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Advances in Deficit-Regulated Irrigated Potato Research

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Abstract: Potato is one of the most important food crops worldwide, and its yield and quality are directly affected by irrigation management. Loss-in-adjustment irrigation is a water-saving and efficient irrigation strategy, which stimulates plant root development and improves water use efficiency by reducing the amount of irrigation during specific periods of the crop growth cycle, thus realizing the purpose of saving water and increasing yields. The purpose of this paper is to summarize the research progress on deficit-regulated irrigation in potato in recent years, to explore its impact on potato growth and development, yield formation, and quality enhancement, and to suggest potential avenues for future research.

Keywords: potato; deficit irrigation; yield; quality; soil temperature

1. Introduction

With the increasing water stress and uncertainty caused by climate change, effectively utilizing limited water resources has become a major challenge for agricultural production. Potato, as one of the crops with high water demand, often requires a large amount of water input to ensure high and stable yields under traditional irrigation systems. Therefore, it is particularly important to explore new irrigation techniques that are more water-efficient and do not compromise — or may even enhance — crop production. As an emerging irrigation method, regulated deficit irrigation (RDI) has attracted much attention for its ability to save water while maintaining or even improving crop productivity.

It was concluded that potatoes, being shallow-rooted plants, are highly susceptible to fluctuations in soil moisture [1]. Low soil moisture content can directly impact the yield and quality of potatoes, resulting in diminished productivity and inferior produce [2]. At the same time, the scale of potato farming in China is expanding, with the planted area increasing year by year [3]. Traditional potato cultivation, characterized by large-scale furrow irrigation, consumes substantial amounts of water per application. This method not only causes significant water waste but also results in relatively low water use efficiency (WUE) [4]. To support sustainable rural development and agricultural modernization, there is an urgent need to identify and implement effective water management practices for potato cultivation in China, with the aim of optimizing water use and enhancing crop yield and quality.

Consumers are becoming increasingly concerned about nutritional balance. Water and irrigation regulation have long been acknowledged as safe strategies to enhance crop

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quality, especially in the growth of potatoes. Research has shown that regulated deficit irrigation technology can effectively reduce the amount of irrigation water and improve water-use efficiency while ensuring adequate moisture for potato growth. Through precise control of soil moisture, this technology promotes deeper root system development and enhances drought resistance, thereby achieving both water conservation and increased yield. In addition, regulated deficit irrigation can improve the starch content and nutritional value of potato tubers, better meeting consumer demand for healthy food.

2. The Impact of Regulated Deficit Irrigation on Potato Growth, Yield, Quality, and Water Utilization

The potato growth cycle can be subdivided into five main stages: germination, seedling stage, tuber formation, tuber growth, and starch accumulation. Studies have shown that differences in irrigation levels affect crop yields, and that under certain conditions, the right amount of irrigation can increase crop yields. Potato yields increased as irrigation levels increased. Particularly at the tuber formation stage, moderate water limitation had only a slight negative effect on potato yields. One study found that there are differences in the water requirements of potato at different stages of its growth cycle, especially at the tuber formation and expansion stages, where potato is more sensitive to water [5]. If excessive deficit irrigation is implemented during these critical periods, it may adversely affect tuber yield and size. Therefore, water restriction at these sensitive stages should be avoided when developing a rational irrigation strategy. Studies have shown that moderate deficit irrigation can reduce water consumption to some extent while maintaining high yield levels. However, excessive water restriction has the potential to trigger yield decline. Therefore, determining the optimum level of deficit is one of the key factors in improving irrigation efficiency.

Other researchers indicated that the primary indicators of potato quality encompass total sugar content, protein content, starch content, organic acid content, and reducing sugar content, among others [6]. Mild water deficit treatments during the tuber growth phase do not appear to significantly reduce total sugar and starch content. In fact, in some cases, these treatments can even enhance these qualities, though often at the cost of reduced protein and organic acid levels. Moderate water stress can promote improved food processing performance indicators in some cases; however, extreme drought conditions may trigger undesirable consequences, such as hollow centers or increased internal defects in tubers.

The primary goal of employing controlled deficit irrigation methods is to enhance the efficiency of water resource utilization. Soil temperature and moisture conditions have significant effects on plant growth. Some researchers discovered that water deficit irrigation, also known as water stress, had a significant impact on potato yield, with a p-value of less than 0.05. One study pointed out that deficit drip irrigation reduces the water consumption of the crop and improves water-use efficiency [7]. During the potato tuber formation stage, moderate deficit irrigation did not reduce yield. Other studies have also shown that the highest overall potato quality was achieved under mild and moderate water stress during the seedling stage. However, some studies have reported contrasting results, indicating that mild water deficit treatment led to a significant 12.7% decrease in potato yield, although it also resulted in a 14.2% increase in water use efficiency compared to full irrigation. Another study concluded that the reduction in crop yield under controlled deficit irrigation conditions was justified by the gains in water-use efficiency and crop quality [8].

Potato is a water-demanding crop with varying water requirements across different growth stages. At the peak of photosynthesis, the rate does not increase further with higher soil moisture, while transpiration continues to rise, leading to inefficient water utilization. Other researchers found that through the implementation of effective regulated

deficit irrigation strategies, the water-use efficiency per unit area can be significantly improved, which is particularly important in water-scarce regions [9]. Adequate irrigation should be applied during the tuber growth stage. Mild water deficit treatments during potato tuber formation effectively reduce over-branching and contribute to higher crop yields. Suitable water deficit strategies at this stage have also been shown to enhance the sugar, protein, and starch content of potatoes. It also significantly reduces organic acid levels, further enhancing potato quality.

3. The Effect of Soil Temperature of Irrigated Potato Farmland with Deficit Regulation at Different Fertility Periods

Reasonable irrigation management is one of the key approaches to maintaining suitable soil temperature. One study found that during the potato seedling stage, the soil temperature at 5, 10, and 15 cm depths initially increased and then decreased with prolonged sunlight exposure, while at 20 and 25 cm depths, it continued to rise [10]. Some studies have shown that surface soil temperature fluctuates significantly on a daily basis, while such variation decreases with increasing soil depth. Another study found that the soil temperature under deficit-regulated irrigation was higher than that under full irrigation [11].

4. Potato Food Security and Prospects

In arid regions, potato production plays a critical role in ensuring food security. Due to limited water resources, agriculture in these areas faces considerable challenges. However, as a drought-tolerant crop, potato can thrive under water-scarce conditions, providing a stable food source for local communities. One study found that potato is not only rich in starch, vitamins, and minerals, but also capable of producing high yields within a short growing cycle, helping to alleviate food shortages effectively [12,13]. Therefore, expanding potato cultivation in arid areas is essential for strengthening local food security.

Through the promotion of advanced irrigation technologies, soil improvement, and the selection of drought-resistant varieties, potato yield and quality can be further enhanced, providing a more reliable foundation for food security in water-scarce regions. Another study also emphasized that ensuring food security through potato production in arid regions is closely tied to sustainable agricultural development [14]. Given the fragility of the local ecosystems, overexploitation and improper land use can lead to land degradation and desertification.

Moreover, the rising cost of water due to its increasing scarcity has imposed new pressures on agricultural production. Farmers are often forced to pay higher water prices, which significantly increases production costs. More importantly, a reduction in the area planted with potatoes will directly affect food supply. It is essential to recognize the close connection between water scarcity and food security. Only by fundamentally addressing water shortages and ensuring the stability of food supply can we achieve sustainable development and prosperity for human society.

One study highlighted the importance of protecting the ecological environment in developing potato production in arid areas [15]. It emphasized the need for scientific farming methods, effective land management, and the maintenance of soil fertility and biodiversity.

At the same time, strengthening scientific and technological support is key to enhancing the production capacity and food security level of potatoes in arid regions. Another researcher demonstrated that introducing and cultivating high-quality varieties, developing efficient water-saving irrigation technologies, and promoting green pest control can significantly improve potato yield and quality, reduce production costs, and increase market competitiveness [16,17].

Additionally, strengthening farmers' technical training and improving their scientific literacy and production skills are crucial for the sustainable development of potato production in arid regions.

Finally, the government and various sectors of society should increase support for potato production in arid areas, formulate relevant policies, and provide financial, technical, and market assistance to farmers.

5. **Conclusion**

This article explores the impact of controlled deficit irrigation on potato growth, yield, quality, and water use efficiency in arid regions. The study indicates that reasonable irrigation management, especially applying moderate water deficit irrigation during key growth stages of potatoes, not only improves water resource utilization efficiency but also enhances crop yield and quality. Moderate water stress at certain stages helps increase starch, sugar, and protein content in potatoes, while excessive water restriction may lead to yield decline and internal defects.

Additionally, proper soil temperature management is crucial for improving potato yield and quality. The research shows that soil temperature under deficit irrigation is higher than under full irrigation within a certain range, particularly in deeper soil layers, which could help maintain a suitable microclimate to promote tuber growth.

For potato production in arid regions, in addition to enhancing water management and technological support, ecological environmental protection should also be prioritized. Introducing high-yield drought-resistant varieties, developing water-saving irrigation technologies, and providing technical training to farmers can effectively improve productivity and ensure local food security. Furthermore, government policy support and assistance from various sectors of society are key to ensuring the sustainable development of potato production.

In conclusion, potato production in arid regions faces challenges from water scarcity and land degradation. However, through scientific irrigation practices and rational agricultural measures, it is possible to improve both yield and quality while protecting the environment. These efforts will contribute to ensuring food security in the region.

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