6 Interaction between substrate and nutrient supply

6.1 Effects of substrate on nutrient retention and release

Different organic and inorganic components show clear differences in nutrient adsorption, fixation, and slow release. In soilless strawberry cultivation, low-peat substrates containing wood fiber and compost can retain a relatively large proportion of Ca (76%~88%), Mg (70%~85%), and N (61%~81%) after use, while K is mainly removed through aboveground biomass. This indicates that different elements have specific retention patterns, which should be considered when designing fertigation strategies (Vandecasteele et al., 2023a).

Substrates amended with compost can supply large amounts of P and K, reducing fertigation input by 10%-50% and lowering nutrient losses in drainage. However, during long spring cultivation cycles, when compost mineralization slows down, additional N input is required (Vandecasteele et al., 2018). Similarly, biochar or lignocellulosic materials can act as nutrient adsorbents, recovering nitrate, phosphate, Ca, and sulfate, and stabilizing the chemical properties of nutrient solutions. At the same time, they may increase pH and change K dynamics, thereby affecting nutrient availability (Haraz et al., 2020).

The addition of organic amendments can increase cation exchange capacity (CEC), pH buffering capacity, and the storage of NH_4^+ and K, while reducing P fixation, thus improving fertilizer use efficiency. This effect is especially obvious in sand–coco coir mixed substrates. The buffering effect of different substrates is closely related to pH regulation and ion balance. Substrates rich in coco coir have strong pH buffering capacity and nutrient storage ability, which can promote vigorous plant growth. However, if fertilization does not match crop demand, it may lead to excessive nutrient accumulation (Xu et al., 2021). Compost and spent mushroom substrate often contain high nutrient levels at the early stage, promoting root and shoot growth and increasing marketable yield. However, their mineralization rate changes over time, so nutrient supply should be adjusted in stages to avoid excess in the early stage and deficiency later.

In contrast, substrates with low CEC, such as sand or mixtures with a high proportion of wood fiber, have weaker buffering capacity, and nutrient concentrations in the root zone are more directly affected by fertigation management. Although this allows for rapid adjustment, improper fertilization can more easily lead to osmotic stress or nutrient deficiency.

6.2 Regulation of the rhizosphere environment

Besides chemical properties, substrates also influence nutrient uptake efficiency by regulating the physical environment of the rhizosphere, especially aeration, water distribution, and temperature. Studies in soilless cultivation show that root function depends on sufficient oxygen supply. When aeration is poor or waterlogging occurs in the root zone, nutrient uptake and plant growth are inhibited even if nutrient solution concentration is high (Balliu et al., 2021).

Studies in both hydroponic and soil systems indicate that moderate increases in rhizosphere oxygen can improve root length, root volume, root activity, and P uptake capacity, thereby increasing yield and quality. However, both excessive and insufficient oxygen can inhibit growth (Wang et al., 2022; Nitu et al., 2024). Under waterlogged or low-oxygen conditions, even with adequate nutrient supply, the uptake of K, Mg, and Ca decreases, and shoot growth is also restricted. This shows that good aeration is a prerequisite for efficient fertilizer use.

Substrate structure, such as pore distribution, water-holding capacity, and bulk density, determines the balance between water and oxygen. Mixed substrates of peat, coco coir, and compost or organic composites, combined with inorganic nutrient supply, can improve both aeration and water retention, thus promoting root development and increasing strawberry yield (Prasad et al., 2022). Materials such as wood fiber can increase porosity and moisture, but they immobilize nitrogen during decomposition, so additional N fertilization is needed to maintain nutrient balance.

In addition, substrate pH regulation is critical for nutrient availability. Most macronutrients are most easily absorbed at pH 6~6.5, while higher pH reduces the solubility of micronutrients and disrupts nutrient balance. This has been confirmed in container experiments with peat substrates (Ferrarezi et al., 2022).