Research Progress of Regulated Deficit Irrigation Technology in Watermelon (Citrullus lanatus) Cultivation

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Abstract. Regulated deficit irrigation (RDI) technology provides a new way to solve the contradiction between agricultural water supply-demand and the shortage of water resources. The paper briefly introduces the concept of RDI technology and its water-saving mechanism, and then describes the specific application of RDI technology in watermelon planting and the impact of RDI on watermelon growth dynamics, photosynthetic physiological characteristics, water productivity, and quality. It is concluded that timely and appropriate RDI of watermelon can not only improve the quality of the watermelon and maintain or even increase the yield, but also increase the water use efficiency (WUE). Finally, the main problems existing in the watermelon RDI technology are summarized, and its application is prospected, in order to obtain new results in the follow-up research of watermelon RDI.

1. Introduction
The shortage of water resources in the 21st century is a common problem facing the world. In recent decades, the process of economic globalization has been accelerating, the number of people has increased year by year, and the social demand for water resources has increased dramatically, the contradiction between water supply and demand has become increasingly acute, which has seriously affected the realization of the sustainable development goals of human society. Especially for agriculture in arid regions, the scarcity of rainfall, uneven distribution within a year and insufficient irrigation water resources not only restrict the development of the planting industry, but also hinder the development of regional and even the national economy, and this situation will become more and more severe over time. Therefore, it is imperative and also an objective demand to increase the investment of funds and scientific research in the field of agricultural water-saving, and build efficient water-saving agriculture [1].

Watermelon is a herbaceous plant of the Cucurbitaceae, which is rich in nutrients and has various functions such as clearing heat, quenching thirst and diuresis, etc., it is known as the "King of summer melons and fruits" and is cultivated all over the world [2]. The water consumption of watermelon is larger and more sensitive to the change of soil moisture. The amount of water supply affects its growth and development, fruit yield and quality. Therefore, the rationality of water management is directly related to the benefits of watermelon cultivation. In addition, with the continuous improvement of people’s consumption levels, people’s focus on melons and fruits has gradually changed from the original quantity to quality, and the requirements for quality have continued to increase. At the same time, the melon and fruit planting industry in arid areas is also faced with limited water resources to ensure maximum yield and quality. This has attracted the attention of a large number of domestic and
foreign scholars, who have also done corresponding research and reports, and have achieved fruitful results. This paper comprehensively discusses the research status and progress of watermelon RDI.

2. Brief introduction of RDI technology

RDI was proposed in the mid-1970s of the 20th century, the main content: Because some genetic characteristics of crops or growth hormones tend to affect the physiological and biochemical effects of plants, if appropriate RDI is artificially applied at certain stages of crop growth, the proportion of photosynthetic products distributed to different tissues and organs of the plant will be affected, thus reducing the growth of some nutrient organs of the plant and the synthesis of organic matter, and ultimately saving water and increasing the quality of the plant. Studies have shown [3-7] that the key to the fact that the RDI of crops can save irrigation is that the roots of the crop can sense the lack of soil water, and at the same time transmit the stress signal to the aboveground part of the crop in time, thereby inducing the closing of stomata and crop transpiration, and causing a decrease of water demand. Studies also have shown [8-10] that the main reason why crop RDI can increase crop yields is: when drought stress is applied to crops, different tissues and organs of the same plant show different sensitivity to adversity threats, making the vegetative growth of crops will be correspondingly inhibited due to suitable drought stress, but their reproductive growth can still continue, so that the impact during the adversity stress period is minimized; Moreover, when the drought stress is relieved, the water supply to the crop is restored, after rewatering, the organic matter accumulated in the stress stage can still be used for the growth of the crop itself to make up for the loss caused by the drought stress [11].

3. Research progress of RDI in watermelon

3.1. Water consumption pattern and water deficit design of RDI in watermelon.

Watermelon has a relatively large water demand, and the water demand varies with different growth stages. Related study found that the water demand process of watermelon presents a bimodal curve, that is, as the plant gradually grows up from the seedling stage, the water demand gradually increases, and reaches the first peak in the extension vine stage; the water demand decreases during the flowering and fruit setting period, and after fruit set successfully enters the swelling period, the water demand increased rapidly, reaching the second peak and the highest value in the whole growth period; After the fruit is basically finalized, it enters the variable flesh period, and the water demand of watermelon drops rapidly [12-13].

Li (2010) adopted the daily water surface evaporation of the E601 evaporation dish as the control index of irrigation water quantity, and concluded that the comprehensive evaluation benefit of watermelon was better when the evaporation coefficients were set at 0.75, 0.75, 1.25, and 1.00 at the seedling stage, flowering-fruiting stage, swelling stage, and ripening stage, respectively [14]. Wang (2007) showed that the smallest water consumption was the severe water deficit in the fruiting-swelling stage, and the water consumption was 344.65mm and 357.69 mm, respectively; the largest was the full water supply treatment, which was 416.36mm and 433.37 mm, respectively [15]. The study results of Pang (2005) are basically the same as those of Wang F., the sensitivity of watermelon to water is in descending order from setting fruit - swelling, swelling-ripening, flowering-setting fruit, sowing-flowering [16]. Yang et al. (2003) pointed out that in watermelon cultivation, 80~90% of maximum field holding could be controlled according to the seedling stage, 60~70% at the extension vine stage, and 80~90% at the fruiting stage [17]. Liu (2015) studied the influence of different drip irrigation frequencies on the RDI watermelon, and concluded that the optimal drip irrigation frequency strategy was to drop water once every 4 d in the seedling stage and the swelling stage, and to irrigate water once every 2 d and 6 d in the flowering and fruit-setting stage, respectively [18]. Wu et al.(2008) found that when the soil moisture and leaf area index (LAI) of watermelon were maintained at 70.92%~81.24% and 1.44–1.32, respectively, the ventilation and lighting of plant population were relatively better, which could improve the photosynthetic efficiency of leaves and promote the
accommodation of dry matter[19]. Abdelkhalik et al. (2019) suggested that adequate water supply should be adopted under the condition of adequate irrigation, and RDI could be applied at the stage of fruit ripening under the condition of insufficient irrigation [20]. Yang et al. (2017) conducted RDI experiments on greenhouse watermelons in northwest China, and concluded that watermelons growing in winter-spring had better WUE and quality, with a total irrigation volume of 114 mm, and the distribution amounts of 25, 12, 62 and 15 mm respectively at seedling stage, extension vine stage, swelling and ripening stage [21].

3.2. Effects of RDI on the Growth Dynamics of Watermelon
Water deficit significantly inhibits the enlargement and division of plant cells, directly affects the internal structure and physiological characteristics of plants, which are manifested through external morphology, such as the increase of root cap ratio, and the decrease of plant height, number of leaves and leaf area [22-25]. Zheng (2009) showed that a moderate water deficit in watermelon seedlings had a compensatory effect on the growth of the main vine and LAI, but the degree of water deficit was too large to inhibit the growth and development of the plant [26]. Yin (2012), a greenhouse watermelon deficit-irrigation alternate irrigation test showed that the growth of plant height, the greater the deficit of odd irrigation, the faster the growth of plant height after compensation by even irrigation [27]. Mo et al. (2016) showed that water stress inhibited the growth of both wild watermelon M20 and domesticated watermelon Y34, but the rhizomes of M20 increased significantly compared to Y34, and M20 had denser trichomes and more sensitive stomatal control and higher leaf water status [28].

3.3. Effects of RDI on Photosynthetic and Physiological Characteristics of Watermelon
Drought and insufficient soil water will, to some extent, restrict the photosynthesis and biological productivity of crops, crop photosynthesis is the most important physiological process for crops to synthesize organic matter and produce biomass. Therefore, soil water is very important to the photosynthesis of crops. Li (2010) found that the daily variation of photosynthetic rate of watermelon leaves showed a similar "double-peak" curve, the daily variation of transpiration rate showed a similar "single-peak" curve, and the daily variation of WUE of single leaves showed a "V" type [14]. Wang (2007) showed that different degrees of water deficit at the sowing-flowering stage reduced the stomatal conductance, transpiration rate and photosynthetic rate of leaves, and the extent of their effects was aggravated with the aggravation of water deficit, the different water deficit treatments in the fruit setting-swelling stages reduced the leaf transpiration rate, and the severe water deficit also reduced the leaf photosynthetic rate and WUE [15]. Zheng et al. (2009) showed that low water treatment would increase stomatal resistance, CO2 diffusion was blocked, and the photosynthetic rate was the lowest, but WUE of single leaf was the highest [29]. Yu et al. (2012) conducted water deficit experiments on the two main sand-pressed land cultivars 'NNK1' and 'sh204', showed that under 10% water stress, the photosynthetic physiological characteristics of the two test materials had the same changing trend, under 5% drought stress, the photosynthetic rate of 'NNK1' showed a uniform decrease, and the decrease in transpiration rate and stomatal conductance was smaller than that of 'sh204', showing a better adaptive capacity [30].

3.4. Effects of RDI on water productivity and quality of watermelon
The ultimate goal of crop cultivation is to obtain higher yields and increase planting income under the premise of ensuring crop quality. Wu et al. (2008) pointed out that during the fruit swelling period, the watermelon growth was relatively large, so sufficient water supply should be ensured to promote the rapid growth of the fruit, and water should be stopped 10 days before the fruit ripening to ensure the accumulation of sugar and the quality of the fruit [19]. Qin et al. (2020) found that, compared with the control group, RDI improved the WUE of watermelon and had no significant effect on the yield [31]. Srinivas et al. (1989) and Yesim et al. (2003) showed that water deficit significantly reduced the size of watermelon, decreased the number of watermelon fruits, and significantly increased the soluble solid content [32-33]. Saraiva et al. (2017) conducted RDI tests on watermelons with different ground
cover types, and watermelons with adequate water supply under rice husk or white plastic film had the highest yield and relatively good quality [34]. Kuscu et al. (2015) showed that RDI led to a significant decrease for watermelon yield in the sub-humid region, and that water deficit treatment during the whole growth period reduced the yield by 31% compared with adequate water supply treatment, but saved 50% of water, and the content of soluble solids and total sugar was relatively high [35]. Wang et al. (2007) results showed that the mild water deficit during the fruit setting-swelling stages not only improved the VC content and soluble solids concentration of the fruits, but also increased the yield, compared with the control, reaching about 40 t/hm², with the highest WUE and irrigation water use efficiency (IWUE) [36]. Zheng et al. (2009) showed that the content of soluble sugar under moderate water treatment during fruit swelling period increased by 19.68%~17.79% compared with the control treatment, but the yield was only 76.72%~72.43% of the control treatment [29]. Liu et al. (2014) found that irrigation treatment at medium frequency at seedling stage, high frequency at flowering and fruiting stage, medium frequency at fruit expansion stage and low frequency at maturity stage had higher fruiting rate and single fruit quality, and the total fruit production and IWUE were the highest, and had a high content of total VC and the highest content of soluble protein and central soluble solids [37].

4. Problems and perspectives
Numerous studies have shown that RDI technology is an effective water-saving irrigation method. For economic and food crop cultivation, it is necessary to in-depth study its response mechanism to water deficit, the limited irrigation water resources should be utilized to fully exert the compensation effect of water deficit, minimize the loss caused by water deficit, and continuously improve the economic and ecological benefits of agricultural production. The aforementioned trial of RDI of watermelons has also demonstrated that this technology plays an important role in water-saving irrigation and increasing yield. In practice, however, there are still the following problems: First, the comprehensive indicator system for watermelon water deficit is not comprehensive, such as the period and extent of deficit, the duration of deficit, and irrigation method; Second, the design factor of RDI test is single, and different gradients are designed only with soil water as the influencing factor, the soil nutrients, gas and heat are not taken into account, which is also very important for the growth of watermelon. Third, in the face of the shortage of irrigation water resources in the region, we can use saline water or domestic sewage to carry out RDI experiments and popularize their application, which can not only alleviate the contradiction between supply and demand of water resources, but also hopefully solve the problem of reuse of saline water or sewage. Fourth, there is insufficient research on the comprehensive implementation technology of RDI. In the cultivation process, the irrigation method and corresponding agricultural technical measures that are compatible with RDI are optimized, such as the use of water-retaining agents, wheat straw, sand and gravel, and other mulching technologies. High-tech technologies, such as artificial intelligence, remote sensing technology, geographic information technology, etc., are organically combined with watermelon water monitoring and management to further improve field management efficiency and realize intelligent and precise RDI.

Nowadays, water resources are becoming increasingly scarce, which makes the available water resources less and less, especially the agricultural water is more precious, however, in the long-term exploration and research of agricultural saving-water, the RDI technology provides an effective way to solve this problem. For efficient water-saving watermelon cultivation, with interdisciplinary research and cooperation in the future, the RDI system of watermelon will be integrated with corresponding agronomic measures, engineering measures and monitoring measures, and continuously develop towards systematization, informatization and intelligentization [12].

5. Conclusions
Watermelon is one of the fruits that are commonly eaten all over the world. Although it consumes a lot of water, the growing season is relatively short, the economic benefits are significant, and the income-generating effect of farmers is considerable [38]. The comprehensive analysis of the above results
showed that the rehydration after moderate water deficit in the seedling stage would promote the growth of watermelon, while the water demand in the fruit expansion stage is larger, so the water supply should be guaranteed to be sufficient, and moderate water deficit in the mature stage could effectively improve the nutritional quality of watermelon and has little influence on the yield. In a word, the application of RDI technology in watermelon cultivation can make efficient use of water, improve watermelon yield and quality at the same time, and effectively alleviate the problem of insufficient water resources to a certain extent.

Acknowledgments
The authors would like to thank the Key Research and Planning Projects of Gansu Province (No. 18YF1NA073) and the National Natural Science Foundation of China (No. 51669001) for the funding & lab facilities.

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