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Review papers

Hydrological problems of water resources in irrigated agriculture: A management perspective

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ABSTRACT

The development of irrigated agriculture is necessary for fulfilling the rising food requirements of the burgeoning global population. However, the intensification of irrigated agriculture causes the twin menace of waterlogging and soil salinization in arid and semiarid regions where more than 75% of the world's population lives. These problems can be managed by either adopting preventive measures which decrease the inflow of water and salt or by employing remedial measures which increase the outflow. This paper presents an overview of various measures used for the management of waterlogging and salinity problems. The background, processes involved, and severity of waterlogging and salinity problems are provided. The role of drainage systems, conjunctive use of different water sources, use of computer-based mathematical models, and the use of remote sensing and GIS techniques in managing the problems are discussed. Conclusions are provided which could be useful for all the stakeholders.

Contents

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1. Introduction

1.1. Rationale

The global population is increasing continuously and is expected to reach the 9.7 billion mark in 2050 from the current 7.4 billion (United Nations, 2015). This 2.3 billion increase in population needs about 60% more foods in the next 35 years (FAO, 2013). The provision of irrigation is vital for achieving food security (Bowmer and Meyer, 2014; Das et al., 2015) and it will remain important as its share in world food production will rise from the current level of 40% to more than 45% by 2030 (Faures et al., 2007). This is particularly important in arid and semiarid regions where annual precipitation is highly erratic, both in quantity and in distribution, to ensure a harvestable crop (Postel, 1999; Singh, 2011; Shamir et al., 2015). However, without appropriate planning and management, the intensification of irrigated agriculture could result in declining agro-ecosystems (Tilman et al., 2002; Han et al., 2011). For example, more than one third of the world's irrigated land is affected by waterlogging and secondary salinization (Heuperman et al., 2002) and this condition poses a threat for food security. The problems are particularly serious in areas underlain by poor quality groundwater as salts accumulate in the soil surface through capillary action or directly as a result of waterlogging (Houk et al., 2006).

1.2. Environmental threat

The threat of irrigation-induced soil and groundwater salinization is increasing and becoming a major issue in hydrology, agronomy, and soil sciences (Ward et al., 2002; Singh et al., 2010; Valipour, 2015). The yield reductions in various crops due to waterlogging and salinization have been reported by researchers around the world (Grassini et al., 2007; Milroy et al., 2009). Qureshi et al. (2008) presented an assessment on the sources, causes and extent of waterlogging and salinity problems in the Indus Basin. Waterlogging also causes huge environmental damages in the form of damaged roads, buildings and other structures, and spread of endemic diseases. Askri et al. (2010) reported that the waterlogging and salinization of irrigated lands are of great concern for the sustainability of irrigated agriculture in the modern oases of South Tunisia. A similar concern about waterlogging and salinization was also expressed by Ibrakhimov et al. (2011) for the Khorezm region of Uzbekistan, where water supply exceeded the crop water requirement and that condition led to a rise in the watertable. Some aspects of waterlogging and soil salinization are reported by Barrett-Lennard (2003), Al-Sefry and Sen (2006), Guganesharajah et al. (2007), Singh and Panda (2012a, 2012b), and Aslam et al. (2015).

Heavy seepage losses from the unlined canal networks, percolation from irrigation fields, poor water management, inadequate drainage, low-lying areas, and under-exploitation of poor quality groundwater are the specific factors contributing to the problems of waterlogging and salinization (Mehta, 2000; Goyal et al., 2005). Since the waterlogging and salinization are the results of disturbed water and salt balances in the rootzone and subsoil, the solution of these problems lies in the restoration of these balances (Smedema, 1990). This can be achieved by either preventive measures which decrease the inflow of salt and water or by remedial measures which increase the outflow. Installation of drainage systems, conjunctive use of saline groundwater, canal lining, use of management models, and application of remote sensing and GIS techniques are among the specific measures, adopted to solve the problems. As far as the author is aware, different management alternatives for waterlogging and salinity have not been reviewed recently. This paper presents an overview of various measures used for the management of waterlogging and salinity problems.

First, the paper describes the significance of the hydrological problems of water resources in irrigated agriculture. The processes in the waterlogging and salinization problem, the severity of the problem, the role of drainage systems, the conjunctive use of different water sources, use of computer-based mathematical models, and the application of remote sensing and GIS techniques are discussed and some conclusions are presented.

2. Background

2.1. Mechanism

Waterlogging and salinization is commonly referred to as a 'twin menace' because these are usually coinciding processes in irrigated land (El-Ashry and Duda, 1999; Singh, 2012a, 2012b, 2013). Nevertheless, they are actually two rather different processes which are not always occur simultaneously (Smedema, 1990). For example, irrigation during the rainy season may lead to waterlogging without salinization while irrigated land may become salinized without waterlogging when insufficient fresh water is applied for leaching and/or no drainage system is available (Ritzema et al., 2008). Evaporation, transpiration, and poor drainage systems are the major processes involved in the salinization of irrigated lands, which are further aggravated by poor management practices.

The weathering of parent material of soil is the primary source of salts in irrigation water. In arid and semiarid regions, due to high evaporative conditions, salt concentration is gradually increased in the water sources and soil profile (Michael, 2009). In the rainy season when the watertable rises and approaches the surface, the land is temporarily waterlogged and salinity is reduced. But, after the rain and with the onset of winter, water is lost by evaporation and salts are deposited on the surface (Bennett et al., 2009). In humid regions, the released salts are transported to lower layers and finally by streams to the ocean. The salts deposited by irrigation are leached down to lower layers of the soil by the rainfall. On the contrary, in arid and semiarid regions the released salts may not be transported far away because of insufficient rainfall and whatever leaching of salts may occur, it would mostly be temporary. Moreover, the salts which move down due to rain come back again to the surface by capillary action during the hot season.

2.2. Plant responses

Waterlogging causes plants to become shallow-rooted (Barrett-Lennard, 1986) which results in salinization as salts move up due to capillary action that ultimately makes the land unsuitable for agriculture (Hillel, 1994). Wichelns (1999) reported that the root-zone available to plants becomes restricted once a watertable rises within 2 m of the soil surface. Ghassemi et al. (1995) and Hillel (2000) presented the processes of irrigation-induced waterlogging and salinization of land. The effects of waterlogging and salinization are the greatest in heavy soils with slow drainage, while the effective duration of waterlogging lasts longer than in lighter soils (Ponnamperuma, 1984).

Waterlogging causes a reduction in root respiration by reducing oxygen availability, which can cause the death of root cells or even the complete death of roots under prolonged waterlogging periods (Araki, 2006; Teakle et al., 2007). Waterlogging also reduces the soil fertility by reducing the rates of nitrogen fixation by legumes. Mirshel et al. (2005) reported that decreased vegetative growth due to waterlogging was the result of restricted nitrogen supply to the shoot. Robertson et al. (2009) reported that waterlogging