6.2 Water and fertilizer management techniques

Water and nutrient supply constitute the important material basis for high cucumber yield formation. Cucumber has a relatively shallow root system and is sensitive to root-zone moisture and aeration conditions. Appropriate irrigation promotes root growth, nutrient uptake, photosynthesis, and fruit enlargement, whereas prolonged water deficit causes leaf wilting, reduced photosynthetic rate, flower and fruit abortion, and restricted fruit development. Excessive irrigation, however, can lead to root-zone hypoxia, nutrient leaching, and increased disease incidence. Nitrogen, phosphorus, and potassium are the primary nutrients required for cucumber growth and yield formation. Nitrogen affects leaf growth and photosynthetic capacity, phosphorus promotes root development and floral bud differentiation, and potassium participates in assimilate transport, fruit enlargement, and fruit quality formation. Micronutrients such as calcium, magnesium, and boron are also closely associated with cell wall stability, enzyme activity regulation, and fruit quality. Studies on multi-nutrient optimization have demonstrated that irrigation and nitrogen fertilizer significantly promote cucumber yield, whereas magnesium can improve reducing sugar and amino acid contents and alleviate nitrogen deficiency effects through interactions with nitrogen, thereby reducing nitrate accumulation (Li et al., 2023).

Integrated water and fertilizer management technologies can simultaneously deliver water and nutrients to the root zone through drip irrigation systems, enabling precise supply, improving water and fertilizer use efficiency, and reducing resource waste and environmental risks. Under arid climatic conditions, experiments combining different irrigation levels and nitrogen fertilizer rates have shown that moderate deficit drip irrigation combined with appropriate nitrogen application can achieve relatively high yield while improving fruit size and SPAD values, indicating that moderate water-saving practices do not necessarily reduce cucumber yield (Bello et al., 2023). Greenhouse soil cultivation studies have also shown that moderate irrigation combined with suitable nitrogen fertilizer application can achieve near-maximum yield, high water-use efficiency, and desirable fruit quality, whereas excessive nitrogen application may slightly increase yield but reduce nitrogen-use efficiency. Therefore, the key to cucumber water and fertilizer management lies not in simply increasing inputs but in achieving coordinated water and nitrogen supply according to plant demand, cultivation substrate, and environmental conditions.

In substrate cultivation, solar greenhouse systems, and high-input protected cultivation systems, the interaction between water and fertilizer exerts even greater influence on cucumber yield and resource-use efficiency. Studies on substrate bag cultivation have shown that high irrigation levels combined with standard nutrient solution application can achieve the highest yield, whereas appropriately reducing fertilizer application improves nitrogen-use efficiency. Meanwhile, water-use efficiency tends to decrease with increasing irrigation levels. Studies conducted in solar greenhouses on the North China Plain further demonstrated that sufficient water and fertilizer supply can maximize leaf area index, dry matter accumulation, and yield, whereas moderate reductions in water and fertilizer input have relatively small effects on yield but significantly improve water- and nitrogen-use efficiency and may even enhance fruit quality under certain conditions (Wang et al., 2025). In addition, aerated irrigation can alleviate root-zone hypoxia under high water and fertilizer conditions, thereby increasing cucumber yield and nitrogen-use efficiency. These findings indicate that efficient water and fertilizer management in cucumber production should shift from the concept of “high input for high yield” toward the coordinated improvement of yield, quality, and resource-use efficiency.

6.3 Optimization of cultivation patterns

Optimization of cultivation patterns is an important strategy for improving canopy light-use efficiency, source-sink coordination, and yield per unit area in cucumber. It mainly includes planting density, row spacing configuration, pruning method, vine training method, pruning timing, and spatial arrangement. Traditional high-density planting systems can increase plant number per unit area, but excessive density often causes canopy overcrowding, poor ventilation and light penetration, premature senescence of lower leaves, and increased disease incidence, thereby restricting fruit set and fruit enlargement. Modern greenhouse cucumber production places greater emphasis on optimizing population structure by adjusting planting density, stem number, and spatial leaf distribution to achieve balance among yield per unit area, productivity per plant, and fruit quality. Greenhouse