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Overview of water-saving irrigation methods in arid/ semi-arid areas

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Abstract. Water-saving strategies play an important role in improving the resilience of water scarcity in arid and semi-arid areas. This paper has compared the advantages and disadvantages of four kinds of water-saving irrigation methods commonly used in arid/semi-arid areas: rainwater harvesting irrigation, plastic film mulching technology, deficit irrigation, and alternate furrow irrigation. The finding of this study is that biological water-saving which can improve the biological drought tolerance is more cost-effective of further study than the technological water-saving. It can be seen that the latter two (biological water-saving irrigation measures) have lower cost, stronger operability and more promising development prospects. In addition, future research is suggested to focus more on automatic intelligence to pursue accurate irrigation.

1. Introduction

With the development of the human economy and population explosion, the proportion of fresh water resources that can be directly available for agricultural production keeps decreasing [1]. This can lead to the expansion of arid areas, the intensification of drought, soil erosion, and ecological deterioration. Hence, it has been increasingly important to adopt the sustainable approach to scientifically allocate water, improve crop water productivity, and reduce soil water demand pressure in arid and semi-arid regions. Within this context, to utilize water resources more efficiently and balance the yield and economic benefits, various water-saving irrigation technologies have been studied as valuable strategies in arid areas [2].

How to make better use of these water-saving irrigation technologies according to local conditions has become the interest of research in farmland water conservancy. This paper refers to a large number of research literatures related to water-saving and drought-resistant irrigation, summarizes common water-saving irrigation methods in arid/semi-arid areas, and proposes future research directions.

2. Main irrigation strategies in arid/semi-arid areas

2.1 Rainwater harvesting irrigation

China is one of the main water-poor countries, the arid and semi-arid areas account for about half of the land areas [3]. Due to the lack of groundwater and surface water in arid areas, precipitation has become the main source of agricultural irrigation. However, the annual change rate of rainfall in arid and semi-arid areas is relatively large and the rainwater utilization efficiency is low [4]. Rainwater harvesting irrigation can not only retains rainwater runoff as the water source for irrigation and makes full use of it, but also prevents soil erosion and improves the ecological environment.

Rainwater-harvesting irrigation techniques use limited water resources for supplementary irrigation during crops' critical water demand periods. These irrigation techniques include rainwater harvesting, storage, transportation and utilization. Historically, people have used water cellars, dry wells, karez and reservoirs [5] to collect rainwater, but due to terrain and technical constraints, the development of rainwater-harvesting irrigation techniques is slow [5].

Recently, rainwater harvesting irrigation has been developing rapidly. Scholars have developed various techniques such as CIS remote sensing technology to evaluate the feasibility of regional rainwater utilization [6], impervious treatment of rainwater collecting surface, the material and efficiency of the catchment [3], combination of other water-saving measures (e.g., drip irrigation and sprinkling irrigation) for drought resistance, seed preservation and seedling preservation[4]. At present, rainwater harvesting irrigation has formed a certain scale in arid areas, and the "121 rainwater harvesting project" implemented in the Dingxi region of Gansu province, China has made great progress, from single irrigation to water and soil conservation, water pressure alleviation and ecological benefits improvement [7].

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2.2 Plastic film mulching technology

At present, the effects of plastic film mulching technology are mainly on border irrigation and furrow irrigation[8]. In border irrigation, the membrane is laid on the border fields, where crops are grown. In furrow irrigation, crops are planted on groove slope or ridge back, while membrane is tiled on the bottom of the ditch, groove slope and part of the ridge back [8]. In both methods, the water flows from the upper layer of the membrane into the soil through the seedling holes /the manual watering holes, and the membrane gaps enable water to infiltrate the soil, which results in low ground roughness rate and the loose soil [8]. These methods also can keep heat and entropy, and improve the economic benefits of crops [9]. Moreover, some studies have shown that it is feasible to strengthen tomato seedlings by changing the color of the mulch, in which the tomato seedlings treated with red light have vigorous nutrient growth, large accumulation of dry matter and rapid leaf area expansion [10].

Despite the above advantages, plastic film mulching technology may cause environmental pollution. In order to solve this polluted problem, in recent years, scholars have devoted themselves to the research of new green materials, such as photolysis membrane, biodegradable membrane, etc[11]. Research on plastic film mulching technology also focuses on how to improve soil aeration condition, increase soil available nutrients content [12], and reduce greenhouse gas emission from using such technology [13]. At the same time, they have actively developed the technology of mechanical recovery and reuse of the residual membrane, which not only ensures the sustainable development, but also further improves the ability of mechanization[9].

2.3 Deficit irrigation

Deficit irrigation is a strategy aiming to balance yields and maximum water productivity through capitalizing the regulation and supplement effect of plants themselves [2]. The irrigation amount in this strategy is not proportional to the water requirement of the whole process of crop growth and development [1]. The principle of regulated deficit irrigation (see Fig 1) is that when a certain amount of water stress is applied to crops, the water deficit and the reduction of cell turgor will hinder the growth of cell elongation, so the leaves are smaller and the photosynthetic area is reduced. With the increase of stress degree, the water potential decreases obviously, and the content of abscisic acid (ABA) in cells increases, so that the net photosynthetic rate also decreases, and the dry matter in crops is retained. After the rehydration of crops, the positive response mechanism appears in the crops, which accelerates the growth of crops and improved drought tolerance[15].

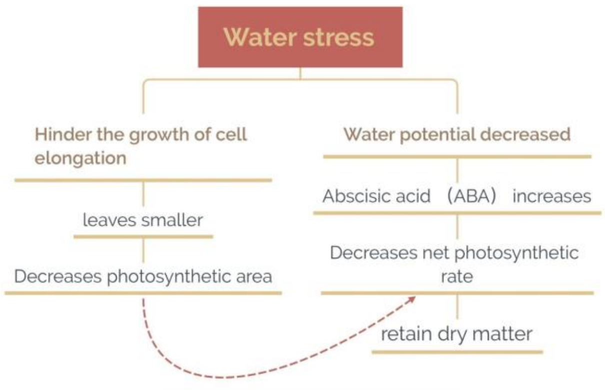

Fig 1. The principle of regulated water stress

Due to the different water requirements of different crops, in order to prevent the development from moderate water deficit to serious water shortage in production, Each region should carry out research on different crops and soils, so as to establish an optimized crop water deficit evaluation system[16], and the gradual development from extensive irrigation to precision irrigation has become the focus of research[17].Currently, the evaluation methods of crop water deficit is much from the ecological perspective, but in order to improve the drought resistance of crops, more scholars hope affecting crop genetic material[15], at the same time, under the condition of without affecting crop yields, regulated deficit irrigation will affect the crop of protein, sugar, fat and other components will become the direction of further research[18].

2.4 Alternate furrow irrigation

In most developing countries such as China, furrow irrigation is still the main irrigation method. Alternate furrow irrigation is an appropriate water-saving technique which is developed in traditional furrow irrigation[19]. The principle of alternate furrow irrigation is similar to water stress (see Fig. 1). The research on alternate furrow irrigation in arid and semi-arid areas in some developed countries, such as the United States, has been going on for many years since the mid-1960s.However, these preliminary studies mainly focus on the relationship between irrigation water and yield, and the theoretical exploration on how to achieve the mechanism of water-saving and yield increase of crops is less[20].

This water-saving irrigation technology based on the improvement of the traditional furrow irrigation method, the controlled root zone alternating furrow irrigation avoids the disadvantages of large investment and difficult operation of water-saving measures such as sprinkling irrigation and micro-irrigation, so it has a broad field application prospect. At present, studies indicated that alternate water and fertilizer irrigation could maintain maize’s high root activity and normal physiological metabolism (nitrate reductase activity, photosynthesis, etc.), and improve the water use efficiency of leaves, so as to save water and increase yield[21].

Alternate furrow irrigation is suitable for the irrigation of crops with wide row spacing. Therefore, scholars try to apply the mechanism of narrow row close planting crops (e.g., wheat), improve water-saving efficiency and reduce crop diseases, so as to integrate alternate furrow irrigation and develop it into ecological irrigation areas[19].

2.5 Comparison of main irrigation strategies in arid/semi-arid areas

Based on their impact on crops, we made an inadequate comparison of the advantages and disadvantages of four sustainable water-saving irrigation technologies, as shown in Table 1.

Table 1. Comparison of advantages and disadvantages of main irrigation strategies in arid/semi-arid areas.

Irrigation strategies	Advantages	Disadvantages	Refer-ence
Rainwater harvesting irrigation	• Impounding stormwater runoff as a source of irrigation • Make full and effective use of local stormwater runoff • Prevent soil erosion • Improve the ecological environment	• Lack of integration of the key techniques (i.e. harvesting, storage, transportation and utilization) and other water-saving irrigation measures • High cost of development and maintenance of concrete rainwater collecting surface • Low durability and potential environmental pollution of plastic rainwater collecting surface • Low rainwater utilization efficiency	[4], [5], [6]
Plastic film mulching technique	• Reduce surface evaporation and deep leakage • low ground roughness rate and the loose soil • Preserve heat and entropy • Improve the uniformity of irrigation	• Causes microplastic pollution to the terrestrial environment • The broken plastic film affects the absorption of soil nutrients • Reduce soil organic matter • Increase greenhouse gas emissions	[8], [9], [12], [13]
Deficit irrigation	• Improve crop quality and drought tolerance • Balance economic benefits and output	• Excessive water shortage will lead to dead seedlings	[14], [15]
Alternate furrow irrigation	• Keep the root soil loose and well ventilated • Prevent groundwater level from rising, soil nutrient loss and crop lodging • Serve as a drain during the rainy season	• Can not be widely used in field cultivation of narrow row crops(e.g.,wheat) • Difficult to design alternate irrigation time and its flow rate	[20], [21], [22]

As shown in Table 1, the first two methods use technologies to achieve water-saving objective, while the latter two are based on the physiological and genetic potential of the crops themselves. By comparison, it can be seen that the latter two (biological water-saving irrigation measures) have lower cost, stronger operability and more promising development prospects. In addition, future research would focus more on automatic intelligence to pursue accurate irrigation. This is only the author's incomplete comparison, its conclusion still has some limitations.

3.Conclusion

The purpose of this study is to provide references for selecting water-saving irrigation technologies according to local conditions. This study has compared the advantages and disadvantages of the four sustainable water-saving irrigation technologies (i.e., rainwater harvesting irrigation, plastic film mulching technique, deficit irrigation, alternate furrow irrigation) that are commonly used in arid/semi-arid areas. The findings of this study are that deficit irrigation and alternate furrow irrigation are more operable and less costly than rainwater harvesting irrigation and plastic film mulching technique.

To save water effectively in dry areas and build energy-saving, environmentally friendly and intelligent ecological irrigation areas, more in-depth research is required to carry out in the future to improve the recycling of water resources, as below.

3.1 Intelligent irrigation

Intelligent irrigation systems use automatic water supply facilities to supply water to crops, which can not only reduce the waste of water but also promote the normal growth of crops. Future research is suggested to further develop Fuzzy-PID control strategies to realize intelligent irrigation and enhance the accuracy of relevant equipment controllers through adjusting the corresponding parameters[23,24].

3.2 IoT-based accurate irrigation

GIS can be useful in making environmental index decisions according to the water demand of crops, but the meteorological data and soil moisture information monitored by GIS are of low timeliness at present. Therefore, one of the future directions is to develop membrane bag irrigation system based on IoTs technology [25], which can improve the efficiency, accuracy and intelligence of current water-saving irrigation technologies.

3.3 Green ecological materials

In areas that use traditional irrigation methods, the use of bricks, plastics and other materials has seriously damaged the habitat of organisms and greatly reduced the diversity of microorganisms in the soil. Therefore, green ecological materials have become a critical research direction. Take plastic mulch as an example, biodegradable materials, such as plant fibers and other biorenewable membranes, have become one of the research focuses as they can largely replace plastic mulch and reduce microplastic pollution in soil [26].

3.4 Industrial wastewater recycles

There are still a large number of trace elements in the treated industrial wastewater, which can be used by the growth of crops. However, the heavy metal contaminated ions remained in the treated industrial wastewater can cause environmental pollution. Therefore, more technologies need to be developed in the future to treat heavy metal contaminated ions in industrial wastewater so that it can be recycled to irrigate crops [27].

3.5 Combination of water and fertilizer

In the study of biological water-saving measures, irrigation and fertilization should be integrated in terms of time, quantity and methods. Some studies have shown that the coupling of organic fertilizer and nitrogen fertilizer may reduce water stress and improve water status of plants during deficit irrigation[28].The adjustment of water and fertilizer is very important for crops, so the future research can examine the combination of organic fertilizer, inorganic fertilizer and water in biological water-saving measures to improve crop stress resistance and increase crop yield.

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