Review on the Synergistic Effects and Regulation Mechanisms of Water-Nitrogen Coupling in Watermelon Production

Zhengjun Zhang, Xietian Chen, Chenli Zhou and Hengjia Zhang*

College of Agriculture and Biology, Liaocheng University, Liaocheng, Shandong 252059, China
*zhanghengjia@lcu.edu.cn

Abstract. Water and nitrogen are pivotal ecological factors that govern watermelon growth, yield development, and quality enhancement. Their synergistic interaction directly impacts resource utilization efficiency and ecological benefits. Building on recent research findings, this study systematically examines how water-nitrogen coupling influences photosynthetic characteristics, growth patterns, yield quality, nutrient uptake, and greenhouse gas emissions in watermelons. It provides an in-depth analysis of the underlying mechanisms governing physiological metabolism, resource allocation, and environmental regulation. The paper also identifies current research limitations and future research directions, aiming to establish theoretical foundations and technical support for precision water-nitrogen management in high-quality watermelon production.

Keywords: Watermelon; Water and nitrogen coupling; Photosynthetic characteristics; Yield and quality; Regulation mechanism

1 Introduction

Watermelon (*Citrullus lanatus*), a globally cultivated gourd crop, exhibits remarkable sensitivity to water and nitrogen supply during its growth cycle. Water serves as the fundamental medium for photosynthesis, nutrient transport, and metabolic processes, while nitrogen is essential for synthesizing biological macromolecules like proteins and chlorophyll[1]. The synergistic interaction between these two elements (water-nitrogen coupling) accordingly directly determines watermelon's growth status, yield levels, and quality characteristics. Currently, major production areas in China (Hexi oasis irrigation zones and Northwest sandy fields) face widespread challenges in water and fertilizer management, resulting in inefficient resource utilization, increased environmental pollution risks, and inconsistent product quality[2]. For this reason, clarifying the impact of water-nitrogen coupling on watermelon growth, uncovering its underlying regulatory mechanisms, and establishing scientific management models hold significant theoretical and practical importance for promoting efficient, high-quality, and sustainable development in the watermelon industry. In recent decades, researchers have conducted extensive water-nitrogen coupling experiments across diverse cultivation models,

© The Author(s) 2026
L. L. Kuan et al. (eds.), *Proceedings of the 2026 3rd International Symposium on Agricultural Engineering and Biology (ISAEB 2026)*, Advances in Biological Sciences Research 56,
https://doi.org/10.2991/978-94-6239-847-4_20

ecological regions, and environmental conditions, as a result, abundant research data that lays the foundation for systematically summarizing advancements in this field.

2 Effect of Water and Nitrogen Coupling on Growth, Development, Yield and Quality of Watermelon

2.1 Response of Photosynthetic Characteristics

Photosynthetic characteristics serve as the core indicators reflecting crop material production capacity. Specifically, water-nitrogen coupling significantly influences watermelon photosynthetic efficiency through coordinated regulation of photosynthetic organ functions and metabolic processes. Wen[2] demonstrated in the Hexi oasis irrigation zone under plastic film drip irrigation that the W2N2 treatment maintained higher net photosynthetic rate (Pn), transpiration rate (Tr), and stomatal conductance (Gs), meanwhile, all three parameters exhibiting bimodal daily variations. Wang[3]further confirmed that optimal water-nitrogen combinations significantly enhanced chlorophyll content, reduced feedback inhibition from photosynthetic product accumulation. Wang et al.[4]found that the W2N2 treatment increased watermelon Pn by 32.1%, significantly higher than conventional CO_2 levels during the same period, this phenomenon indicates that the interaction between environmental factors and water-nitrogen coupling can further optimize photosynthetic efficiency. Notably, the threshold of water-nitrogen coupling for optimal photosynthetic performance varies with soil types and irrigation methods; sandy field watermelons require milder water deficit to maintain high photosynthetic efficiency compared with oasis irrigated field watermelons, while excessive nitrogen supply easily leads to stomatal limitation and reduced photosynthetic capacity.

2.2 Regulation of Growth and Development

From the perspective of individual plant construction, water-nitrogen coupling demonstrates significant synergistic regulation on watermelon morphogenesis and material accumulation, with distinct variations across different growth stages. Cai[5] et al. revealed in their Hexi region study that under the 65% field capacity (FC) soil moisture coupled with medium nitrogen, the main vine length and stem diameter increased by 29.81% and 9.96% respectively compared to the control, in addition, the aboveground dry matter accumulation surged by 66.71%. The dry matter allocation showed a stronger preference for fruit development, with fruits constituting 84.57% of dry matter during maturity. Gao[6] et al. found that severe water deficit combined with low nitrogen inhibited growth, reducing main vine length and leaf area index by over 23% compared to optimal combinations, with dry matter allocation favoring vegetative organs and fruit development being suppressed. Comparative analysis of existing studies shows that sandy field watermelon is more sensitive to water-nitrogen imbalance than oasis irrigated watermelon: compacted sandy soil has poor water and fertilizer retention capacity, so slight water and nitrogen stress can significantly reduce plant growth rate and photosynthetic potential, while loam soil can buffer short-term water and nitrogen

deficit to maintain stable plant growth. Ma[7] et al. demonstrated in compacted sand field trials that this interaction significantly influenced photosynthetic potential and growth rate.

2.3 The Formation of Yield and Quality

When it comes to yield formation, The impact of water-nitrogen coupling on watermelon yield follows the law of diminishing returns, with a clear optimal combination range. Wang[3]found that the optimal water-nitrogen combination for drip irrigation under plastic film in the Hexi oasis irrigation area is nitrogen application at 240 kg/hm² and soil moisture at 60%~70% FC. Under this treatment, the weight of a single watermelon reached 4.48 kg, and the total yield reached 92.245t/hm², increasing by 38.27% and 14.85% compared to the control, respectively. Gao[4] et al. also confirmed that medium nitrogen coupled with mild to moderate water deficit is key to achieving high watermelon yields, while excessive or insufficient water-nitrogen supply leads to reduced yields. Wen[2] discovered that under W2N2 treatment, the central sugar content in watermelons reached 11.8%, which increased by 12.5% under high nitrogen and high water treatment, with coordinated performance in appearance quality indicators such as fruit firmness and skin thickness.

2.4 The Impact of Environmental Effects

Water-nitrogen coupling regulates watermelon growth and farmland ecology, where greenhouse gas fluxes and soil properties are core research focuses[8]. Research on drip-irrigated watermelon in the Hexi Irrigation District verified notable water-nitrogen effects on soil NH_3 and N_2O emissions: nitrogen application exceeding 240 kg/hm² raised NH_3 volatilization by 35.2% relative to medium nitrogen dosage, while moderate water deficit (60% field capacity) cut N_2O emissions by 28.7% versus full irrigation[9]; matched water and nitrogen regimes thereby alleviate agricultural non-point source pollution. For soil conditions, residual soil nitrate and ammonium nitrogen after watermelon harvest ranged from 62.47–79.15 and 41.65–51.24 mg/kg respectively. The 20 cm soil layer had the best temperature stability, creating an optimal soil environment for watermelon root growth[10]. Existing environmental effect studies are mainly concentrated on short-term single-season field tests, while long-term cumulative effects of continuous water-nitrogen coupling on soil fertility evolution and soil microbial community structure remain unclear.In terms of nitrogen metabolism, appropriate water-nitrogen combinations significantly enhance the activity of key enzymes such as nitrate reductase and glutamine synthetase[11]. Additionally, water-nitrogen coupling regulates stomatal movement to balance photosynthesis and transpiration, improving water use efficiency while maintaining photosynthetic product synthesis, achieving the synergistic effect [12]

2.5 Mechanisms of Physiological and Metabolic Regulation

Water-nitrogen coupling achieves precise regulation of watermelon growth by

modulating the activity of key enzymes and metabolic processes. In terms of nitrogen metabolism, appropriate water-nitrogen combinations significantly enhance the activity of key enzymes such as nitrate reductase and glutamine synthetase. NR, as the rate-limiting enzyme for nitrogen assimilation, shows a 52.3% increase in activity under medium nitrogen (200 kg/hm²) and 65% FC water conditions compared to the control, promoting nitrogen conversion and utilization[13]. In antioxidant metabolism, water-nitrogen coupling enhances the activity of antioxidant enzymes like catalase (CAT) and peroxidase (POD), alleviating oxidative damage caused by water or nitrogen stress [14]. Wen [2] found that under W2N2treatment, the CAT activity in watermelon leaves reached 23.6U/ (g·min), a 38.6% increase compared to extreme water-nitrogen treatments, effectively scavenging reactive oxygen species and protecting photosynthetic organ function. Additionally, water-nitrogen coupling can regulate the content of osmotic regulators such as soluble proteins and proline, enhancing watermelon's drought and stress resistance[15]. Wei[16] studied under CO_2-enriched conditions and found that water-nitrogen coupling further increases the content of osmotic regulators in plants, enhancing metabolic stability and laying the physiological foundation for high light efficiency and high yield.The regulation of water-nitrogen coupling on watermelon growth exhibits a distinct threshold range, beyond which the synergistic effect becomes significantly weakened. Shang multiple studies [17], the optimal water-nitrogen threshold for watermelon growth is determined by nitrogen application of 216-264 kg/hm² and soil moisture maintained at 50%-74% FC. Within this range, the water-nitrogen synergy reaches its peak, resulting in optimal growth, yield, and quality. When nitrogen application exceeds 264 kg/hm² or soil moisture falls below 50% FC, nitrogen surplus or water stress becomes limiting factors, leading to reduced yield and deteriorated quality[4]. Ma et al.[9] further confirmed this threshold effect through establishing a water-nitrogen coupling model for sand-pressed field watermelons. The model-derived optimal irrigation volume of 808-876 m³/hm² and nitrogen application of 231-279 kg/hm² showed high consistency with field trial results. This threshold effect fundamentally reflects the alignment between water-nitrogen supply and watermelon demand.

3 Research Lacks and Future Prospects

Despite significant achievements in watermelon water-nitrogen coupling research, there are still shortcomings: first, research regional and scenario limitations are prominent. the research is geographically concentrated in arid and semi-arid regions such as the Hexi Oasis Irrigation Area, while studies on water-nitrogen coupling effects in scenarios like southern humid areas and protected cultivation are insufficient, resulting in a lack of region-specific water-nitrogen management parameters; second, the research dimension is single, focusing mostly on phenotypes such as growth and yield, with unclear molecular mechanisms; third, the research on the interaction between environmental factors and water-nitrogen is inadequate, and long-term experiments are lacking to reveal the sustained effects of water-nitrogen coupling; fourth, long-term ecological effect research and intelligent technology integration are lacking. the transformation of

research achievements is weak, as field experiments have a low degree of integration with modern technologies such as integrated water and fertilizer management.

4 Conclusion

Water-nitrogen coupling profoundly shapes watermelon growth, yield, and quality, and the accumulated evidence consistently points to a moderate rather than maximal input strategy. Under film mulch drip irrigation, the W2N2 regime sustains high photosynthetic efficiency, channels dry matter toward fruit, and raises both yield and quality while curbing NH_3 and N_2O emissions. These benefits, however, are context-dependent: sandy-field systems are more sensitive to imbalance than oasis loam soils, and optimal thresholds shift with soil texture and irrigation method. Current knowledge remains largely limited to short-term arid-region trials; molecular mechanisms, long-term soil and microbial dynamics, and performance in humid or protected environments still need investigation. Addressing these gaps will be key to moving from empirical recommendations to region-adapted, digitally supported decision-making for sustainable watermelon production. Future research needs targeted breakthroughs in the following aspects: first, carry out joint experiments in multiple ecological zones and establish water-nitrogen systems for different scenarios to support precise management; second, use technologies such as transcriptomics to clarify the molecular pathways of water-nitrogen coupling regulating watermelon growth and the role of key genes; third, focus on environmental factors such as extreme climates, and evaluate the ecological effects of water-nitrogen coupling through long-term experiments; fourth, integrate modern technologies such as drip irrigation and intelligent irrigation to develop a precise water-nitrogen regulation system for watermelons and optimize water and fertilizer supply. fifth, focus on efficient resource utilization and environmental protection, and construct a "high-yield, high-quality, low-consumption and emission-reduction" water-nitrogen coupling model to promote the green development of agriculture.

Acknowledgements

This work was mutually supported by the Science Foundation of Shandong Province (No. ZR2024MC190), the Scientific Research Foundation for High-level Talented Scholars of Liaocheng University (No.318042401), and the National Natural Science Foundation of China (No. 52269008, 51669001).

References

1. L. Xue, Z.M. Ma, A.Y. Zhao, The effect of nitrogen-water coupling on ammonia and nitrous oxide emissions from drip-irrigated watermelons in Hexi irrigation district. Journal of Drought Region Geography, 48(05), 801-811 (2025)

2. D. Wen, Response of photosynthetic characteristics, yield and quality of oasis under mulch drip irrigation watermelon to water-nitrogen coupling [D]. Gansu Agricultural University, (2024). DOI:10.27025/d.cnki.ggsnu.2024.000176.
3. Y.Y. Wang, Study on the Water-Nitrogen Coupling Effect of Watermelon under Membrane Drip Irrigation in Hexi Oasis Irrigation Area [D]. Gansu Agricultural University, (2023) .DOI:10.27025/d.cnki.ggsnu.2023.000213.
4. C.G. Wang, T.T. Hong, Z. Zhang, Effects of nitrogen-enriched water coupled with CO_2 concentration on nutrient uptake and yield of watermelon [J]. Journal of Northwest Agronomy, 31(09),1121-1130 (2022)
5. Z.W. Cai, S.Y. Zhao, B.H. Liu, The effect of nitrogen-water coupling on watermelon growth during the ripening period in Hexi region [J]. Cold and Drought Agricultural Science, 3(04),364-370 (2024)
6. Y.X. Gao, H.G. Li, The effect of water-nitrogen coupling on watermelon growth and yield [J]. China Agricultural Abstracts-Agricultural Engineering, 36, (01),41-45 (2024). DOI:10.19518/j.cnki.cn11-2531/s.2024.0009.
7. B. Ma, J.C. Tian, H. Shen, Water and nitrogen coupling model and validation for photosynthetic dry matter and yield of watermelon in sandy soil [J]. Journal of Agricultural Engineering, 32(20),129-136 (2016)
8. Y. Liu, Nitrogen coupling effects of drip irrigation in alternating root zones under organic fertilizer nitrogen substitution and its impact on watermelon growth. Huaibei Normal University, (2019)
9. B. Ma, J.C. Tian, H. Shen, Water and nitrogen coupling model and validation for photosynthetic dry matter and yield of watermelon in sandy soil [J]. Journal of Agricultural Engineering, 32(20),129-136 (2016)
10. B.D. Zhang, The effect of different fertilizers on the quality and yield of watermelon under drip irrigation [J]. China Melons and Vegetables, 24(06),17-19 (2011). DOI:10.16861/j.cnki.zggc.2011.06.005.
11. X.C. Wang, The effect of alternating root zone drip irrigation and fertilization on the growth of tomato and watermelon and the migration and utilization of fertilizer nitrogen [D]. Huaibei Normal University, (2018)
12. J. Zhou, The effect of different biofertilizers on the yield and quality of watermelon [J]. China Agricultural Technology Extension, 33(12),45-46 (2017)
13. C.H. Wei, W.B. Dong, Y.Q. He,Effects of novel organic fertilizers on growth, yield and quality of watermelon in continuous cropping [J]. Northern Horticulture, (08),20-24 (2017)
14. X.L. Shang, J.P. Zhang, X.H. Li, The effect of different types of fertilizer on the growth of watermelon leaves, the speed of melon swelling and yield [J]. Jiangsu Agricultural Science, 42(07),158-159 (2014)
15. B.D. Zhang, The effect of different fertilizers on the quality and yield of watermelon under drip irrigation [J]. China Melons and Vegetables, 24(06),17-19 (2011). DOI:10.16861/j.cnki.zggc.2011.06.005.
16. L. Wei, H.W. Zhang, J. Zhang, Effects of different nitrogen, phosphorus and potassium fertilizer application rates on watermelon yield and quality [J]. China Agricultural Technology Extension, 26(12),33-34 (2010)
17. Q.M. Shang, Z.G. Zhang,The effect of different concentrations of nitrogen and potassium fertilizers on the seedling of watermelon in the hole tray based on earthworm manure [J]. China Melon and Vegetable, (05),9-11 (2005). DOI:10.16861/j.cnki.zggc.2005.05.004.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

