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Progress of Deficit Mulched Drip Irrigation for Potatoes

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Abstract: Submembrane drip irrigation offers several key benefits, including efficient water and fertilizer usage, strong adaptability to various environments, a reduction in pest and disease pressures, and increased crop yield and income. Research shows that this irrigation method can reduce water consumption by over 80%, enhance land use efficiency, decrease labor requirements, and improve water resource utilization. This paper examines the development and application of sub-film drip irrigation for potato cultivation under controlled deficit irrigation conditions. The goal is to enhance potato yield, improve quality, and optimize water usage efficiency, ultimately contributing to increased productivity and economic benefits for agricultural production.

Keywords: drip irrigation under membrane; potato; yield; water use efficiency

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1. Introduction

Potatoes are a major global food crop, playing a key role as both a staple food and a significant cash crop and industrial raw material. In China, the area dedicated to potato cultivation accounts for approximately a quarter of the global total, with the country consistently ranking as the world's top producer for many years [1,2]. Potato farming in China spans a wide geographical area, with the northern, southwestern, and southern regions being the primary areas of production. The northern region, in particular, serves as the dominant production area, encompassing provinces such as Inner Mongolia, Heilongjiang, and Jilin [3]. With the continuous improvement of living standards and dietary habits, potatoes have become increasingly important in the market as one of the main food sources. In terms of cultivation techniques, researchers have developed methods tailored to specific regions, taking into account the unique soil and climate conditions that affect potato growth [4]. These methods include soil improvement, fertilizer management, pest and disease control, all of which contribute to enhancing potato yield and quality [5]. Among these, sub-film drip irrigation has emerged as an effective method to achieve high yields and quality in potato cultivation [6]. This technology integrates film cultivation with drip irrigation, covering the drip irrigation lines or capillaries with a layer of film. The technique directs water from the drip holes straight to the crop roots, ensuring that the soil remains loose and maintains optimal moisture levels. With the film in place, evaporation is significantly reduced, and water consumption in the field is cut to just 50% of that used in traditional irrigation methods [7]. This paper explores the use of sub-film drip irrigation technology for adjusting water loss in potato cultivation, aiming to provide a theoretical foundation for establishing an optimal irrigation model that minimizes water wastage while maximizing potato growth and productivity.

2. Submembrane Drip Irrigation Profile

Drip irrigation technology, introduced in the 1970s in traditional farms of the Jordan River Gorge in Israel, has proven to be an effective irrigation solution, particularly for developing countries [8]. This method has shown considerable success in Palestinian agriculture, conserving 25-35% of water while boosting crop yields by up to 146% [9]. In the mountainous border regions of Peru and Bolivia, potatoes are cultivated in modest rural greenhouses using drip irrigation, where the greenhouses help mitigate the effects of frost and drought. This approach has led to yields as high as 7 kg/m², representing a 500% increase compared to traditional farming methods [10]. In recent years, drip irrigation technology has rapidly expanded in the northwest, northern, and northeastern regions of China, especially in areas like Xinjiang, where it has proven effective in saving water while improving efficiency. Sub-membrane drip irrigation technology, in particular, can save 20-30% more water than conventional irrigation methods, such as flood irrigation, channel seepage control, and pipeline water transmission. When compared to sprinkler irrigation, it uses 50% less water, and with sub-film drip irrigation, water savings can reach up to 75% [11]. By delivering water and nutrients directly to the crop roots, this technology significantly enhances water use efficiency and increases crop yields, playing a crucial role in supporting sustainable agricultural development, especially in regions facing water scarcity and arid conditions.

3. Effect of Water Deficit Regulation of on Potato Yield

Fertilizer is delivered directly to the potato roots through the drip irrigation system, which minimizes fertilizer loss through volatilization. This method ensures good dissolution, rapid absorption, and enhanced fertilizer utilization efficiency [12]. Xing et al. investigated the impact of under-membrane drip irrigation on potato yield and found that it improved soil water content by nearly 20%, increased yield by approximately 1.09 times, and raised soil temperature by 9% compared to conventional irrigation without mulch [13]. She et al. demonstrated that an optimized irrigation strategy, with intervals of 204-262 mm and fertilization (N-P-K) rates between 200-24-248 to 247-42-306 kg/ha in sandy soil conditions, could maximize tuber yield, net revenue, water productivity, and apparent fertilizer recovery, all reaching ≥90% of their optimal values in northern China [14]. Badr et al. observed that the application of drip irrigation and fertilization strategies on sandy soil increased potato yield by 13% and 22%, compared to weekly or bi-weekly fertilization approaches, respectively [15]. Overall, under-membrane drip irrigation plays a key role in enhancing potato yields by precisely controlling the water and nutrient supply. This not only improves crop productivity and resource efficiency but also contributes to the advancement of sustainable agricultural practices.

4. Effect of Water Deficit Regulation on Water Use Efficiency in Potato

The core aspect of under-membrane drip irrigation for potatoes lies in the precise and controlled delivery of both water and fertilizers directly to the crop roots. This method ensures that the crop receives the necessary nutrients and moisture at the most optimal time and in the exact quantities needed for maximum growth. Such precise regulation minimizes water wastage, significantly reduces deep seepage, and ensures that water is available in the root zone where it is most needed, thus avoiding inefficiencies common in traditional irrigation methods. Furthermore, the use of mulch in combination with this system plays a crucial role in regulating soil temperature. Mulching increases the soil temperature in the arable layer, which helps to enhance root development and accelerate plant growth. Additionally, the mulch layer serves to reduce water evaporation, helping to conserve moisture, especially during the potato's reproductive period, when water demand is high. By improving water retention and reducing evaporation losses, the system conserves water and significantly enhances drought resistance, an essential factor in arid and semi-arid regions where water is a limiting resource [16,17].

These combined factors — reduced water consumption, increased drought resistance, and improved soil conditions — work together to significantly enhance the water use efficiency of potato cultivation, which ultimately leads to higher yields and improved dry matter accumulation in the crop. Studies have shown that under-membrane drip irrigation can reduce water consumption by more than 30% compared to conventional border and furrow irrigation methods, while also achieving up to 50% higher water use efficiency. This translates into not only water savings but also an increase in the overall yield of the potato crop, demonstrating the effectiveness of the technique in improving both resource use and crop output [18]. Furthermore, trials have found that under-membrane drip irrigation improves water utilization efficiency by 28.5% when compared to traditional tillage methods, highlighting its superior performance in terms of water management and crop productivity [19].

Additionally, the implementation of different levels of drip irrigation has been observed to significantly increase water use efficiency. Studies have indicated that applying 66% of field holding capacity achieved the highest water use efficiency, compared to 100% and 33% of field holding capacity. This finding underscores the potential for optimizing water use while maintaining high crop yields, which is critical for sustainable agricultural practices in regions facing water scarcity [20].

5. Effects of Water Deficit Regulation on the Hydrothermal Environment of Potato Soil

Soil moisture and temperature are critical factors influencing plant growth and development, as they directly affect various physiological processes. Both soil moisture and temperature play a key role in root growth, water absorption, and nutrient uptake. Additionally, these factors indirectly impact plant health and productivity by regulating soil microbial activity and nutrient cycling. The interaction between soil moisture and temperature significantly influences crop yield and quality, making it essential to optimize these conditions for the best plant performance [21].

Studies have shown that mulched-film drip irrigation can greatly improve the hydrothermal properties of the soil. By stabilizing soil moisture levels and mitigating temperature fluctuations, this method reduces the daily maximum soil temperature by an average of 1-2°C. This reduction in temperature creates a more favorable environment for root development and water absorption, which in turn boosts water use efficiency and promotes higher crop yields [21].

During the early growth stages of potatoes, mulching irrigation has been found to enhance the soil's hydrothermal environment. The increased soil temperature during this period promotes faster root development and nutrient uptake, leading to healthier plants. Furthermore, the reduction in soil water content helps optimize root respiration, allowing for more efficient dry matter accumulation, especially during the rainy season. By maintaining an optimal balance between moisture and temperature, this technique improves both the efficiency of water and nutrient utilization and overall productivity [22].

In conclusion, by carefully regulating soil moisture and temperature, under-membrane drip irrigation enhances the crop's ability to utilize water and nutrients effectively. This not only leads to increased productivity but also reduces resource wastage and improves soil health, providing a foundation for sustainable agricultural practices. These benefits offer a scientific basis for the promotion of sustainable farming systems and support the long-term viability of crop production in the face of environmental challenges [22].

6. Problems and Solutions

Potato cultivation is widespread and involves various varieties, with specific geographical requirements. However, certain challenges persist, particularly in regions with low levels of mechanization, which remains a significant issue. In many areas, the integration of drip irrigation technology and agronomic practices is still underdeveloped. For instance, many farmers manually lay and retrieve drip irrigation tapes, which are prone to damage such as scratches and tears, leading to significant water leaks in the fields [23]. Additionally, while the use of mulch films effectively conserves water and retains heat for crops, their non-biodegradable nature causes long-term harm to the agro-ecosystem [24].

To address these issues, it is essential to develop a dynamic model for potato cultivation that considers different soil properties, climatic factors, and variety characteristics. This model can help identify the most effective irrigation system to optimize yield potential [25]. The introduction of precision agriculture techniques, such as the use of "3S technology" (GIS, GPS, and remote sensing), can further enhance agricultural practices by enabling farmers to precisely plant seeds and apply fertilizers using drone technology [26]. In order to promote standardized and high-quality production, it is also necessary to address the challenge of agricultural film waste. This can be achieved by regulating film thickness and gradually transitioning to degradable films. Degradable films offer similar protective benefits during the early growth stages of crops but do not harm the soil, thus helping to preserve the environment [27].

7. Conclusion

In conclusion, the application of under-membrane drip irrigation technology for potatoes plays a crucial role in conserving water resources, enhancing yield and quality, reducing production costs, and improving land utilization. Building on existing technologies, further research is needed to explore the integrated effects of soil moisture, fertilizer, air, and temperature. Additionally, developing low-cost biodegradable drip irrigation equipment, large-scale plant protection machinery, and other intelligent agricultural technologies tailored to local conditions is essential. Strengthening the foundational theoretical research on key technologies, as well as fostering farmers' awareness of water conservation and improving water management systems, are key areas for advancing this technology. These efforts will be critical for the stable and efficient adoption of under-membrane drip irrigation in potato farming in the future, ensuring its sustainable and widespread implementation.

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