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A Review of Targeted Studies on Controlled Drainage and Water Efficiency in Iran[1]

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Abstract

Introduction: To produce the food requirements of the growing population in the world and to make optimal use of available water resources, it is necessary to increase agricultural water productivity. This can contribute to the goals of food and environmental security. Controlled drainage can be a solution to achieve higher water productivity values.

Materials and methods: This study aims to summarize the evaluation of the performance of implemented drainage systems and examine their strengths and weaknesses. It can create a basis for planners and designers to have a more comprehensive view of optimal design in future plans and the effect of drainages.

Results: The literature review shows that in the free drainage system, with the increase in the distance of the drains, the depth of drainage decreased and the surface runoff increased. Increasing the depth in the free drainage system caused the total amount of rainfall to penetrate the soil, and as a result, the volume of drainage increased and the amount of runoff decreased. Drains with shallow depths lead to the increased possibility of waterlogging during heavy rains. With the increase in drainage depth, the amount of the total output salt load increased significantly in both free and controlled drainage systems. Finding the best drainage design option is essential from the viewpoint of environmental and economic issues.

Conclusions: The use of new drainage management technologies and consideration of environmental issues are essential for the success of drainage projects and the effective

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improvement of water efficiency. Today, not only modeling, designing, implementing and proper monitoring of the agricultural drainage network is important, but we have to pay attention to the special and modern issues of drainage engineering, including monitoring and safe removal of pollutants. In new drainage engineering projects, drainage and the environment should be investigated simultaneously.

Keywords: Drainage management, Drainage system, Water efficiency, Waterlogging, Water productivity.

1. Introduction

Providing food has become one of the main priorities of Iran's statesmen in recent decades. Considering the limitations of resources and production factors, one should try to use the available resources and inputs efficiently and optimally. In this case, with the current level of input usage, production can be increased or the current production amount can be produced with fewer inputs. This is possible by increasing the productivity indices. In many areas where irrigation water is scarce, drainage water is used to meet crop water needs. Reuse is sustainable only when the drainage water is of sufficient quality. Drainage water can be contaminated with trace elements, toxic organic matter, and industrial and municipal waste in open main drains. Contaminated drainage water can lead to various problems such as disturbances in the physicochemical properties of the soil, health problems related to water, and possible contamination of food products (Madramootoo et al., 1997). The limitation of the country's water resources, which is caused by the continuous increase in demand in various sectors of agriculture, industry, drinking, and the environment, has resulted in the maximum use of the available water resources (Javani et al., 2018). In order to increase water productivity to address this limitation, it is necessary to act through planning and optimal allocation of inputs. It is obvious that the determination of the water efficiency index alone cannot identify the factors and obstacles that cause its reduction. It is necessary to identify the cases of unfavorable consumption and to find direct and indirect operational improvement solutions.

Due to the improvement of irrigation management on the farm, the use of new irrigation methods, including rain and drip irrigation, has increased water productivity (Javani et al., 2018). In order to control the water crisis and prevent the further subsidence of groundwater, there is no solution except for a reduction in the harvest, but in response to the increasing demand for water, the uses should be optimized. In Iran, more than 90% of water is consumed in the form of evapotranspiration in agriculture and urban green spaces, so the management of harvesting and consumption of water in the agricultural sector plays an essential role in these conditions. In most of the countries with arid and semi-arid regions such as India and Iran, the agricultural sector is the most important user of water, and more than 70% of all withdrawn water is mainly used for irrigation of irrigated lands.

Water limitation crisis and its management are studied based on four stages: development stage, exploitation stage, allocation stage, and restoration stage. In the development stage, the amount of available water is still not limited and

the demand for water consumption is increasing strongly. The exploitation phase begins after the end of the development phase and when the supply of new water resources is limited through construction activities. In this phase, more and more attention is focused on water management. The allocation phase begins when the available water resources decrease and the development decreases. In this phase, the focus is on increasing water productivity, in which demand management is considered one of the important issues in the restoration phase. Efforts are being made to re-establish the balance between renewable resources and consumption in the river basins. After the three stages mentioned in many areas, the water is more than the renewable water resources, which causes a continuous decrease in groundwater. Balancing measures in this case can include reducing the area of irrigated lands, reducing population growth, and limiting industrial and urban development in the river basin.

With increasing pressure on the food supply, some countries will seek to develop new lands, which are likely to be located in problematic and low-quality lands. This message is clear that in the future, providing the food security of the world can face challenges. At the same time, preserving the water ecosystems due to the limited water resources of the planet requires spending much more financial and human resources for proper water management. Among the effective measures in the restoration stage are creating maintenance systems, carrying out institutional reforms, improving the management of exploitation, reducing water loss, minimizing the discharge of pollutants to water resources, and finally increasing water productivity (Davari & Salarian, 2015).

In general, the long accumulation of water in an area (water retention phenomenon) will increase pollution. For this reason, drainage in a building or any other structure is required to maintain the healthy condition of the structure and prevent land subsidence, flooding, routing of materials, and structural damage. Drainage is also essential in agriculture to maintain plant health, better productivity, and remove excess salts soluble in water (Javani et al., 2018).

Water, as the most limiting factor in the production of agricultural products, plays an important role in providing food for the growing population. Therefore, it is necessary to use the country's limited water resources efficiently and optimally and increase its productivity. The goal of increasing water productivity in agriculture is to maximize the profit from the consumption of water resources in the agricultural sector. Today, the main

function of drainage is not only the removal of excess water from the soil profile but also the management of the water table (Javani et al., 2018). As a structural change to improve the productivity of paddy lands, underground drainage changes the hydrology of these lands (Darabi et al., 2021). Drainage is one of the activities that have been emphasized for a long time in order to maintain the stability of crop production and control the balance of salts in the soil. According to the literature, the implementation of the drainage system in the irrigated lands was considered necessary, but now with the change of attitude in this regard, more balanced recommendations are presented. For example, some experts believe that drainage should not be conducted unless it is necessary (Akram & Tajik, 2017). The traditional attitude governing the design of drainage systems considered the purpose of drainage to be only increasing plant performance and improving the conditions of the growing environment, and did not consider the environmental effects of drainage plans.

In the new approach, it is necessary to pay serious attention to environmental goals, in addition to agricultural goals, and in particular, the risks caused by the discharge of sewage with unfavorable quality into the environment (Darabi et al., 2021). Controlled drainage (CD) is one of the watershed management methods, which has many advantages, including reducing the volume of discharged drainage, reducing the loss of chemical fertilizers from agricultural lands, and as a result, reducing environmental pollution, increasing plant transpiration, increasing the relative yield of the product and improving the water consumption efficiency. By managing the water level and controlling the drainage output, the groundwater level can be maintained at an optimal level, so that in addition to the possibility of using groundwater resources by plants, the volume of the output drainage can also be reduced. In other words, the basis of CD is to reduce the intensity of drainage as long as the crop yield does not decrease due to soil saturation. In the CD system, the water level is maintained at a small depth from the ground surface using the control structure. By reducing the hydraulic gradient and increasing the capillarity upward flow potential, shallow water level reduces the deep penetration below the root zone. The flow lines in this system are shallower than free drainage and are mainly concentrated near the soil. The main problem of conventional underground drainage systems is that in most cases, these systems drain the land too much, a large amount of salt is removed from the land along with the drainage, the water table is kept very low, and therefore the irrigation efficiency decreases. In fact, by controlling the outflow from the drainage pipes, CD ensures that moisture is stored in the soil and thus the plant can

use the water stored in the ground during the drought season. Among the factors that are effective on plant use of shallow groundwater, we can mention soil water retention capacity, soil water transmissivity coefficient, plant evapotranspiration requirement, plant root distribution, and the amount of salinity affecting plant growth. Therefore, plants might show different responses to climatic conditions and soil, and water levels in groundwater (Akram & Tajik, 2017; Darabi et al., 2021).

In the presence of shallow groundwater, even saline groundwater can be used to provide part of the plant's water needs. Of course, in such a situation, attention should be paid to the possibility of salinization of land as a result of the accumulation of salt in the soil, which can be solved or moderated by applying more precise management in CD conditions. About 40% of the world's food is produced in irrigated lands, and only nearly a quarter of these lands have drainage systems. Estimates show that by 2023, only 12% can be added to water resources. By this year, in order to provide food, the amount of production of irrigated land should increase by 80%. Such an increase is only possible with better management of water resources. An innovative management tool such as CD promises a bright horizon for reducing water consumption in the agricultural sector. This method not only saves water consumption, but also reduces the large volume of water drain and helps to improve the chemical quality of the outflow. Today, the CD is widely accepted and used not only in countries such as US, Canada, and European countries, but also in countries such as Egypt and Pakistan. For each case, successful studies are available that show CD can be used in some parts of Iran, especially in Khuzestan.

Researchers believe that in the future, CD, both in wet and dry areas, will be a key component of sustainable water management and will play an active management role in the exploitation of water resources. Based on the research conducted, the goals of watershed management and CD include all the goals of normal drainage in addition to protecting soil water, increasing yield by reducing or eliminating stress from dehydration, and reducing the transfer of nutrients and pollutants through drainage. The objectives of the design and management of the reservoir-level control system are as follows: controlling the salinity and sodium condition of the soil; reducing or removing the water stress of the plant; minimizing the harmful effects on the environment; preserving the obtained water from rainfall and reducing the need for irrigation; and maintaining soil moisture conditions in such a way that performing other operations such as protective tillage is more effective and beneficial. Also, the

advantages of CD include: reducing the volume of drainage; reducing the volume of outflow salt; reducing phosphorus and nitrogen loss and maintaining soil fertility; reducing the wastage of herbicides, pesticides and trace elements; reducing the destruction of drainage receiving sources; creating balance in soil water; increasing irrigation efficiency; and increasing water productivity. There has been a history of experimental or practical CD in countries such as the Netherlands, Italy, China, Finland, Canada, Malaysia, New Zealand, and Iran, and it was initially used in sandy and organic soils. Of course, experience has shown that this method is also applicable in heavier soils. CD, due to its positive environmental aspects and increased yield, has expanded greatly in the last 20 years in wet areas of the US. In North Carolina, CD has increased corn yield by 25% in dry land and 15% in fallow land. Besides, the use of CD has reduced the volume of drainage by 30%, the volume of nitrate by 55%, and the volume of phosphorus by 35%.

In a five-year lysimeter experiment with cotton-sunflower-alfalfa rotation in the San Joaquin Valley of California with a semi-arid climate and heavy soil with a salinity of 5 dS/m, it was observed that by using free drainage treatments and controlling water level in 1 m of the soil surface, 8% of cotton, 25% of sunflower, and 15% of alfalfa have received their water from groundwater. In the Netherlands, CD is mostly used to reduce the volume of drainage entering surface water resources and prevent pollution. In Egypt, the motivation for using CD is the lack of water, and its implementation began in rice fields. Water saving from CD has been more than 50%. In addition, reducing one irrigation round, saving farmers' work time, and reducing energy consumption in pumping up to 43%, and return of investment in installing control tools after two cropping seasons have been among the results of the implementation of CD. In general, in the studies conducted by the Egyptian Drainage Research Institute between 1996 and 2000, it has been observed that the implementation of CD in the form of an irrigation improvement project saves 1050 m^3 of water per ha per year and 32% reduction in irrigation time in paddy fields. In the gardens of southeastern Australia with arid and semi-arid climates, CD has been used in order to reduce the volume and salinity of drainage water. Compared to normal drainage, CD has reduced the volume of drainage water and only about 5% of soil salts have been released into the environment. Although raising the water table in the CD method has many benefits in reducing water consumption and the volume of saline drainage, it can accumulate salt in the soil. Therefore, to stabilize the CD system, continuous monitoring of soil salinity and its management is necessary. In

Australian gardens, an increase in soil salinity has been observed in all layers, and the highest salinity has been reported in the soil depth of 0 to 30 cm. Although during the two years of conducting the CD experiment, there was no decrease in yield due to salinity, the sustainable use of this method requires attention and, if necessary, correction of the soil salinity. Considering the washing periods among the drainage control periods and creating free drainage conditions during the winter rainfall or during the first irrigation of the growing season are among the appropriate management strategies to prevent the risk of soil erosion (Akram & Tajik, 2017; Darabi et al., 2021).

2. Materials and methods

Evaluating the performance of implemented drainage systems and examining their strengths and weaknesses can create a basis for planners and designers to have a more comprehensive view for optimal design in future plans to increase water productivity. Several studies on CD systems in Iran are reviewed in this work. For this purpose, the effect of drainage on increasing water productivity is investigated thoroughly.

3. Results

In order to investigate the efficiency of drainage, the results obtained in the conducted studies are summarized below:

In a study by Javani et al. (2018), the collected information included the amount of drainage controlled with variable depth during the plant growth period, the temporal and spatial changes of the water level, and the yield of corn and wheat crops. They showed that in the CD_{ch} and CD_{70} treatments, the volume of drainage from the drains decreased by 51.2 and 43.8% in the corn crop and by 46.6 and 33.1% in the wheat crop, compared to the free drainage (FD). The results also showed that the water level in FD has more fluctuations than in the CD treatments. The amount of fodder yield in corn crop in CD_{ch} and CD_{70} treatments increased by 24.9 and 19.1% and by 41.3 and 26.6% in wheat grain yield, compared to the FD treatment. Finally, the results showed that the efficiency of irrigation water in the CD treatments, especially CD_{ch} treatment, was more than the FD treatment. With the implementation of the CD system, in addition to reducing the outflow, the amount of environmental damage caused by the drainage downstream of the fields is also reduced.

In a research by Darabi et al. (2021), after proving the capability of the model to estimate the DRAINMOD drainage level and salinity during the winter cultivation seasons in equipped and renovated paddy fields with

underground drainage, the effect of FD and CD systems was evaluated from different aspects. In FD, with the increase in the distance of the drains, the depth of drainage decreased and the surface runoff increased. Based on the results, the drainage distances of more than 90 m in the FD system and drainage distances of more than 30 m in the CD system was not suitable due to the lack of proper control of the water level and not providing suitable conditions for storing rainfall. Increasing the depth in the FD system caused the total amount of rainfall to penetrate into the soil, and as a result, the volume of drainage increased and the amount of runoff decreased. Drains with shallow depth lead to increased possibility of waterlogging during heavy rains. With the increase in drainage depth, the amount of the total output salt load increased significantly in both systems. Comparing the simulation results of salt concentration at different soil depths showed an increase in salt concentration in the CD system compared to the FD system, indicating the better performance of the CD in preserving the salt load.

Gholami Astalkhi Kohi et al. (2021) reported that in order to control the water level during rice harvesting and secondary crop cultivation in paddy fields, the construction of drainage systems is inevitable. Finding the best drainage design option is very important from the viewpoint of environmental and economic issues. This study was conducted with the aim of investigating the performance of open drainage in controlling waterlogging levels in the cultivation of rice plants and the second plant in paddy fields. The results of the simulation showed that the open drainage with the depth and width of 200 and 170 cm during the period of rice cultivation and the secondary crop, exerted drainage equal to 726,440 and 169,960 cm^3 per unit length of the drain, and the reaction coefficient of 0.293 and 0.583, respectively, and had the highest performance in controlling the water level.

4. Conclusions

The use of new drainage management technologies and attention to environmental issues are essential for the success of drainage projects and the effective improvement of water efficiency. Today, not only modeling, designing, implementing, and proper monitoring of the agricultural drainage network is important, but considering the special and modern issues of drainage engineering, including bioreactors, drainage buffers, natural filters, and monitoring and safe removal of heavy metals, nitrates, antibiotics, and fertilizers is of great importance. Agricultural pollutants should be considered during drainage, in a way in drainage engineering projects, drainage, and the environment, should be investigated simultaneously.

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