blue-green algae like Microcystis in a wide range of pH conditions. If used properly, they have a relatively small impact on the water's acidity and alkalinity, produce little dissolved organic carbon, and can decompose microcystin-LR and chlorophyll a. Moreover, these oxidants also have a strong killing effect on marine flagellates that are harmful to fish, making them a potential alternative to chlorine in ship ballast water treatment and coastal water management.

However, although chemical treatment can take effect quickly, it also brings some environmental and management issues. For instance, copper preparations and some synthetic herbicides may gradually accumulate in sediments or aquatic organisms, thereby posing long-term ecological risks. At the same time, when herbicides or oxidants cause a sudden death of a large number of algae, toxins and organic substances in the cells will rapidly be released into the water, which may increase toxicity in a short period and lead to oxygen deficiency in the water body. Some recent review studies have also pointed out that in practical applications, most chemical treatment measures are difficult to improve water quality in the long term, indicating that relying solely on chemical agents is insufficient to solve the problem of excessive nutrients at the watershed level (Table 1) (Lan et al., 2024). Some recently emerged nano-material oxidants and photocatalysts can improve treatment efficiency and selectivity, but they also raise new issues, such as the fate of nanoparticles in the environment and whether they will be toxic to the ecosystem. The current situation is unclear. Therefore, in practical management, chemical methods are more often used as emergency or short-term control measures. When using these agents, strict control of dosage, enhanced monitoring, and their integration into a prevention-oriented comprehensive management strategy are necessary.

Table 1 Innovative fertilizer technologies for reducing eutrophication (Adopted from Lan et al., 2024)

Fertilizer Technology	Nutrients Provided	Mechanism	Suitable Crops
Slow-Release Fertilizers (SRFs)	Nitrogen, Phosphorus, Potassium	Gradual nutrient release aligned with crop uptake	Cereals, horticultural crops, turfgrass
Controlled-Release Fertilizers (CRFs)	Nitrogen, Phosphorus, Potassium	Coating controls nutrient release over time	Vegetables, fruits, ornamental plants
Nitrification Inhibitors	Nitrogen	Inhibits nitrification, reducing nitrate leaching	Maize, wheat, rice
Urease Inhibitors	Nitrogen (Urea-based)	Prevents rapid urea conversion, reducing ammonia loss	Rice, cereals, pasture
Enhanced Efficiency Fertilizers (EEFs)	Nitrogen, Phosphorus	Combines slow and controlled release with inhibitors	Various crops including cereals, fruits, vegetables
Polymer-Coated Fertilizers	Nitrogen, Potassium	Encapsulated nutrients in a polymer for controlled release	High-value crops like fruits, vegetables, ornamentals
Biochar-Enhanced Fertilizers	Nitrogen, Phosphorus, Potassium, micronutrients	Uses biochar to retain nutrients and reduce leaching	Cereals, legumes, vegetables
Struvite Fertilizers	Phosphorus, Nitrogen, Magnesium	Mineral compound with slow nutrient release	Horticultural crops, cereals

4.3 Biological methods: using microorganisms, filter-feeding organisms and aquatic plants

Biological control methods involve using predator relationships, species competition, or microbial actions to inhibit the growth of harmful algae. This approach is generally considered more environmentally friendly and more in line with natural ecological laws. Microbial control mainly includes the use of bacteria, fungi, or actinomycetes that can kill algae, or the use of some microbial groups to cause the cell lysis of algae, inhibit their growth, or cause the aggregation, sedimentation, and gradual decomposition of algae cells, thus forming a process of "aggregation-lysis-degradation-nutrient regulation". Relevant research and reviews indicate that some strains with algicidal effects, such as certain streptomyces, vibrio, and the algicidal fungus known as D7, not only can reduce the number of algae in water bodies, but can also, to a certain extent, lower the nutrient salt levels in water, thereby simultaneously alleviating the problems of algal blooms and excessive nitrogen and phosphorus (Anabtawi et al., 2024; Pan et al., 2025). Most related studies are still at the stage of laboratory or medium-scale simulation tests, and there is not sufficient evidence to prove that they can improve the long-term water quality of