevent inflow of water from unwanted sources. A short evaluation is already made by Frank Bondgaard at SEGES (Bondgaard, 2015).

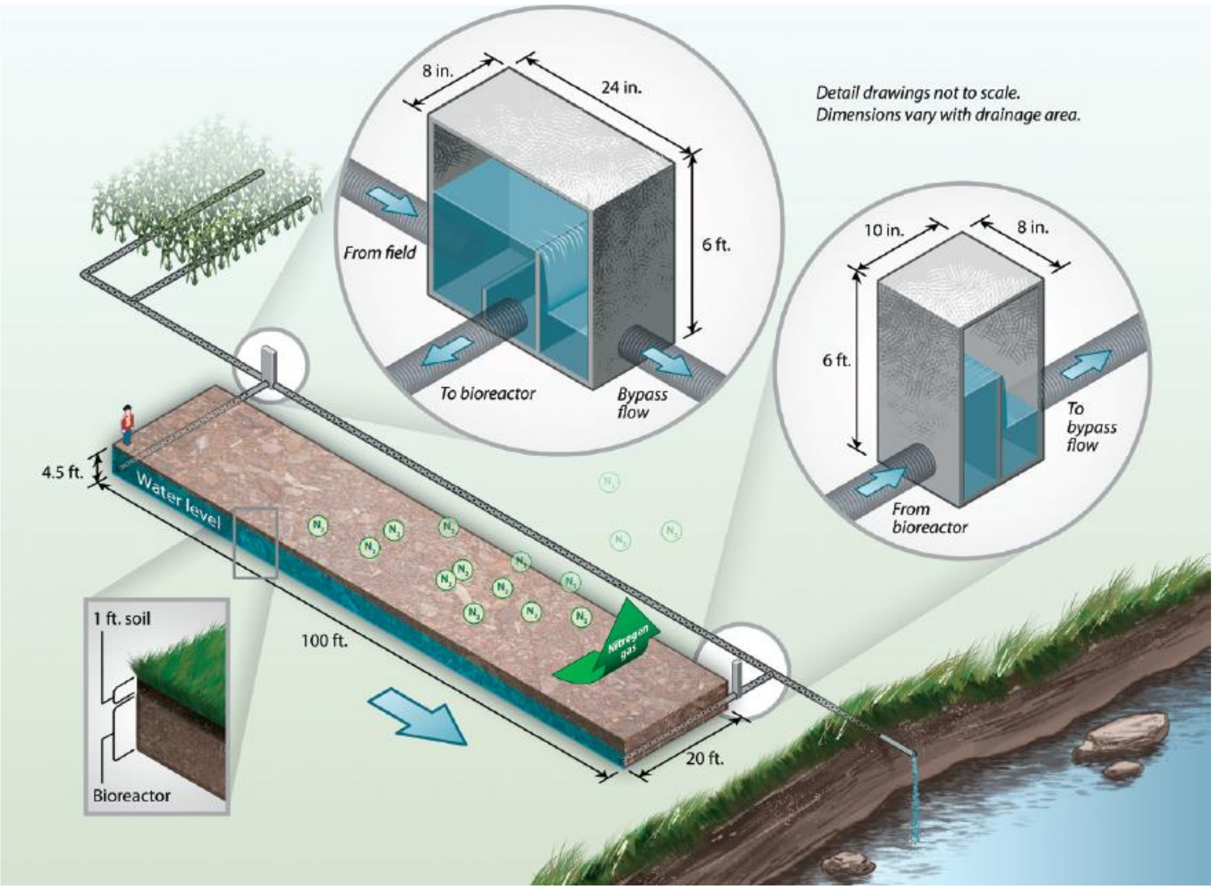


Figure 2. A 30 x 6 x 1 m ditch is lined and filled with woodchip as carbon source and subsequently covered with soil and sown with grass (Christianson and Helmers, 2011).

The mechanism of removing nitrate from water is facilitated by denitrifying bacteria feeding on carbon source under anaerobic conditions.

To maintain the effect of the bioreactor the carbon source and adequate saturated conditions for denitrification have to be present. The quality of the carbon source, flow characteristics and level of saturation are also important factors. Longevity is expected to be several decades, but experimental data is available for 10 years, the oldest (20 years) treating septic water or other waste waters. As with most environmental measures, a thorough investigation of site specific conditions is crucial for optimizing function and efficiency. Retention time is an important factor affected by the general design and seasonal changes in flow rates. Retention time and removal rates are also related to the nitrate concentration of the inflow water. Too long retention time with low levels of nitrate can lead to unwanted by-products, and the opposite scenario will exceed the denitrifying capacity of the system. In case of the latter a bypassing system may be required (Schipper et al., 2010). A slope is required to lead the water through the matrix and prevent water being backed up in the field.

Different carbon sources have been investigated. Sawdust, different wood types of different particle size and different residues from field production, e.g. straw and corn stalks. The latter more labile sources often leads to higher removal rates, but are depleted faster and needs replacement, whereas less available carbon sources like wood enhances the longevity of the system.

Biological processes generally increase with increased temperature and the microbial activity of denitrification has an optimum temperature of 25 – 35 C, but has been shown to occur at a wide range of temperatures (Rivett et al., 2008). Schipper et al. (2010) refers to experiments that confirm that denitrification processes continuo through the winter season with temperatures down to 1 – 5 C.

High amounts of dissolved oxygen can lead to decreased levels of nitrate removal because aerobic bacteria out-compete denitrifiers, therefore water high in dissolved oxygen entering large bioreactors with longer retention time denitrifying bacteria will not be out-compete as might be the case for smaller facilities with a shorter retention time (Rivett et al., 2008). Several field trials and laboratory experiments confirm that a minimum retention time of 1 hour is required to deplete dissolved oxygen in oxygen saturated inflow water. So there is an important relationship between the retention time and removal rates. Weigelhofer and Hein (2015) found that the efficiency of nitrate removal decreased with increased nitrate concentration, but Schipper et al. (2010) found no relationship between removal rate and increased nitrate concentration where concentration range of 3,1 – 49 NO_3^--N mg/L was tested. Despite this, Bondgaard (2015) evaluates the inflow nitrate concentration to be the most important factor that affects the removal rate. Although a low level of nitrate can lead to aerobic degradation of the carbon source experiments show that a minimum level of 3g available NO_3/m^3 is needed in order to maintain denitrification (Schipper et al., 2010).

Christianson et al. (2012) have made an extensive review and displays a wide variation in the effect of the bioreactor, from almost no effect up to nearly 100 % nitrate removal. The majority of the publications are from the US Midwest (Illinoi and Iowa), two from Canada and one from New Zealand. One of the most recent publications collected in this study show an average nitrate removal rate of 23 and 50% in the first and second year respectively, varying from 12 – 95 %, corresponding to a removal of 17,1 kg N/ha. The experiment also combined controlled drainage, which also showed a positive, but uncertain, effect in removing nitrate from drainage water (Woli et al., 2010).

Table 1, Excerpt from table 1 in Christianson et al. (2012)

Source	Volume, m^3	Treatment area, ha	Influent NO_3^-–N concentration mg/L	Retention time	Percent reduction	Site
Blowes et al. (1994)	0,2	NA	3 – 6	1 – 6 d	Nearly 100%	Canada
Wildman (2001)*	27,2	5,3	1 – 18	NA	Nearly 100%	Great Britain
Chun et al. (2009)	0,3	NA	10,4 – 33,7	15,6 – 19,2	Nearly 100%	USA
Verma et al., (2010)*	55,8	2,2	5 - >20	NA	81 – 98%	USA
Woli et al. (2010)	76,9	14,0	2,8 – 18,9	26 min – 2,8 h	23 – 50%	USA
Christianson et al., 2012	18,0	1,2	1,2 – 8,5	NA	22 – 74%	USA

*these references were not possible to find.

For the most part the studies of bioreactors focus on the removal of N from the drainage water, though Weigelhofer and Hein (2015) also report on removal of PO_4-P, but nitrate removal is still their main focus. The study is a laboratory experiment and it tested two types of material, 100% straw and a mixture of straw and sand to simulate streambed conditions and the setup was able to simulate variable flow rates and desiccation. Three different concentrations of nitrate (from 4,7 – 6,8 mg /L NO_3-N) and two flow rate velocities were tested. These concentrations are comparable to concentrations in inlet concentration in drainage water in Fillerup pilot area (Jensen, 2015).

The laboratory experiment of Bock et al. (2015) has a stronger focus on P removal and the objective of the study is to investigate if the effect of adding biochar with three different retention times (18, 48 and 72 hours) to the bioreactor matrix would enhance N and P removal and also mitigate the release of nitrous oxide (N_2O). The motivation for using biochar is the many positive effects on soil properties that have been recorded (Sohi et al., 2010). The matrixes containing biochar showed a reduction in the residence time needed to remove the same amount of nitrate. The biochar treatment also showed reduced nitrous oxide emission compared to control. Removal rate of P in the control was 8 % of inlet concentration and the biochar treatment enhances the rate of removal to 65 % of inlet concentration (4,5 mg P/L). Biochar also had a positive effect on nitrate removal; from 13 % to 94 %. The effect was most pronounced in the shortest retention time (18h). But biochar is a heterogenic group of materials and its properties depend on many factors (origin and processing), which can lead to more complex responses (Bock et al., 2015).

There have been no experiments with farming on top of the bioreactor, so it remains a measure that has to be placed in the field margin (Christianson et al., 2012).

Nitrous oxide emission is a result of incomplete denitrification, low pH and excess organic carbon. The emission of methane is a result of anaerobic digestion of organic material and can therefore happen in a bioreactor, but are evaluated to be small compared to wetlands (Weigelhofer and Hein, 2015). Elgood et al. (2010) have measured N_2O emission, and reports that the rates are comparable to emissions from arable land and the authors conclude, but judging by the high nitrate removal rate the denitrification reaction is assume to be complete.

During times with high temperature and close to complete nitrate removal there are reports of formation of hydrogen sulfide gas as a result of sulfate reduction because the source of nitrate is close to depletion. Sulfate reduction is also related to formation of methylation of mercury (Christianson et al., 2012). During the start-up phase, which can be up to 3 – 6 months, Schipper et al. (2010) reports on of dissolved organic carbon emissions, another harmful effluent. Also small amounts of nitrite, ammonium and phosphorus has been reported, but evaluated as being of low importance (Schipper et al., 2010)

Controlled drainage combined with saturated buffer strip

Controlled drainage is the elevation of the up-stream water level during autumn and winter through the use of regulation wells. This gives altered hydrological properties of the soil and can enhance the denitrification. Flat and drained areas are suitable for this measure where the water table can be raised uniformly. On sandy soils this can lead to more transport of water down to groundwater and potentially passing through a reducing zone, and reducing flow through drainage. The potential for this measure regarding N demineralization is evaluated to be high because 50% of Danish fields is said to be drained and so 300.000 ha could be suitable, but with a risk of P mobilization as several parameters influence this dynamic (Hoffmann et al., 2009). As with the other measures that rely on the denitrification process, there is a risk that the process is not completed and nitrous oxide is produced (Eriksen et al., 2014).

There are ongoing experiments to test the effect of controlled drainage in Denmark, but no results are published yet (Eriksen et al., 2014). Very promising results have been shown in Swedish experiments. In Southern Sweden Wesström and Messing (2007) found a significant reduction in loads of both P and N from the drain outflow and even an increase in N uptake by crops.

Jaynes and Isenhart (2014) have combined controlled drainage with a 20 m wide buffer zone, the drains are cut inside the buffer zone and connected to a perpendicular perforated pipe (parallel to the stream) where the drainage water will seep into the buffer zone soil. The requirement for this facility to work is that the perpendicular pipe is level (0% slope). A short evaluation of this measure is already made (Bondgaard, 2015)

Swedish researchers have ongoing projects that combine the setup of IBZ with controlled drainage on flat areas in Southern Sweden. These areas are similar to some areas in Denmark so results from these projects are highly relevant in gathering documentation about the effect of this combination of measures (Feuerbach, 2014).

N and P removal rates

Table 2, compilation of results of the effects of nutrient retention/removal.

Measure	**Author**	**N**	**P**
ATS	Kangas and Mulbry (2014)	125 mg $N/m^2/day$	25 mg $P/m^2/day$
Drainage water for protein fodder	Pallesen (2015)	880 kg N/ha water surface	22 kg P/ha water surface
Buffer zones, fixed width	Eriksen et al. (2014)	37 – 58 kg N/ha/year	2 – 20 ton/ha/year
Buffer zones, harvested	Eriksen et al. (2014)	Currently not enough data	11 – 83 tons/year when planted trees reduce bank erosion
Buffer zones, integrated (IBZ)	Jensen (2015)	30% removal	50 – 60% removal
Controlled drainage	Jaynes and Isenhart (2014)	228 kg N over a two year period	
	Eriksen et al. (2014)	Currently not enough data	-/+ (1
Bioreactor	Bock et al. (2015)	97% removal	65% removal
	Weigelhofer and Hein (2015)	42,6 – 55,7 g NO_3^- $N/m^3/day$*	5,2 – 12,8 g PO_4-P $/m^3/hour$*
	Christianson et al. (2012)	See table 1	
Bioreactor (denitrification wall)	Schipper et al. (2010)	0,01 – 3,6 g $N/m^3/day$	
Bioreactor (denitrification bed)	Schipper et al. (2010)	2 – 22 g $N/m^3/day$	
Bioreactor and controlled drainage	Woli et al. (2010)	17 kg N/ha	
Soil amendment	Habibiandehkordi et al. (2015)		Ochre: 15 – 19% soluble reactive P (SRP) Al-WTR: 61 – 62 % SRP
	Wagner et al. (2008)		No significant effect
Wetlands, mini, constructed	Eriksen et al. (2014)		+/- (1
Wetlands, matrix	Christensen et al. (2009)	120 – 190 kg N/ha/year	

1: special care of P is necessary to achieve a positive effect/ avoid detrimental effects (Eriksen et al., 2014)

*I question the units here, but have not investigated the matter any further.

Roots and infiltration

As mentioned earlier, an explicit wish for more knowledge on trees effect on soil infiltration has been expressed. The majority of literature on this topic is on compacted and /or urban soil (Bartens et al. (2008); Meyer et al. (2014)). As a result only a limited amount of articles has been included in this study. An attempt on finding literature on the specific species of alder (*Alnus glutinosa*) used in the pilot areas of the integrated buffer zones as also been conducted. This species has been selected based on the research of Christen and Dalgaard (2013) because it is an endemic species to Denmark and known for its deep rooting system (Schmidt-Vogt, 1971), and able to grow under waterlogged soil conditions. As expected it was not possible to find much, but one article by Dittert et al. (2006) has contributed with an interesting study.

An extensive literature study by Angers and Caron (1998) confirms the various effects tree roots have on soil. Roots, both dead and alive have a positive effect on soil structure and enhances the processes of aggregation of soil particles, an important component in the structure and function of the soil. A good soil structure will enhance porosity and thus infiltrations. Because of the deep going roots of black alder (*A. glutinosa*), it has also been used in an experiment of structural regeneration of compacted forest soil, with good results (Meyer et al., 2014).

An experiment on two-year old alder trees growing in waterlogged conditions was performed by Dittert et al. (2006). Their main findings was that the water logged conditions reduce the root mass, fewer coarse roots were developed and that the majority of the root mass was concentrated in the uppermost soil layer (Dittert, 2006). Root to shoot ratio (dry weight) decreased as a result of 7 months of waterlogged conditions compared to the control. The total root density decreased and 90% of total root length was concentrated in the top 20 cm of the soil. The morphological response of the root was to develop highly branched roots in the upper layer, and only few thick roots going down to the maximum depth of the pot (70 cm). See appendix 1.

These findings have implications on the assumption that the alder tree has deep roots and therefore enhances the infiltration rate of the soil. Very few other studies have investigated the morphological response to waterlogging on roots. Personal communication with Hanslin (2015, 20 September) also mentions that saturated soil conditions can result in shallow root growth.

The main function of the integrated buffer zones (IBZ) is to remove nitrate from the drainage water that is lead through the saturated soil in which red alder is planted. The primary mechanism of nitrate removal is through denitrification, but some is also assimilated by biomass production. Alder is potentially a nitrogen fixating tree when it lives in symbiosis with ectomycorrhizal fungi, and the nutrient turnover efficiency is dependent on this symbiosis (Belanger et al., 2013). A study by Batzli and Dawson (1999) investigates the ability to fixate N as a result of waterlogged conditions. Flooding reduced the nitrogenase activity in the roots, and this function was only restored after 50 days of flooding. These results imply that the trees that grow under waterlogged conditions over longer periods will restore their ability to fix nitrogen from the air and not utilize the nitrate in the drainage water.

Discussion of results, possible combination of measures

The following is a discussion of the investigated problem and relevance to Danish conditions: “What are the relevant measures within the buffer zone to retain nutrients, including cutting-edge research, based on international literature”. I argue that there is a need for many different measures for the farmer to have the necessary flexibility in choosing the environmental measure that is the most suitable on a particular farm. My overall evaluation is that the reviewed measures show promising results where bioreactors, controlled drainage, ATS and soil amendments are potential new measures in Danish buffer zones. Conclusions on the efficiency of the particular measure on the basis of the results presented in table 1 and 2 are not easily made. Knowing that the premise for optimal effect is highly site specific, summing up on specific reduction rates might not be what is most relevant.

Denmark has a wide variety of environmental conditions and thus need a wide range of measures and substantial field trials with scientific monitoring of new measures are still of utmost importance. Furthermore the advisory service needs tools to evaluate the landscape elements (e.g. maps of erosion risk etc.) for communication purposes and aiding the farmer in making an informed decision on what measures would have the best effect on the farm. Table 3 is a brief summary of the reviewed measures and the practical considerations for implementation in a Danish context will be discussed further. The morphological effect on root growth on waterlogged conditions will also briefly be discussed.

Table 3, Schematic overview over the reviewed measure

Measure	**Nutrient target**	**Unwanted effects**	**Practical considerations in a Danish context**
IBZ	Both N and P	Greenhouse gas emissions, release of P	Placement for optimal effect. Site specific investigations of hydrology and topography etc.
ATS	Both N and P	No effect if algae fails to grow	Cost and maintenance. Specific knowledge for proper installation.
Bioreactors	Mainly N, but biochar addition can mitigate P losses	Greenhouse gas emissions, mercury methylation, dissolved organic matter.	Size and design. Detailed knowledge of tile drain discharge rates
Controlled drainage	Mainly N	Greenhouse gas emissions	More trials are needed
Soil amendments	Mainly P	Release of P from WTR	Testing of several compounds are needed

Assuming that all measures have a positive effect on water quality, the IBZ is the only measure with additional positive effects on nature and ecosystem services. Though this has other repercussion as it can be subject to the nature preservation law (se discussion below).

Relating results of international literature to Danish conditions

One of the criteria in selecting literature was to keep within climatic conditions that were comparable to Denmark. This could of course lead to new ideas from the international literature being overlooked. But dry areas with a negative water balance or the tropics would have very different environmental issues related to agriculture.

Conditions in the US Midwest are to some degree transferable to Danish conditions. Both areas have intensive agriculture and have similar amounts of precipitation. E.g. in Iowa the average precipitation (1996 – 2010) is 876 mm/year (Jaynes and Isenhart, 2014) and in Denmark the average from 1961 – 1990 is 712 with large regional differences. Since 1990 the precipitation has increased somewhat, to 745 mm/year (Anonymous, 2015a). The hydrology is an important aspect in nutrient transportation and is the argument for making this comparison, though the distribution of rainfall may be different.

The ATS and the bioreactor described in Christianson et al. (2012) are installations that are 30 and 50 m long, respectively, but still placed in the field margin, this implies that they are much wider compared to the 2 – 9 m wide buffers in Denmark. The following quote by Kangas and Mulbry (2014) "*Spreading the combined flow over more raceways (and therefore decreasing the flow rate over each raceway) yielded the same amount of removed N and P, but decreased the calculated areal removal rate*" may imply that size and shapes of ATS can be altered. An extensive cost analysis is presented in the publication of Kangas and Mulbry (2014) but these cannot easily be translated to a Danish context, but as a rough estimation, the cost of the power driving the pumps accounts from app. 80 % of the total costs. Assuming that the solar power technology will become cheaper and more easily accessible, several smaller and shorter raceways would be interesting to test.

Different sources of water treatment residuals as soil amendment in combination with vegetated buffers both show promising results. It could possibly be a method of reducing the necessary width of the buffer zone by making it more efficient. But retaining P without removing it means that it accumulates, and so the utmost care must be taken not to create other environmental problems as the release of P and heavy metals.

When the effect of the bioreactor is dependent on so many factors already mentioned, the correct dimensions can be difficult to predict. Detrimental side effects like greenhouse gas-, methylated mercury and dissolved organic carbon emissions can result from both too high and too low nitrate removal rates. It is not easy to draw conclusions on how to ensure the best possible effect of a bioreactor based on the literature. It is an even more difficult task to recommend a design adapted to Danish conditions and the size of Danish buffer strips. Christianson et al. (2012) suggests that a certain retention time can be set by treating a portion of the peak-flow with a by-pass system (seen in both figure 2 and 3) to ensure a more stable saturation and retention time; this will also alleviate the system being overloaded by storm events.

Furthermore, hydraulic conductivity also relates to the retention time, and therefore the matrix material is crucial. Sawdust has a lower hydraulic conductivity than woodchip 0,35 and 11,6 cm/s respectively, though a finer material may be degraded more rapidly.

Weigelhofer and Hein (2015) found that a flow velocity of 0,02 cm/s over 2 m distance removed close to 100% of inflow nitrate concentration of 4,6 to 5,6 mg NO_3^--N/L . This equals a retention time of 2,7 hours. Regarding longevity, the temperature response to degradability is not yet tested (Schipper et al., 2010), nor is the possibility to farm on top of the bioreactor (Christianson et al., 2012). There are also challenges in optimizing bioreactor function regarding seasonality and to synchronize temperature to water flow. The combination of high flow-through because of high precipitation in late autumn to early spring and low microbial activity because of low temperatures in the same period is difficult to manage. One possibility is to have a system where the retention time and flow through capacity can be manipulated so it can be increased at low temperatures,

According to the presented material the minimum requirement for maintaining denitrification is said to be 3 mg NO_3^--N/L, but results presented in table 2 suggests that concentrations have been lower than this. Therefore I wanted to investigate further the results of Wildman (2001), but this master thesis was not possible to find.

Implications of changed root growth in water saturated conditions

It has been established that alder trees potentially have a deep rooting system (Schmidt-Vogt, 1971) and such a rooting system can increase the rate of infiltration of water (Christen and Dalgaard (2013); Angers and Caron (1998)). Discovering the response of saturated soil water conditions on root growth and nitrogen fixation of alder (Dittert et al., 2006, Batzli and Dawson, 1999) may have implications on management of the IBZ. To avoid the trees developing a very shallow rooting systems, dry periods, by emptying the ponds in the IBZ, can be necessary. Or the design could be changes so that the trees were less exposed to waterlogged growing conditions. The species seem to have a high degree of plasticity in the ability to fixate nitrogen, so it might not be possible to manipulate the tree into utilizing the nitrate in the drainage water instead of fixating atmospheric N. The preliminary results from Fillerup (Jensen, 2015) show an effective infiltration rate (not shown), but it might not be as a result of the alder roots, but rather of other soil conditions. But the presence of roots will supply the soil with carbon and therefore be an important source of energy for denitrifying bacteria.

The pilot scheme

At the meeting of 30th of October in the BufferTech project, a concrete wish for developing “a broad pallet of environmental measure” was emphasized to ensure flexibility and the possibility of local adaptation. In a document received from my supervisor Irene A. Wiborg, it is stated that the purpose of the pilot scheme is to honor voluntary initiatives taken to reduce nitrate leaching and thereby contributing to the development of this broad pallet of environmental measures (Anonymous, 2015b). Furthermore it enhances the possibility for the farmer to find, or get motivated by, measures that the farmer wants to engage in, regardless of their rational. This can give the farmer a sense of ownership (Christen and Dalgaard, 2013).

But there are very few measures that are approved for this scheme and they can only be swapped with catch crops. Not all farmers want to remove the catch crops, and so this creates a very rigid situation where there is not much room for innovation and motivation. The farmer and the advisory service are caught in a situation that bites its own tail, the effect of the measures are not documented, and the willingnes and the funds for testing several different measures in a wide variety of landscapes are lacking.

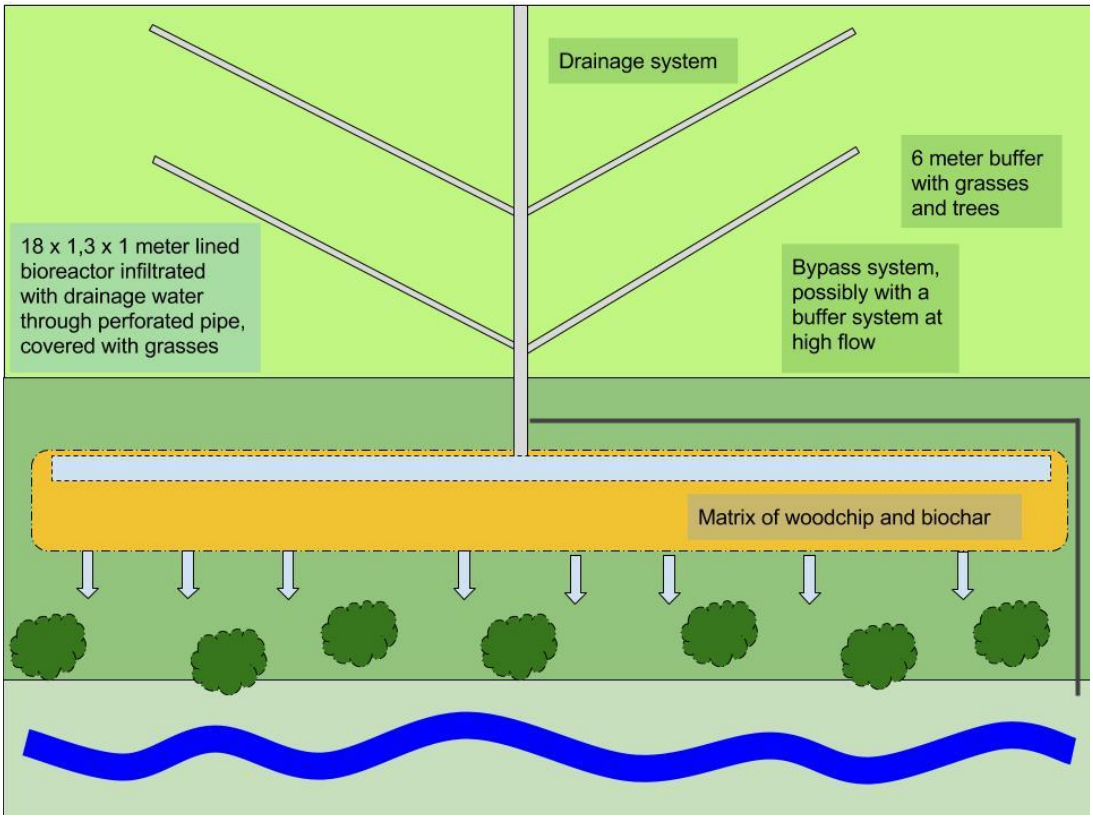
There is a need for opening up for flexibility and actual use of the pilot scheme (Wiborg, A 2015, personal communication, 20 October).

Combination of environmental measures

Based on the literature and the section on regarding bioreactor design I will in the following present an idea of one possibility to combine several measures and to adapt the measure to the buffer zones in a Danish context.

In the report by Bondgaard (2015), he suggests to couple a bioreactor with saturated buffer zones tested by Jaynes and Isenhart (2014), where the bioreactor effluent will infiltrate underground into the buffer zone soil, or being led into a wetland. My proposition is somewhat different; the main concern here is to try to make the buffer zone as narrow as possible. To avoid occupying a long rectangular area perpendicular to the stream to construct a bioreactor (see figure 2), one possibility could be to combine diffuse infiltration of drainage water as Jaynes and Isenhart (2014) show in their study (see the section on controlled drainage) and leading the drainage water through a long but narrower bioreactor (parallel to the stream) with a woodchip and biochar matrix. This way the infiltration of water from the tile drains will be more diffuse and could possibly obtain a sufficient retention time in the bioreactor matrix without it being 30 m long. A finer material to lower the conductivity and increase the retention time in a smaller installation is also possible solution. The addition of biochar has similarly been shown to decrease the retention time needed (Bock et al., 2015). This could possibly also be combined with controlled drainage.

Extrapolation of results from Weigelhofer and Hein (2015) would suggest that a 1,3 m wide bioreactor (as seen in figure 3) with a hydraulic conductivity of 0,02 cm/s would have a retention time of 1,8 h. An inflow concentration of 4,6 – 5.6 mg NO_3^-- N/L would then yield a removal rate of approximately 66%. The study of Weigelhofer and Hein (2015) was conducted in a lab under steady and controlled conditions and in a much smaller scale than would be required in the field so these suggestions are merely a thought experiment. A bioreactor surface of 9,3 m^2 for every 1,2 – 1,4 ha drained area is suggested by Verma et al., (2010) (referred to by Christianson et al. (2012)).



Figur 3. My proposition of combining the principle of the underground bioreactor with a biochar enhanced matrix and diffuse infiltration of drainage water into a narrow and vegetated buffer zone.

Figure 3 shows a bioreactor with the dimensions of 18 x 1,3 x 1 meter and thus a volume of 23,4 m^2 and according to the argumentation above; it would possibly treat an area of 16,5 – 19,5 ha. Filled with sawdust it could have an efficiency of 66%. This design resembles what is called a denitrification wall in the German catalogue of environmental measures (Holstein et al., 2012). When showing this drawing to Frank Bondgaard, he was concerned about the possibility of driving on top of the bioreactor to accommodate the need for mauver machinery for field work. There has been no mentioning in the literature of the possibility to drive on top of the bioreactor. Christianson et al. (2012) mentions that there have been no attempts to farm on top of the bioreactor and the proposition of this makes me think that it might be possible to drive on top of the facility. The degree of wetness of the bioreactor area is important both in terms of the possibility to drive on top of it and in the question of backing up water into the field. Equally important is all the other factors previously mentioned leading to detrimental effects of emission of unwanted substances.

This combination will not target surface runoff, but according to Bock et al. (2015), the biochar amended woodchip matrix can increase the removal of P from drainage water. Because the tile drains are underground, the buffer zone can still include various types of grass (roots from woody plans might interfere with the perforated pipes) to slow down surface runoff and trees can still be planted to stabilize the stream bank. Model simulations of the buffer zone width on P retention capacity (Kronvang et al., 2014) are the basis of setting the buffer zone to 6 m in figure 3. This combination could be suggested on areas with low erosion risk.

The farmer's decision making process

Making a thorough investigation of the landscape elements on a farm is the alpha and omega in securing any environmental measure to have the optimal effect on surface waters nearby. But uncertainties in the available data make it a complex process with several possible outcomes. The entire decision-making process of what measure is the most efficient will then be based on additional factors than just the physical conditions of the land. An argument for choosing one measure over the other is the cost effectiveness, where the most reductionist meaning of the term is kroners per amount of nutrients retained (kr/kg N or P). And it is a question of resources; a farmer has to gain "something" in return for the effort in engaging in implementing environmental measures on her/his property, but it is not always a logic reason for the motivation of the farmer. Therefore, the monetary cost effectiveness as the single deciding factor cannot always be used to determine the best solution for a farmer, or predicting what the farmer is inclined to choose. This thought assumes that the farmer is always utility optimizing, which is not always the case (Hasler, B 2015, personal communication, , March). Buckley et al. (2012) also points out that a farmer's willingness to engage in riparian buffer zones depends on attitudinal and farm structural factors as well as the economic factor. So it can be argued that the farmer is utility optimizing, but on the basis of many more parameters than economy.

Another barrier for getting farmers engaged in environmental measures is the fear of land being irrevocably taken out of production because of nature preservation laws. If farmers establish environmental measures (as IBZ or wetlands) that enhances the biodiversity, there is a very real chance that the area starts harbouring species that classify the area as a type of nature that is protected by the nature preservation law (§3) and/or the EU habitat directive (appendix 4 species). The nature preservation law can be circumvented by technicalities such as: application for the right of repatriation (tilbageførelsesret) and avoiding the area to be classified as nature by labelling the measure "a technical facility" (Wiborg, A 2015, personal communication, 20 October). One of the big advantages of the covered bioreactor over the constructed wetland with filter matrix (Eriksen et al., 2014) is the lack of surfaces of open water and thereby avoiding the area developing into nature protected under §3.
Honoring the individual decision process of the farmer and avoiding the area being taken out of production permanently can be arguments for including technical, expensive and labor intensive measures as the Algae Turf Scrubbers as a relevant measure to investigate in a Danish context. The few farmers I have met and heard of during my internship have given me some insight to the diversity of the assumptions of their behavior.

Conclusion and recommendations – it is not about the measure, it is about the process

The reviewed material used in this report have shown that measures like bioreactors, controlled drainage, soil amendment and Algae Turf Scrubbers show promising results and that testing these measures can be highly relevant in Danish conditions. Also, the argument is made that because the effect of any environmental measure is highly site specific, dependent on several factors with high variability, the choice of an environmental measure cannot be made solely on the basis of either economy nor landscape elements.

Figure 4 is an attempt to visualize the decision process, though only more parameters could be included. The farmer has a certain production system, more or less knowledge about the land and certain interests. The landscape elements set the premises of what nutrient losses are at risk but with a great deal of overlapping and complicating factors. This analysis is at the basis of choosing the right environmental measure to ensure effective nutrient retention. In this process extensive knowledge of soil conditions, topography, hydrology, draining system etc. is needed. The advisory service needs a way to convey this data to the farmer to help him/her making an informed decision in how to manage specific demands for reducing losses of nutrients. This can be through visualization through maps of e.g. erosion risk and through emphasising aspects of production gain by mitigating loss of soil. A mitigation strategy based on site specific conditions, that includes more parameters of the farmer's decision process together with the site specific knowledge of the farmer, can help alleviate the challenges of making the overall differentiated and targeted environmental mitigationplans.

Of the measures mentioned in this paper, only the IBZ specifically targets surface runoff and soil erosion by decreasing the energy of the water flow by establishing rough vegetation. Soil amended with WTR will to some extent also target this issue. The other measures are primarily based on targeting what comes out of the drains.

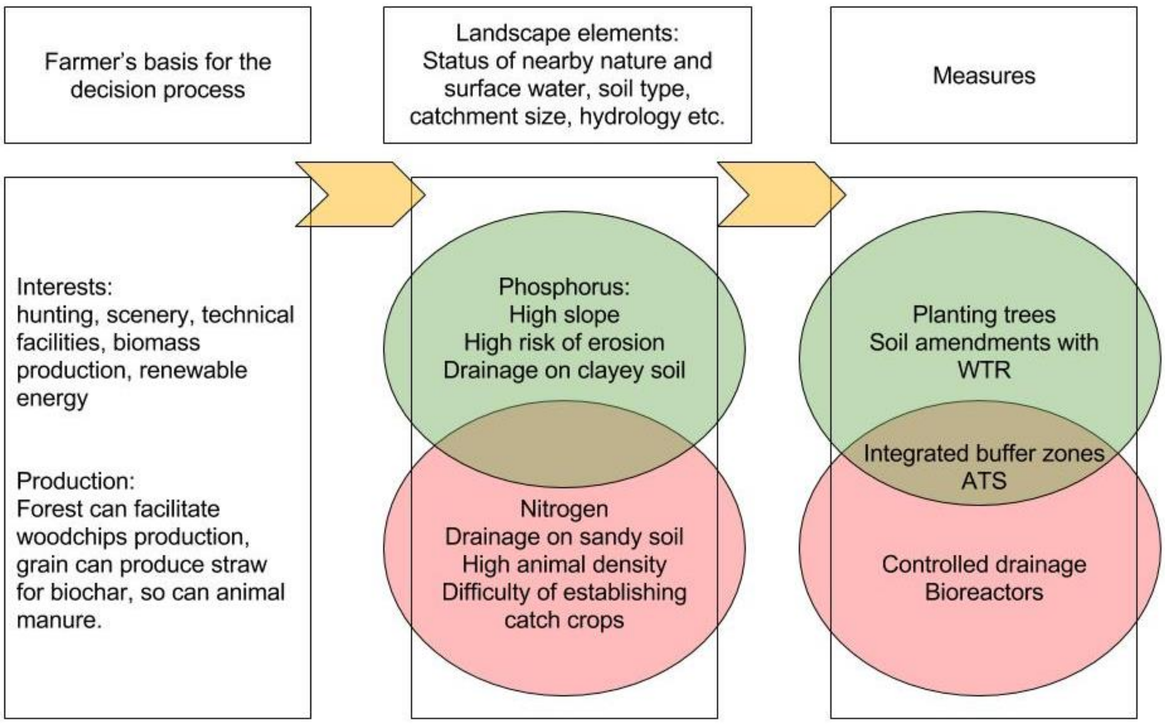


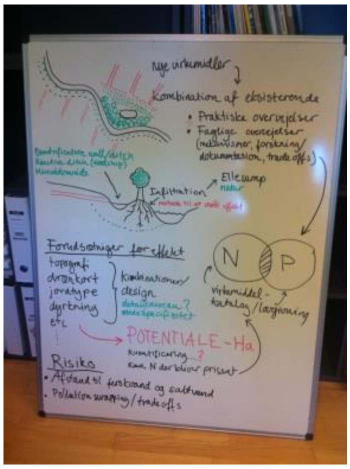
Figure 4. A schematic and simplistic overview over elements in the decision process to choose environmental measures.

Perspectives and reflections on the internship

This internship has been a tremendous learning experience. The achieved knowledge and collected literature are highly relevant for my further academic work. An internship in general and on SEGES specifically can be recommended to all students. It is an ideal opportunity to put the knowledge achieved through previous studies into a more practical and tangible context where one can show that you can perform a task that is requested by the business partner. Through a business project on SEGES the student has a unique chance to link the academic scientific knowledge together with the complex reality, and getting insight of the everyday life in the workplace. These aspects have been interesting to observe. I have witnessed and learned about procedures, such as the intranet and setup of a meeting summary, and the tedious task of documentation. The importance of terminology has been an issue in that the name of the IBZ has been changed from “intelligent” to “integrated” and through the emphasis on the Danish term having very negative connotations in press and with farmers. And the explicitness of the ever present need for productivity and optimization of sales surprised me.

The personal contact is an important approach for setting up a commercial collaboration, and this can be established in many ways. In my experience a good place to start is contacting professors and teachers at the University to hear what connections they have to businesses. Once a relation to a supervisor with the business partner is established, a fruitful collaboration presupposes that the frames of expectations from both parties are well established and that the business partner gets something in exchange for investing time in the student. Taking into consideration the supervisor's often busy schedule it is important to have a sense of how and when it is appropriate to ask for help, ask questions or personal interaction in general. I received a thorough introduction to the people in the department, which was very helpful in my later work, both in terms of knowing their field of work but also in terms of the personal level of making conversation.

From the left: my work desk at SEGES, excursion to Spjald with the BufferTech stakeholder group, and drawings on whiteboard attempting to structure the process.



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Appendix 1

Respons on rootgrowth as a results of waterlogged growingconditions (left) compared to normal growingconditions (right).
(Dittert et al., 2006)