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Controlled drainage and subirrigation – A water management option to reduce non-point source pollution from agricultural land

Ingrid Wesström*, Abraham Joel, Ingmar Messing

Swedish University of Agricultural Sciences, Department of Soil and Environment, P.O. Box 7014, SE-750 07 Uppsala, Sweden

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ABSTRACT

Losses of nutrients from arable land significantly contribute to the eutrophication of lakes and coastal waters. Consequently agricultural nutrient and water management strategies have been emphasized during the last decades. The problem of excessive drainage at certain times of the year in conventional drainage systems (CD) can in many cases be overcome by implementing controlled drainage strategies (CWT). The data for this paper is based on water management projects, at both plot and field scales, which have been carried out in Southern Sweden during the period 2002 to 2005. The studies included water table strategies in which the subsoil was subjected to various degrees of water status at different times of the year by means of controlled drainage system. They were run on one site with small plots and two sites with field scale plots, and each site consisted of one CD plot and three CWT plots.

Compared to CD, CWT had lower subsurface runoff all years of measurement. Nitrogen (N) and phosphorus (P) concentrations in subsurface drainage water revealed no significant differences between CWT and CD. N and P losses, in contrast, tended to be lower in CWT than in CD, possibly due to lower runoff volumes in CWT. The yearly losses of NO_3-N, Total-N, PO_4-P and Total-P through the drainage system were on average 40% lower in CWT than in CD. The yield and N uptake by crops, in most measurements, were higher in CWT due to more water available during the cropping season and thereby improved N efficiency of the applied fertiliser. The results from the experiments revealed that controlled drainage has a potential to lower non-point source leaching of nutrients from agricultural land, improve N and P use efficiency and increase yields.

1. Introduction

Artificial land drainage has played an important role in the development of agriculture in the Nordic-Baltic countries. Installation of drainage systems has increased both the area of land available for crop production and the time during which the fields can be tilled and harvested. However, the positive developments in modern agriculture also have led to environmental side-effects where losses of nutrients in agricultural drainage water have become a major contributor to eutrophication (Enefalk, 2000; Brandt and Ejhed, 2002). Therefore nutrient and water management strategies have been emphasized during the last decades. A conventional drainage system works with the same drainage intensity over time, whether there is a need for drainage or not. One of the challenges of on-going drainage research is to develop a groundwater control system that maintains the benefits of an efficient drainage system, ensuring maximum nutrient efficiency and crop yield, without removing more water than necessary.

The problem of excessive drainage at certain times of the year can be overcome by using controlled drainage (Wesström & Messing, 2007; Wesström et al., 2001; Drury et al., 1996; Lalonde et al., 1996; Tan et al., 1993; Evans et al., 1989; Gilliam et al., 1979). This method allows the regulation of the height of the groundwater table by regulating the riser in the drain outlet. During periods of minimum drainage requirements, the groundwater level in the field is allowed to rise to the same level as that in the riser, decreasing the drainage intensity and creating saturated conditions to a selected part of the subsoil. The retention time of water in soil increases, potentially leaving more water available for evapotranspiration and for interim storage of soluble nutrients (Wesström et al., 2003).

In Southern Sweden precipitation deficits make it impossible to maintain an elevated groundwater level with controlled drainage throughout the summer. Without rainfall or a high groundwater table a controlled drainage system would thus most of the year not store enough water in the soil to grow an optimal crop on sandy

* Corresponding author. Tel.: +46 18 671183; fax: +46 18 673156.
E-mail address: Ingrid.Wesstrom@slu.se (I. Wesström).

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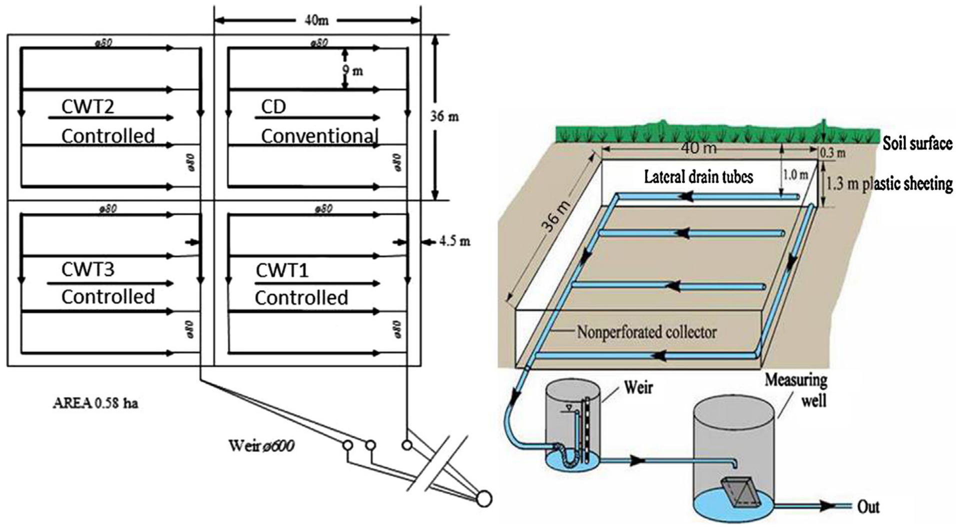

Fig. 1. Sketch of the experimental site at Gärds Köpinge.

soils. Therefore, additional water needs to be supplied to the field in order to reach optimum yield levels.

In 2002, a field experiment was initiated to assess the effects of controlled drainage/subirrigation systems (CWT) compared to conventional subsurface drainage systems (CD) on water and nitrogen balances under the climatic conditions on sandy soils in Southern Sweden. The main objective of the studies presented in this paper was to provide and evaluate a system, that satisfies both drainage and supplemental irrigation needs, in order to reduce water related stress, and thus increase crop yield, and at the same time protects the environment by reducing nutrient load to the recipient. Groundwater control strategies were used to subject the subsoil to various degrees of water status. Supplementary water was applied in CWT during vegetation period and the effects on drain outflow, nutrient losses, nitrogen flow and crop yields were measured. In this paper results on N and P losses, crop yields, N-uptake and changes in mineral N content in soil are presented.

2. Material and methods

2.1. Experimental sites

In 2002, field experiments on controlled drainage/sub irrigation systems were initiated at three sites in Southern Sweden. One trial was conducted at plot scale at a field site established in the year 2000 in Gärds Köpinge, Skåne County (55°55′ N, 14°10′ E) and two trials at field scale were laid out in Bottorp and Ragnabo, Kalmar County (56°35′ N, 16°13′ E and 56°23′ N, 16°04′ E, respectively). The aim of these latter trials was to establish demonstration experiments in practical operation scale. The measurement program was not as extensive as in the plot experiment at Gärds Köpinge.

The topsoil (0–30 cm) at Gärds Köpinge was a weakly structured loam with an organic matter content of 6%. The subsoil (30–70 cm) was loamy sand with very low organic matter content. The topsoils (0-30 cm) at Bottorp and Ragnabo were weakly structured sand with an organic matter content of 6%. The subsoils (30–70 cm) were sandy loam with very low organic matter content. The low organic matter content in the subsoil at all sites restricted the main microbiological activity to the topsoil. The root depths were also limited, to about 45 cm, due to the soil texture with single grain structure in the subsoil. A non-structured clay layer, found at a depth of 0.7–1.3 m, effectively restricted downward seepage of water at all sites.

Since the experimental layout differed at the three sites direct comparisons were not possible. Still, the three experimental sites together gave valuable information on the performances of controlled drainage under different conditions and crop management.

2.2. Water management systems

The experimental site at Gärds Köpinge (Fig. 1) consisted of four drained plots (36 m × 40 m). One plot was drained with conventional subsurface drainage (CD) (drains at 1 m depth) and three plots with controlled drainage (CWT) (drains at 1 m depth connected to weir at 0.5 m depth). The plots were isolated by plastic sheeting to a depth of 1.6 m to prevent lateral leakage and subsurface interactions. The CWT plots were drained separately, each with the outlets connected to a control structure with a weir allowing the water table to potentially rise to the pre-selected maximum height at 0.5 m depth, which was not changed throughout the seasons. Runoff from CD and from the CWT weir control structures was measured separately with a tipping bucket in a common manhole.

The demonstration experiment at Bottorp consisted of four plots, with a total area of 4.9 ha. It had one control plot with a conventional drainage system (CD) and three plots with controlled drainage/subirrigation systems (CWT). The individual plot areas were 0.7, 1.4, 1.9 and 0.9 ha, respectively. The original drainage system was installed in 1936 and consisted of tiles at 1 m depth with a spacing of 16 m. In each plot, the weir control structure was installed and connected to the existing tile drainage system. In CWT plots, the water table could potentially rise to 0.5 m below soil surface but the levels were lowered when the farmer needed to do field operations. Prior to this installation the main tile drains were cleaned out and corrugated plastic drain tubes were inserted into them. Runoff from each weir was measured separately with a Woltmann water meter (Maddalena) in the pipe leading from the outlet of the control structure.

The demonstration experiment at Ragnabo was made up of four plots with a total area of 4.0 ha, one control plot with conventional drainage system (CD) and three plots with controlled drainage/subirrigation systems (CWT). The individual plot areas were 0.8, 1.4, 0.9 and 0.9 ha. The original drainage system had gradually been expanded over the years. The oldest parts were from the 1920s. The drainage system consisted of tiles at a depth 0.7 m with a spacing of 10–14 m. The tiles had regularly been cleaned out. Four weir control structures, one for each plot, were connected to the existing drainage system. Three control structures had outlets in the existing main drains and one had outlet in an open ditch with its outlet in the nearby Baltic Sea. The water table could potentially