Analysis of Green Prevention and Control Technologies for Crop Diseases and Pests

Lin Yongyang
Tianjin Chengjian University, Tianjin 300384, China;

Abstract: Against the background of sustainable development in modern agriculture, green prevention and control technologies for crop diseases and pests constitute an important pathway for ensuring food security and maintaining coordinated ecological development. Using literature review, field investigation, and data analysis, this paper summarizes the development status, major types, and application effects of green prevention and control technologies. Green prevention and control mainly include four categories: biological control, physical control, ecological regulation, and scientific pesticide application. Biological control is implemented through natural enemy insects and microbial pesticides; physical control is conducted by means of colored sticky board trapping and sex pheromone trapping; ecological source regulation is achieved by optimizing crop layout and breeding disease-resistant varieties; and scientific pesticide reduction is promoted through precise pesticide application. Practices in typical regions show that the integration of multiple technologies can reduce pesticide use by 30%–50% and increase crop yield by 5%–15%, while also improving the quality of agricultural products and reducing ecological pollution. At present, the promotion of these technologies still faces challenges such as inconsistent standards, relatively high implementation costs, and insufficient farmer acceptance. Accordingly, this paper proposes countermeasures including improving technical standards, strengthening agricultural technology publicity and training, improving policy support mechanisms, and promoting industrialized development, so as to provide theoretical and practical reference for the popularization and application of green prevention and control technologies.
Keywords: crop diseases and pests; green prevention and control; biological control; sustainable agriculture; pesticide reduction

1. Introduction

Due to the increasing dependence of global agricultural production on chemical pesticides, crop disease and pest control is facing considerable pressure. According to a 2023 report by the Food and Agriculture Organization of the United Nations, annual global crop losses caused by diseases and pests account for approximately 20%–40% of total production, resulting in direct economic losses of more than USD 220 billion. In China, data released by the Ministry of Agriculture and Rural Affairs in 2022 show that pesticide use has declined for six consecutive years, but the total amount remains large, exceeding 2.5 million tons per year, with chemical pesticides accounting for more than 85%. This poses certain risks to the environment and food safety. The development of modern agriculture has placed higher requirements on green prevention and control technologies. Green prevention and control technologies are based on ecology and use biological, physical, ecological, and rational pesticide application methods to effectively control crop diseases and pests while protecting the environment.

2. Technical System of Green Prevention and Control for Crop Diseases and Pests

2.1 Mechanisms and Application of Biological Control Technologies

Biological control technology is a method of pest control based on the natural restrictive relationship between natural enemies and pests, using natural enemy organisms to control pests. It mainly includes three approaches: natural enemy insect control, microbial pesticide control, and the application of biological-source pesticides. Natural enemy insect control involves the artificial breeding and release of predatory and parasitic insects, such as using *Trichogramma* to control corn borers and *Encarsia formosa* to control greenhouse whiteflies. Its principle is that natural enemy insects directly suppress pest reproduction through predation, parasitism, or competition. Microbial pesticide control uses the pathogenicity of bacteria, fungi, viruses, and other pathogenic microorganisms to selectively kill pests. For example, *Bacillus thuringiensis* (Bt) has a good control effect on lepidopteran larvae.

In actual production, biological control technologies have been effectively applied to major crops such as rice, corn, and vegetables [1]. Taking rice disease and pest control as an example, biological control methods such as releasing ducks in paddy fields, releasing *Trichogramma*, and applying *Beauveria bassiana* can effectively control major pests such as the rice leaf roller and striped stem borer, with control effects exceeding 80%, while reducing chemical pesticide use by 60%–70%. From 2020 to 2023, the application area of biological control technologies nationwide increased by 15.3% annually, with a cumulative promoted area of more than 800 million mu-times, showing strong development momentum and broad prospects.

2.2 Principles and Practice of Physical Control Technologies

Physical control technology uses the characteristics of physical factors and adopts methods such as mechanical barriers, color trapping, and pheromone trapping to affect pest physiological activities, thereby reducing the incidence of pest damage. Colored sticky board trapping is designed according to pests' preference for light of specific wavelengths. Yellow sticky boards can trap small insects such as aphids, whiteflies, and leafhoppers, while blue sticky boards are highly attractive to thrips. Sex pheromone trapping imitates the molecular structure of sex pheromones released by female insects, preventing males from locating females for mating and thereby interrupting pest reproduction. It is most widely used in the control of lepidopteran pests.

In recent years, physical control technologies have developed rapidly in protected agriculture. Technologies such as insect-proof nets, silver-gray plastic film mulching, and frequency-vibration insecticidal lamps have been widely applied in greenhouses. Statistics show that from 2019 to 2023, the number of frequency-vibration insecticidal lamps installed nationwide increased from 670,000 to 1.05 million, with an average annual growth rate of 11.9%. In the vegetable production area of Shouguang, Shandong Province, the use of physical control technologies such as insect-proof nets, yellow board trapping, and sex pheromone trapping achieved a vegetable disease and pest control effect of more than 75%, reduced chemical pesticide use by 45%, and greatly improved vegetable quality.

2.3 Methods and Effects of Ecological Regulation Technologies

Ecological regulation technology reduces the incidence of crop diseases and pests by reasonably planning and designing agricultural ecosystems and creating environmental conditions unfavorable to disease and pest occurrence. It mainly includes farmland habitat regulation, crop layout optimization, and cultivation system improvement. Farmland habitat regulation involves planting nectar plants around farmland and constructing ecological corridors to provide living space for natural enemy insects and improve the self-regulation capacity of farmland ecosystems. Crop layout optimization uses differences in crop sensitivity to diseases and pests and adopts methods such as intercropping, relay cropping, and crop rotation to disrupt the food chains and life histories of diseases and pests [2]. Cultivation system improvement enhances crop stress resistance and reduces opportunities for disease and pest infection by adjusting agronomic measures such as sowing time, planting density, and fertilization. In the main corn-producing areas of the North China Plain, the promotion of planting patterns such as corn–soybean intercropping and winter wheat–summer corn rotation has greatly reduced the occurrence of major pests such as corn borers and aphids. Monitoring results from 2021 to 2023 show that in areas where ecological regulation technologies were applied, the average incidence of crop diseases and pests decreased by 25%–35%, the number of natural enemy insects increased by 40%–60%, and the farmland biodiversity index rose significantly, which is conducive to achieving sustainable agricultural development.

2.4 Breeding and Popularization of Resistant Varieties

Breeding resistant varieties is an important component of the green prevention and control technology system for crop diseases and pests. It reduces the incidence of diseases and pests by breeding crop varieties containing resistance genes, thereby achieving green prevention and control, and is an important measure for realizing sustainable agricultural development. In recent years, with the development of molecular biology and genetic engineering, substantial progress has been made in resistant variety breeding. The combination of traditional crossbreeding methods with modern molecular marker-assisted selection has greatly improved the speed and accuracy of resistant variety breeding. The application of molecular marker technology enables breeders to screen plants carrying resistance genes in earlier generations, thereby accelerating the breeding process and improving breeding efficiency. In addition, the application of gene editing technologies such as CRISPR-Cas9 has also provided a new approach for the precise improvement of crop resistance, making resistant variety breeding more accurate and efficient.

The popularization and application of resistant varieties are highly beneficial to control effectiveness and economic returns in agricultural production. For example, in rice production, the large-scale planting of rice blast-resistant varieties has greatly reduced the incidence of rice blast, saved 40%–60% of fungicide use, and maintained relatively stable yields. In corn cultivation, the planting of varieties resistant to fall armyworm has effectively curbed the occurrence of this pest, reduced pesticide applications by two to three times, and saved costs. However, the popularization and application of resistant varieties still face several problems, mainly including the durability of resistance genes, the risk of resistance loss caused by adaptive evolution of diseases and pests, and regional differences in varietal adaptability requirements under different ecological environments. Therefore, reasonable rotation schemes for resistance gene use should be formulated, broad-spectrum resistant varieties carrying multiple resistance genes should be bred, and regional adaptability assessment of resistant varieties should be strengthened to ensure that resistant varieties can function properly in different ecological zones, thereby laying a sound genetic foundation for green prevention and control of crop diseases and pests [3].

3. Evaluation and Optimization of Green Prevention and Control Technologies

3.1 Quantitative Evaluation Methods for Control Effects

The quantitative evaluation of the control effects of green prevention and control technologies is conducted on the basis of a scientific monitoring system and evaluation indicators. In general, quantitative evaluation is carried out using the disease and pest occurrence severity index, the relative value of control effectiveness, and pest population dynamic parameters. The disease and pest occurrence severity index is obtained through standardized investigation of the occurrence area, damage degree, and loss rate of diseases and pests under different treatments. The evaluation of control effects adopts a randomized block design and conducts comparative analysis among the green prevention and control treatment area, the conventional control area, and the blank control area. Pest population dynamic monitoring uses sex pheromone traps, light trapping, and other methods to regularly investigate the number of adult pests, so as to understand population changes and the influence of control technologies on pest populations.

The evaluation methods also include crop yield and quality analysis as well as investigation of natural enemy insect diversity, so as to comprehensively reflect the overall effectiveness of green prevention and control technologies. A systematic evaluation conducted in 152 green prevention and control demonstration areas nationwide from 2021 to 2023 showed that biological control technologies achieved a control effect of 78.5% against major pests, physical control technologies achieved 71.2%, ecological regulation technologies achieved 68.9%, and integrated control technologies achieved more than 85.3%, far exceeding the control effects of single technical measures.

3.2 Construction of a Cost–Benefit Analysis Model

The cost–benefit analysis model for green prevention and control technologies analyzes three aspects: technology input cost, output benefits, and environmental benefits, and constructs a multi-objective optimization evaluation system. Technology input costs include direct costs such as the purchase of biological agents, physical control equipment costs, labor costs, and technical training costs, as well as indirect costs such as technology extension, monitoring, and evaluation. Output benefits are based on economic benefits such as crop yield increase, quality improvement, pesticide reduction, and cost savings, and include the calculation of direct economic benefits and market premium returns. Environmental benefits quantify the environmental gains brought by reduced pesticide use, such as increased soil microbial diversity, reduced groundwater pollution risk, and decreased pesticide residue detection rates in agricultural products.

The cost–benefit analysis model uses financial evaluation methods such as the net present value method and the benefit–cost ratio, and conducts sensitivity analysis to determine whether technology application is economically feasible. According to a national survey on the costs and benefits of green prevention and control technology application from 2020 to 2023, the average input cost of green prevention and control technologies was CNY 185 per mu, which was CNY 42 higher than that of conventional chemical control. However, due to reduced pesticide use, increased yield, and improved quality, an additional net income of CNY 67 per mu could be obtained, with an input–output ratio of 1.36, indicating good economic benefits and development potential [4].

3.3 Technology Integration Optimization Strategy

The integration optimization of green prevention and control technologies is based on systems theory and combines individual technologies such as biological control, physical control, ecological regulation, and resistant varieties to form an integrated control technology scheme suitable for local conditions. Technology integration follows the principle of niche complementarity and reasonably matches various technical measures and application timing according to different disease and pest species and their occurrence characteristics. For example, in the control of major rice diseases and pests, a “four-in-one” control measure is adopted, with resistant varieties as the foundation, ecological regulation as the prerequisite, biological control as the main approach, and physical control as a supplementary measure, achieving coordination in both time and space. Technology optimization also includes the adjustment of key technical parameters, such as the release density of natural enemies, the replacement cycle of sex pheromone lures, and the application rate of biological pesticides. The optimal combination of technical parameters is determined through field trials.

Regional technology integration models formulate corresponding technical standards and operating procedures according to the climatic characteristics, crop types, and disease and pest occurrence conditions of different ecological regions. In the rice-growing areas of South China, the control of rice blast and sheath blight is the main focus, and methods such as disease-resistant varieties, biological pesticides, and ecological regulation are adopted [5]. In the corn-growing areas of Northeast China, the control of corn borers and aphids is the main focus, and measures such as sex pheromone trapping, release of *Trichogramma*, and biological pesticide control are adopted. In 2023, a total of 1,847 integrated green prevention and control demonstration areas were established nationwide, with a core demonstration area of 26.8 million mu and a radiating promotion area of more than 120 million mu. The effects of technology integration and application were evident, laying a sound foundation for large-scale promotion.

4. Promotion and Application Models of Green Prevention and Control Technologies

4.1 Screening of Regionally Adaptive Technologies

The promotion of green prevention and control technologies should be adapted to local conditions and selected according to the natural environment, crop types, and disease and pest species in each region. According to data from the National Agro-Tech Extension and Service Center from 2019 to 2023, the adaptability of green prevention and control technologies varies greatly among different ecological regions. In the North China Plain, the combination of physical control and biological control produces the best effect, with control effectiveness reaching more than 85%, whereas in the hilly areas of southern China, the combination of ecological regulation and rational pesticide use is more suitable. The screening of regionally adaptive technologies should consider local natural enemy species of major pests, climatic conditions, soil types, and other factors, establish a technology applicability evaluation indicator system, and select major technical measures suitable for local promotion.

4.2 Construction of a Demonstration and Extension System

The establishment of a sound demonstration and extension system is an important guarantee for the large-scale promotion and application of green prevention and control technologies. From 2020 to 2023, the Ministry of Agriculture and Rural Affairs established more than 1,500 green prevention and control demonstration areas nationwide, with a demonstration area of more than 80 million mu, forming a three-level extension network of "expert guidance–technical personnel implementation–farmer participation." The demonstration and extension system is led by county-level agricultural technology extension stations, establishes technical demonstration fields, and uses field observation, technical training, comparative experiments, and other forms to help surrounding farmers understand the practical effects of green prevention and control technologies. At the same time, the role of new business entities such as farmers' professional cooperatives and professional plant protection service organizations should be actively utilized to promote the large-scale application of green prevention and control technologies.

4.3 Analysis of Factors Influencing Farmer Acceptance

Farmers' acceptance of green prevention and control technologies affects the promotion of these technologies. According to a survey of 3,000 farmers in 15 provinces nationwide, technology cost, operational difficulty, control effectiveness, and policy support are the main factors affecting farmer acceptance. Among them, technology cost has the greatest influence on farmer acceptance. When the input cost of green prevention and control technologies is more than 30% higher than that of traditional chemical control, farmers' willingness to accept them decreases significantly [6]. Individual characteristics such as farmers' education level, planting scale, and age also affect acceptance. Farmers with a high school education or above show a 40% higher acceptance of green prevention and control technologies than farmers with a junior high school education or below. At the same time, social factors such as the frequency of technical training, demonstration effect display, and peer influence can also promote farmer acceptance. Increasing technical publicity and training and establishing incentive measures can enhance farmers' enthusiasm for using green prevention and control technologies.

5. Conclusion

This paper summarizes and analyzes green prevention and control technologies for crop diseases and pests and concludes that these technologies have become an important force in promoting sustainable agricultural development. The integration of four technologies, namely biological control, physical control, ecological regulation, and scientific pesticide application, can substantially reduce the use of chemical pesticides while ensuring food security, protecting the environment, and improving the quality of agricultural products [7]. From the perspective of practical application effects, the application of integrated green prevention and control technologies can reduce pesticide use by 30%–50%, increase crop yield by 5%–15%, and raise the pesticide residue detection pass rate of agricultural products to more than 98%, fully demonstrating the great potential and role of green prevention and control technologies in agricultural production. However, the large-scale application of green prevention and control technologies still faces problems such as inconsistent technical standards, high promotion costs, and differences in farmers' technical capabilities. In the future, technical standards for green prevention and control should be formulated as soon as possible, diversified technology extension service systems should be established, policy support and market incentive measures should be strengthened, and the industrialized and large-scale development of green prevention and control technologies should be promoted. Under government guidance, scientific and technological support, and market-driven mechanisms, green prevention and control technologies will play a greater role in ensuring national food security, promoting green agricultural development, and building a beautiful homeland, and they are of great significance for realizing agricultural modernization and ecological civilization construction.

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