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Review

Drain for Gain: Managing salinity in irrigated lands—A review

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ABSTRACT

At present, about 299 Mha (or 18%) of the arable and permanent cropped areas worldwide are irrigated and, although drainage is an important component of irrigation, only 22% of these irrigated lands are drained. As a consequence, salinity and waterlogging problems affect about 10–16% of these areas because the natural drainage is not sufficient for controlling soil salinity levels. Additional, artificial drainage is needed to address this problem. Although the total area under irrigation continues to grow, very little is being invested in drainage systems to sustain the investments in irrigation. This is due in part to drainage being at the end of the pipeline where it has to clean up the "mess" that other activities leave behind: i.e. salts brought in by irrigation water, residues of fertilisers and pesticides etc. However, to move towards more reasonable sustainability, drainage has to be given its appropriate role in agricultural water management. In this paper seven reasons why drainage is needed are discussed, followed by seven aspects of why drainage is different than irrigation, and seven challenges to making drainage work. The paper concludes with a three-step approach reversing the negative trends in drainage management that result in salinity build-up in irrigated lands.

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1. Introduction

At present, about 299 Mha (or 18%) of the arable and permanent cropped area worldwide are irrigated (International Commission on Irrigation and Drainage (ICID), 2015), contributing as much as 40% of the gross agricultural output (Faures et al., 2007). However, despite the importance of drainage as a component of irrigation, only about 22% of these irrigated lands are drained (Schultz et al., 2007). In humid regions drainage is needed to control soil water for better aeration, higher temperatures, and easier workability; by contrast in arid and semi-arid regions its primary function is to prevent irrigation-induced waterlogging and salinization of the soil. In regions with prevailing dry and high evaporative conditions, increased salt concentrations and river depletion have become two inevitable collaterals of irrigated crop production.

Salinity build-up is a slow process so farmers, engineers and government departments all see irrigation as a need for today and salinization as a problem of tomorrow. Thus drainage has a lower priority than other agricultural activities like irrigation, on-farm management, etc. This is due in part to drainage being at the end of the pipeline: to clean up the “mess” other activities leave behind like salts brought in by irrigation water, residues of fertilisers and pesticides, etc. Most people do not like to be reminded of this and therefore ignore it.

On top of this, irrigation needs are changing triggered by land use changes. In the past, large-scale irrigation systems were built to supply water to farmers for a limited number of crops, mainly irrigated by surface water diverted from rivers, streams or lakes. In the last decades there has been a gradual change in land use: urbanization and non-agricultural uses, including ecosystem services, are increasing. This has changed the demand for water. Global climate change may further exacerbate the pressure on supply and demand through changing temperatures and long-term variation in annual precipitation amounts and regional distribution patterns. In addition to the changing climate, cropping patterns are diversifying and field irrigation methods are changing (De Fraiture et al., 2010). Irrigation water demands are no longer homogeneous and surface water is often supplemented with water from other sources: groundwater extraction, (treated) waste water and/or the re-use of drainage water (Singh, 2014). As a result river basins are closing, water resources are becoming increasingly contested, and stakeholders engage in different ways to influence water policies and intervention programmes.

The aforementioned developments have already led to certain changes in water management, however more awareness of the entire system is needed. For example, recent approaches that include multiple water services, have repercussions for the hydraulic design of irrigation and drainage systems (Renault et al., 2007). To optimize water use and control salinity it is important to match rainfall, irrigation and drainage (Van Hoorn and Van Alphen, 2006). In irrigated agriculture, the only agronomically significant criterion for installing drainage is the commercial crop yield. This makes the need for drainage complex as the direct effects of drainage, i.e. controlling the water table and discharge, are mainly determined by the hydrological conditions, the hydraulic properties of the soil, and the physical characteristics of the drainage system (Oosterbaan, 1988). Salinity control is only an indirect effect of drainage, thus water and salt balance analyses are needed to check whether the salt build-up in the root zone stays within acceptable limits (Ayers and Westcot, 1994) and to informed decisions in irrigation and leaching management. For these analyses, the crop tolerance to salinity has to be know. Soil salinity, however, varies in both time and space and the salt tolerance depends upon many plant, soil, water, and environmental parameters. The crop tolerance to salinity is usually expressed as the yield decrease for a given level of soluble salts in the root zone (Maas and Hoffman, 1997). The most common method for measuring soil salinity is to determine the electrical conductivity of the saturation extract (EC_e) in the root zone. Based on an extensive literature review, Maas and Hoffman (1997) concluded that crop yield as a function of average root zone salinity could be described reasonably well with a piecewise linear response function characterized by this salinity “threshold” value below which the yield is not affected, and above which yield decrease linearly with salinity. (Van Genuchten and Gupta, 1993) used the database complied by Maas and Hoffman (1997) to derive a single dimensionless curve to describe the salt tolerance of most crops. More recent studies indicate that the these models overestimate the above mentioned salinity threshold value and nonlinear salinity models are more accurate (Homaee et al., 2002; Saadat and Homaee, 2015). These threshold values for salinity are used to calculate the leaching requirement, which is the fraction of irrigation water entering the soil that must flow effectively through and beyond the root zone to prevent a build-up of salinity resulting from the addition of solutes in the water (Van Hoorn and Van Alphen, 2006). Artificial drainage is needed if the natural hydrological and soil conditions cannot cope with this extra amount of irrigation water. Traditional surface irrigation methods, like basin and furrow irrigation, have field application efficiencies that are generally lower than the leaching requirement; but modern irrigation methods, like sprinkler or drip, can have field application efficiencies that are higher than the required leaching (Brouwer et al., 1989). In light of all the changes in water demand, supply and use, the role of (subsurface) drainage in arid and semi-arid 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 (Schultz et al., 2007).

Although subsurface drainage practices have evolved from manual to large-scale mechanized installations (Ritzema et al., 2006), the fundamental design methodology and management criteria have not changed in the last 50 years (Ayars and Evans, 2015). Although the installed systems are technically sound and cost-effective, drainage development has lagged behind irrigation development (Ritzema, 2009). This is mainly because drainage systems tend to be designed and implemented by government, with the users, the majority of whom are small farmers, having little responsibility for them and providing little input. Often, these farmers are poor and do not have the means to invest in drainage themselves. In the traditional top-down approach standardized designs are generally used with little or no consideration of the location-specific conditions and farmers’ needs and preferences. Furthermore, the emphasis has been primarily on the technical aspects (physical infrastructure), while the organizational aspects (institutional infrastructure) of the drainage systems have been

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