SUB-IRRIGATION AND CONTROLLED DRAINAGE INCREASE YIELDS AND MITIGATE ACID LOADING IN FINNISH CULTIVATED ACID SULFATE SOILS

L'IRRIGATION SOUTERRAINE ET LE DRAINAGE CONTRÔLÉ AUGMENTENT LES RENDEMENTS ET ATTÉNUENT LA CHARGE ACIDE DANS LES SOLS SULFATÉS ACIDES FINLANDAIS

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ABSTRACT

The cultivated acid sulfate soils (ASS) on the coast of Gulf of Bothnia in Western Finland are highly valued for their excellent crop yields. However, efficient drainage induces the release of acidity and dissolved metals from ASS to watercourses due to oxidation of sulfidic materials in their subsoil. In this 4-year study, possibilities to couple better yields and improved quality of drainage water by controlled subsurface drainage (CD) and sub-irrigation (CDI) were investigated. Spring barley and spring wheat were grown on the fields during 2010 - 2014. The yields were above the Finnish average. However, due to relatively wet summers the yields in CDI were higher than those of CD or reference field with conventional drainage (Ref) only in 2014. In CDI the groundwater table could be kept above the sulfidic horizon nearly throughout the summers. In CD the period during which sulfidic material was exposed to oxygen was shorter than in Ref. The titratable acidity of drainage waters was the lowest in CDI. However, the acidity of drainage water was still high in all the systems, probably owing to retained acidity in the soil.

RÉSUMÉ

Les sols sulfatés acides (SSA) cultivés le long de la côte ouest finlandaise sont réputés pour leurs hauts rendements. Cependant, le drainage efficace entraîne la libération d'acidité et de métaux dissous depuis les SSA vers les cours d'eau, du fait de l'oxydation de matériaux sulfidiques. Dans cette étude, différentes alternatives ont été examinées afin d'améliorer conjointement les rendements et la qualité des eaux de drainage: le drainage souterrain contrôlé (abréviation en anglais: CD) et l’irrigation souterraine (abréviation en anglais: CDI). L'orge et le blé de printemps ont été cultivés de 2010 à 2014 et les rendements ont été supérieurs à la moyenne finlandaise. Néanmoins, à la suite d'étés assez humides, les rendements en CDI ont été supérieurs aussi bien à ceux en CD qu'à ceux du champ de référence en drainage conventionnel (Ref) uniquement en 2014. En CDI, la nappe phréatique a pu être maintenue au-dessus de l'horizon sulfidique presque durant tous les étés. En CD, la période durant laquelle les matériaux sulfidiques ont été exposés à l'oxygène a été plus courte que dans Ref. Le niveau d'acidité des eaux de drainage a été le plus bas en CDI durant les automnes. Cependant, il est encore resté élevé dans tous les systèmes, probablement du fait de l'acidité conservée dans le sol.

Keywords: sub-irrigation, controlled drainage, acid sulfate soils, yield, acidity

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1. INTRODUCTION

Acid sulfate soils (ASS) are located worldwide mainly on coastal and floodplain areas. In Europe the largest ASS areas in agricultural use are in Finland. Most of them locate on the coast of the Gulf of Bothnia. Their parent material is the previous bottom sediment of Litorina Sea (from 8000 - 3000 BP) and they most commonly meet the criteria of *Sulfic Cryaquepts* according to Soil Taxonomy (Yli-Halla et al. 1999).The isostatic uplift after the previous glaciation has elevated the ASS from the sea and they have been reclaimed for cultivation most extensively since the 18th century. Now they are highly valued for their excellent crop yields.

In Finland, annual precipitation exceeds evapotranspiration but water deficit and surplus vary seasonally. Efficient land drainage is necessary in spring in order to create suitable conditions e.g. for tillage and sowing, and in autumn to ensure harvesting. However, in summers water deficit may restrict crop growth. Therefore, irrigation is occasionally needed.

The acid loadings from ASS fields have caused deterioration of ecosystems in their recipient waters. Reclamation of fields for cultivation and their efficient drainage lowers groundwater promoting oxidation of sulfidic materials in their subsoils. In the past, however, the ASS fields were drained for cultivation without knowing their negative consequences to environment. In order to mitigate environmental hazards practical water protection measures are needed for their sustainable cultivation. Furthermore the global climate change is assumed to bring along extreme droughts which might lower the groundwater and facilitate penetration of oxygen deeper into the subsoil resulting in increased hazards.

Fig. 1. The Location of the experimental field.
The Litorina Sea submerged areas are in grey.

The aim of this study was to find out whether controlled drainage (CD) and sub-irrigation (CDI) can mitigate environmental hazards caused by ASS soils and what impact these methods have on yields. The hypothesis was that the higher groundwater caused by CD and CDI have twofold benefits: 1) higher groundwater prevents the oxidation of sulfidic material in subsoils and 2) it provides plants with water during droughts.

2. Materials and methods

The experimental field was established in Söderfjärden on the western coast of the Gulf of Bothnia on the Baltic Sea in Finland in 2010 (Uusi-Kämppä et al. 2011, Fig. 1). Starting at the depth of 1.5 m, the subsoil of the area contained sulfidic material consisting of pyrite (FeS_2) and reactive monosulphides (Boman et al. 2008) and has up to 0.8% of S. The soil was classified as a *Sulfic Cryaquept* after Soil Taxonomy and the texture of soil was silty clay loam excluding the Ap horizon (Österholm et al. 2015). The average annual temperature in the region was 4.2 °C and the precipitation 552 mm (1981-2010) (Finnish Meteorological Institute 2015).

The total area of experimental field was 18.4 ha and it was drained with subsurface pipes at a depth of 1.1 m in a uniform manner. The field was divided into three differently managed sections : 1) controlled drainage (CD), 2) sub-irrigation (CDI) and 3) reference field with conventional subsurface drainage (Ref) (Fig. 2.). The field was surrounded and sections were separated by a plastic sheet down to the depth of 1.8 m preventing the lateral flow between sections and seepage to the main drain. In CD and CDI the regulation depth of groundwater was set up at 0.6 m below the soil surface by control wells in summers and at 0.7 m in winters. In CDI, water was pumped into the drainage system when the groundwater was observed to be below the regulation depth (Österholm et al. 2015).

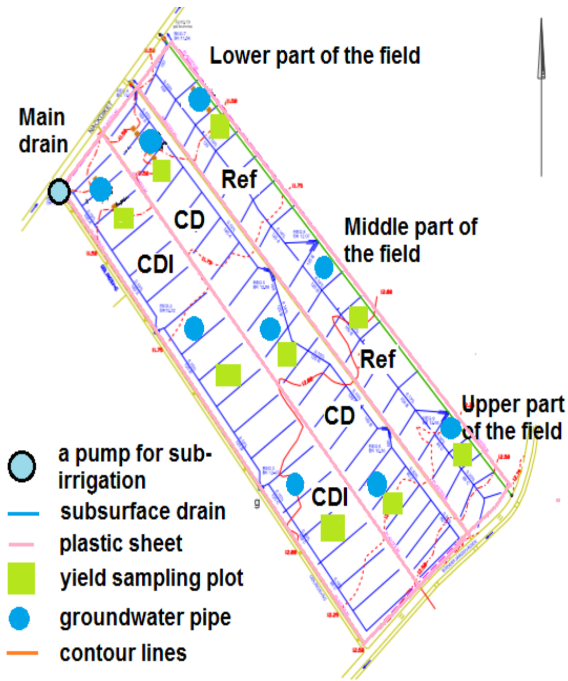

Fig.2 The map of the experimental field of Söderfjärden.

Groundwater table in the lowest part of each section was monitored using a groundwater sensor and a logger (EHP-GWL600 and EHP-QMS, EHP Technic, Finland) installed in groundwater pipes reaching the depth of 2.5 m as well as manually twice a week or on a monthly basis. In the middle and upper part of the field groundwater table was monitored manually. In the present study the groundwater tables are presented relative to the mean sea level (MSL, Finnish N60 system). The discharge water from each management was sampled twice a week or on a monthly basis. Acidity of water (mmol dm^{-3}) was determined according to the standard (SFS 3005) by titrating with NaOH to the end point of pH 8.3.

The field was cultivated uniformly and all the farming operations were done simultaneously, only the water management was different between the sections. The grain yield (given at 15% moisture content) was estimated by harvesting an area of 13–21 m^2 in triplicate from each drainage system (Fig. 2). The quality of the yield was estimated by determining the test weight (kg hl^{-1}) and 1000-seed weight.

3. Results

The amount of water pumped into the CDI field ranged annually from 12 to 50 mm in 2010-2014. The CDI section was sub-irrigated 4 times in 2012 and 2014 but only 2 times in summer 2013. Groundwater table was on average 15 cm higher in CD and 30 cm higher in CDI than in Ref in 2011-2014 but taking into account only the summers the difference was larger, up to 0.9 m. In the lowest part of field in CDI the groundwater did not drop to the horizon containing sulfidic materials practically in any summer. In CD the groundwater table drop down to the critical horizon containing sulfidic material for a remarkably shorter time than in Ref (Fig. 3a). In the upper part of field sulfidic horizon was occasionally above the groundwater table in all managements, but the smallest number of days was in CDI (Fig. 3c).

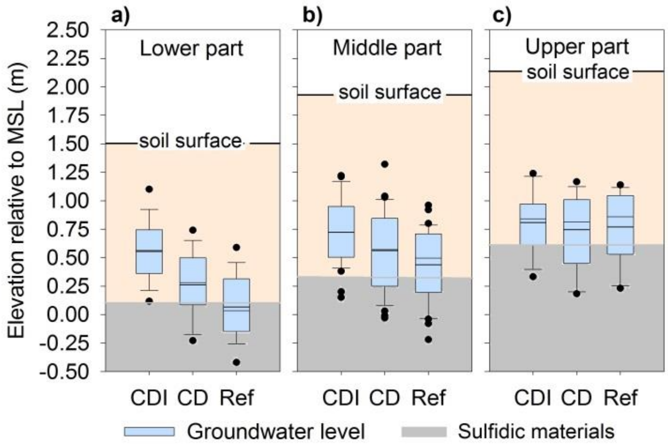

Fig. 3. Groundwater table in the different parts of the field in the sub-irrigated (CDI), in the controlled drained (CD) and in the reference field with conventional drainage (Ref) during 1st May to 30th August, 2011-2014. The depths are presented relative to mean sea level (MSL). The light blue boxes indicate the 25th and 75th percentiles, the whiskers the 5th and 95th percentiles and the black plots are outliers (the number of observations = 31–564). The solid lines indicate the medians and the dotted lines the means of the data. The data in a) was monitored continuously by loggers and in b) and c) recorded manually.

The acidity of drainage water was lower in springs than in autumns (Fig. 4), and in autumn the decreasing pattern was observed during the years 2010 - 2014. The acidity of drainage water ranged from 1.4 – 3.1 mmol dm^{-3} in springs and from 1.7 – 3.7 mmol dm^{-3} in autumns. In autumns, the median acidity of the drainage water was lowest in CDI and highest in Ref in all the years. The significant difference ($P<0.01$) in acidity was found between CDI and Ref only in autumns.

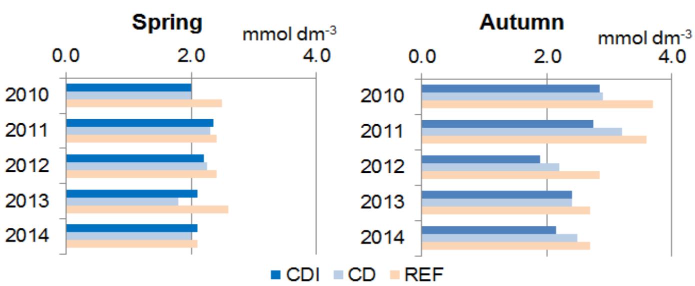

Fig. 4. Median acidity of the drainage water of the sub-irrigation (CDI), the controlled drained (CD) and the reference field with conventional drainage (Ref) in springs and autumns during the years 2010-2014.

The weather conditions had a marked effect on the yields of the differently managed sections. In 2011-2014 the mean summer precipitation ranged 107-137% of the long-term average and only in 2010 precipitation was slightly lower than the average (97%, Finnish Meteorological Institute 2015). However, the distribution of precipitation varied from one summer to another. In summer 2013, the growth of spring wheat suffered occasionally from too wet conditions in CDI and the highest yield was gained in Ref. On the contrary, in 2014 the highest yield was harvested from CDI (Fig. 5). According to preliminary results there were no significant differences in the test weights or in 1000-seed weights between the managements. The yields in all the managements were higher than the averages in Finland. In 2014, the yield of spring wheat from CDI was 5900 kg ha^{-1}. The corresponding average yield in Finland was 4020 kg ha^{-1}.

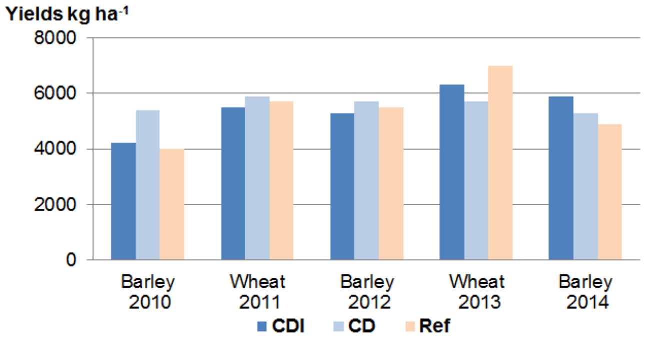

Fig. 5. The yields of spring barley and wheat in the sub-irrigated (CDI), in the controlled drained (CD) and in the reference field with conventional drainage (Ref). The yields are presented at the moisture content of 15%.

4. Discussion

The highest groundwater table was observed in CDI and it stayed above the critical sulfidic horizon practically throughout the experimental period. The plastic sheet which prevented lateral flow between the sections and also seepage to the main drain (Österholm et al. 2015) evidently contributed to the success of sub-irrigation and elevation of the groundwater table. The acidity of drainage water was higher in autumns than in springs indicating that some oxidation of sulfidic materials occurred in summers although the summers were mainly wetter than average. For example the large fish kills (2006) occurred when the summer precipitation percentage was only 35-50% of the long-term average (Finnish Meteorological Institute 2015). In CDI, the lowest acidity of drainage water in autumns seems to be related to the highest groundwater table. However, the acidity of drainage water was still high in CDI. One reason for only moderate decrease in acidity in CDI might be the retained acidity, contained in jarosite and schwertmannite, which release acidity when soil pH rises. This is assumed to occur also in Finnish ASS soils (e.g. Virtanen et al. 2014). The yields benefited sub-irrigation only in one summer due to the relatively wet summers. In all the managements, the yields of spring barley and spring wheat were above the Finnish average due to the fertility of acid sulfate soils.

5. Conclusions

We conclude that leaching of acidity from cultivated ASS fields could be mitigated at least slightly by controlled drainage and especially by sub-irrigation. However, the effect was not substantial probably because of the retained acidity in the field. In dry summers, controlled drainage and sub-irrigation might benefit farmers by increasing the yields and environment by lowering acidity. However, because of the lack of dry summer during the experimental period that hypothesis could not be effectively tested.

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