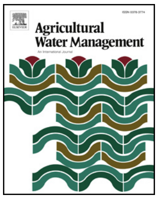
Agricultural Water Management 208 (2018) 393–405

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat



Managing controlled drainage in irrigated farmers' fields: A case study in the Moghan plain, Iran

Hamidreza Javani Jouni[a], Abdolmajid Liaghat[a], Alireza Hassanoghli[b], Ritzema Henk[c,*]

[a] Department of Irrigation and Reclamation Engineering, University of Tehran, Tehran, Iran
[b] Agricultural Engineering Research Institute, Agricultural Research, Education and Extension Organization, Karaj, Iran
[c] Water Resource Management Group, Wageningen University, Wageningen, The Netherlands

ARTICLE INFO

Keywords:
Controlled drainage
Leaching
Nutrients
Soil salinity
Crop yield

ABSTRACT

Conventional free subsurface drainage practices in the Moghan Plan, in northwest Iran, result in low irrigation efficiency and excessive volumes of drainage water causing extensive environmental problems. Controlled drainage (CD) is promoted to boost crop yields and reduce subsurface drainage flows and leaching of nutrients. This study was conducted to test management options for CD in irrigated farmers' fields in the Moghan plain. Three options were tested: subsurface drains at 2 m with free outflow (FD), controlled drainage at 70 cm below soil surface (CD70) and controlled drainage with a varying depth depending on the crop stage (CDch). Irrigation gifts were based on the daily measured soil water content and thus varied per drainage treatment. In winter, wheat and barley were grown followed by maize in summer. For each crop and treatment, three replicates were made. The highest crop yields (for all crops) were found with CDch, followed by CD70. For wheat, the yields were respectively 27% and 41% higher in the CD70 and CDch compared to FD. For barley these increase was respectively 23% (CD70) and 34% (CDch) and for maize (forage yields) 19% (CD70) and 25% (CDch). The same trends were observed in water use efficiencies (WUE): compared to FD, the WUE was 26% in CD70 and 40% higher in CDch; for barley these increases were respectively 19% (CD70) and 32% (CDch), and for maize (forage yields) 30% (CD70) and 44% (CDch). Controlled drainage not only reduced subsurface drainage rates, but also nitrate and phosphorous losses. The average drain discharges with CDch were respectively 33%, 45% and 44% lower than FD for wheat, barley and maize. Flow-weighted NO_3 concentration in drainage discharge of CD70 and CDch were, respectively, 15% and 9% for wheat, 9% and 13% for barley, and 8% and 7% for maize lower than in FD. Soil salinity decreased in FD, but slightly increased in the CD treatments. Thus, although controlled drainage clearly has advantages above free drainage practices, to optimize CD management options, more research is needed on the long-term effects of controlled drainage on soil salinity.

1. Introduction

The increasing global population is expected to reach 9.6 billion by 2050 (UN Department of Economic and Social Affairs Population Division, 2015). Providing environmentally safe food for this growing population is one of the biggest challenges we face now and in the future (Baker et al., 2012; Hanson, 2013). To be able to meet this challenge and to banish hunger from the world, food and feed production will need to be doubled in the coming 25–50 years (Molden, 2007). Yet, there are limits to the amount of land available for agriculture. Therefore, maintaining and increasing the productivity of existing agricultural areas is of paramount importance.

At present, as much as 35–40% of the gross agricultural output comes from the just 22% (about 299 Mha) of the arable and permanent cropped area worldwide that is irrigated (International Commission on Irrigation and Drainage (ICID), 2017). Irrigation often allows very significant increases in agricultural productivity. However, less than 25% of these irrigated lands are drained (Schultz et al., 2007). Consequently, salinity and waterlogging problems now affect about 10–16% of the irrigated arable and permanent cropped areas worldwide. Salinity and waterlogging problems hinder and limit the productivity. As there is not much scope for increasing the total irrigated area, the majority of the increase in output from irrigated agriculture will have to come from investments in improved irrigation and drainage practices in existing agricultural areas (Schultz et al., 2005).

Drainage of agricultural lands is an instrument for production growth, a safeguard for sustainable investment in irrigation, and a tool for conservation of land resources (Ritzema et al., 2006). In arid and

---

* Corresponding author at: Water Resource Management Group, Wageningen University & Research, P.O. Box 47, 6700 AA, Wageningen, The Netherlands.
E-mail addresses: hr_javani@ut.ac.ir (H.J. Jouni), Aliaghat@ut.ac.ir (A. Liaghat), a.hassanoghli@areeo.ac.ir (A. Hassanoghli), henk.ritzema@wur.nl (R. Henk).

https://doi.org/10.1016/j.agwat.2018.06.037
Received 15 December 2017; Received in revised form 19 June 2018; Accepted 27 June 2018

semi-arid regions its primary function is to prevent irrigation-induced waterlogging and salinization of the soil (Ritzema, 2016). In regions with prevailing dry and high evaporative conditions, increased salt concentrations and river depletion have become two inevitable collaterals of irrigated crop production. The role of subsurface drainage in these regions has changed from a single-purpose measure for controlling waterlogging and/or salinity to an essential element of integrated water management under multiple land use scenarios that can better control water levels (Schultz et al., 2007; Vlotman et al., 2007).

Conventional, free-outflow, drainage systems are usually designed for the wettest period of the year. However, as drainage rates are not constant over the year, the free outflow conditions may lead to excessive water and nutrient losses (Ballantine and Tanner, 2013). There are a number of approaches to manage these problems, including the use of cover crops to immobilize and recycle soluble nutrients (Hoorman, 2009; Jones and Jacobsen, 2009), the use vegetated drainage ditches, wetlands, or the use of/installation of reactive barriers to increase capture and transformation of soluble nutrients (Strock et al., 2010). However, the most promising practice is controlled drainage, an approach that controls drainage outflow.

Controlled drainage (CD) is a system for physically restricting discharge with adjustable gates installed at the outlet of the drain with inline control structures (Gilliam et al., 1979; Evans et al., 1995; Skaggs et al., 2010; Frey et al., 2016). Also known as drainage water management (DWM), it is a best management practice used to reduce drainage water volumes and nutrient loads to receiving streams (Gunn et al., 2015) CD is a strategy to control water levels in the growing season and has been shown to increase crop production and drainage water quality (Fisher et al., 1999; Noory and Liaghat, 2009). Environmental and agronomic benefits associated with controlled drainage such as yield increase and reduced drainage pollution to the environment are well documented (Woli et al., 2010; Skaggs et al., 2012; Sunoara et al., 2014; Jaynes and Isenhart, 2014; Nash et al., 2015).

In Iran, excessive volumes of drainage water cause extensive environmental problems. For example in the Moghan Plan, in northwest Iran, low irrigation efficiency in combination with conventional, free-flowing, subsurface drainage systems, with drains at a depth of about 2 m, has resulted in excessive drainage water volumes. The deep drains also drain water from the deeper soil layers. The drainage water is not only excessive in volume, but also of low quality due to leaching of nutrients. The huge amount of low-quality drainage flows creates many problems for downstream farmers and negatively affects the quality of the water in the Aras River. While CD, in the Moghan plain and in other parts of Iran, has been studied as a method to reduce drainage volumes, most research has been at the lysimetric scale: field scale is research is hardly done. Therefore, the objective of this study was to assess the performance of two types of controlled drainage at field scale on drainage flows, nutrient leaching, water and salt balances, irrigation and water use efficiency, and crop yields, and to compare their performance to conventional drainage practices. Strock et al. (2011) reported an average subsurface drainage volume reduction of 40% from a review of 15 peer-reviewed studies. Sands et al. (2008) measured an annual reduction in drainage outflow of 20% over a six-year study in south-central Minnesota. Gunn et al. (2015a,) quantified the effect of managed subsurface drainage on daily subsurface drainage volumes on a private field in North West Ohio. Their results showed that controlled drainage water management effectively reduced daily subsurface drainage volumes by 40% to 100% depending on the location. Darzi-Naftchali and Ritzema (2018) looked at the effect of three strategies for managing subsurface drainage systems, i.e. free drainage (FD), mid-season drainage (MSD) and alternate wetting and drying (AWD) and concluded that MSD and AWD resulted in significantly lower drainage rates, salt loads, and N losses compared to FD, with MSD having the lowest rates.

The effect of CD on water quality has also been studied. Sunohara et al., (2016) looked at water quality benefits of controlled drainage in eastern Ontario, Canada. They used data from nine growing seasons of maize, soybean and forage where controlled drainage and conventional drainage were practiced. Water quality parameters included nitrate, ammonium, and total phosphorus and dissolved reactive phosphorus. They measure respectively 60, 51, 58 and 66% reductions in above drainage water fluxes and improvement water quality targets as a result of controlled drainage. Several other studies also reported reductions in flow rates and nitrogen (N) loads ranging from 18% to 80% (Evans et al., 1989; Drury et al., 2009; Adeuya et al., 2012; Cooke and Verma, 2012; Helmers et al., 2012; Jaynes, 2012; Gunn et al., 2015). However, next to the ability of controlled drainage to reduce surface water nitrate loads, controlled drainage can also have some potentially deleterious effects. The higher water table has been found to increase the mobilization of phosphorus from within the soil profile (Valero et al., 2007) and an increase in nutrient-laden surface runoff has also been reported (Skaggs et al., 2010; Tan and Zhang, 2011; Ball Coelho et al., 2012). Other studies, however, show a reduction of phosphorus by controlled drainage (Wesstrom and Messing, 2007).

Riley et al. (2009) show that differences in crop yield between conventional drainage and drainage water management can be inconsistent. Some studies report an increase in maize yield with 10%–20% (Fisher et al., 1999 and Hunt et al., 1993) while others, e.g. Ng et al. (2002), observed an increase of 64%. This variation in controlled drainage performance and degree of impact is influenced by factors such as climate conditions, soil, drainage design, control structure management and field management practices (Skaggs et al., 2010, 2012; Christianson and Harmel, 2015a, 2015b; Negm et al., 2017).

As already noted, current/conventional drainage practices in the Moghan plain of Iran result in excessive volumes of low quality drainage water, leading to downstream problems. These problems threaten food production and water quality in this important agricultural region. While controlled drainage is recognized as a potential strategy for better management of drainage volumes, most studies on controlled drainage have been done in humid regions where drainage is needed to remove excess rainfall (Strock et al., 2011). Very little research, however, has been done for controlled drainage in irrigated areas, where drainage is mainly needed to control salinity. There is an urgent need to improve drainage management to reverse the negative trends in salinity build-up in irrigated lands (Ritzema, 2016). The objective of this study was to assess the performance of two types of controlled drainage at field level on drainage flows, nutrient leaching, water and salt balances, irrigation and water use efficiency, and crop yields, and to compare their performance to conventional free-flowing drainage practices.

2. Material and methods

2.1. Study area, experimental design and site descriptions

The research was conducted in two fields (about 32 ha), located in the Moghan plain, Ardabil Province, North Iran (47°46′44″ N, 39°36′14″ E). In the Moghan plain, a relatively flat area with alluvium soils deposited by the Aras River, an irrigation and drainage network of about 90 000 ha was constructed in the 1970s. The elevation of this area varies between 50 to 600 m + MSl. The climate is semi-arid and temperate, with a long-term (1985–2015) average annual precipitation of 275 mm, with a maximum and minimum of respectively 386 mm and 111 mm. Average air temperature is 15.2 °C, with a maximum of 41 °C in July and a minimum of −16.5 °C in January, and an average humidity of about 71%. The fields have a heavy textured, low permeability soil and need subsurface drainage for economically viable crop production. They are relatively flat, with an average slope of 0.5%, which make these sites suitable for controlled drainage. The physical and chemical properties of the soil profile from the surface to the depth of the drainpipes are presented in Tables 1.

The existing subsurface drainage system consist of parallel lateral subsurface drains (perforated corrugated plastic pipe of 200 mm