GEORGE BROWN PRESS
JOURNALS, BOOKS & PROCEEDINGS

GBP Proceedings Series

Article

2025 International Conference on Agricultural Sciences, Economics, Biomedical and Environmental Sciences (SEMBE 2025)

Research Progress on the Effects of Water and Nitrogen Regulation on Potato Yield, Quality, Soil Environment, and Water and Nitrogen Use Efficiency

Zhiyuan Liu [1,2,3], Hengjia Zhang [1,*] and Haiyan Li [3]

[1] College of Agriculture and Biology, Liaocheng University, Liaocheng, Shandong, 252059, China
[2] Yimin Irrigation Experimental Station, Hongshui River Management Office, Zhangye, Gansu, 734500, China
[3] College of Water Conservancy and Hydropower Engineering, Gansu Agricultural University, Lanzhou, Gansu, 730070, China
* Correspondence: Hengjia Zhang, College of Agriculture and Biology, Liaocheng University, Liaocheng, Shandong, 252059, China

Abstract: In the context of intensifying global water scarcity, enhancing the efficiency of water and fertilizer use in potato cultivation is of great importance. This study explores how various irrigation and nitrogen management strategies affect potato yield and quality, as well as their impact on water and nitrogen use efficiency and soil conditions. The results demonstrate that appropriate coordination of water and nitrogen inputs can significantly improve potato photosynthetic activity, promote tuber development, and enhance both yield and quality. At the same time, such strategies can help mitigate negative environmental impacts and support the goal of sustainable agricultural development. However, an oversupply of water and nitrogen may lead to imbalanced soil nutrients, alter soil physical and chemical properties, increase nitrate levels, and raise the risk of groundwater contamination. In regions with arid climates and fragile ecological conditions, potato yields tend to fluctuate greatly, with practices such as over-irrigation and excessive fertilization still commonly observed. Therefore, optimizing water use, reducing fertilizer input, and formulating sustainable management strategies are crucial for maintaining stable potato yields and promoting efficient use of irrigation technologies in agricultural systems.

Keywords: potato; water and nitrogen management; yield; quality

Received: 26 March 2025
Revised: 02 April 2025
Accepted: 20 April 2025
Published: 14 May 2025

1. Introduction

Water plays a vital role in supporting both agricultural productivity and the broader development of human society. As population growth accelerates and demands for water in agriculture, industry, and domestic life increase, issues such as pollution and waste have intensified the global water crisis, making water scarcity an increasingly critical constraint on social and economic progress [1]. Among the world's major food crops, the potato (Solanum tuberosum L.) ranks fourth in production after maize, wheat, and rice. In China, potatoes serve not only as a common food item but are also valued for their high starch content, placing the country at the forefront of global potato output, ahead of India, Ukraine, and the United States [2]. Potato tubers are rich in essential nutrients including protein, starch, fat, reducing sugars, and dietary fiber, as well as various minerals and vitamins [3]. Compared to staple crops like wheat, potatoes have higher vitamin C content and contain more protein and reducing sugars than many vegetables [4]. Their excellent

nutritional profile, storage potential, and adaptability in cooking make them a staple ingredient in diverse cuisines.

While genetic traits set the foundation for crop yield and quality, environmental factors, particularly nitrogen availability and water supply, are key determinants in shaping plant growth, productivity, and nutrient composition [5]. Globally, irrigated agriculture accounts for approximately 70% of total freshwater consumption, and in arid regions, Figure 1 can surpass 90% [6]. However, irrigation systems are often criticized for their inefficiency, especially in water-limited environments [7]. As such, refining irrigation and nitrogen management practices in potato farming is essential for boosting water use efficiency and addressing water shortages in dry and semi-dry regions [8]. Nitrogen plays a pivotal role in potato development, and its deficiency hinders root formation, chlorophyll synthesis, and photosynthetic efficiency, ultimately reducing yield [9]. Conversely, applying nitrogen in excess not only raises production costs but also contributes to environmental problems such as soil degradation, nitrate leaching, and groundwater pollution [10,11]. In many potato-producing areas, the excessive application of water and fertilizers is common, often exceeding what the plants can absorb. This leads to a drop in the efficiency of yield gains per unit of input, highlighting a diminishing return on investment in water and fertilizer use [12-14]. Therefore, optimizing irrigation methods to reduce inefficiencies and improve resource utilization is a key solution to managing water scarcity and fertilizer overuse in arid agricultural zones [7].

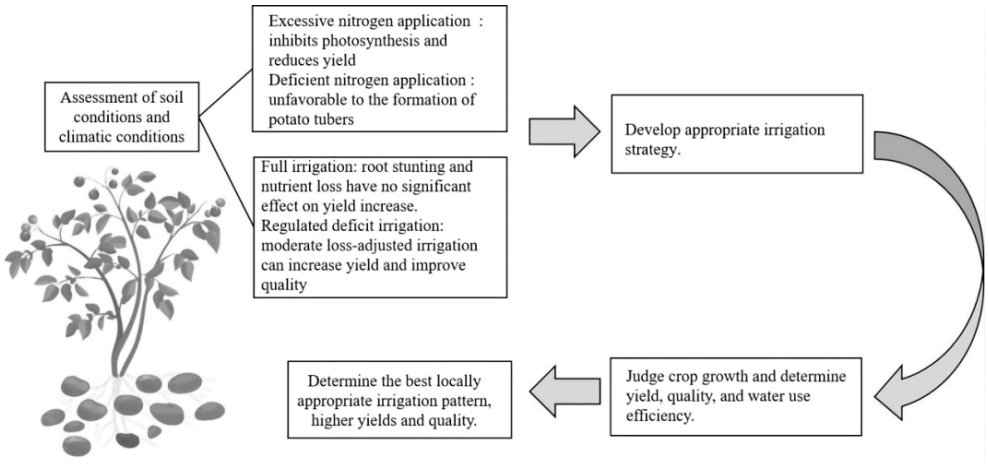

Figure 1. Formulating the Process of Water and Nitrogen Irrigation System for Potatoes.

2. The Effects of Water and Nitrogen Regulation on Potato Yield, Quality, Soil Environment and Partial Factor Productivity of Fertilizer

2.1. Yield and Quality

Water and nitrogen are essential factors that play a crucial role in determining potato yield and tuber quality [5]. Employing a well-balanced and scientifically informed strategy for water and nitrogen regulation can significantly improve photosynthetic efficiency, enhance stomatal conductance, and promote the accumulation of assimilates, ultimately leading to increased yields. In water-deficient environments, an appropriate level of nitrogen application can mitigate drought-induced reductions in photosynthetic activity, helping maintain higher levels of carbon assimilation. However, when nitrogen is supplied in excessive quantities, it may suppress photosynthesis, thereby resulting in yield losses [15,16]. Nitrogen availability also has a pronounced influence on tuber initiation and enlargement. A suitable nitrogen input promotes stolon elongation and increases tuber number, whereas both under-application and over-application hinder tuber development and reduce productivity [17]. Adequate nitrogen levels can also enhance the starch and protein concentrations in tubers, thereby improving their nutritional and processing

quality. In contrast, excessive nitrogen may negatively impact quality parameters [18-22]. Both the method of irrigation and the manner in which nitrogen is applied have significant effects on potato growth and final output [18]. Advanced irrigation technologies, such as subsurface drip irrigation, enable the precise delivery of water and nutrients to the crop root zone. These systems not only minimize evaporation losses but also help preserve soil structure, support healthy root expansion, and enhance overall water use efficiency. As a result, they contribute to improvements in both yield and quality [22]. On the other hand, over-irrigation and high nitrogen input can result in nutrient leaching and water loss, which may negatively affect plant growth and tuber yield [19]. In potato cultivation, the coordinated management of water and nitrogen is essential for optimizing agronomic outcomes. Proper integration enhances photosynthesis and tuber formation, boosts yield and quality, minimizes environmental impact, and supports the goals of sustainable agricultural practices [18].

2.2. Soil Environment

Effective irrigation and nitrogen management are essential components in potato cultivation, particularly due to their considerable impact on the soil environment. Proper coordination of these inputs not only improves tuber yield and quality but also contributes positively to maintaining soil health [18]. When nitrogen fertilizers are applied appropriately alongside suitable irrigation regimes, they can boost soil organic matter levels, enhance soil structure, and improve the soil's capacity to retain water and nutrients [15]. Additionally, this combination promotes microbial activity in the soil, increases biodiversity, enhances enzyme function, and ultimately strengthens soil fertility and productivity [16].

Water and nitrogen input have a significant bearing on the physical and chemical characteristics of agricultural soils. Inadequate supply can degrade soil structure and reduce nutrient availability, leading to reduced crop yields. Conversely, over-application can cause nutrient imbalances, which may negatively affect the soil's physical composition and chemical status. For instance, excessive nitrogen use may lower soil pH, disrupt microbial populations, inhibit root development, and reduce nutrient uptake efficiency [17]. Moreover, high levels of water and nitrogen inputs may cause nitrate accumulation in the soil, elevating the risk of leaching and groundwater pollution [18]. Mismanagement can also increase soil erosion and nutrient runoff, undermining long-term soil productivity and sustainability [19]. Employing conservation-oriented agricultural practices, including the use of cover crops and reduced tillage, helps prevent soil degradation, limits erosion, and supports the maintenance of healthy soil ecosystems [21].

2.3. Water and Nitrogen Use Efficiency

The efficiency of water and nitrogen use plays a vital role in supporting crop development, and thus, optimized management of these inputs is key to narrowing the gap between actual and potential yields. Partial factor productivity (PFP) of fertilizer, defined as the tuber fresh weight produced per unit of nitrogen, phosphorus, or potassium applied, serves as a straightforward and important metric to assess fertilizer use efficiency in potato production [23]. Among the various factors influencing fertilizer utilization in potatoes, the application rate of fertilizer exerts the strongest impact, followed by irrigation volume, while varietal differences have a relatively minor effect [24]. Through precise regulation of water and nitrogen input, the efficiency of nitrogen absorption and utilization by potatoes can be notably enhanced, thereby increasing the PFP of nitrogen fertilizer [15]. A balanced combination of nitrogen supply and irrigation improves plant growth, boosts biomass accumulation, and ultimately leads to higher nitrogen use efficiency [16]. Furthermore, proper nitrogen application can minimize nitrogen loss and volatilization from the soil, thereby reducing environmental risks and improving the cost-effectiveness

of fertilizer use. In irrigation management, aligning water application with the specific requirements of crops can significantly raise both water and fertilizer use efficiency [25].

3. Problems and Prospects

Well-planned water and nitrogen management approaches can significantly boost potato yields, improve the quality of agricultural soils, conserve vital water and nitrogen inputs, and promote environmentally sustainable agricultural practices. This is particularly beneficial in water-deficient arid regions, where such strategies not only mitigate irrigation water shortages but also contribute to the restoration of the soil ecosystem, thereby providing a solid technical foundation for sustainable agricultural progress. Although research on water and nitrogen dynamics in potato cultivation has achieved considerable progress, a deeper and more precise understanding of the crop's specific water and nutrient needs across various developmental stages remains necessary. Furthermore, conventional studies that focus solely on dual-factor interactions often fail to capture the complexities of real-world agricultural systems. Future investigations should aim to elucidate the crop's nuanced responses to water and nutrient availability at different phenological phases, tailoring precise management strategies to local agroecological conditions. In addition, multi-factorial studies using systematic and scientifically robust methods are essential for understanding complex interactions, optimizing input use, and advancing efficient, eco-friendly, and sustainable crop production systems.

4. Conclusion

In the context of increasing global water scarcity, optimizing water and nitrogen management strategies in potato cultivation plays a crucial role in enhancing crop productivity, improving resource use efficiency, and promoting sustainable agricultural development. This review highlights that appropriate water and nitrogen inputs significantly improve photosynthetic activity, tuber formation, and crop quality, while also positively influencing soil structure, fertility, and ecological function. Conversely, excessive water and nitrogen inputs may lead to soil degradation, nutrient imbalances, and heightened environmental risks such as nitrate leaching and groundwater pollution. Therefore, the development of region-specific, growth stage-targeted irrigation and fertilization strategies is essential to ensure efficient resource utilization and reduce ecological impacts. Future research should move beyond traditional two-factor analyses to incorporate more complex interactions among environmental and agronomic variables, aiming to construct integrated, precise, and adaptive water-fertilizer management systems. These efforts will provide a solid foundation for green and sustainable agricultural practices in arid and semi-arid regions.

Funding: This work was mutually supported by the National Natural Science Foundation of China (No. 52269008, 51669001), the Industrial Support Plan Project of Gansu Provincial Department of Education (No. 2022CYZC-51), the Key Research and Planning Projects of Gansu Province (No. 18YF1NA073), the Scientific Research Foundation for High-level Talented Scholars (No. 318042401) of Liaocheng Universtiy, and the Open Project of Liaocheng Universtiy Landscape Architecture Discipline (No. 31946221236).

References

1. X. Han, Y. Zhao, X. Gao, S. Jiang, L. Lin, and T. An, "Virtual water output intensifies the water scarcity in Northwest China: Current situation, problem analysis and countermeasures," *Sci. Total Environ.*, vol. 765, p. 144276, 2021, doi: 10.1016/j.scitotenv.2020.144276.
2. L. D. Stearns, T. A. Petry, and M. A. Krause, "Potential food and nonfood utilization of potatoes and related byproducts in North Dakota," *Agric. Econ. Rep.*, no. 322, pp. 2–6, 1994, doi: 10.22004/ag.econ.23364.
3. A. Drewnowski, "The Nutrient Rich Foods Index helps to identify healthy, affordable foods," *Am. J. Clin. Nutr.*, vol. 91, no. 4, pp. 1095S–1101S, 2010, doi: 10.3945/ajcn.2010.28450D.

4. C. R. McGill, A. C. Kurilich, and J. Davignon, "The role of potatoes and potato components in cardiometabolic health: A review," *Ann. Med.*, vol. 45, no. 7, pp. 467–473, 2013, doi: 10.3109/07853890.2013.813633.
5. L. Lassaletta, G. Billen, B. Grizzetti, J. Anglade, and J. Garnier, "50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland," *Environ. Res. Lett.*, vol. 9, no. 10, p. 105011, 2014, doi: 10.1088/1748-9326/9/10/105011.
6. Q. Hu, Y. Yang, S. Han, and J. Wang, "Degradation of agricultural drainage water quantity and quality due to farmland expansion and water-saving operations in arid basins," *Agric. Water Manag.*, vol. 213, pp. 185–192, 2019, doi: 10.1016/j.agwat.2018.10.019.
7. C. Perry, P. Steduto, R. G. Allen, and C. M. Burt, "Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities," *Agric. Water Manag.*, vol. 96, no. 11, pp. 1517–1524, 2009, doi: 10.1016/j.agwat.2009.05.005.
8. J. Ju, D. Li, Y. Cui, and D. Sun, "Optimizing the water and nitrogen management scheme to enhance potato yield and water–nitrogen use efficiency," *Agronomy*, vol. 14, no. 8, p. 1651, 2024, doi: 10.3390/agronomy14081651.
9. K. Dang, C. Ran, H. Tian, D. Gao, J. Mu, Z. Zhang, Y. Geng, Q. Zhang, X. Shao, and L. Guo, "Combined effects of straw return with nitrogen fertilizer on leaf ion balance, photosynthetic capacity, and rice yield in saline-sodic paddy fields," *Agronomy*, vol. 13, no. 9, p. 2274, 2023, doi: 10.3390/agronomy13092274.
10. W. Shen, Y. Ni, N. Gao, B. Bian, S. Zheng, X. Lin, and H. Chu, "Bacterial community composition is shaped by soil secondary salinization and acidification brought on by high nitrogen fertilization rates," *Appl. Soil Ecol.*, vol. 108, pp. 76–83, 2016, doi: 10.1016/j.apsoil.2016.08.005.
11. M. Hu, H. Xue, A. J. Wade, N. Gao, Z. Qiu, Y. Long, and W. Shen, "Biofertilizer supplements allow nitrogen fertilizer reduction, maintain yields, and reduce nitrogen losses to air and water in China paddy fields," *Agric. Ecosyst. Environ.*, vol. 362, p. 108850, 2024, doi: 10.1016/j.agee.2023.108850.
12. Z. Ju, D. Li, Y. Cui, and D. Sun, "Optimizing the water and nitrogen management scheme to enhance potato yield and water–nitrogen use efficiency," *Agronomy*, vol. 14, no. 8, p. 1651, 2024, doi: 10.3390/agronomy14081651.
13. X. Wang, B. Yang, L. Jiang, S. Zhao, M. Liu, X. Xu, and W. Zhou, "Organic substitution regime with optimized irrigation improves potato water and nitrogen use efficiency by regulating soil chemical properties rather than microflora structure," *Field Crops Res.*, vol. 316, p. 109512, 2024, doi: 10.1016/j.fcr.2024.109512.
14. B. Shrestha, M. Darapuneni, B. L. Stringam, K. Lombard, and K. Djaman, "Irrigation water and nitrogen fertilizer management in potato (Solanum tuberosum L.): A review," *Agronomy*, vol. 13, no. 10, p. 2566, 2023, doi: 10.3390/agronomy13102566.
15. T. M. Darwish, T. W. Atallah, S. Hajhasan, and A. Haidar, "Nitrogen and water use efficiency of fertigated processing potato," *Agric. Water Manag.*, vol. 85, no. 1–2, pp. 95–104, 2006, doi: 10.1016/j.agwat.2006.03.012.
16. J. Ju, D. Li, Y. Cui, and D. Sun, "Optimizing the water and nitrogen management scheme to enhance potato yield and water–nitrogen use efficiency," *Agronomy*, vol. 14, no. 8, p. 1651, 2024, doi: 10.3390/agronomy14081651.
17. L. Zhao, L. Zhang, N. Cui, C. Liang, and Y. Feng, "The evaluation of regional water-saving irrigation development level in humid regions of Southern China," *Water*, vol. 11, no. 1, p. 172, 2019, doi: 10.3390/w11010172.
18. W. Yan, J. Qin, Y. Jian, J. Liu, C. Bian, L. Jin, and G. Li, "Analysis of potato physiological and molecular adaptation in response to different water and nitrogen combined regimes," *Plants*, vol. 12, no. 8, p. 1671, 2023, doi: 10.3390/plants12081671.
19. I. R. Fandika, P. D. Kemp, J. P. Millner, D. Horne, and N. Roskruge, "Irrigation and nitrogen effects on tuber yield and water use efficiency of heritage and modern potato cultivars," *Agric. Water Manag.*, vol. 170, pp. 148–157, 2016, doi: 10.1016/j.agwat.2015.10.027.
20. L. Wu, L. Li, Z. Ma, et al., "Improving potato yield, water productivity and nitrogen use efficiency by managing irrigation based on potato root distribution," *Int. J. Plant Prod.*, vol. 16, pp. 547–555, 2022, doi: 10.1007/s42106-022-00205-4.
21. M. A. Badr, W. A. El-Tohamy, and A. M. Zaghloul, "Yield and water use efficiency of potato grown under different irrigation and nitrogen levels in an arid region," *Agric. Water Manag.*, vol. 110, pp. 9–15, 2012, doi: 10.1016/j.agwat.2012.03.008.
22. L. N. dos Santos, E. E. Matsura, I. Z. Goncalves, E. A. Barbosa, A. A. Nazário, N. F. Tuta, et al., "Water storage in the soil profile under subsurface drip irrigation: Evaluating two installation depths of emitters and two water qualities," *Agric. Water Manag.*, vol. 170, pp. 91–98, 2016, doi: 10.1016/j.agwat.2015.09.025.
23. G. Zhao, X. Luo, Z. Wang, G. Sheng, W. Liu, and Y. Wang, "Effects of subsurface drip fertigation on potato growth, yield, and soil moisture dynamics," *Front. Sustain. Food Syst.*, vol. 8, p. 1485377, 2024, doi: 10.3389/fsufs.2024.1485377.
24. Y. Xing, T. Zhang, W. Jiang, P. Li, P. Shi, G. Xu, et al., "Effects of irrigation and fertilization on different potato varieties growth, yield and resources use efficiency in the Northwest China," *Agric. Water Manag.*, vol. 261, p. 107351, 2022, doi: 10.1016/j.agwat.2021.107351.
25. N. Vázquez, A. Pardo, M. L. Suso, and M. Quemada, "Drainage and nitrate leaching under processing tomato growth with drip irrigation and plastic mulching," *Agric. Ecosyst. Environ.*, vol. 112, no. 4, pp. 313–323, 2006, doi: 10.1016/j.agee.2005.07.009.