Furthermore, an appropriate NH_4^+:NO_3^- ratio (25:75) increased N, P, and K accumulation and capsaicin content by upregulating the GS/GOGAT pathway and genes related to capsaicin biosynthesis (Zhang et al., 2020).

6 Case Studies

6.1 High-yield chili production systems under optimized nitrogen input

Studies in both greenhouse and open-field chili production systems show that high yield does not depend on excessive fertilization, but on moderate and well-matched nitrogen application. In northwest China, sweet pepper grown under drip fertigation achieved the highest or near-highest yield when nitrogen was applied at 150~190 $kg{\cdot}N{\cdot}ha^{-1}$ combined with 75%~80% ETc. At the same time, fruit quality remained good, and water and nitrogen use efficiency were significantly improved compared with higher nitrogen and irrigation levels (Xiang et al., 2018).

In subtropical monsoon regions, when soil moisture is maintained at 65%~80% of field capacity and nitrogen is applied at 6 g/plant, green pepper yield can reach about 580~620 g/plant. A slightly lower nitrogen level (3 g/plant) results in the highest water use efficiency (WUE) and nitrogen use efficiency (NUE) (Dai et al., 2022).

By optimizing nitrogen rates and combining them with controlled-release fertilizers or nitrification inhibitors, integrated nitrogen management can further increase yield and nitrogen recovery in open-field chili production. At the same time, nitrogen input can be reduced by about 38% compared with conventional farmer practices (Ma et al., 2022).

6.2 Strategies to improve capsaicin content in specialty chili cultivars

For high-pungency dried chili, a medium urea rate (562.5 kg/ha) can produce the highest capsaicinoid content and yield. This is mainly due to increased placenta biomass, higher total phenol content, enhanced activity of PAL and capsaicin synthase, and upregulation of genes related to capsaicinoid biosynthesis, while the activity of degradation enzymes is reduced (Zhang et al., 2024).

In the cultivar “Longjiao No. 5”, adjusting the NH_4^+:NO_3^- ratio to 25:75 increases capsaicin and dihydrocapsaicin content in the placenta. It also enhances GS/GOGAT enzyme activity and related gene expression, and promotes fruit weight gain (Zhang et al., 2020).

Under low-phosphorus soil conditions, inoculation with mycorrhizal fungi improves the uptake of nitrogen, phosphorus, and potassium, and increases capsaicin content in chili fruits. This provides an effective way to achieve high pungency and high mineral nutrition with lower input (Pereira et al., 2024).

Comparisons between greenhouse and open-field cultivation show that the local piquín variety has significantly higher pungency under greenhouse conditions, indicating that controlled environments play an important role in enhancing capsaicin potential (Díaz-Sánchez et al., 2021).

6.3 Comparative analysis of conventional and precision nitrogen management

Precision water and nitrogen management performs better than traditional high-input and fixed nitrogen application systems in terms of resource use efficiency and environmental outcomes, while maintaining yield.

In greenhouse sweet pepper, long-term drip fertigation experiments show that moderate water and nitrogen combinations (such as 75%~90% ETc and 150~225 $kg{\cdot}N{\cdot}ha^{-1}$) significantly improve yield, water use efficiency (WUE), and nitrogen partial factor productivity compared with the conventional treatment of 105% ETc and 300 $kg{\cdot}N{\cdot}ha^{-1}$ (Wang et al., 2022).

A “prescription-adjustment” fertilization system based on crop evapotranspiration (ETc), nitrogen uptake models, and soil NO_3^- monitoring can reduce irrigation by 17% and nitrogen input by 35% without reducing yield. At the same time, nitrate leaching is reduced by about 58% compared with conventional management (Granados et al., 2013).