120 kg N ha^{-1}) is sufficient to maintain yield. This indicates that fertilizer input and nitrate leaching can be reduced while maintaining productivity (Tang et al., 2023) (Figure 1).

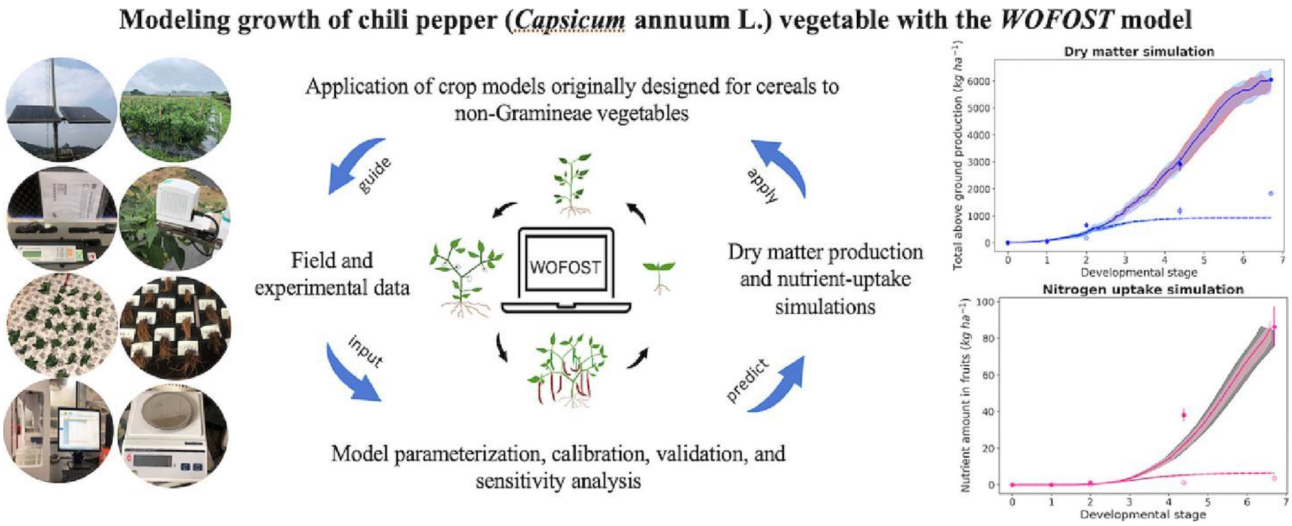

Figure 1 Growth simulation of chili pepper (*Capsicum annuum* L.) based on the WOFOST model and dynamic analysis of dry matter accumulation and nitrogen uptake (Adapted from Tang et al., 2023)

3.4 Yield response under different nitrogen application levels

The yield response of chili and sweet pepper to nitrogen typically follows a curvilinear pattern. As nitrogen application increases from zero to an optimal range, yield gradually increases; beyond this range, yield stabilizes or even declines. Field and pot experiments show that maximum or near-maximum yields can be achieved at 100~230 kg•N•ha^{-1} for chili, 150~225 kg•N•ha^{-1} for greenhouse sweet pepper, and about 120 kg•N•ha^{-1} for open-field processing chili. Further increases in nitrogen application do not result in additional yield gains (Han et al., 2021; Subedi et al., 2023). Excessive nitrogen application (>230~300 kg•N•ha^{-1} or high-concentration nutrient solutions) can reduce yield, shorten the fruiting period, or cause leaf toxicity, indicating that excess nitrogen is not only agronomically inefficient but also environmentally harmful. Results based on the WOFOST-Chili model and multi-objective optimization of water and nitrogen show that extremely high nitrogen levels cannot simultaneously achieve maximum yield, highest NUE, and optimal environmental benefits. Instead, moderate nitrogen application represents the best compromise for high-yield chili production (Vadillo et al., 2024).

4 Regulation of Capsaicin Biosynthesis by Nitrogen

4.1 Overview of capsaicin biosynthetic pathways

Capsaicin biosynthesis originates from the convergence of two metabolic pathways. One is the phenylpropanoid pathway, which provides the aromatic structural unit vanillylamine derived from phenylalanine. The other is the branched-chain fatty acid pathway, which supplies the C9 acyl group from valine or leucine.

In the phenylpropanoid pathway, phenylalanine is first deaminated to form cinnamic acid, which is further converted into ferulic acid derivatives, and then into vanillin and vanillylamine. At the same time, branched-chain amino acids are converted into fatty acid CoA thioesters. The final step is an acylation reaction, in which an acyltransferase links vanillylamine with fatty acyl-CoA to form capsaicin and related capsaicinoids. This process mainly occurs in the placenta tissue of the fruit.

4.2 Key enzymes and genes involved in capsaicin synthesis

During capsaicin biosynthesis, the key enzymes include phenylalanine ammonia-lyase (PAL), cinnamate 4-hydroxylase (C4H), 4-coumarate CoA ligase (4CL), hydroxycinnamoyl transferase (HCT), and caffeoyl-CoA O-methyltransferase (COMT) in the phenylpropanoid branch, as well as branched-chain amino acid aminotransferase (BCAT), ketoacyl synthase (KAS), and acyl-CoA ligase (ACL) in the fatty acid branch (Kabita et al., 2019).