6.3 Optimization model of substrate-nutrient combinations

Building an efficient production system requires coordinated design of substrate characteristics and nutrient management strategies, rather than considering them separately. Long-term strawberry experiments show that in substrates with added compost or reduced peat content, fertigation strategies must be recalibrated to account for nutrients supplied and retained by the substrate itself. When compost mineralization is high in autumn, inputs of N, P, and K should be reduced. In extended spring cultivation, when the internal nutrient supply capacity of the substrate declines, inputs should be increased.

Current optimization approaches increasingly rely on quantitative models that link substrate physicochemical properties with plant performance. For example, structural equation modeling has been used to analyze how vermicompost indirectly promotes plant growth, fruit morphology, and yield by altering substrate nutrients, microbial activity, and enzyme activity (Bai et al., 2025).

7 Case Studies and Practical Applications

7.1 Regulation model based on vermicompost

Under continuous greenhouse cultivation, substrate degradation and continuous cropping obstacles are key factors limiting the stability of strawberry yield and quality. Bai et al. (2025) conducted a study under greenhouse conditions in Hebei, China, using a randomized block design with the strawberry cultivar “Xiangye.” They compared the effects of different substrate types and vermicompost application methods on plant growth, yield, and quality. The experiment included two background conditions: new substrate (0 years) and substrate continuously cultivated for 2 years. On this basis, three treatments were set: no vermicompost (CK), cattle manure-derived vermicompost, and sludge-derived vermicompost. The experiment covered a full strawberry growing season. Plant growth parameters (plant height, leaf area, root length), substrate physicochemical properties (nutrient content, microbial quantity, enzyme activity), yield, and fruit quality indicators (soluble sugars, vitamin C, and amino acids) were systematically measured.

The addition of vermicompost significantly improved the substrate environment. Compared with the control, nutrient content in the substrate increased by about 12.04%~42.54%. At the same time, microbial populations and related enzyme activities were clearly enhanced, while the content of phenolic autotoxins decreased significantly. This effect was more obvious in continuously cropped substrates, indicating that vermicompost plays an important role in alleviating continuous cropping obstacles. The improved substrate environment further promoted plant growth. In the treatment groups, plant height, leaf area, and root length increased by about 15.01%~32.77% and 23.75%~32.78%, showing that root vitality and nutrient uptake capacity were enhanced.

Under new substrate conditions, yield increased by about 18.29%, while in continuously cropped substrate the increase reached 19.64%. Fruit quality was also improved. During the peak fruiting stage, soluble sugar content increased by about 9.62%~42.62%, and both vitamin C and free amino acid contents increased significantly, indicating improvements in both flavor and nutritional value (Figure 2).

7.2 Substrate cultivation combined with integrated water-fertilizer management

In greenhouse soilless cultivation systems, the traditional practice of using a fixed nutrient solution throughout the whole growth period often cannot meet the different nutrient requirements of strawberries at different growth stages. Yu et al. (2023) conducted a greenhouse experiment in the Xiaotangshan Modern Agricultural Demonstration Park in Beijing, China, based on dynamic adjustment of nutrient solution according to growth stages. The study used an elevated substrate cultivation system with strawberry ‘Ssanta’ as the test material. Under volcanic rock substrate, horticultural substrate, and commercial substrate conditions, they compared the traditional Yamazaki standard nutrient solution (control) with an optimized nutrient solution adjusted according to growth stages. The treatment increased nitrogen supply during the vegetative stage, gradually increased potassium supply and adjusted the K/Ca ratio during flowering and fruit expansion stages, and optimized the ratio of NO_3^--N to NH_4^+-N.