# Development of Plant Protection Methods

Subjects: Agricultural Engineering

Contributor: Jiaqiang Zheng , Youlin Xu

Over thousands of years, the history of human survival and development has been accompanied by the struggle against plant pests, among which plant target recognition, plant protection methods and plant protection machinery constitute the three elements of plant protection. Plant protection practices have been enriched around the world. Six types of plant protection methods have been developed, including the agricultural method, the physical method, the biological method, the chemical method, plant quarantine and integrated pest management (IPM).

plant protection methods and subdivision measures
plant protection machinery
pesticide application technique
pesticide spraying technology
plant target recognition

## 1. Introduction

Plant protection practices have developed through three stages: the natural-farming-based stage, the pesticide-priority-based stage and the integrated-management-based stage. A lot of different plant protection methods have emerged [1][2][3][4][5][6][7][8][9][10][11]. Each plant protection method as summarized is subdivided into 6 measures and the total 36 measures are classified, as shown in **Figure 1**.

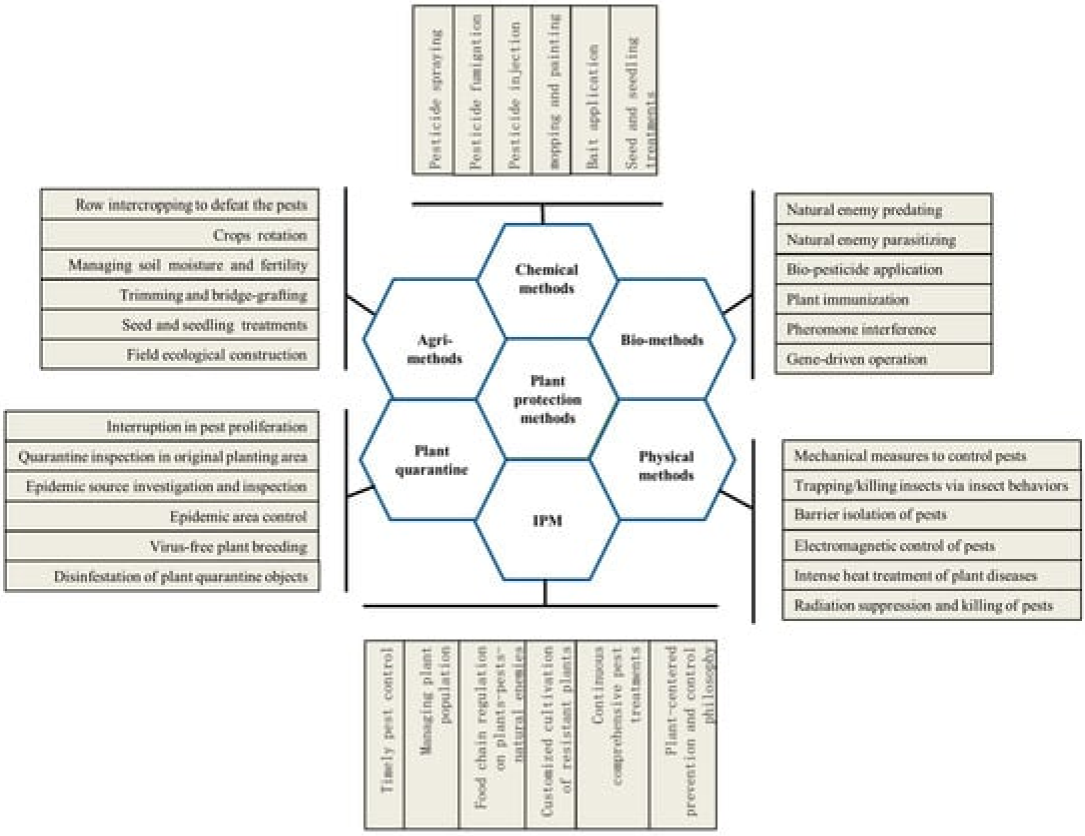


**Figure 1.** Plant protection methods and subdivision measures.

## 2. Agricultural Practice Methods

Ancient thoughts on plant protection through agricultural practices can be found in Chinese agricultural works, especially in the four immense ancient agricultural books, which are “Works of Fan Shengzhi” written more than 2000 years ago, “Important Arts for the Peoples Welfare” written about 1500 years ago, “Book on Agriculture” written about 630 years ago and “Complete Treatise on Agriculture” written about 380 years ago. By analyzing these works in the literature and the recent development trends of plant protection around the world [1][2][7][8][11][12][13], agricultural practice methods of plant protection can be summarized into six measures, that is, row intercropping to defeat pests, crop rotation, management of soil moisture and fertility, trimming and bridge-grafting, seed and seedling cultivation treatments and field ecological construction (**Figure 1**).

### 2.1. Row Intercropping to Defeat Pests

Row intercropping refers to the diversification of planting time and space, including fallow cultivation, which can effectively prevent the outbreak of plant pests. Even during outbreaks of plant pests, partial losses can be avoided due to different habits and growth periods of different crops. About 1500 years ago, the book “Important Arts for the Peoples Welfare” stated that “Planting mung beans or adzuki beans under the mulberry trees not only enhances the good harvesting of the two beans, but nourishes and benefits the mulberry trees” [14][15]. Biologist Rachel Carson believed that planting a grain on a large scale provides conditions for a sharp increase in the number of certain insects, and she stated that "obviously then, an insect that lives on wheat can build up its population to much higher levels on a farm devoted to wheat than on one in which wheat is intermingled with other crops to which the insect is not adapted" [13].

## 2.2. Crop Rotation

Due to continuous cropping being acknowledged as a risk for bringing outplant pests, most crops require rotation. Reasonable crop rotation refers to the rotating practice of host crops that are susceptible to plant pests with non-host and resistant crops, and certain rotations of terrestrial plants and aquatic plants can reduce the number of the pathogenic bacteria or insect eggs in the soil. Moreover, crop rotation can eliminate accompanying parasitic or non-parasitic weeds and restrain weeds' harm. About 380 years ago, the book "Complete Treatise on Agriculture" stated that "If the mountainous region can be planted, then planting millet in summer and wheat in winter can be used as a hoe for weeding" and "For those who raise their fields high and can grow cotton or rice, planting cotton for two years and plowing rice for one year. Then the weeds roots will rot, the soil fertility will increase, and the pests will not grow. You do not plant cotton for more than three years, otherwise pests will grow" [15][16]. Rational application decisions regarding crop rotation patterns can minimize the yield loss in infected fields [1].

## 2.3. Managing Soil Moisture and Fertility

Specific conditions of rain, dampness, cold and heat in the field are direct reasons for the occurrence of plant pests, that is, an appropriate management of soil moisture and fertility can effectively prevent the occurrence of plant pests. About 300 years ago, the book "Outlines of Agriculture·Principles of Cultivating Crops" stated that "Five types of insects all occur as the results of the rain and dampness, the diurnal dryness, and the fumigation of cold and heat" [7]. About 380 years ago, the book "On Agriculture" stated that "If five types of pests were not controlled, then plant crops would not grow. Those who irrigate the fields must first cover the fields with water for collecting the heat, and quickly remove water. Then, using new water to cover the fields will result in no harm to plant crops" and a variety of plant diseases and insects "occurred with the dampness and dryness, and the sharp warming in the winter" [7].

## 2.4. Trimming and Bridge-Grafting

When the branches and roots of trees suffer from plant pests (including accidental damage caused by freezing, burning, gnawing and improper fertilizer application, plant girdling or reverse grafting, etc.), the tree bark can rot or leave major wounded scars that cut off the conducting tissue of the tree cortex and block nutrient delivery. Therefore, the normal growth of trees is affected and the trees gradually weaken. In severe cases, it can cause pruning or withering of the entire tree. Generally, it is necessary to avoid causing wounds during agricultural operations and reduce the opportunity for pathogens to invade said wounds. For wounded trees, the timely trimming of wounded branches is suggested to treat pests and prevent diseases. Bridge-grafting technology used for treating wounded trees appears to be a feasible process in reconstructing conducting tissues and reconnecting nutrient delivery tissues; thus, the interrupted sap flow is re-established and the flow of sucrose is restored from the canopies of the trees to the root systems. Combined with comprehensive measures to maintain reasonable water and fertilizer management and pruning branches to reduce load, the tree is strengthened and its age extends.

### 2.5. Seed and Seedling Treatments

Seed and seedling cultivation treatments refer to the selection of early-maturing and pest-free varieties through long-term planting experiences to prevent pest-induced harm to plants. Seed breeding treatments apply biological, physical, chemical and other technologies to protect seeds, control pests and diseases and guarantee normal crop growth. More than 2000 years ago, “Works of Fan Shengzhi”introduced some principles and techniques for selecting and reserving good seed varieties and stated that “A handful of wheat seed and a handful of Chinese mugwort are stored in the earthen ware or stone tools, then the doubling harvest will be achieved when timely sowing” [15] according to the belief that “If the mother is strong, the child will be good, and if the mother is weak, the child will be sick”. This is because the volatile aromatic oil in mugwort leaves has insecticidal and sterilization effects. Seed coating treatments use nanomaterials, specifically nanoparticles and nanofibers whose permeability, small size and high surface area offer significant benefits in boosting seeds’ mechanical properties, germination and vigor indices by enhancing seed water uptake, and nutrient absorption [17].

### 2.6. Field Ecological Construction

Field ecological construction includes additional plowing, fine hoeing, field environmental remediation, etc. Additional plowing and fine hoeing require investing a large amount of production materials, labor and related technologies and enhancing the soil fertility through meticulous deep plowing operations with diligent laborers. More than 2200 years ago, the book “Master Lü’s Spring and Autumn Annals·Rendi stated the following: “The ridge in the upper field and the ditch in the lower field must be abandoned; Five times of plowing and hoeing must be finished and thoroughly examined before seeding; The deep cultivation should reach the moisture content in the lower layer of the field soil, then the growth of large weeds or insects could be avoided” [7]. Therefore, deep plowing is very important for controlling plant pests; it is especially necessary to plow and hoe carefully and thoroughly before sowing. Field environmental remediation (field ecology) refers to improvements in the field environment through the cleaning of fields, disinfection of soil exposed to sunlight, etc., effectively reducing the breeding areas of bacteria and pests and especially reducing the source of overwintering pests. About 1500 years ago, the book “Important Arts for the Peoples Welfare” introduced a procedure of field ecological construction aimed at killing plant-harming insects, that is, “The shoveling is the best way to raise seedlings which is better than ploughing and hoeing. The shovel handle is about 66.67 cm long and the blade is about 6.67 cm wide, used for soil cutting and weeding. When winter rain and snow come to an end, the snow could be covered and trampled on the ground and not let it fly away with the wind; the snow is trampled and covered again if the snow come again. So the land will be protected in the spring, and the insects will be frozen and die. Then the next year will be suitable for crops” [14].

## 3. Physical Methods

Physical methods mainly utilize principles and measures such as mechanical, electromagnetic, heat treatment and radiation methods to kill harmful pests or control their harm. The six measures of physical methods are categorized as follows: mechanical measures to control pests, trapping and killing insects through insect behavior, barrier isolation of pests, electromagnetic control of pests, intense heat treatment of plant diseases and radiation suppression and killing of pests (**Figure 1**).

## 3.1. Mechanical Measures to Control Pests

Mechanical measures to control pests include manual operation, mechanical suction, sound-induced control, ultrasonic control, mechanical weeding and combination measures. Manual operation is the most environmentally friendly but also the most arduous measure of pest control. About 1000 years ago, an emperor of the Song Dynasty issued the world's first law of insect pest control "The Imperial Edict of Locust Control", which required county officials to personally capture locusts in areas where locusts were rampant. According to the law, people who excavated and caught locusts could directly exchange them for money and food [18]. Pneumatic sucking and capturing machines and photoelectric trapping machines can be developed for locust control [19]. The sound-induced control of pests is a measure that uses a simulation or recording of insects chirping and other sounds played in the field to concentrate the capture of harmful pests or uses sound to enhance the attractiveness of traps to harmful pests [20]. Ultrasonic control uses mechanical waves with different frequencies and times; ultrasonic stress effects can affect the activities of acetylcholinesterase (AChE), feeding behavior and location distribution of plant pests to control pest-induced harm [21]. Mechanical weeding generally uses rollers, harrows, shovels, hoes, etc., to carry out weeding between plants and rows. About 630 years ago, "Wang Zhen's Book of Agriculture" mentioned the hand harrow for weeding and stated that "When weeding, the farmers grasp them to rake the weeds and mud among ridges in the field. [The weeds] are submerged in the muck in the furrows. In this manner the fields can be fertile and high-yielding. This method is superior to the use of hoes. The tool substitutes for both hands and feet. With this tool, many fields can be weeded, doubling the number of fields that can be weeded in a day" [22]. Intelligent inter-plant weed control technologies such as laser weeding robots have been developed in recent years [23][24]. Of course, more mechanical measures or combinations with other measures could be developed for plant pest control.

## 3.2. Trapping/Killing Insects via Insect Behaviors

Trapping and killing insects through insect behaviors refers to using light, color plates, baits and habitats to attract plant pests according to their specific animalistic tendencies (such as those involving light, wave, color, taste, etc.) or behaviors (such as hiding, laying eggs, overwintering, etc.) by meeting certain environmental conditions. Plant pests can be lured to physical devices such as pre-hidden traps, water pits and high-voltage power grids to cut off their escape. And physical devices can cooperate with certain chemical agents or manual treatments to prevent and control harmful plant pests. Among them, trapping and killing insects using light is based on insects' phototaxis instinct and is achieved using black-light lamps, frequency oscillation lamps, low-energy LED lamps, dual-color lamps and high-pressure mercury lamps to monitor and control plant pests [25].

### 3.3. Barrier Isolation of Pests

Barrier isolation of pests refers to the establishment of physical barriers to forcibly isolate plant pests or the use of tempting attacks or forced driving to attract plant pests away from their survival habitats and prevent the spread of harmful plant pests. Measures for the barrier isolation of pests include building arched rain shelters, bagging fruits, banking up areas with earth, digging blockage ditches, coating surfaces with white glue, using fly nets [26], spraying high-fat membranes, covering surfaces with slippery wax, etc. Possible biomimetic strategies have been studied for their use in repelling insects and reducing the adhesion of crawling insects to target plants, through methods such as covering plant surfaces with slippery wax and insect-repellent coatings made from natural products [27].

### 3.4. Electromagnetic Control of Pests

Electromagnetic control of plant pests is mainly aimed at the biophysical (especially bio-electrical) characteristics of plant diseases, insects and weeds. High-voltage electric fields, short-term electric pulses or ultra-high-frequency electromagnetic field pulses are applied to quickly destroy biological tissues and control harmful plant pests, these includes measures of electric shock [28] and electromagnetic-field weed control [29], which are harmless to people and ecosystems.

### 3.5. Intense Heat Treatment of Plant Diseases

Intense heat treatment of pests mainly refers to the use of steam disinfection, hot-water disinfection, circulation disinfection, flame disinfection and comprehensive disinfection, that is, using heat transfer media such as light, humid air, hot water, steam and far-infrared heating to transmit sufficient heat to plant diseases to cause bacterial inactivation or even death without affecting normal plant growth. Using fire to control plant pests has existed since ancient times. About 1500 years ago, the book "Important Arts for the Peoples Welfare" stated that "Take ripen wheat seeds, … and expose them to extreme dryness in the burning sun" [14]. Steam disinfection involves the use of dense high-pressure steam to improve soil drainage and permeability, killing pathogenic organisms in the soil. An indoor and outdoor steam treatment system was developed which consists of an enclosure and temperature monitoring and testing systems [30]. Numbers of naturally infected transplants were significantly reduced by fungicides and heat treatment (5 min at 49 °C) inside a greenhouse [31]. Far-infrared heat treatment can prevent and control citrus Huanglongbing (HLB) and consists of a heat treatment enclosure, far-infrared lamps, a temperature recorder and sensors [32].

### 3.6. Radiation Suppression and Killing of Pests

Measures of radiation suppression and killing of pests mainly utilize the electromagnetic radiation energy generated by periodic changes in electric and magnetic fields and transmitted through space to suppress or slow down the growth of harmful pests. Applications of electromagnetic radiation (from low to high frequencies) have been developed and have the potential to be developed for plant pest control, including radio waves (RF) [33], microwaves [34], infrared rays [35], visible light [35], ultraviolet rays, X-rays, γ radiation [36], etc.

# 4. Bio-Methods

Biological control methods mainly utilize the inter-species relationships between natural organisms, as well as information (such as physical, chemical, behavioral, etc.) related to ecosystems and genetic engineering, to control harmful pests, such as plant pathogens, insects and weeds, by restraining one or more organisms while protecting beneficial biological populations. Six measures are summarized, including natural enemy predating, natural enemy parasitizing, bio-pesticide application, plant immunization, pheromone interference and gene-driven operation (**Figure 1**).

## 4.1. Natural Enemy Predating

Suitable environments and facilities can be created to protect those insects that are native and natural enemies of plant pests and improve the predatory ability of natural enemies to prey on plant pests for the healthy growth of crops. Natural predatory enemies consist of two types of predatory arthropods and chordates. Predatory arthropods include lacewings, ladybugs, ants, dragonflies, ground beetles, mantis, robber flies, syrphid flies, predatory mites and other insects, as well as spiders. Predatory chordates include insectivorous birds, mammals and amphibious animals. More than 1600 years ago, the "Book of Southern Vegetation" stated that "If there were no such ants in the southern citrus trees, the fruits of the citrus trees would be bitten by insects, and there would be no complete fruit" [5]. The mentioned ants, yellow ants, were said to protect southern citrus trees from damage caused by beetles and the insect control performance of yellow ants depends on the collective strength of the ants, so the yellow ants were sold together in the nest. Over 1400 years ago, the book "Biographies in the Southern Dynasties" recorded that there were birds eating locusts and stated that "In the field when autumn falls, a thousand groups of birds suddenly arrive and the locusts disappear in the twinkling of an eye" [15]. During the Song Dynasty, it is said that "Frogs can feed on insects and catching frogs must be banned" [15].

## 4.2. Natural Enemy Parasitizing

Natural parasitic enemies, including natural parasitic insects such as parasitic wasps, parasitic flies, etc., and parasitic pathogenic nematodes such as nematodes, protozoa and microsporidia can kill plant pests by specifically parasitizing themselves inside or outside plant pests' bodies. Natural parasitic enemies (such as *trichogramma*) can be released appropriately through manual and mechanical operations or with gyroplanes and unmanned aerial vehicles, and there are also applications where *trichogramma* pupae can be dispersed into aqueous solutions for foliar spraying [37][38][39].

## 4.3. Bio-Pesticide Application

Bio-pesticides are formulations that use living organisms and active substances produced by biological metabolic processes to control harmful pests. Bio-pesticides include microbial pesticides, botanical pesticides, mineral-derived pesticides, biochemical pesticides, etc. Botanical and mineral-derived pesticides have been used to control plant diseases and pests for a long time. About 2700 years ago, the book of "Zhou Rites"recorded various methods of using bio-pesticides to treat pests such as "using coir lotus to fumigate the pests" and "using the illicium anisatum to fumigate the pests” [15]. In the book “Zheng Xuan’s Annotation for the Zhou Rites” written about 2000 years ago, it was said that illicium anisatum has effect of killing insects through fumigation [15]. About 600 years ago, the book “Complete Treatise on Agriculture” reported that “The method of controlling pests in the nearby fields is mostly to use lime and tung oil on the leaves kill the pests” [16]. Microbial pesticides, such as bacteria, fungi, viruses and other agents, are mainly sprayed to control plant pests. Entomopathogenic fungi can be used for endophytism, plant disease antagonism, plant growth promotion and rhizosphere colonization to play ecological roles as microbial control agents against pests in the forms of insects and plant pathogens [40]. Certainly, biological activity needs to be protected during bio-pesticide application because the flow of a biological pest control agent through an abrupt contraction could hydrodynamically damage entomopathogenic nematodes [41]. There exists a linear relationship between the spherical top of a flat-fan nozzle orifice structure and the viability of microbial pesticides [42].

## 4.4. Plant Immunization

Plant virus vaccines (plant immunity inducers) can activate or prime plant immunity. Plant immunization refers to resistant substances produced by exogenous organisms or molecules through the induction or activation of plants, which produce resistance to certain pathogens or inhibit the growth of pathogens and have the functions of inhibiting viruses and protecting plants. Plant immunity inducers, composed of active and beneficial microorganisms that conform to cultivation, can damage crop virus tissue and can be derived from animals, plants, microbes or their metabolites, active molecules produced during interactions between plants and microbes or natural/synthetic compounds. The identification of these compounds has accumulated considerable resources for the development of plant immune-induced pesticides. Transcripts derived from integrated viral elements (EVEs) may be beneficial to host plants by conferring levels of virus resistance and/or causing persistence/latency of viral infections [43]. After application, beneficial bacteria multiply in large numbers, forming a protective film around the crop, inhibiting bacteria and virus synthesis [44].

## 4.5. Pheromone Interference

The principle of pheromone interference in plant pest prevention and control is in using sex pheromones, aggregation pheromones, alarm pheromones, trace pheromones, dispersal pheromones, as well as queen pheromones, Nasonov pheromones, etc., to interfere with or block the transmission of information between harmful pests [45][46]. Without changing the production process of ordinary sun-shading nets, sun-shading and insect-prevention nets utilizing the slow release of pheromones have been developed through generalized pheromone modification and slowly release pheromones under ultraviolet driving and control plant pests from outside and inside the nets [47].

## 4.6. Gene-Driven Operation

By using gene-driven editing, the genes of diseases and insects can be knocked out through knockout, modification and replacement and healthy genes can be inserted into the plant genome; thus, plants can directly develop resistance against diseases and insects. RNA interference technology can be used to target the specific genes that play a crucial role in the growth and development of plant pests or important physiological processes. It introduces artificially synthesized exogenous double-stranded RNA into the body of plant pests to silence the expression of specific genes, affect their growth, development and reproduction and reduce their population density. Through transgenic and gene-editing methodologies, some wheat traits, including disease resistance, stress tolerance, growth and development regulation, etc., can be modified [48]. Gene drives have the potential to provide significant benefits in terms of the control of undesirable species, flexible management of resistance at the landscape scale and an overall more efficient and targeted use of pesticides that are highly elaborate and rely on complex interactions between genetic, genomic, biological and ecological specificities of targeted pests [49].

## 5. Chemical Methods

The Nobel Committee's words while presenting the 1970 Peace Prize to Dr. Norman E. Borlaug were as follows: "He had helped provide bread for a hungry world." The Green Revolution has developed high-yielding crops in an effort to feed hungry people, but these crops must be accompanied by agrochemicals and artificial fertilizers. There are four physical types of pesticide formulations: gas, liquid, gel/foam (hydrogels) and solid (nanoparticles) [50]. The formulations may be used as droplets, dusts, mists, aerosols, fogs, granules, etc.

### 5.1. Pesticide Spraying

Pesticide spraying refers to spreading pesticide formulations, such as emulsifiable concentrates, aqueous pesticides, wettable powders, soluble powders, colloidal suspensions, aerosols and solid powders, to targets by means of spraying, fogging or dusting to control plant pests. Spraying techniques spray liquid pesticides in the form of droplets by different methods, such as mechanical, pneumatic and electrostatic methods, etc. The fogging technique is a method of vaporizing liquid or solid fogging agents through thermal devices; the agents are then condensed in the air to form fine droplets that diffuse and uniformly adhere to target pests. Dusting techniques use mechanically generated wind forces to disperse low-concentration pesticide powders, causing the pesticide powder particles to suspend in the air and then deposit on plants to control target pests.

### 5.2. Pesticide Fumigation

Pesticide fumigation treatment uses fumigant compounds (such as bromomethane, aluminum phosphide, sulfuryl fluoride, etc.) to control insects, bacteria and other harmful pests in enclosed spaces. The toxic gases generated by the volatilization, gasification and sublimation of pesticide fumigants at room temperature enter the respiratory system of insects directly through their spiracles in a unimolecular gaseous state, causing them to be poisoned and die. Due to the high efficiency, good penetration, strong mobility and contact efficiency in enclosed spaces with limited area, pesticide fumigation treatment can fully exert control efficacy because pesticide fumigants can self-diffuse into any corner of an enclosed space and reach an effective insecticidal concentration in a short period of time.

### 5.3. Pesticide Injection

Relying on the conduction mechanism of plant vessels (capillary, infiltration, transpiration, etc.) to transport pesticides to the entire plant body to control pests, pesticides may be injected directly into the xylem of tree trunks or into the soil underneath the soil's surface layer, near the roots. Pesticide injection applications include soil injection, trunk injection, wormhole injection or blockage, root pesticide embedding, etc.

### 5.4. Pesticide Mopping and Painting

Pesticide mopping and painting measures apply liquid pesticides to certain parts of plant targets (such as tender crop stems or barked tree trunks) through mopping and painting, poisonous rings and other measures according to the diffusion ability and contact killing and inhaling functions of pesticides. There are several modes of action for pesticide mopping and painting measures, such as blockage, adhesion, repulsion and poisoning, in achieving a comprehensive pest control effect.

### 5.5. Bait Application

Based on the food chemotaxis of harmful pests, bait application applies an appropriate amount of a pesticide or toxic agent to food that harmful pests like to eat. Baits, prepared with a certain shape and color as attractants, are released (thrown) into plant rows, tree trays, rat holes and places of pest activity to deceive and lure the harmful pests to feed. Generally, certain physical trapping devices, chemical toxins or manual operation measures are combined to trap or kill pests.

### 5.6. Seed and Seedling Treatments

The critical time to control plant pests is in the early stages of plant growth, especially before the tillering stage, because infection at this time has the greatest impact on agro-forestry yield. However, seed quality might be reduced by certain seedborne diseases or destroyed by pests. Seed and seedling pesticide treatments can reduce, control or repel pests that attack seeds or seedlings without requiring plant protection practices throughout the growing season after the plants become self-sufficient. Preparation measures during seed processing or before sowing, such as seed dressing, soaking and coating with pesticides, are carried out for seed disinfestation and seed protection to protect seeds and young seedlings from pathogenic organisms in the soil. Seedling treatment involves the selection of appropriate pesticide types and dosages based on crop types and the occurrence of harmful plant pests in various regions. Effectively controlling harmful pests such as diseases, insects and rats that cause harm during seed germination and seedling growth after sowing or transplanting can ensure that crops are not harmed by pests.

## 6. Plant Quarantine

Plant quarantine is a legislative measure to prevent the accidental spreading, infestation and extension of dangerous harmful organisms (diseases, insects, weeds and other harmful pests) along with the movement and circulation of planting materials and plant products or soil; it is also used to prevent the introduction, colonization and expansion of all harmful organisms, which can harm agriculture, forestry and other ecosystems in a particular country/region. Plant quarantine is categorized into six measures, that is, interruption in pest proliferation, quarantine inspection in original planting area, epidemic source investigation and inspection, epidemic area control, virus-free plant breeding and disinfestation treatment of plant quarantine objects (**Figure 1**).

## 6.1. Interruption in Pest Proliferation

Interruptions in pest proliferation are the most effective and direct plant quarantine measure to fundamentally eliminate dangerous diseases, insects and weeds. Advanced X-rays, DNA probes, enzyme-linked immunosorbent assays (ELISA), electron microscopy, electrophoresis, electronic scanning, chromatography and pest attractants, monoclonal antibodies and fluorescence immunity are applied at entry–exit inspection ports to detect potentially harmful organisms, strangle the spread of invasive organisms from the source and block their spreading hazards. For example, a plant pest quarantine and identification system used an insect DNA barcoding identification kit for detection, selected gene fragments, designed new primers and performed amplification sequencing on target genes to determine the nucleotide diagnostic sites (identification characteristics) of wood beetle insect species and compared and identified dangerous insect species and their similarity [51].

## 6.2. Quarantine Inspection in Original Planting Area

Quarantine inspection in original planting area refers to inspections conducted by plant quarantine agencies during the production period of transferred plant seeds, seedlings and other propagating materials and plant products in agricultural and forestry production areas. Through initial pest identification in accordance with laws, inspections should be conducted to prevent the spread of contaminated plant products whether there are quarantined objects or other dangerous diseases, insects and weeds. Inspections have the characteristics of initiative, simplicity and reliability, which can effectively prevent the spread of dangerous plant organisms between regions. Inspections mainly carry out quarantine acceptance, investigation and identification, quarantine tracing, quarantine visa and control treatments of contaminated plant product [52].

## 6.3. Epidemic Source Investigation and Inspection

Seeds, seedlings and other propagating materials being imported that are suspected of carrying dangerous diseases, insects and weeds must be isolated for trial planting through epidemic source investigation and inspection. Under strict control conditions of isolation and trial planting, it is necessary to investigate the entire production process from seed germination to seed reproduction, inspect hidden diseases, insects, and weeds to avoid the accidental omission of plant quarantine sampling at entry ports, prevent the missed detection of pathogenic physiological races and viral diseases transmitted by individual seedlings due to the inability to detect them quickly and effectively and overcome shortcomings in entry port inspections and in the field inspection of originating areas. Before trial planting, temporal forecast epidemiological models and spatial pattern quantification can be developed to learn the spatiotemporal dynamics of plant diseases [53].

## 6.4. Epidemic Area Control

In the event of the spread of plant quarantine objects, impacts to the local geographical environment and transport conditions, etc., epidemic area control should be designated, brought under strict control and implemented through different measures, such as blockading and eradication, according to epidemic areas (where quarantine objects are found to be harmful), low-pest- or disease-prevalence areas (where a certain harmful pest is less prevalent and is placed under effective monitoring, control or eradication measures) and pest-free or disease-free areas (where no harmful pest is found) to prevent the spread of plant quarantine objects from the epidemic area and the introduction of plant quarantine objects into pest-free areas [54].

## 6.5. Virus-Free Plant Breeding

Plant viruses affect the growth and development of plants; the infectivity and proliferation of plant viruses especially pose a huge threat to plants. To prevent the cross-border spread of plant viruses during the trading of host plants, elimination of viruses in plants and virus-free plant breeding are necessary, that is, using tissue culture technology to detoxify valuable plant reproductive materials and reproduce sterile seedlings in large quantities. The elimination of viruses in plants and virus-free plant breeding include stem tip tissue culture, in vitro grafting of tender buds, detoxification through thermotherapy and treatment chemotherapy and combination methods (first thermotherapy treatment followed by stem tip tissue culture or the use of antiviral agents to inhibit the proliferation of plant diseases combined with stem tip tissue culture). Tissue culture, usually adopted to regenerate plantlets in biotechnological breeding programs, represents a less used tool in eliminating viruses from plants. With regard to viruses, thermotherapy was successfully applied against viruses belonging to 13 families and an unassigned genus. An interpretation of thermotherapy effects considers new metabolic “pathways” triggered by the natural antiviral response emitted by infected plants, with particular reference to virus-induced gene silencing. Instead, some plants (such as grapevine, apple, potato, etc.) viruses can be eliminated with chemotherapy and tissue culture. Viruses belonging to nine families were reportedly eradicated in a previous publication. Several groups of antiviral drugs belong to inosine monophosphate dehydrogenase inhibitors, S-adenosylhomocysteine hydrolase inhibitors and neuraminidase inhibitors [2].

## 6.6. Disinfestation of Plant Quarantine Objects

When harmful pests are found in plant seeds, seedlings or plant products that can be killed or eliminated under certain conditions, pest control measures can be applied to deal with the contaminated products. During the dormancy or growth periods of plant materials, disinfection treatments can be performed to effectively block and control quarantined plants and prevent the spread of dangerous harmful pests. Depending on specific requirements for the transportation of imported and exported plant products and the epidemic situation, alternative disinfestation treatments can be applied to high-quality marketable imported and exported products, including mechanical treatment, washes and chemical dips, fogs and aerosols, pesticide fumigation, anaerobic disinfestation, thermal agent treatments, freezing and low-temperature treatment, controlled atmosphere, cobalt-60 irradiation, etc. In order to disinfest soils for remediation from contaminating quarantine pathogens, anaerobic (non-chemical) soil disinfestation and inundation were applied as separate treatments [55]. Related technologies can be studied to disinfect plant quarantine objects and have been applied in food grains; such technologies include microwaves, radio waves, infrared, ohmic heating and novel drying methods along with non-thermal methods such as cold plasma, irradiation, ozonation and nanotechnology [56].

# 7. Integrated Pest Management

IPM is a plant protection method that integrates, coordinates and optimizes the application of necessary measures such as physical control, biological control, chemical control, agricultural methods, plant quarantine, etc. Based on the interaction mechanisms between pests and environments and dynamic changes in pests populations, the overall role of natural control factors in the ecosystem is taken into account to control populations of harmful pests within an allowable threshold of economic harm for a long time in order to achieve optimal economic, ecological and social benefits. But there are some IPM roadblocks and adoption barriers: low levels of farmer adoption and insufficient IPM technology diffusion are invariably ascribed to different factors, some of which closely related to local farming contexts, such as a weak farmer knowledge base, user preferences and risk aversion, vested interests and corporate responsibility, traditional practices and emerging IPM technologies, hard and soft policy levers, cultural barriers and a decline in public interest of science [41]. Therefore, based on a large amount of global related research [3][4][7][11], six IPM measures are summarized, that is, timely prevention and control, plant population control and management, food chain regulation of natural enemies of plant pests, customized cultivation of resistant plants, continuous comprehensive pest treatments and plant-centered prevention and control philosophy (**Figure 1**).

## 7.1. Timely Pest Control

Given increasing concerns about the environmental impact of pesticides, judicious microbiome modification via nutrient management for modifying plant-associated microbiomes to fortify plant health may enable people to hit multiple birds with one stone [3]. The concept of timely prevention and control is in developing the best strategy that is also harmless to natural enemies and the environment based on the hazard threshold of plant pests. Only when the number of pests and pathogens reaches a certain threshold and endangers the normal growth of crops can scientific prevention and control be carried out in a timely manner. The optimization of natural pest control by adoption of specific management practices at local and landscape scales, such as establishment of non-crop areas, low-impact tillage and temporal crop rotation, could significantly reduce dependence on pesticides and foster yield stability through ecological intensification [57]. More than 2000 years ago, the books “Master Huainan·Main Skilling” and “Garden of Eloquence·Xiuwen” advocated that “You must not burn fields with fire before insects hibernate” meaning that one must recognize and protect the existence and reproductive rights of insects [6]. About 1500 years ago, the book “Important Arts for the Peoples Welfare” stated that “The farmers who cultivate the land in October and November do not directly oppose the natural law, but it really harm the hibernating insects, and the land will be infertile and non-moisturized which may result in the thin and scarce harvest” [7].

## 7.2. Managing Plant Populations

Based on the allelopathic effects of plants, several parallel implementation measures can be explored for plant population control and management. Ecological regulation can be achieved through a combination of plant population management measures, such as field-cleaning engineering, functional plant populations, plant push–pull technology, natural enemies for pest control, biological control, physical control and even moderate chemical control with selective pesticides. Multiple cropping systems can regulate pests, in the broadest sense, by preventing their growth, reproduction or dispersal and can modify pest foraging or reproduction directly (i.e., bottom–up control) or increase the abundance of natural enemies of pests, which are mainly insect herbivores (i.e., top–down control). Pests can be controlled using pull or push–pull strategies for which the basic principle consists in promoting habitats that are unsuitable for pests and/or suitable for pest control auxiliaries. Push–pull strategies use repellent "push" plants to discourage pests from settling on crops and "pull" plants to attract them to neighboring plants [58]. In a push–pull system, trap and repellent plants are used to control populations of stem borers. Insects are trapped on highly susceptible trap plants (pull) and repelled from the main crop by repellent intercrops (push) [59].

## 7.3. Food Chain Regulation of Natural Enemies of Plant Pests

Natural enemies have been shown to be effective agents for controlling insect pests in crops. But the density of pollen beetles has significantly decreased with an increased proportion of non-crop habitats in the landscape. In addition, the overuse of pesticides can lead to population decline among beneficial insects like natural enemies and pollinators [57]. So, the food chain regulation of natural enemies of plant pests must be emphasized to ensure optimal conditions for the survival and normal reproduction of ecological natural enemies, through utilizing beneficial insects in nature and artificially releasing insects to control local plant diseases, insects and weeds. Approaches toward benefiting ecological natural enemies include protecting local natural enemies, artificially breeding natural enemies, introducing ecological natural enemies and accurately releasing natural enemies.

## 7.4. Customized Cultivation of Resistant Plants

Customized cultivation of resistant plants involves the use of genetic variations in plant stress-factor resistance to select populations or individuals with resistance or tolerance to biotic stresses of pests, through certain customized cultivation pathways. Through transgenic and gene-editing methodologies, some wheat varieties were created that showed disease resistances to powdery mildew, rusts, scab and yellow mosaic virus [48]. In order to obtain durable resistance, alternative strategies for the deployment of R genes and the use of quantitative race non-specific resistance were advocated. Two approaches are taken into account, that is, plant transformation and marker-assisted selection. A change in focus from durability of the plant phenotype to that of the crop phenotype was advocated [60].

## 7.5. Continuous Comprehensive Pest Treatments

In response to the complexities associated with the prevention and control of plant pests, continuous comprehensive pest treatments can be developed. Continuous comprehensive pest treatments should first consider the use of mechanical, physical and agricultural measures to prevent harmful plant pests then consider the development of plant resistance and tolerance, plant immune grafting, chemical pheromones, inter-species and intra-species crop diversity and biological control and, finally, apply chemical control. For example, pesticides must be applied because relative yield loss is positively associated with pest density, but the economic return of management actions is a major criterion for farmer decision making. As the cost-effectiveness of current pesticide-based pest management is often questioned, the relationship between surrounding landscape composition and pest densities and crop injury is analyzed with mixed-effects models through comparing the various elements in the full cascade from natural enemy and pest abundance to crop injury, yield loss, labor and economic performance in [61]. That is, the more ecologically based pest management strategies could comprehensively be taken into account such as continuous comprehensive pest treatments through agricultural, physical, chemical and/or biological control, etc. Pesticide nanoformulations including nanomaterials as active ingredients and nanoemulsions of biopesticides need to be explored [62].

### 7.6. Plant-Centered Prevention and Control Philosophy

The concept of “Agroecological Crop Protection(ACP)” was proposed and emphasized a crop-centered philosophy instead of a pest-centered philosophy for plant protection [4]. From the spatiotemporal perspective of the “Eight Ps”, agricultural and ecological plant protection includes pests and plants, pesticides, policies, people, production, participation and profits. The scope of harmful pests (pest-centered) in traditional IPM can be broadened and extended through endowing plants, pesticides, policies, people, production, participation and profits to be unified into a plant-centered concept for plant ecosystem optimization practices. Then, the novel methods for sustainable plant protection can be continually found and explored from the perspectives of biodiversity and soil health by directly or indirectly optimizing the interactions between plant, pests and microbial communities, in order to make ecological functions less susceptible to biological stress and improve the health status of agro-forestry ecosystems.

## References

1. Bargués-Ribera1, M.; Gokhale, C. Eco-evolutionary agriculture: A study in crop rotations. bioRxiv 2018.
2. Panattoni, A.; Luvisi, A.; Triolo, E. Review. Elimination of viruses in plants: Twenty years of progress. Span. J. Agric. Res. 2013, 11, 173–188.
3. Kang, S.; Lumactud, R.; Li, N.; Bell, T.; Kim, H.; Park, S.; Lee, Y. Harnessing Chemical Ecology for Environment-Friendly Crop Protection. Phytopathology 2021, 111, 1697–1710.
4. Deguine, J.P.; Aubertot, J.N.; Flor, R.J.; Lescourret, F.; Wyckhuys, K.A.; Ratnadass, A. Integrated pest management: Good intentions, hard realities. A review. Agron. Sustain. Dev. 2021, 41, 38.
5. Cheng, L. Biological Control in Ancient China. Acta Phytopathol. Sin. 1981, 8, 23–26.

6. Zhang, R.; Zhang, T.; Ji, W. The Ecological Thoughts in Chinese Traditional Agriculture and its Utilization. Acta Ecol. Sin. 1996, 16, 100–106.
7. Yan, H. An Ancient Form of Animal Rights Theory-The Theory and Technology of Pest Controlling in Ancient China. J. Nanjing Univ. Sci. Technol. 2005, 18, 85–87.
8. Zheng, J.; Zhou, H.; Xu, Y. Precision Pesticide Application Technique; Science Press: Beijing, China, 2006; ISBN 7-03-016636-1.
9. Bode, L.E.; Bretthauer, S. Agricultural chemical application technology: A remarkable past and an amazing future. Trans. ASABE 2008, 51, 391–395.
10. Stone, C.; Mohammed, C. Application of remote sensing technologies for assessing planted forests damaged by insect pests and fungal pathogens: A review. Curr. For. Rep. 2017, 3, 75–92.
11. Belyakov, N.V.; Nikolina, N.V. Plant protection technologies: From advanced to innovative. J. Phys. Conf. Ser. 2021, 1942, 012072.
12. Wang, Z. On the Record of Locust Plagues in the History of Qin Dynasty. J. Zhengzhou Univ. 2020, 53, 90–98, 124.
13. Carson, R. Silent Spring; Tianjin People’s Press: Tianjin, China, 2019; ISBN 978-7-201-15036-9.
14. Jia, S.X.; Miao, Q.Y.; Miao, G.L. Important Arts for the Peoples Welfare; Shanghai Ancient Books Publishing House: Shanghai, China, 2006; pp. 29, 42, 52, 311. ISBN 7-5325-4421-4.
15. Gong, G.; Yang, W. Ancient Practice of Pest Prevention and Control of Biodiversity and Its Implication for Today. J. Shanxi Agric. Univ.Soc. Sci. Ed. 2013, 12, 871–875.
16. Xu, G.Q.; Chen, H.L.; Luo, W.H. Complete Treatise on Agriculture; Yuelu Publishing House: Changsha, China, 2002; pp. 33, 562, 607. ISBN 7-80665-211-6.
17. Zaim, N.S.H.B.H.; Tan, H.L.; Rahman, S.M.A.; Abu Bakar, N.F.; Osman, M.S.; Thakur, V.K.; Radacsi, N. Recent Advances in Seed Coating Treatment Using Nanoparticles and Nanofibers for Enhanced Seed Germination and Protection. J. Plant Growth Regul. 2023, 42, 7374–7402.
18. Pan, C. The Development of Integrated Pest Control in China. Agric. Hist. 1988, 62, 1–12. Available online: http://www.jstor.org/stable/3743477 (accessed on 7 October 2023).
19. Liu, Q.; Zhou, Q.; Cong, X.; An, A.; Nie, Y. Study on Locust Trapping Behavior Regulation Induced by Photoelectric Light. Prog. Mod. Biomed. 2015, 15, 45–52.
20. Mizrach, A.; Hetzroni, A.; Mazor, M.; Mankin, R.W.; Ignat, T.; Grinshpun, J.; Epsky, N.D.; Shuman, D.; Heath, R.R. Acoustic trap for female Mediterranean fruit flies. Trans. ASAE 2005, 48, 2017–2022.
21. Zha, Y.; Wu, X.; Zhang, Z.; Chen, J.; Chen, Q. Influence of ultrasound on juvenile hormone titers in Monochamus alternatus Hope (Coleoptera: Cerambycidae). Sci. Rep. 2021, 11, 1450.

22. Hammers, R.L. Picturing Tools for a Perfect Society: Wang Zhen's 'Book of Agriculture' and the Northern Song Reforms in the Yuan Dynasty. J. Song-Yuan Stud. 2012, 42, 279–308.
23. Kshetri, S.; Jiken, J.J.; Steward, B.L.; Tang, L.; Tekeste, M.Z. Investigating the effects of interaction of single-tine and rotating -tine mechanisms with soil on weeding performance using simulated weeds. Trans. ASABE 2019, 62, 1283–1291.
24. Zhang, L.; Tang, K.; Zhao, Y.; Wang, X.; Yu, D.; Lu, X.; Wang, X. Optimization of leg structure parameter of quadruped laser weeding robot. Trans. CSAE 2020, 36, 7–15.
25. Shimoda, M.; Honda, K. Insect reactions to light and its applications to pest management. Appl. Entomol. Zool. 2013, 48, 413–421.
26. Huang, B.; Lin, G.; Wang, X.; Zhang, X. Control effects of fly nets to the pests of vegetables in greenhouses. Plant Prot. 2013, 39, 164–169, 187.
27. Feat, A.; Federle, W.; Kamperman, M.; van der Gucht, J. Coatings preventing insect adhesion-An overview. Prog. Org. Coat. 2019, 134, 349–359.
28. Zhu, L.; Xue, S.; Chen, J.; Yan, Q. Parameter optimization on killing aphid by using high-voltage electrostatic discharge. Trans. CSAE 2013, 29, 46–51.
29. Davis, F.; Wayland, J.; Merkle, M. Ultrahigh frequency electromagnetic fields for weed control: Phytotoxicity and selectivity. Science 1971, 173, 535–537.
30. Jia, Z.; Ehsani, R.; Zheng, J.; Xu, L.; Zhou, H.; Ding, R. Heating characteristics and field control effect of rapid citrus huanglongbing steam heat treatment. Trans. CSAE 2017, 33, 219–225.
31. Freeman, S.; Nizani, Y.; Dotan, S.; Even, S.; Sando, T. Control of Colletotrichum acutatum in Strawberry Under Laboratory, Greenhouse, and Field Conditions. Plant Dis. 1997, 81, 749–752.
32. Zhang, J.; Lin, G.; Chen, H.; Wen, S.; Yin, X.; Deng, X. Experiment on Temperature Field Distribution Characteristics of Citrus HLB Far Infrared Heat Treatment. Trans. CSAM 2019, 50, 175–188.
33. USDA. Radio Frequency Puts the Heat on Plant Pests. Agric. Res. 2003, 51, 15. Available online: https://agresearchmag.ars.usda.gov/ar/archive/2003/feb/radio0203.pdf (accessed on 14 September 2023).
34. Rahi, G.; Rich, J. Potential of microwaves to control plant-parasitic nematodes in soil. J. Microw. Power Electromagn. Energy 2008, 42, 5–12.
35. Gaetani, R.; Lacotte, V.; Dufour, V.; Clavel, A.; Duport, G.; Gaget, K.; Calevro, F.; Da Silva, P.; Heddi, A.; Vincent, D. Sustainable laser based technology for insect pest control. Sci. Rep. 2021, 11, 11068.

36. Wang, Y.; Wu, P. Inactivation of Tilletia controversa Kuhn by Cobalt 60-γ radiation. Plant Quar. 1993, 7, 267–268.
37. Li, D.; Yuan, X.; Zhang, B.; Zhao, Y.; Song, Z.; Zuo, C. Report of Using Unmanned Aerial Vehicle to Release Trichogramma. Chin. J. Biol. Control. 2013, 29, 455–458.
38. Bzowska-Bakalarz, M.; Bulak, P.; Bereś, P.K.; Czarnigowska, A.; Czarnigowski, J.; Karamon, B.; Pniak, M.; Bieganowski, A. Using gyroplane for application of Trichogramma spp. Against the European corn borer in maize. Pest Manag. Sci. 2020, 76, 2243–2250.
39. Gauthier, P.; Khelifi, M.; Dionne, A.; Todorova, S. Technical feasibility of spraying Trichogramma ostriniae Pupae to control the European corn borer in sweet corn crops. Appl. Eng. Agric. 2019, 35, 185–192.
40. Jaber, L.; Ownley, B. Can we use entomopathogenic fungi as endophytes for dual biological control of insect pests and plant pathogens? Biol. Control 2018, 116, 36–45.
41. Fife, J.P.; Derksen, R.C.; Ozkan, H.E.; Grewal, P.S.; Chalmers, J.J.; Krause, C.R. Evaluation of a contraction flow field on hydrodynamic damage to entomopathogenic nematodes-a biological pest control agent. Biotechnol. Bioeng. 2010, 86, 96–107.
42. Zhai, E.; Zheng, J.; Zhou, H.; Ru, Y.; Li, J. Effects of flat-fan nozzle wear on application of microbial pesticides. J. For. Eng. 2018, 3, 109–116.
43. Takahashi, H.; Fukuhara, T.; Kitazawa, H.; Kormelink, R. Virus Latency and the Impact on Plants. Front. Microbiol. 2019, 10, 2764.
44. Yang, B.; Yang, S.; Zheng, W.; Wang, Y. Plant immunity inducers: From discovery to agricultural application. Stress Biol. 2022, 2, 5.
45. Abid, I.; Laghfiri, M.; Bouamri, R.; Aleya, L.; Bourioug, M. Integrated pest management (IPM) for Ectomyelois ceratoniae on date palm. Curr. Opin. Environ. Sci. Health 2021, 19, 100219.
46. Wu, S.; Shen, Z.; Fang, M.; Hong, W.; Wo, L.; Liu, T.; Deng, J. Application effect of sex pheromone disorientation on prevention and control of Grapholitha molesta Busck in yellow peach orchard. China Plant Prot. 2020, 40, 52–54.
47. Zhang, J.; Nong, W.; Wang, F. Broad-spectrum pheromone appear in the insect repellent world. China Science Daily, 12 February 2019. Available online: https://news.sciencenet.cn/sbhtmlnews/2019/2/343344.shtm(accessed on 14 February 2019).
48. Yu, M.; Tang, H.; Ye, X. Progresses on Wheat Improvement by Using Transgenic and Genome Editing Technologies. J. Plant Genet. Resour. 2023, 24, 102–116.
49. Legros, M.; Marshall, J.M.; Macfadyen, S.; Hayes, K.R.; Sheppard, A.; Barrett, L.G. Gene drive strategies of pest control in agricultural systems: Challenges and opportunities. Evol. Appl. 2021, 14, 2162–2178.

50. Stejskal, V.; Vendl, T.; Aulicky, R.; Athanassiou, C. Synthetic and Natural Insecticides: Gas, Liquid, Gel and Solid Formulations for Stored-Product and Food-Industry Pest Control. Insects 2021, 12, 590.

51. Ye, J.; An, Y.; Qian, L.; Yang, X.; Xu, M.; Wu, C.; Wei, C.; Niu, L.; Gan, Y. Development and application of quarantine insect DNA barcoding technology. Chin. J. Appl. Entomol. 2015, 52, 382–389.

52. National Forestry and Grassland Administration. Technical Rules for Producing Site Quarantine of Forestry Plants; LY/T 1829-2020; National Forestry and Grassland Administration: Beijing, China, 2020.

53. Van Maanen, A.; Xu, X. Modelling plant disease epidemics. Eur. J. Plant Pathol. 2003, 109, 669–682.

54. Ministry of Agriculture. Regulations on Plant Quarantine; Ministry of Agriculture: Beijing, China, 1992.

55. Van Overbeek, L.; Runia, W.; Kastelein, P.; Molendijk, L. Anaerobic disinfestation of tare soils contaminated with Ralstonia solanacearum biovar 2 and Globodera pallida. Eur. J. Plant Pathol. 2014, 138, 323–330.

56. Sirohi, R.; Tarafdar, A.; Gaur, V.K.; Singh, S.; Sindhu, R.; Rajasekharan, R.; Pandey, A. Technologies for disinfection of food grains: Advances and way forward. Food Res. Int. 2021, 145, 110396.

57. Matteo, D.; Gudrun, S.; Jochen, K.; Ingolf, S. Complementarity among natural enemies enhances pest suppression. Sci. Rep. 2017, 7, 8172.

58. Gaba, S.; Lescourret, F.; Boudsocq, S.; Enjalbert, J.; Hinsinger, P.; Journet, E.; Navas, M.; Wery, J.; Louarn, G.; Malézieux, E.; et al. Multiple cropping systems as drivers for providing multiple ecosystem services from concepts to design. Agron. Sustain. Dev. 2015, 35, 607–623.

59. Khan, Z.R.; Pickett, J.A.; Van den Berg, J.; Wadhams, L.J.; Woodcock, C.M. Exploiting chemical ecology and species diversity: Stemborer and striga control for maize and sorghum in Africa. Pest Manag. Sci. 2000, 56, 957–962.

60. Pink, D.; Hand, P. Plant resistance and strategies for breeding resistant varieties. Plant Prot. Sci. 2002, 38 (Suppl. S1), 9–13.

61. Zou, Y.; de Kraker, J.; Bianchi, F.; Xiao, H.; Huang, J.; Deng, X.; van der Werf, W. Do diverse landscapes provide for effective natural pest control in subtropical rice? J. Appl. Ecol. 2020, 57, 170–180.

62. Kumar, S.; Nehra, M.; Dilbaghi, N.; Marrazza, G.; Hassan, A.A.; Kim, K.H. Nano-based smart pesticide formulations: Emerging opportunities for agriculture. J. Control. Release 2018, 294,

131–153.