23rd International Congress on Irrigation and Drainage
8-14October 2017, Mexico City, Mexico

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# CONTROLLED DRAINAGE AND SUB-IRRIGATION – AN OPTION TO SAVE WATER IN CROP PRODUCTION IN FINLAND

# LE DRAINAGE CONTRÔLÉ ET L'IRRIGATION SOUTERRAINE – UNE OPTION POUR CONSERVER DE L'EAU DANS LA PRODUCTION AGRICOLE EN FINLANDE

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## ABSTRACT

In humid areas like Finland, the annual precipitation exceeds evaporation. Therefore, efficient land drainage is necessary for cultivation. However, during the dry growing period the water deficit may restrict crop growth, thereby occasionally necessitating irrigation. In our study we compared conventional subsurface pipe drainage (D), controlled drainage (CD) and sub-irrigation (CDI) in three fields in an 18.4 ha experimental area in Söderfjärden, Finland during 2010-2015. In that region the average long-term air temperature, precipitation and evaporation during the period of June-August were 14.9 °C, 180 mm and 349 mm, respectively. The runoff from CD and CDI fields was regulated with control wells, and CDI was sub-irrigated when groundwater dropped below the regulation level. The lateral flow of groundwater between the fields and seepage to the main drain was prevented by vertical plastic sheets reaching impermeable subsoil. Subsurface pipes were installed at a depth of 1.1 m, with spacing of 20 to 40 m. The fields were cultivated uniformly and all the farming operations were identical in all the fields excepting that the water management treatments were different in the three fields. The groundwater table, runoff and soil moisture were monitored continuously in the lowest part of the field, and groundwater was observed biweekly at two other places of the field. Grain yields of barley (Hordeum vulgare) and spring wheat (Triticum aestivum) were determined. Water deficit was calculated on the basis of the water balance of the fields during the water regulation period. In the sub-irrigated field, the water deficit was alleviated by sub-irrigation by an average of 50 mm in comparison to the conventional subsurface pipe drainage. During a summer (2015) when sub-irrigation was not possible due to lack of irrigation water, the controlled drainage alleviated the water deficit by 25 mm. Soil moisture at a depth of 70 cm was higher and the water table was markedly higher in the sub-irrigated field than in the other fields during the regulation period. Grain yield was higher in CDI compared to D in a summer during which evaporation roughly corresponded to the long-term average values. The summers were wet and supposedly factors other than water deficit had a stronger impact on yields in other summers. Controlled drainage together with sub-irrigation is an option for storing water for crop production. The technical solution used in this study may also be useful elsewhere in other circumstances.

**Keywords**: Drainage, Controlled drainage, Sub-Irrigation

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## RÉSUMÉ

Dans les régions humides comme la Finlande, la précipitation annuelle dépasse l'évaporation. En conséquence le drainage du terrain est nécessaire pour la cultivation. Néanmoins, pendant la période de la cultivation sèche l'irrigation peut être nécessaire à cause du déficit de l'eauqui restreint le développement de la production agricole. Cette recherche met en comparaison le drainage par un tube conventionnel souterraine (D), le drainage souterrain contrôlé (CD) et l'irrigation souterraine (CDI) dans trois domaines dedans une région expérimentale de 18.4 ha à Söderfjärden, en Finlande pendant 2010-2015. Pendant les mois de juin à août la température moyenne de longue échelle de la région était celui de 14.9 °C, la précipitation celui de 180 mm et l'évaporation celui de 349 mm. Le trop-plein des domaines de CD et celui de CDI étaient réglés avec des puits de contrôle, et le CDI était contrôlé avec l'irrigation souterraine lorsque le niveau de l'eau souterraine diminue sous le niveau de la régulation. Le flux latéral de l'eau souterraine entre les domaines et l'infiltration à l'égout principal étaient empêchés par feuilles en plastique qui atteignaient le sous-sol imperméable. Les tubes souterrains étaient installés à la profondeur de 1.1m, avec 20 à 40 m d'espacement entre les tubes. Les domaines étaient cultivés dans une manière uniforme, uniquement la gérance de l'eau était différente entre eux. La nappe phréatique souterrain, le trop-plein et l'humidité de la terre étaient surveillés continuellement dans le niveau le plus bas des domaines, et l'eau souterraine était observé bimensuellement dans deux autres lieux des domaines. Les rendements du grain de l'orge (*Hordeum vulgare*) et le blé de printemps (*Triticum aestivum*) étaient déterminés. Le déficit de l'eau était calculé avec le balancement de l'eau des domaines pendant la période de la régulation. Dans le domaine de l'irrigation souterraine, le déficit de l'eau était ralenti par l'irrigation souterraine. Le niveau moyen du ralentissement était celui de 50 mm en comparaison du drainage par un tube conventionnel souterraine. Puisque l'irrigation souterraine n'était pas possible pendant l'été 2015 en raison de l'insuffisance de l'eau de l'irrigation, le niveau du ralentissement était celui de 25 mm. L'humidité de la terre à la profondeur de 70 cm était élevée et la nappe phréatique était nettement élevée dans le domaine de l'irrigation souterraine en comparaison des autres domaines. Le rendement du grain était élevé dans le CDI en comparaison du D pendant l'été où le niveau de l'évaporation correspondait à l'évaporation moyenne de longue échelle. Les étés étaient humides supposément les autres facteurs influençaient les rendements plus fortement pendant les autres étés. La combinaison du drainage contrôlé et l'irrigation souterraine offre une option pour conserver de l'eau pour dans la production agricole. La solution technique utilisé ici peut aussi être utile ailleurs.

## 1. Introduction

Scarcity of fresh water threatens large areas around the globe where the demand for food has been increasing. Therefore the production of food with less water challenges us to develop efficient sustainable water management systems worldwide. In humid areas like Finland, the annual precipitation exceeds evaporation.Therefore efficient land drainage is necessary for cultivation. However, during the dry season the water deficit may restrict crop growth,thereby occasionally necessitating irrigation. Controlled drainage is a sustainable water management option in sub-surface pipe drained fields because ithas been found to decrease the leaching of nutrients (*e.g.* Wesström et al., 2001). The largest acid sulfate soil (ASS) areas in cultivation in Europe exist in Finland on the coast of the Baltic Sea. The poor water quality of surface waters due to acidity and high metal concentrationsis attributable to ASS soil fields (Edén et al., 1999). However, the fields are highly valued by farmers due to their excellent yields. In order to find a solution which would benefitthe environment and crops, controlled drainage and sub-irrigation have been studied since 2010 (e.g. Uusi-Kämppä et al., 2011, Virtanen et al., 2015). Itwas hypothesised that controlled drainage and particularly sub-irrigation alleviate acid leakage from acid sulfate soils and simultaneously provide better yields for the farmers. In this study we focus on the effect of sub-irrigation on water deficit and on yields.

## 2. Study area and experimental fields

The experimental area of18.4ha is located in Söderfjärden, Finland (63◦02'N, 21◦53'E) (Fig. 1). In the region the average long-term air temperature, precipitation in summer (June, July and August, 1981-2010) and evaporation (June, July and August, 1960-1990) were 14.9 °C, 180 mm and 349 mm, respectively. The soil of the experimental area is Sulphic Cryaquepts according to the Soil Taxonomy, and the texture was silty clay loam (Yli-Halla, 2012).

**Figure 1**. Finland is in the Northern Hemisphere between the 60th and 70th parallels of latitude. The experimental field is located on the coast of the Baltic Sea in an area where acid sulfate soils exist (the area with a high probability of ASS has been depicted in grey).

In our study we compared conventional subsurface pipe drainage (D) to controlled drainage (CD) and sub-irrigation (CDI)(Fig. 2). In all fields drain pipes were installed at a depth of 1.1 m, with spacing of 20 to 40 m. The runoff from the field was regulated with control wells in CD and CDI (Fig. 2). In CDI, water was pumped into the lowest regulation well of the drainage system when the groundwater was observed to drop below the regulation level. The lateral flow of groundwater between the fields and seepage to the main drain was prevented by vertical plastic sheets reaching impermeable subsoil (1.8 m) (Österholm and Rosendahl, 2012). The fields were cultivated uniformly and all the farming operations were done simultaneously, with only the water management treatments varying between fields.

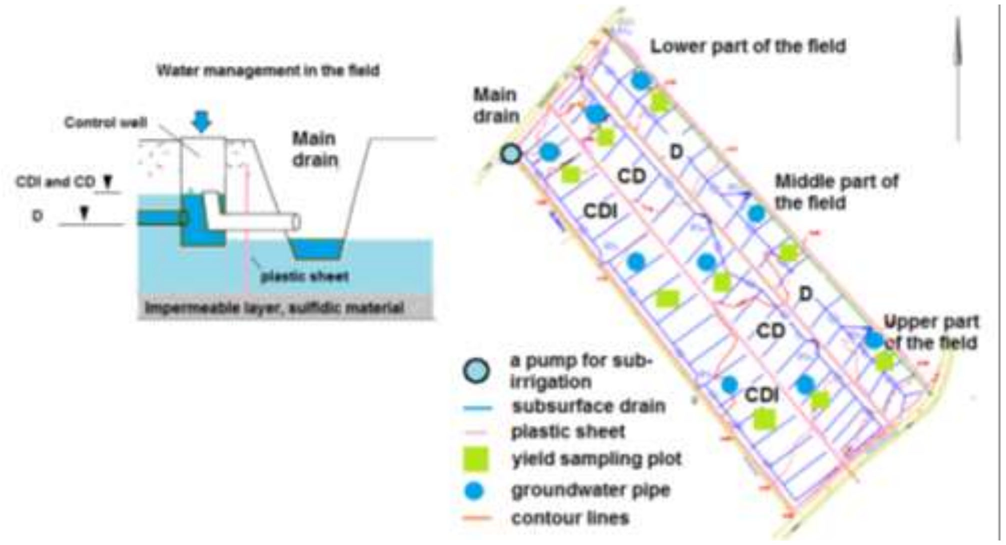

**Figure2.**Schematic drawing of the water management system in the experimental field (left), and map of treatments and measurement points in the experimental field of Söderfjärden (right).

## 3. Material and methods

The groundwater (GW) table in the lowest part of the field was monitored using a groundwater sensor and a logger (GWc, EHP-GWL600 and EHP-QMS, EHP Technic, Finland) installed in a groundwater pipe reaching to a depth of 2.5 m as well as manually biweekly (GWm). The groundwater table was measured manually also in two other groundwater pipes circa 230 – 300 m and 377 - 600 m apart from the lowest part of the field (Fig. 2 and 3).Groundwater depths (GW, m) in this study are depths from the mean sea level.A natural consequence of crop growth is the uptake of water from the root zone which varies according to the growth phase.Crop growth may be limited by water deficit in the soil. In this study the gross water deficit in regulation period was calculated using a simple water balance equation.

$$D = P+I-R-E-\Delta S$$

D=Deficit of water (mm)
P = Precipitation (mm)
I = Sub-irrigation (mm)
R= Runoff during summer (mm)
E = Evaporation (mm)
$\Delta S$ = Change in soil water storage (mm).

The runoff from the drainage system (ultrasonic measurement) in the outlet was logged in the lowest part of the fields every 30 minutes, and R is the cumulative runoff from each field when it was regulated in the summer. Daily evaporation data(Class Pan A) was obtained from the nearest meteorological station (Ylistaro, Pelma, c. 50 km west of the experimental field) but precipitation was measured in the experimental field (EHP Technic, Finland). The amount of sub-irrigation water was calculated based on the capacity of the pump ($l\ min^{-1}$) and the pumping time. The change in water storage of soil profiles was calculated based on the difference of groundwater depths on the first day of regulation and 30th August. Based on literature (Andersson and Wiklert, 1972) it was assumed that on average 5% of the water was draineddue to gravity. Changes in soil water storage were also inspected using the measured soil moisture values (FDR) at a depth of 30 and 70 cm in the lowest part of the fields at the beginning of the regulation and 30th August.

The grain yield (given at 15% moisture content) was determined by harvesting an area of 13–21 $m^2$ in triplicate from each field.

## 3. Results and discussions

### 3.1 Water management and water deficit during summers

Continuous measurements showed a 31±3 cm and 53±3 cm (the mean and the standard deviation, n=492) higher groundwater table in CDI compared with those of CD and D, respectively. The manual measurements did not show as high of a difference as the continuous measurements (Fig. 3). The low measurement intensity of the manual measurements may be the reason for the fact that short-term GW variation between the measurements is not observed. That was supposedly the reason for the different values of the above measurement methods, because the simultaneous manual and continuous measurements did not markedly deviate (Österholm et al., 2015). Thus, the regulation of groundwater and the pumping of water into the lowest control well seemed to raise GW markedly in the lowest part of the field. The plastic sheet was also able to efficiently prevent lateral flow and seepage (Österholmand Rosendahl, 2012) and support the rise of GW in the summer. However, the effect of sub-irrigation varied in the different parts of the field. In the middle of the field the groundwater table was 26±4 cm (mean and standard deviation, n=31) and 16±4cm higher than in CD and D, respectively. In the upper part of the field (about 500m apart from the well where irrigation water was pumped in) the difference was only 6 to 9 cm as compared to CD and D. In CD the groundwater table was on average 10 cm higher than in D in the lowest and middle parts of the field. In the upper part of the field the difference was within the standard deviation of the measurements.

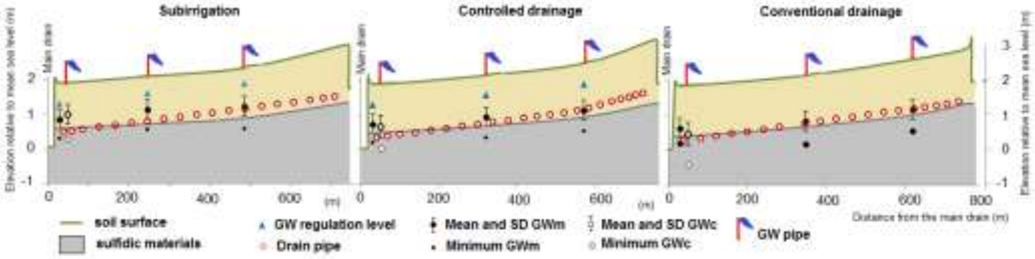

**Figure 3.** Groundwater table variation in different parts of the sub-irrigated field (left), in the controlled drained field (middle), and in the conventionally drained field (right). The drain pipes are depicted in red and the layer containing sulfidic materials in grey. The mean of the continuous measurements (GWc, open circle) and manual measurements (GWm, black circle) are presented with error bars which denote the standard deviation. The lowest points denote the minimum depth observed by the given method during the summers of 2011-2014.

In CDI the water deficit was on average 50 mm less compared with the conventional subsurface pipe drainage during the regulation periods (Table 1). In all the experimental years the precipitation was higher or on the long-term average in the region. The evaporation in the summers (June-August, in Ylistaro, Pelma) varied from 219 mm to 320 mm, being lower than the long-term average (349 mm). However, the precipitation did not cause any high summer runoff in D but in CDI sub-irrigation instead, before rainfall events caused a runoff peak in 2013.That highlights the importance of weather forecasts and sub-irrigation operations. In the late summer of 2014 the main drain was dredged, which caused a lack of irrigation water the following summer, hence sub-irrigation was not possible in 2015.However, in the CDI field only the GW regulation could store 25 mm.

### 3.2 Yields

Barley (*Hordeum vulgare*) and spring wheat (*Triticumaestivum*) were alternating during the growing seasons of 2010-2015, starting with barley in 2010. The GW table regulation was carried out starting in the spring of 2011. The summer of 2010 was considered a calibration period. However, because the plastic sheets, preventing the lateral movement of water from one field to another, were installed in 2010 prior to the growing season, the groundwater level was probably not yet stabilised in 2010 and yields were probably not comparable with the yields in the following years (Fig. 4). In spite of sub-irrigation, yields were about at the same level between treatments (Fig. 4) throughout the years. However, in 2014 sub-irrigation increased the barley yield by 1000 kg ha$^{-1}$ as compared to conventional drainage (Fig. 4). This was the only year when the evaporation was almost on the long-term average level. In the history of recording temperatures in Finland, 2014 was also the second warmest year after 1938, according to the Finnish Meteorological Institute. In the other years water deficits were smaller, indicating that then the effect of other factors may be more important than the water availability for the yield formation. For example, in Finland the growing period is short and therefore the early seedbed preparation usually causes better yields. The field experiment is challenging due to yearly alternating weather conditions and therefore comparable results are difficult to obtain. Because of this, model simulations might be useful in the interpretation of the results.

**Table 1.** The components of water balance and the gross water deficit during the GW regulation periods in the sub-irrigated and conventionally drained fields in Söderfjärdenin the summers of 2011-2015. Note that the regulation period varies yearly because the regulation started only after seedbed preparations.

| | **Time period of groundwater summer** | **2011** | **2012** | **2013** | **2014** | **2015** |
|---|---|---|---|---|---|---|
| | | **20.5.-31.8.** | **26.5.-31.8.** | **25.5.-31.8.** | **15.5.-31.8.** | **6.5.-31.8.** |
| | **Treatment** | **mm** | | | | |
| **Precipitation, P** | | 234 | 180 | 237 | 259 | 289 |
| **Evaporation, E** | | 291 | 285 | 306 | 396 | 237 |
| **Irrigation, I** | | 31 | 50 | 12 | 28 | 0 |
| **Runoff, R** | CDI | 3 | 3 | 12 | 2 | 39 |
| | D | 2 | 1 | 16 | 6 | 55 |
| **Change in storage, ΔS** | CDI | -11 | -9 | -10 | 22 | -24 |
| | D | -36 | -30 | -33 | 15 | -34 |
| **Deficit of water in** | CDI | -39 | -67 | -79 | -89 | -12 |
| | D | -94 | -135 | -119 | -128 | -37 |

## 4. Conclusions

No dry summers occurred during the experimental period. Thus, it was not possible to study the effect of sub-irrigation in a dry summer in this study. However, in a wet and warm summer yields were the highest in the sub-irrigated field, even though generally in wet summers other factors seem to affect yields more than the water deficit. Thus controlled drainage and particularly sub-irrigation may alleviate water deficit in dry summers in Finland. In this kind of water management, plastic sheets preventing seepage as well as farmers' activity in following weather forecasts and the closing and opening of regulation wells are essential. The effect of sub-irrigation can be improved by pumping water into wells also in the upper part of the drainage system. A water reservoir for irrigation may be necessary in dry summers as well. In this study we used a simple water balance equation. It would be interesting to use sophisticated water models for the estimation of the water balance of the experimental fields. Controlled drainage together with sub-irrigation is an option for storing rainwater in soil for crop production. The technical solution used in this study may also be useful elsewhere in other circumstances.

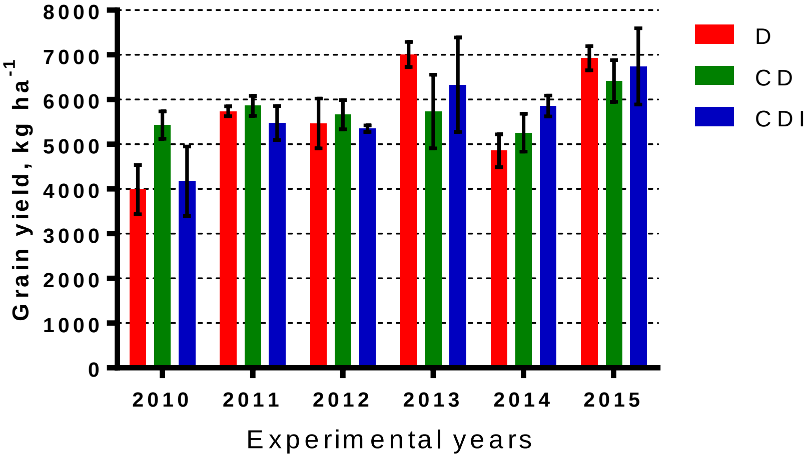

**Figure 4.** Barley (2010, 2012 and 2014) and spring wheat (2011, 2013 and 2015) yields in the conventional drained field (D), controlled drained field (CD) and the sub-irrigated field (CDI). Error bars represent ±SD.

## 5. Acknowledgements

The experimental field was established and the study was started in the EU-Life + CATERMASS project (2010-2012), and continued within a programme (BEFCASS) financed by the Finnish Ministry of Agriculture and Forestry. Additional financial support has been provided by the Drainage Foundation, the OivaKuusisto Foundation, Maa- javesitekniikantukiry and the Renlund Foundation. The authors wish to extend their appreciation to Mr. R. Rosendahl and Mrs. A. Bonde for their invaluable help during the project.

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