A Review on the Interactive Effects and Regulation of Water and Nitrogen in Watermelon

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Abstract. Water scarcity and excessive nitrogen application restrict sustainable watermelon production. This review systematically elaborates water-nitrogen coordinated regulation effects on watermelon growth, yield, quality and ecological environment, and clarifies staged water and nitrogen coupling rules, identifying vine extension and fruit expansion as key regulation periods. The integrated film drip fertigation system combining deficit irrigation and staged nitrogen management is summarized, and regional optimized water-nitrogen models under different climates and cultivation modes are compared. Existing research lacks clear water-nitrogen interaction thresholds, microscopic mechanisms and long-term ecological assessments. Future studies should develop IoT intelligent decision systems, simplify practical technologies and evaluate full-chain environmental benefits to support high-yield, high-quality, efficient and eco-friendly watermelon cultivation.

Keywords: Watermelon, Water and nitrogen regulation, Management model.

1 Introduction

Watermelon (Citrullus lanatus), as an important fresh fruit crop worldwide, holds a significant position in China's agricultural production and consumption market. Its planting area and total output have remained the world's largest for many consecutive years[1]. The stable and healthy development of the watermelon industry is directly related to the economic benefits of millions of melon farmers and the stable supply of the seasonal fruit market[2]. However, watermelon production is a typical resource-intensive industry, highly dependent on water and nutrients, especially nitrogen[3,4]. In the main production areas such as the arid and semi-arid regions of Northwest China and protected cultivation facilities, the coexistence of water scarcity and excessive nitrogen application with low utilization rates has become increasingly acute, posing a core bottleneck to the sustainable development of the industry[5].

Nitrogen determines vine growth, fruit setting and yield, yet blind over-fertilization causes soil nitrate accumulation, secondary salinization, microbial imbalance, ammonia volatilization, N_2O emission and agricultural non-point source pollution[6]. Water

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mediates photosynthesis, nutrient transport and fruit swelling, making irrigation efficiency improvement an urgent challenge under water shortage.

Based on green high-quality watermelon production demands, this review sorts out three core scientific questions to guide subsequent analysis. First, it explores quantitative water-nitrogen coupling thresholds and micro-mechanisms regulating carbon-nitrogen metabolism. Second, it defines applicable boundaries and benefit trade-offs of regional water-nitrogen models across soils and planting scales. Third, it proposes low-cost intelligent water-nitrogen decision systems and full-chain ecological-economic evaluation frameworks.

2 Water and Nitrogen Demand Patterns and Key Regulation Periods of Watermelon

Watermelon water and nitrogen requirements shift dynamically with growth priorities, forming staged demand characteristics that lay the foundation for phased water-nitrogen regulation[7].

2.1 Water Demand Characteristics and Sensitive Periods

Watermelon has high overall water demand with distinct stage sensitivity. Seedlings need moderate soil moisture for robust growth. The vine extension stage demands 80%–90% full irrigation to build leaf canopy[8]. Stable moisture is required at flowering and fruit setting to avoid fruit drop. Fruit expansion is the critical water-demanding stage, directly determining single fruit weight and total yield. Moderate water control during ripening promotes sugar accumulation and reduces fruit cracking risk[9].

2.2 Nitrogen Demand Patterns and Key Periods

Nitrogen uptake matches vegetative and reproductive growth rhythm. Seedlings need low but balanced nitrogen supply. Nitrogen absorption peaks from vine extension to pre-flowering to support photosynthetic source construction[10]. Adequate nitrogen remains necessary from fruit set to early expansion for young fruit development[11]. Nitrogen demand drops sharply in mid-to-late expansion and ripening; excess nitrogen stimulates vegetative growth and lowers fruit sugar content, requiring strict nitrogen limitation[12].

2.3 Identification of Key Windows for Water and Nitrogen Synergy Regulation

Two core coordinated regulation stages are identified based on coupled water-nitrogen demand. Vine extension to pre-fruit setting (strong plant window): Adopt simultaneous water and nitrogen supply to develop vigorous vegetative organs[13].Fruit expansion to ripening (quality-improving window): Coordinate water and nitrogen in early expansion to guarantee fruit enlargement; apply moderate drought and nitrogen

restriction in mid-late stages to raise sugar content, balancing high yield, fruit quality and resource use efficiency[14]. Precise regulation within these two windows achieves optimal comprehensive benefits.

3 Regionalized Water and Nitrogen Management Models and Practices

Watermelon water-nitrogen schemes must be tailored to local conditions to form region-specific optimized management modes.

3.1 Mediterranean Climate Zone Model

The Mediterranean climate zone is characterized by drought in summer and complete reliance on irrigation. Deficit irrigation or partial root zone drying is commonly applied, with water supply guaranteed during critical periods and moderate deficits implemented during non-critical periods based on crop evapotranspiration[15]. Nitrogen management should focus on preventing leaching. It is recommended to explore the combination of PRD and zonal fertilization to achieve simultaneous water conservation and efficiency improvement[16].

3.2 Semi-arid Climate Zone Model

In semi-arid climate zones, water resources are extremely scarce, and all management should be oriented towards water conservation[17].Deficit irrigation based on evaporation is widely used[18]. Nitrogen management must strictly adhere to “water-based fertilizer application”, avoiding additional stress. It is necessary to develop dynamic nitrogen recommendation models under non-adequate irrigation and vigorously promote mulching technology to retain soil moisture and save water.

3.3 Sub-humid Climate Zone Model

In sub-humid climate zones, irrigation mainly serves as a supplement and regulation to precipitation. Management needs to be highly flexible to cope with uneven rainfall[19]. Studies show that moderate deficit irrigation can still improve water use efficiency. Develop a dynamic decision-making system based on weather forecasts and soil moisture monitoring to achieve intelligent complementarity between natural precipitation and artificial irrigation[20].

3.4 Facility Cultivation and Sand Field System Optimization Model

In the northwest sand field system, supplementary irrigation is needed, with a focus on ensuring water and nitrogen supply during the vine extension and fruit expansion periods[21]. It is recommended to control water and nitrogen within the optimized range

through water and fertilizer integration (such as soil moisture at 65%-75% of field capacity, and nitrogen application rate of about 200 kg·hm^{-2})[22].

3.5 Cross-Comparison and Applicability Boundary Analysis of Regional Water-Nitrogen Management Models

Table 1 summarizes soil moisture thresholds, nitrogen dosage, suitable soil, supporting facilities and limiting factors of each mode. Direct cross-regional copy of these schemes leads to poor yield and resource waste. All models should be adjusted dynamically within applicable thresholds according to local soil texture, irrigation quota and rainfall distribution.

Table 1. Applicability thresholds, matching conditions and limiting factors of regional watermelon water-nitrogen coordinated management models

Model Classification	Core Soil Moisture Threshold	Optimal Nitrogen Rate	Suitable Soil	Supporting Conditions	Main Limitations
Mediterranean Model	Key stages:85%–95% FC; others:50%–65% FC	160–220 kg·hm^{-2}, 4–6 split topdressing	Light well-drained sandy loam	Automatic drip irrigation, medium open field	Poor drainage causes nitrogen leaching; unfit for rainy seasons
Semi-arid Model	Vine stage:75%–85% FC; fruit expansion:80%–90% FC	140–200 kg·hm^{-2}, frequent light fertilization	Film-mulched loess/sandy loam	Small-medium fields, annual irrigation <300 mm	Large-scale planting lacks irrigation water
Sub-humid Model	Dynamic 60%–90% FC regulated by rain	150–210 kg·hm^{-2}, less base nitrogen	Well-drained loam/clay loam	Large fields with moisture & weather monitoring	No monitoring equipment causes regulation delay
Sand Field & Facility Model	Stable 65%–75% FC, frequent light drip	180–200 kg·hm^{-2}, no late nitrogen	Sandy soil/greenhouse substrate	Mulch drip irrigation, intensive small plots	Frequent irrigation raises cost; over-nitrogen induces salinization

4 Conclusion

The coordinated regulation of water and nitrogen is the core scientific and technological measure to solve the dual predicament of water scarcity and excessive nitrogen fertilizer application faced by the watermelon industry and drive its development towards high quality, high efficiency, and high sustainability. The water and nitrogen requirements of watermelon show distinct stage-specific patterns, with the vine extension period and fruit expansion period being two key strategic windows for implementing coordinated regulation. The integrated water and fertilizer management technology system based on subsurface drip irrigation, deficit irrigation, precise nitrogen fertilizer scheduling, and real-time monitoring feedback has been proven to be an effective way to achieve

water and fertilizer conservation, yield increase, quality improvement, and efficiency and emission reduction. For different climate zones such as the Mediterranean, semi-arid, and sub-humid regions, as well as specific systems such as facilities and sand fields, regionally optimized management models with distinct characteristics have been developed.

However, current research still has shortcomings in revealing the deep mechanisms of water and nitrogen interaction, quantifying environmental and ecological costs, and improving the intelligent precision and regional adaptability of technical models. The focus should be on developing intelligent water and nitrogen decision-making systems based on the Internet of Things, big data, and crop models, establishing a long-term evaluation system that takes into account economic and ecological benefits, and developing and promoting simplified and practical technologies. Ultimately, this will promote the transformation and upgrading of water and nitrogen management in watermelon from traditional experience-based models to digital, intelligent, and green smart precision models.

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Disclosure of Interests

The authors have no competing interests to declare that are relevant to the content of this article.

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