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Salinization of agricultural lands due to poor drainage: A viewpoint

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ABSTRACT

A timely and adequate water supply to crops is a requirement for sustainable food production to the burgeoning world populace. Although sufficient water supply is necessary for crop production, the excess water in the rootzone is detrimental to crop growth and yield. Poor land drainage and associated salinization correspond to severe threats to the long-term sustainability of irrigated agriculture as these cause a reduction in crop growth and yield. To provide ideal aeration in the rootzone, an apt drainage is necessary on poorly drained agricultural lands. This paper provides an overview of various measures and their suitability and limitations in managing the land salinization and rising groundwater level problems of irrigated areas. The aptness and restrictions of surface drainage, subsurface drainage, mole drainage, tile drainage, vertical drainage, and biodrainage in managing the problems of agricultural lands are explored in the paper. Conclusions are provided that can be of use to the readers.

1. Rationale

The improvement of irrigated agriculture is crucial in feeding the mushrooming world populace (Xie et al., 2018; Singh, 2018a,b) which is likely to reach between 9 and 10 billion in 2050 (United Nations, 2017). However, with no apposite land drainage provisions, this improvement can result in irrigation-induced environmental problems in agroecosystems (Foley et al., 2005; Singh, 2018c). In excess of one-third of the world's irrigated terrain is affected by land salinization or rising groundwater level problems (Wichelns and Oster, 2006; Singh, 2016a,b). Bakker et al. (2010) reported that some 30 million hectares (Mha) are affected by these problems, whereas about another 80 Mha are affected to a little extent. Ritzema et al. (2008) reported that above 8.4 Mha are affected by land salinization problems in India.

Land drainage is one of the main inputs to get better yields per unit of accessible agricultural area (Bos and Boers, 1994). Reducing soil submergence, salinity control, and making new land accessible for agriculture are the three main objectives of agricultural drainage (Singh and Panda, 2012a,b). Thus, an effective drainage system not only improves the existing agricultural lands but also brings new areas under cultivation. The total arable land has increased from 1371 Mha in 1961 to 1533 Mha in 2009 globally. It is, however, anticipated to cut yet again to 1385 Mha in 2060 on account of the continuing urbanization (Ausubel et al., 2013). For that reason, the required rise in farm production will have to come from enhanced irrigation and drainage practices in existing agricultural areas (Schultz and de Wrachien, 2002).

Poor land drainage and associated salinization correspond to severe threats to the long-term sustainability of irrigated agriculture (Milroy et al., 2009; Bahceci et al., 2006; Singh, 2015a,b, 2016c). Guang et al. (2012) and Hossain et al. (2011) reported the crop yield reduction due to land salinization and shallow groundwater level during different crop-growth stages. Dinka and Ndambuki (2014) addressed the problems and possible solutions of land salinization and low groundwater level which are caused by poor drainage conditions. To provide ideal aeration in the rootzone, an apt drainage is necessary on poorly drained agricultural lands. A suitable drainage system in the agricultural lands also helps in maintaining ideal soil moisture for the plants which is helpful in achieving the desired farm productivity (Singh et al., 2010; Akkaya Aslan and Gundogdu, 2007; Singh, 2018d). This paper provides an overview of various measures and their suitability and limitations in managing the land salinization and rising groundwater level problems of irrigated areas. The aptness and restrictions of diverse drainage systems in managing the problems of agricultural lands are explored in the paper.

2. Background

Irrigation-induced land drainage and salinization problems are old and these have affected agricultural lands in dry areas for centuries (Jacobsen and Adams, 1958). Maierhofer (1962) mentioned the failure of ancient civilizations due to land salinization and rising groundwater level problems. There is a sign that the importance of land drainage was understood and practiced very early in irrigated agriculture (Wen and

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Lin, 1964). Grassini et al. (2007) reported that poor drainage related land salinization and rising groundwater level problems are serious in irrigated areas across the world. Tyagi (2014) reported that about 110 Mha of irrigated lands are affected by these drainage problems in the semiarid and arid zones. Presently, over 30 Mha of irrigated lands are significantly damaged by the salt buildup and about 0.5 Mha are reported to be lost from farming annually as a result of land salinization.

In poorly-drained lands, the rising groundwater level causes plants to turn into shallow-rooted which results in salinization because salts move up due to capillarity (Hillel, 1994). Plant rootzone becomes constrained once the groundwater level goes up inside 2 m from the land surface (Wichelns, 1999). Smedema (1990) reported the processes of land salinization, corrective measures, and the harm done by the irrigation-induced processes. He also described some illustrative cases on the problems and their solutions. Irrigation water application means an input of salts. Ritzema et al. (2008) estimated that a 1912 mm irrigation application with 0.3 dS/m water will put in 3.7 tons of salts annually in a hectare of land if a drainage outlet is not present. Since groundwater quality is often relatively saline, even a small amount of capillary rise can increase rootzone salinity (Singh 2014a,b).

3. Land salinization mechanism

A prompt and adequate water supply to crops is a necessity for sustainable food production in dry areas where crop water requirement is principally supplied by irrigation thanks to inconsistent annual precipitation (Singh and Panda, 2013; Das et al., 2015; Singh, 2014c,d). Due to elevated evaporative demands, the salt concentration is progressively enlarged in the soil profile in dry areas (Williamson et al., 1987; Singh, 2013, 2011). Salinity is reduced in the rainy season when the groundwater level moves toward the surface (Michael, 2009). But, following the rain, water is evaporated leaving the salts on the surface (Bennett et al., 2009). Shallow groundwater levels might take the salts to the surface at some areas. In some locations, groundwater has high levels of salts and irrigating with such waters speeds up the salt buildup in the soil profiles. Moreover, the salts could be added via sub-surface inflows (Murty, 1998).

Poor drainage-induced land salinization and rising groundwater level problems are severe in irrigated areas across the world (Grassini et al., 2007). Irrigation water adds some salts in the soil profile and to avoid salinization, these salts require to be leached out of the vadose zone by water percolating to the subsoil. This percolated water needs to be drained off to circumvent groundwater level rise from a low watertable. The vulnerability of irrigated land to irrigation-induced salinization is mounting and becoming a key issue in sustainable farm production (Blann et al., 2009). The joint effects of salinization and land submergence are more detrimental to farm production than the individual ones (Singh, 2017a,b).

4. Environmental perspective

The hazard of irrigation-induced salinization and rising watertable are growing and becoming a key issue in sustainable crop production (Singh et al., 2012; Singh, 2012a,b). Milroy et al. (2009) reported the yield reductions in various crops due to salinization and submergence. Qureshi et al. (2008) provided a review on the causes, sources, and degree of salinization and submergence problems in the Indus Basin. Rootzone salinization and submergence considerably cut the total crop yield in wheat by poor grain filling (Hossain et al., 2011). The joint salinization and submergence effect is more detrimental to crop yields than the individual effect of salinization and submergence (McFarlane and Williamson, 2002). Katerji et al. (2000) reported that, apart from rootzone salinization and submergence, the climatic characteristics and variety of crops also play an important role in determining the crop yield. Aslam et al. (2015), Guganesharajah et al. (2007), and Al-Sefry and Sen (2006) addressed some aspects of salinization and rising watertable of irrigated areas.

The installation of a drainage system has many direct and indirect effects. The direct effects include the reduction of the amount of water stored in or on the soil and removal of water from the agricultural fields (Muma et al., 2017; Murty, 1998). However, the direct effects are generally not the key aims of drainage. The indirect effects comprise better aeration of rootzone which leads higher crop yield through deeper crop's rooting (Nousiainen et al., 2015), better fertilizer use, less weed growth, less denitrification, and less crop choice restriction. Leaching of salts through drainage prevents further salinization of the rootzone and make irrigated land sustainable for the long-term (Martinez-Beltran et al., 2007; Jafari-Talukolaee et al., 2015). Drainage makes soil drier which leads better land accessibility, greater land bearing capacity, better soil workability, better soil structure which improves permeability, and increased activities of microfauna which also improves permeability, and higher soil temperatures which allows the earlier crop's growth (Alakukku et al., 2010). Besides the aforementioned advantages, the installation of drainage systems has some environmental concerns as well. For example, when open drains are put up, the natural streams' flows are changed and saline drainage effluent is discharged to rivers. All these activities have some negative effects on the environment which are hard to foresee in total. But if the system is carefully planned, the impacts on the environment can be kept within the acceptable limits.

5. Management options

Land salinization and rising groundwater level cause vast ecological harms such as spoiled buildings and roads and spread water-related diseases (Sloan et al., 2016). Smedema (1990) reported that land salinization and submergence are the results of disturbed salt and water equilibrium in the vadose zone and the reinstatement of these equilibriums could solve the problems. Increasing the outflow or decreasing the inflow of water and salt from the agricultural lands will achieve the purpose. The installation of a drainage system has many direct and indirect effects (Murty, 1998). The direct effects include the reduction of the sum of water stored in the soil and removal of water from the agricultural lands (Muma et al., 2017). Leaching of salts through drainage prevents further land salinization and makes irrigated agriculture sustainable for the long-term (Jafari-Talukolaee et al., 2015; Martinez-Beltran et al., 2007). Surface drainage is the safe removal of surplus water from the land surface through constructed channels (Schultz et al., 2013). Its creation and continuance are easy. However, it takes substantial terrain outside farming. Failure to take away water from the vadose zone and hindrance with the agricultural operations and irrigation system are its other drawbacks.

While surface drainage takes away the surplus water from the land surface before it enters the vadose zone, subsurface drainage lowers the groundwater table and provides a better environment in the rootzone (Xian et al., 2017). Agricultural lands suffering due to salinization and shallow groundwater level by and large require subsurface drainage (Akram et al., 2013; Chahar and Vadodaria 2010). Occasionally, an arrangement of both, subsurface and surface drainage, happens to crucial in regions suffered due to land salinization and low groundwater level problems (Azhar et al., 2010). Such an arrangement is also necessary for a monsoon climatic condition as subsurface drainage alone cannot handle runoff abundance. Subsurface drainage has been in use for over a century to maintain the groundwater depths and salinities of agricultural areas to a suitable level (Tiwari and Goel, 2017).

Tile drains are a form of subsurface drainage and consists of small pipes of concrete or burnt clay and established at a particular depth from the ground (King et al., 2014). Filipovic et al. (2014) reported that gravel should be used above tile drains as a backfill material in areas which have heavy soils and shallow groundwater level conditions. The subsistence of a gravel layer with better hydraulic conductivity on top