

Future *Rubus chingii* models should therefore be dynamic rather than static, using growth and physiological indicators to update recommended water and nutrient inputs over time. In industrial strawberry, a closed-loop framework quantified stage-specific responses of growth and photosynthetic traits across seedling, flowering, and harvest stages, achieved a model error of only 0.60%, and identified optimal ranges of water, nitrogen, and potassium that balanced high yield, high efficiency, and low pollution (Li et al., 2026). Kiwifruit likewise showed that the critical periods and thresholds for improving physical quality differed from those for chemical quality, with stage II-III deficits favoring physical traits and stage III-IV deficits more strongly improving chemical quality (Zha et al., 2023). Because perennial berry crops also show strong stage dependence in dry matter accumulation and nutrient uptake, *Rubus chingii* regulation models should be built around phenology-specific demand curves and then calibrated for cultivar-specific yield and medicinal-quality targets (Bao et al., 2023).

7.2 Promotion of integrated water and fertilizer technologies and green efficient cultivation practices

A second major direction is the promotion of integrated water-fertilizer technologies, especially drip fertigation and deficit-based coupling strategies that raise production efficiency while lowering resource losses. Large meta-analyses show that water-fertilizer integration with drip irrigation increased yield by 12.5%, WUE by 34.5%, and NUE by 31.3%, and was particularly suitable for fruit trees in medium-textured soils. A second China-wide meta-analysis similarly found that drip fertigation increased yield by 12.0%, water productivity by 26.4%, and NUE by 34.3%, with fruit crops showing the largest NUE gains (Li et al., 2021). Reviews of drip fertigation further show that targeted delivery to the root zone reduces evaporation, runoff, and deep percolation while enabling stage-specific nutrition and better economic returns, which makes it a strong candidate technology for green and efficient *Rubus chingii* cultivation (Kaviyazhagan et al., 2025).

For *Rubus chingii*, integrated systems should emphasize spatiotemporal coupling of irrigation and fertilization, moderate deficit control, and reduced conventional fertilizer input rather than simply increasing supply intensity. In watermelon, intelligent drip fertigation tailored irrigation thresholds and fertilizer allocation to crop stage, reduced irrigation, N, P₂O₅, and K₂O inputs by 33%, 46%, 72%, and 57%, respectively, without compromising yield or fruit quality (Bao et al., 2023). In pear, suitable coupling treatments improved fruit shape, yield, primary fruit rate, and fruit quality, indicating that integrated management can simultaneously strengthen productivity and commodity traits (Li et al., 2024). Grape studies further show that optimal irrigation and fertilization intervals differ between wet and dry years, so future *Rubus chingii* systems should include climate-responsive adjustment rules rather than one fixed annual formula (Peng et al., 2024).

7.3 Application of smart agriculture technologies for precision water and fertilizer management and quality regulation

A third development direction is the application of smart agriculture technologies to support real-time diagnosis, automated control, and quality-oriented regulation. Precision water-fertilizer systems increasingly rely on sensors, remote sensing, GIS, IoT communication, and AI-assisted decision support to monitor soil moisture, fertility, and crop growth in real time (Xing and Wang, 2024). Reviews of smart sensing in specialty crops show that proximal sensors, UAV hyperspectral imaging, and data-fusion models can diagnose crop nutritional and water status non-destructively and replace uniform input strategies with crop-responsive management (Khoddamzadeh et al., 2026). More general IoT reviews reach the same conclusion: soil moisture, pH, temperature, and nutrient sensors provide real-time field data, while variable-rate application and predictive analytics allow inputs to be delivered only where and when needed (Mansoor et al., 2025).

For *Rubus chingii*, the practical value of smart agriculture will depend on translating these tools into closed-loop fertigation and quality-regulation platforms. In greenhouse tomato, an intelligent drip irrigation and fertigation system combined automatic control with flow-meter monitoring to ensure treatment-specific water delivery. In tomato and watermelon, FDR sensor-linked intelligent fertigation increased dry matter accumulation, nutrient uptake, root growth, yield, and quality while markedly reducing irrigation inputs and nutrient leakage. Broader smart-irrigation studies show that machine-learning systems can integrate sensor and weather data, achieve high