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Electric Discharge-Generating Devices Developed for Pathogen, Insect Pest, and Weed Management: Current Status and Future Directions

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Abstract: Electrostatic techniques have introduced innovative approaches to devise efficient tools for pest control across various categories, encompassing pathogens, insects, and weeds. The focus on electric discharge technology has proven pivotal in establishing effective methods with simple device structures, enabling cost-effective fabrication using readily available materials. The electric discharge-generating devices can be assembled using commonplace conductor materials, such as ordinary metal nets linked to a voltage booster and a grounded electric wire. The strategic pairing of charged and grounded conductors at specific intervals generates an electric field, leading the charged conductor to initiate a corona discharge in the surrounding space. As the applied voltage increases, the corona discharge intensifies and may eventually result in an arc discharge due to the breakdown of air when the voltage surpasses the insulation resistance limit. The utilization of corona and arc discharges plays a crucial role in these techniques, with the corona-discharging stage creating (1) negative ions to stick to pests, which can then be captured with a positively charged pole, (2) ozone gas to sterilize plant hydroponic solutions, and (3) plasma streams to exterminate fungal colonies on leaves, and the arc-discharging stage projecting electric sparks to zap and kill pests. These electric discharge phenomena have been harnessed to develop reliable devices capable of managing pests across diverse classes. In this review, we elucidate past achievements and challenges in device development, providing insights into the current status of research. Additionally, we discuss the future directions of research in this field, outlining potential avenues for further exploration and improvement.

Keywords: arc discharge; conductor; corona discharge; electric field; ionic wind; negative ion; ozone generation; plasma stream; spark irradiation; voltage booster

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1. Introduction

A dipolar electric field can be generated by pairing charged and grounded conductors. Common conductor materials, such as ordinary metal nets, plates, and wires, are suitable for this purpose. The charging and grounding of conductors are achieved by connecting them to a voltage booster and grounded wire, respectively. A voltage booster is a tool used to increase the initial voltage (12 V) to the desired levels. Using the enhanced voltage, a negative voltage booster extracts negative charge from the ground and supplies it to a conductor connected to the voltage booster (negative charging of a conductor) [1].

Conversely, a positive voltage booster draws free electrons from a conductor, leaving a positive charge on it (positive charging of a conductor) [1].

In the configuration of two conductors mentioned above, a negatively or positively charged conductor induces an opposite charge on a grounded conductor through electrostatic induction [2], forming a dipolar electric field between the opposite charges of these two conductors. In this electric field, as the applied voltage is increased, corona discharge initially occurs in the space surrounding the charged conductor at a certain voltage. With further increases in voltage, the corona discharge range expands. Eventually, when the applied voltage exceeds a threshold, causing the breakdown of the insulation resistance of the air, an arc discharge with a spark occurs [3]. Thus, the type and intensity of these electric discharge phenomena can be controlled by adjusting the voltage applied to the conductor. This principle has been utilized in the development of various devices for controlling a range of target pests, including pathogens, insects, and weeds [4].

The key feature of the corona-discharging electric field is the generation of an ionic wind (electric wind), negative ions, and ozone gas. Ionic wind refers to the flow of charged particles induced by electrostatic forces during corona discharge at the tips of sharp conductors (such as points or blades) exposed to high voltages [5]. This airflow is significantly enhanced with higher voltages, making it beneficial for incorporating external air into pest control devices [6]. Negative ions play a crucial role in negatively charging targets through ion adhesion, which are transported into the apparatus by the ionic wind [6,7]. Eventually, these negatively charged targets can be captured by a grounded conductor with opposite electrification [6,7]. This mechanism is applicable to precipitating air pollutants [7,8] and airborne microorganisms [6,9–12]. Ozone, a potent antimicrobial agent, can be easily produced using electrostatic techniques [13]. Sterilizing pathogens in water typically involves bubbling ozone-containing air into the water [14]. The strong oxidizing ability of ozone effectively sterilizes microbes in water upon contact with air bubbles containing ozone [15]. This technique is highly effective for safeguarding hydroponic plants from bacterial and fungal pathogens in the aqueous rhizosphere [14].

Arc discharge can be effectively used for pest control due to its powerful impact on targets [16–19] and the ability to electrocute them with a transient current [18]. To create a device for this purpose, a corona-discharging apparatus is employed, typically constructed using two charged and grounded metal nets [16,19]. In this setup, the charged metal net generates a corona discharge when there is no target in the electric field (the space between the nets). However, when a target enters the electric field and is grounded, the apparatus can produce an arc discharge toward the target. Flying insects are easy targets as they perch on the grounded metal net before entering the electric field, making them susceptible to arc discharge-mediated sparks. This process is effective in eliminating flies transmitting viral and bacterial pathogens [18,20]. Additionally, weed seedlings emerging from the ground covered with a charged metal net can also be eradicated by exposing them to sparks [21,22].

In this review article, we present various devices developed for pest control, emphasizing their simple structures and operation based on straightforward electrostatic principles. This simplicity aims to inspire non-technical readers to easily and affordably construct these devices using common materials or adapt them to their specific needs. The goal is to encourage active participation in new research initiatives related to pest control. Ongoing research in this field provides valuable insights for developing dependable pest control methods, ensuring sustainable crop production that can adapt effectively to diverse changes in different agricultural systems.

2. Electric Discharge Generation

Discharge refers to the generation of electric current between opposing poles due to the breakdown of gases in the electric field caused by the potential difference between the conductor poles [3]. The charged conductor initiates a corona discharge in the surrounding space. As the applied voltage increases, the corona discharge intensifies and may eventually result in an arc discharge due to the breakdown of air when the voltage surpasses the insulation resistance limit [3]. The corona discharge phenomenon involves continuous discharge triggered by an uneven electric field formed around the pointed tip of an electrode (needle pole) [23]. The faint light surrounding the tip is known as a corona. The type of corona varies depending on factors such as the polarity of the needle pole (positive or negative charge), the potential difference between the poles (voltage difference), and the distance between the poles. When the needle pole is positively charged, a corona discharge (positive corona discharge) can transition from a faint glow (corona discharge surrounding the tip) to a streamer discharge through a brush-like discharge as the applied voltage increases and/or the distance between the poles decreases. Eventually, the discharge evolves into an arc discharge between the two poles. On the other hand, when the needle pole is negatively charged, corona occurs at lower voltages compared to the positive needle pole. Although a faint glow corona with short streamer discharge forms, it does not grow larger and leads to a complete breakdown in the form of an arc discharge.

3. Ozone-Generative Spore Precipitator

The ability to generate ozone using electrostatic techniques opened up the possibility of integrating ozone production into other electrostatic devices designed for pathogen control. Building on this concept, Shimizu et al. [14] enhanced an electrostatic spore precipitator to generate ozone for sterilizing bacterial and fungal pathogens in the aqueous rhizosphere of hydroponically grown plants (Figure 1), achieving dual protection for tomato plants against leaf infections caused by airborne conidia of *Oidium neolycopersici* and root infections by *Ralstonia solanacearum* and *Fusarium oxysporum* f. sp. *radicis-lycopersici*.

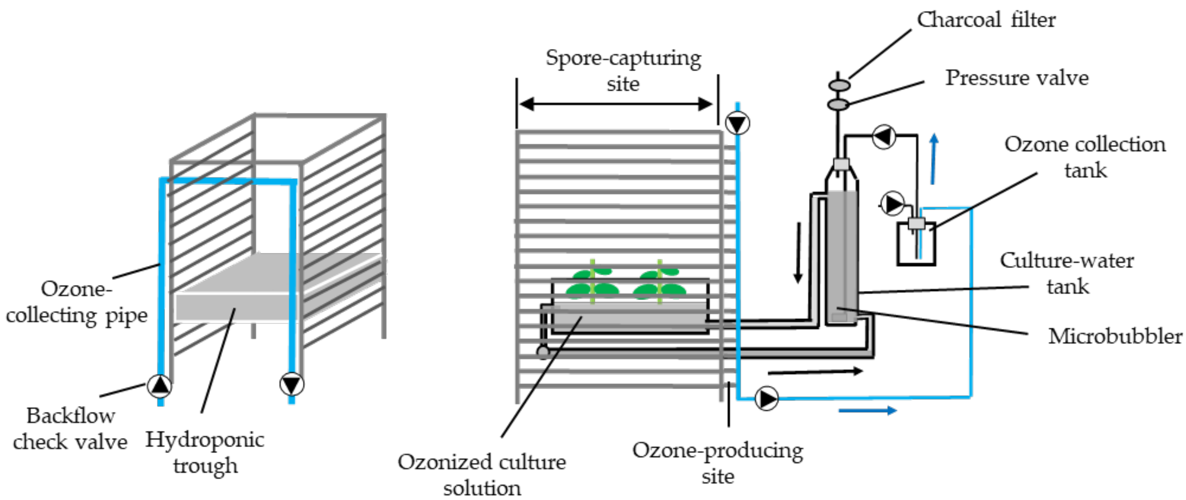

Figure 1. Schematic representation of the dual control system of rhizosphere and aerial pathogens for hydroponic plants by use of an ozone-generative spore precipitator [14]. The device possessed multiple ozone-generative spore precipitation cylinders installed on a rectangular frame at a constant interval. The ozone produced in each cylinder was transferred to an ozone collection tank by an aspirator pump and supplied to the culture solution tank after adjusting the ozone concentration. Finally, the ozonized culture solution was circulated between the tank and hydroponic culture trough. Ozone is highly insoluble in water under normal temperature and pressure and can easily

be converted into oxygen, such that it is impossible to dissolve ozone in water at the required concentrations for disinfection. Sterilization of pathogens in water was conducted by bubbling ozone-containing air into water. The strong oxidizing ability of ozone sterilizes microbes in the water when they come into contact with the air bubbles containing ozone. Black and blue arrows represent the direction of ozone gas and ozonized culture solution, respectively.

In the original spore precipitator design [24], a negatively charged metal wire enclosed in an acrylic cylinder for insulation induced dielectric polarization of the insulator cylinder, resulting in positive polarization of the inner surface and negative polarization of the outer surface (Figure 2A). The negative charge on the outer surface established an electrostatic field (non-discharging electric field) in the surrounding air, attracting spores towards the cylinder through dielectrophoretic movement [25]. After preliminary results showed that positively charging the conductor yielded higher ozone production than negatively charging it, Shimizu et al. [14] demonstrated that positive charging of an inner conductor wire could create a positive charge on the cylinder surface, exerting a similar attractive force on spores (Figure 2B). They then added a corona discharge region for ozone generation at the end of the cylinder, where the tip of a positively charged metal wire was positioned, with a grounded metal ring set at the cylinder's end (Figure 2B). In this configuration, the ozone gas produced was transported to the cylinder's end by the ionic wind and collected in another pipe attached to the cylinder (Figure 2B). Multiple cylinders were used to construct a seedling nursery shelter, effectively protecting hydroponic tomato plants from both phyllosphere and rhizosphere infections (Figure 1).

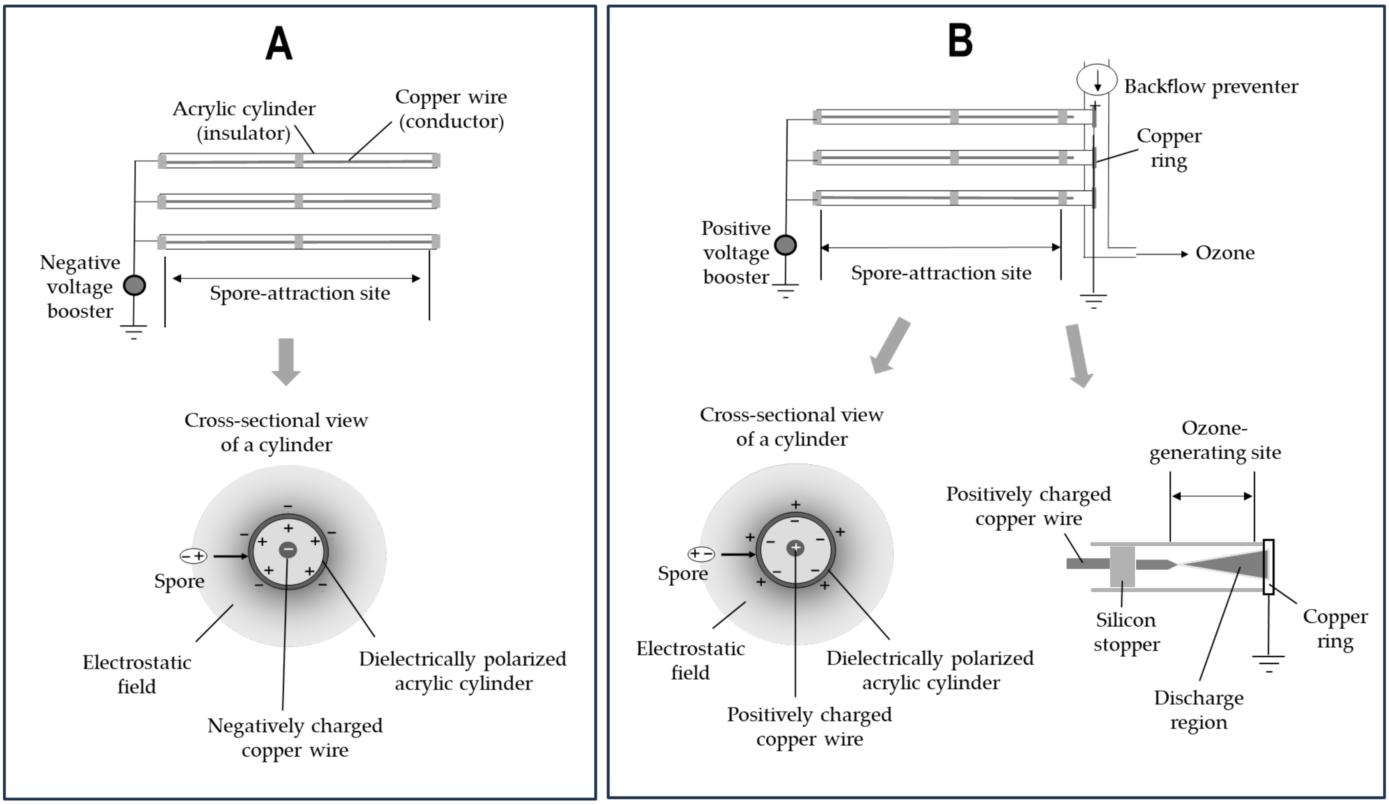

Figure 2. (**A**) Schematic representation of the original spore-precipitation cylinder to trap airborne fungal spores [24]. Copper wire (conductor) was covered with a transparent acrylic cylinder (insulator) and held at the middle, and both ends of the cylinder with insulating silicon stoppers. The cylinders were arranged in parallel. The copper wires were linked to a negative voltage booster (upper). The polarized dielectric cylinder produces an electrostatic field to cause the dipole on the spore. Spores were attracted to the cylinder through dielectrophoretic movement (lower). (**B**)

Illustration depicting a spore-precipitation cylinder designed for ozone production [14]. Each cylinder has a region at one end to generate ozone, and the remaining part of the cylinder is used to capture airborne spores. The copper wire was positively charged, and the electrostatic field was formed in the space around the dielectrically polarized cylinder. The ability to capture spores was the same as that of the original spore-precipitation cylinder. One tip end of the copper wire inside the acrylic cylinder was sharpened to create a needle pole. Continuous corona discharge (streamer discharge) was induced by the electric field between the tip end of the copper wire and a grounded copper ring attached to the cylinder edge. The ozone produced in each cylinder was transferred to a collection tank by an aspirator pump.

4. Portable Device for Eliminating Fungal Pustules on Leaves Using Plasma Stream

In the course of researching discharge generation techniques, a portable device has been developed specifically for tackling fungal pustules on leaves (Figure 3A). This device comprises a copper needle with a pointed tip, serving as the plasma-exposing probe, an insulating acrylic cylinder, and a negative voltage booster [26]. The needle, insulated with a vinyl sleeve except for its pointed tip, was centrally fixed within the cylinder and connected to the voltage booster (Figure 3B). Operating on a negative charge, the needle interacted with a grounded plant. The probe generated a corona discharge around its negatively charged pole, creating a plasma stream via the electric field between the needle pole and the fungal pustule on the leaf surface of the grounded plant (Figure 3B). As the electric field propels positive ions and electrons toward their respective poles, their velocity is contingent upon the applied voltage and the distance between the poles. The movement of electrons led to collisions with molecules like nitrogen and oxygen, producing additional electrons and ions that migrate towards the earth's ground. This cascade effect generated a significant number of positive ions and electrons, thereby forming a plasma [27].

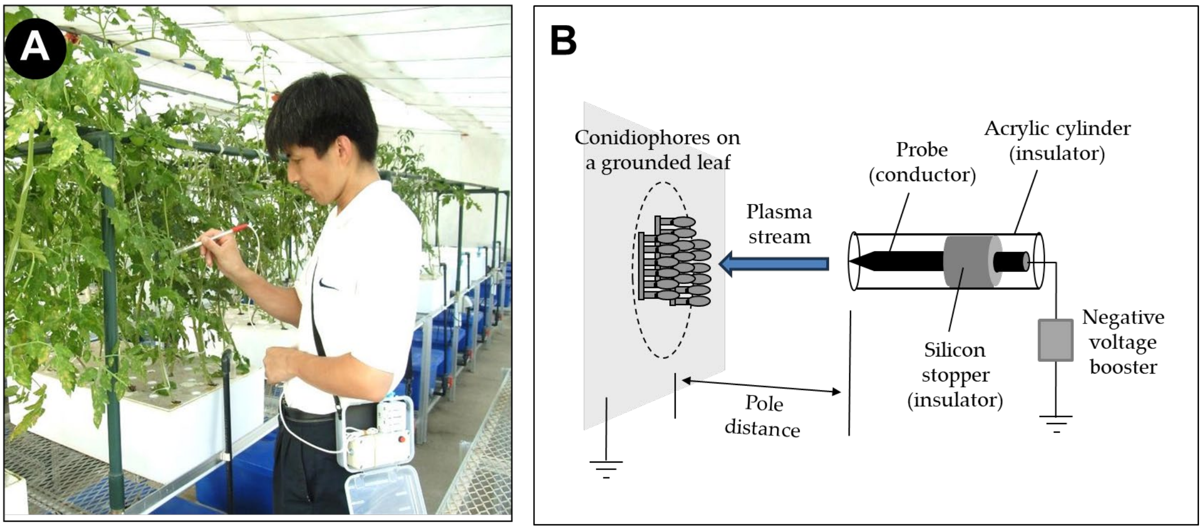

Figure 3. (**A**) A portable plasma-stream exposer with a battery-operated voltage booster [26]. (**B**) The diagram shows the spatial relationship between the charged probe tip and the grounded tomato leaf. The distance between the tip and the leaf was adjusted to determine the optimal tip position at which conidiophores were instantly destroyed by the plasma stream.

The efficacy of this device hinged greatly on the applied voltage and the distance between the poles (the probe tip end and the leaf surface). A corona, identifiable by its blue glow, manifested at the needle tip as the probe neared the leaf surface. The distance for corona formation increased from 16 to 50 mm with voltage escalation from 5 to 30 kV.

Should the probe come too close to the leaf surface, an arc discharge may ensue, causing leaf damage. Optimal distance, tailored to the specific voltage, ensured selective elimination of leaf-surface pustules without detrimental effects on the host plant. In the case of tomato powdery mildew, colonies on leaves were eradicated with 2 s exposures at probe distances intermediate to corona initiation and arcing. This portable device offered an easy-to-use, on-site solution for routine plant care in greenhouses, presenting a non-chemical method for controlling powdery mildew disease.

5. Corona Discharge Devices for Trapping Sidestream Smoke and Droplet-Enclosed Viruses via Negative Ion Adhesion

This device was designed to capture minute airborne particles. Its development was grounded in the following principles: (1) Arranging charged and grounded conductors at specific intervals generated an electric field between them, leading to electrostatic induction where the ground conductor became charged oppositely to the charged conductor. (2) The charged conductor emitted negative ions into its surrounding space, creating an ionic wind directed towards the grounded conductor. (3) The production of negative ions and the strength of the ionic wind increased with the applied voltage. (4) A sufficiently strong ionic wind could draw outside air into the device. (5) Negative ions adhered to targets present in the air drawn into the device, rendering them negatively charged. (6) The negatively charged targets were then carried by the ionic wind to the grounded conductor, where they were captured. Utilizing these electrostatic mechanisms, corona discharge devices were developed to capture tobacco sidestream smoke [7] and droplet-enclosed viruses in the air [6].

Figure 4A depicts the initial device, comprising a negatively charged spiked perforated metal net and a grounded metal net, arranged in parallel at specific intervals. While initially designed to capture secondhand smoke from tobacco, its efficacy extended to capturing plant pathogenic fungal spores and pollen carried by the wind (unpublished work). Figure 4B illustrates a variation in the device where the grounded metal net was substituted with grounded water. This modification enabled the capture of droplet-transmitted viruses in the groundwater of the device, making it applicable to the agricultural sector. This device could effectively remove indoor pollutants, such as pesticides (fungicides, insecticides, herbicides, and hormones), which were dispersed outdoors and entered nearby residential environments (unpublished work).

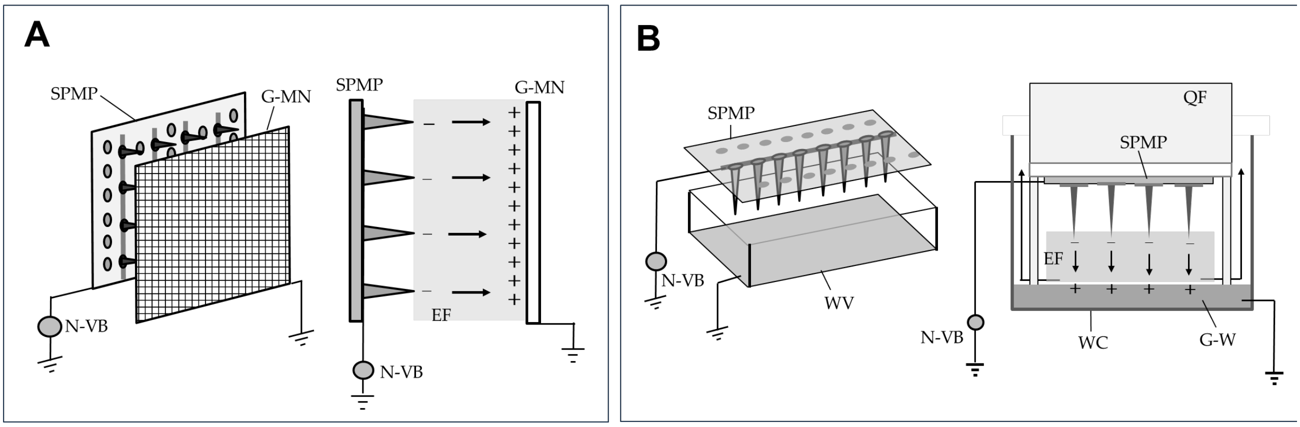

Figure 4. Illustration of two devices designed for trapping tobacco smoke (**A**) [7] and viruses enclosed in droplets (**B**) [6] using corona discharge. The smoke-trapping device consisted of a spiked perforated metal plate (S-PMP) connected to a negative voltage booster (N-VB) and a grounded metal net (G-MN). On the other hand, the droplet-trapping device included the S-PMP connected

to the N-VB, a water vessel (WV), and a plastic quadrangular hood (QH) with four legs. An electric field (EF) was formed between the spike tips and either the G-MN or the surface of the grounded water (G-W). The arrow indicates the direction of the ionic wind generated within the electric field.

6. Insect and Weed Seedling Control with Corona Discharge Devices

6.1. Pest Control

Creating a corona discharge device was straightforward: two identical metal nets were set parallel to each other at regular intervals, with one connected to a voltage booster and the other grounded (Figure 5A). This simplicity enabled easy construction and application for various pest control tasks. The main feature of this metal net device was its ability to emit arc discharge-mediated sparks when a target entered the space between the nets. Initially designed for eliminating insect pests like rice weevils, red flour beetles, azuki bean weevils, and cigarette beetles found in dried grains, the device was enhanced by attaching an insulator board to prevent grains from falling through (Figure 5A) [16]. The setup proved to be simple yet highly effective. The operating principle was straightforward: an electric field formed between the oppositely charged metal nets, with one net negatively charged to induce corona discharge. Corona glow was observed at the convex surfaces of the net, acting as needle poles (Figure 5B). When insects entered this electric field, they effectively became intermediate poles and were subjected to arc discharge-mediated sparks from the negatively charged net due to their conductive cuticle layer (Figure 5C) [16]. This phenomenon, known as insect-mediated arc discharge, was transient but strong enough to exterminate insects completely. Even a mixture of rice grains and insect pests introduced into the electric field resulted in selective electrocution of pests due to the high conductivity of the insect cuticle and the insulative properties of rice grains [16]. Increasing the applied voltage or enlarging the net area increased the rate of insect extermination, as more electricity accumulated and was released to the insects all at once.

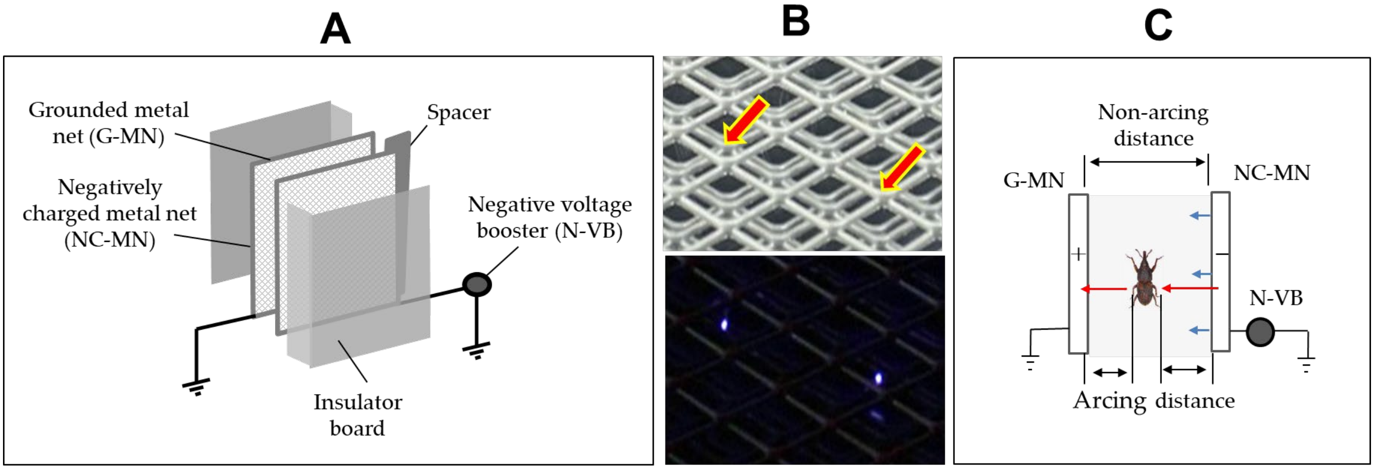

Figure 5. (**A**) Schematic representation of insect-mediated transient arc discharge generating device [16]. The device consists of two identical metal nets: one was a negatively charged metal net linked to a negative voltage booster, and the other was a grounded metal net. The nets are arranged in parallel at a set interval, inducing corona discharge. An insulator board is attached to the outer surfaces of metal nets to prevent grains from falling through the net. (**B**) The glow corona is detected at the convex surfaces of the net, which act as needle poles. (**C**) When the insects enter the electric field between the nets at any location, the insects effectively become intermediate poles and are subjected to arc discharge-mediated sparks from the negatively charged metal net due to their conductive cuticle outer layer. Eventually, the electricity is transferred to the insect and then to the

grounded net via a two-step arc discharge. Blue and red arrows represent corona and arc discharge, respectively.

Positive and negative boosters were available in two charging modes: continuous and pulse charging. All the devices discussed earlier in this paper used continuous charging. This type featured a high electric current output, enabling the creation of a stronger discharge electric field. However, it carried the risk of electric shock if a person unintentionally touched the charged metal net. In the research mentioned, an insulator plate was attached to the outside of the charged metal net to prevent rice grains from spilling out and also served as an electric shock barrier. Therefore, when using a continuous-charging voltage booster, precautions must be taken to prevent electric shock. Kakutani et al. [16] installed a corona-discharging screen on the windows of a piggery to prevent house mosquitoes (*Culex pipiens*) from transmitting the Japanese encephalitis virus (JEV) to the surrounding human population. This was due to serious concerns about the transmission of pathogens from livestock facilities to nearby human communities [28]. The screen comprised a negatively charged metal net with two grounded metal nets on either side. The grounded nets acted as a safety measure to prevent humans from coming into contact with the charged net.

Using a pulse-charging voltage booster was another option for preventing electric shock accidents. This type of booster has been widely employed in agricultural areas to charge electric fences, deterring wild animals from crossing. Accidents involving agricultural electric fences are exceedingly rare. Although unintentional human contact with these fences occurred regularly, it generally resulted in only temporary discomfort [29]. Consequently, this type of voltage generator was considered safe.

Recently, Kakutani et al. [20] developed an electric soil cover to eradicate adult houseflies (*Musca domestica*) emerging from underground pupae in a greenhouse soil bed (Figure 6A). Houseflies pose a risk of transmitting pathogenic *Escherichia coli* O157, which can cause food poisoning in humans who consume contaminated fresh food [30,31]. Housefly larvae develop in cattle feces and ingest *E. coli* O157, allowing adult houseflies to transfer the bacteria from cattle manure used as soil fertilizer to the food supply chain, contaminating cultivated and postharvest crops [32–35]. The soil cover comprised pulse-charged and grounded metal nets [20]. It was positioned on a plastic grating with multiple cells to provide a climbing path for adult houseflies emerging on the soil surface (Figure 6B). Houseflies that climbed up the grating's wall and reached the arcing zone were exposed to arc discharges from the negatively pulse-charged metal net, causing them to be knocked down onto the soil by the impact of the discharge (Figure 6B). The impact was potent enough to kill the houseflies.

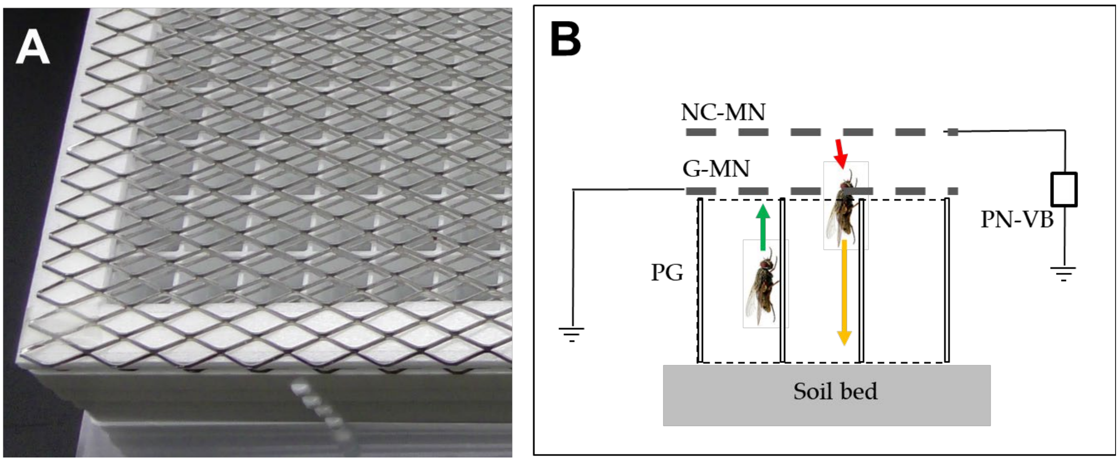

Figure 6. (**A**) Schematic representation of an electric soil cover designed to eliminate adult houseflies emerging from underground pupae [20]. The cover consists of a negatively charged, non-insulated metal net (NC-MN) linked to a pulse-charging negative voltage booster (PN-VB) and a grounded metal net (G-MN). It is positioned on a plastic grating (PG). (**B**) Adult houseflies that emerge from underground pupae climb along the cell wall (green arrow) of the grating and encounter an arc discharge (red arrow) from the pulse-charged net when they reach the arcing zone. Subsequently, they are knocked downward (orange arrow) by the strong impact of the arc discharge.

6.2. Weed Control

Some studies have proposed the use of electrical weeders based on discharge exposure [36–40]. However, the high cost of these machine weeders limited their use, particularly on small farms. Matsuda et al. [18] reported that an electric soil cover, which consisted of multiple negatively charged and grounded metal plates arranged intricately, could simultaneously control houseflies and weeds emerging from the ground soil. They also suggested that a pulse-charged, two-layered metal net could be substituted for this complicated soil cover, enabling easy, safe, and inexpensive management of weed seedlings [21].

For specific weed control requirements, the use of a single pulse-charged metal net or metal wire was scrutinized. The basic mechanism of weed extermination by a pulse-charged metal net was the emission of arc discharge-mediated sparks to weed seedlings that reached the arcing zone of the charged net. The weed seedlings growing in ground soil are electrically grounded and, therefore, susceptible to spark exposure. These characteristics made it possible to regulate the timing of spark emission to the seedlings by changing the distance between the net and the soil surface. A small distance was suitable for instantaneously killing the seedlings that had just emerged from the ground (Figure 7A). Conversely, a longer distance allowed the seedlings to grow with green foliage until they reached the arcing region. Even after the top part of the seedling was disrupted by spark exposure in the arcing region, they continued to enlarge leaves (Figure 7B). Matsuda et al. [22] developed a straightforward electric soil covering method for controlling weed seedlings on slopes using a single pulse-charged metal net with longer legs. The application of non-selective systemic herbicides, which kill the entire plant by spreading throughout its vascular system from the leaves down to the roots [41], posed an increased risk of soil erosion on the slope's surface, which can lead to dangerous landslides [42]. In contrast, the spark exposure treatment by a pulse-charged metal net effectively prevented the seedlings from growing through the net (Figure 8A–C) [22]. These seedlings under the net also helped prevent soil erosion on the slope faces, thanks to their extended root system in the rhizosphere.

The invasive kudzu vine (*Pueraria montana* var. lobata) is a significant problem in agriculture, disrupting crop cultivation. It also poses environmental and social issues by 'climbing electric poles, covering traffic signs, and encroaching on infrastructure like railway tracks and motorways [43]. Controlling kudzu was crucial for both agriculture and landscape preservation. Matsuda et al. [44] found that liana weeds like kudzu can be effectively managed using pulse-charged and grounded metal wires affixed to a fence (Figure 7C). Their research demonstrated that the tip of kudzu vines climbing the fences could be damaged by sparks generated by arc discharge from the charged wire. When the vine touched the grounded wire, a concentrated electric current flowed, damaging the tip and inhibiting further growth (Figure 8D,E).

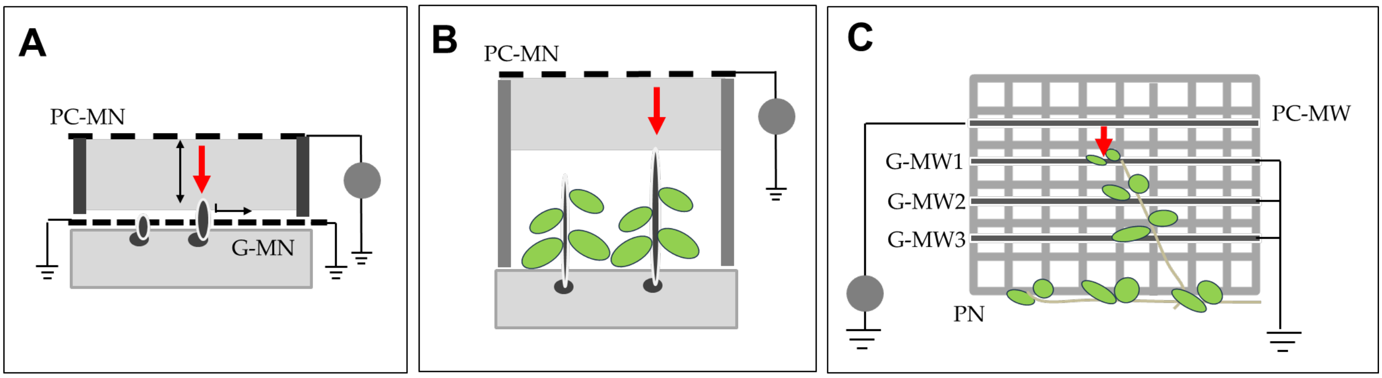

Figure 7. Schematic representation of the experimental devices used to eradicate weed seedlings emerging from the ground (cross-sectional view) (**A**,**B**) and kudzu vines climbing along the net (**C**). (**A**): The device consisted of a pulse-charged metal net (PC-MN) and a grounded metal net (G-MN) to emit arc-discharged mediated sparks to weed seedlings that have just emerged from ground soil [21]. (**B**): The device possessed a single PC-MN with longer legs to emit sparks to the upper part of the seedling [22]. (**C**): The device consisted of a single pulse-charged metal wire (PC-MW) and three grounded metal wires (G-MN1-3) attached to a polypropylene net (PN). The red arrow represents the arc discharge from the charged net and wire [44].

With proper safety measures, a continuous-charged metal net shows promise for efficient weed control due to its high current output. Matsuda et al. [45] proposed an automated electric weeder utilizing such a net attached to a motor-driven dolly for controlling floor weeds in orchard greenhouses. The weeder, remotely controlled, moved across the floor, emitting sparks to eliminate emerging weed seedlings. This approach successfully eradicated both mono- and dicotyledonous weed seedlings, offering a safe and practical weed control solution.

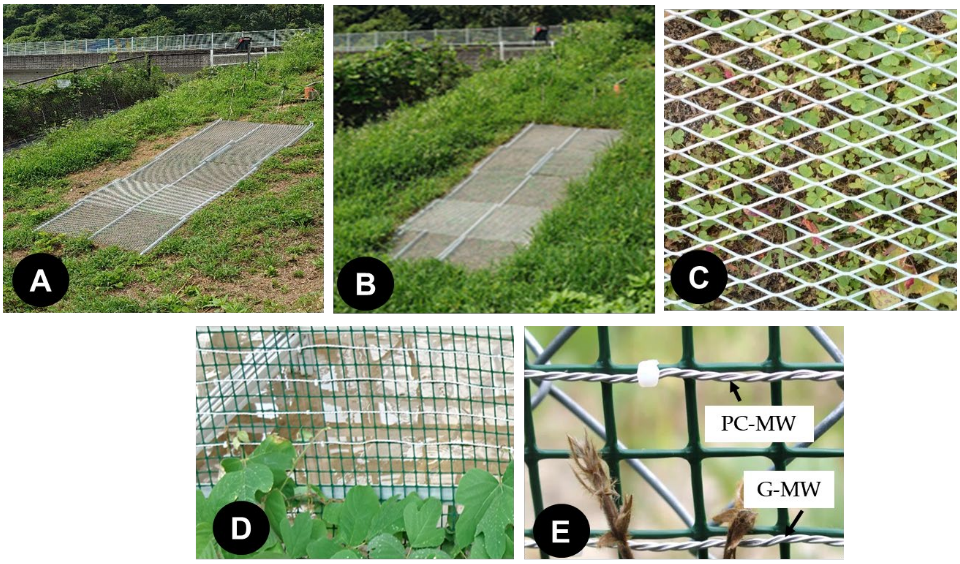

Figure 8. (**A**–**C**) Images depicting the successful application of pulse-charged metal nets for controlling weed seedlings on a slope [22]. (**A**) shows the setup at the beginning of the experiment, while (**B**) displays the condition after 3 months. (**C**), revealing thriving weed seedlings beneath the nets with none penetrating through. (**D**,**E**) (**E**) shows a pulse-charged metal wire (PC-MW) and a grounded metal wire (G-MW) affixed to a fence with nearby kudzu plants for testing purposes, showing fence-climbing vines with their apical tips damaged due to exposure to arc discharge [44]. Image E provides a close-up of (**D**), revealing damaged apical tips.

7. Challenges and Future Directions in Electrostatic Pest Control

Developing pest control methods using electrostatic science involves creating innovative devices that harness electric fields to target specific pests. These electric fields are generated around charged conductors and can be controlled by adjusting the applied voltage. The behavior of the conductor under applied voltages differs depending on whether it is insulated or not. Insulated materials prevent charges from dissipating, but excessive voltage can induce corona or arc discharge even in insulated conductors. However, within a certain voltage range that avoids discharge, a static electric field can be generated, allowing for the creation of devices that attract or repel another charge in the electric field without causing any discharge [4].

Two types of pest control devices have been reported based on these electrostatic principles: one involves a layer of negatively charged insulated metal wires spaced at intervals, paired with a grounded non-insulated metal net (single-charged dipolar electric field screen), while the other consists of two layers of oppositely charged insulated metal wires (double-charged dipolar electric field screen) [4]. The single-charged type effectively repels flying insects towards the grounded metal net, while the double-charged type captures insects that enter the electric field between the oppositely charged wire layers [4]. In laboratory experiments, insulating metal wires can be achieved by simply passing them through commercially available soft polyvinyl chloride tubes. However, in commercially available electric field screens, the conductors must be coated with polyvinyl chloride resin to ensure prolonged outdoor operation with minimal deterioration. This insulation process adds significant cost to production. Conversely, using conductors without insulation coating could greatly reduce production costs if they can effectively capture or repel pests similar to the electric field screens.

The ability to capture targets is anticipated in a corona-discharging device that generates negative ions. In the device described, negative ions are produced around the negatively charged needle poles and are adhered to targets within the electric field, resulting in negative charging. Eventually, the negatively charged targets are captured by the positively charged ground metal net. These devices have shown effectiveness in capturing various airborne targets, covering everything from chemical air pollutants to fungal spores and plant pollen [6,7]. However, despite its success in capturing various targets, the device has struggled to capture small flying insects, which could be effectively trapped by the electrostatic field screen described previously [4]. Since insects can move autonomously, the key challenge lies in creating a force strong enough to overcome their movement for successful capture. To address this challenge, increasing the production of negative ions by adding more needles and increasing the electric current flowing through corona discharge may be necessary. Additionally, enhancing the efficiency of the grounded pole (metal net) to capture negatively charged targets can be achieved by using metal nets with smaller mesh sizes. Another approach could involve the use of a positive voltage booster, which has been shown to generate larger amounts of negative and positive ions in previous studies (unpublished data). These strategies aim to improve the capture efficiency of small flying insects and enhance the overall effectiveness of the device.

The device's ability to repel insects is vital for managing insect pests. Repulsion occurs in two ways: first, insects avoid entering the electric field due to chemical and physical signals, and second, the device physically pushes insects away with sparks. In the previously mentioned single-charged dipolar electric field screen, insects landing on the grounded metal net sense an attractive force on their antennae or legs when inserted into the electric field [4]. Consequently, they fly away without entering the device. This avoidance behavior was observed in numerous insects (82 species), suggesting that the device could effectively repel insects. An alternative to this screen is the corona- and arc-discharging screen. This setup consists of a negatively charged, non-insulated metal net sandwiched between two grounded, non-insulated metal nets. It effectively repels three types of flies: houseflies (*Musca domestica*), greenbottle flies (*Lucilia sericata*), and stable flies (*Stomoxys calcitrans*) (unpublished work). Houseflies and greenbottle flies are deterred from approaching the device due to chemicals in the electric field, while stable flies are physically pushed backward upon entering the electric field since they do not exhibit avoidance behavior. Future research should focus on determining whether significant insect pests avoid the electric field created by this screen and whether non-avoiding insect pests are repelled by spark exposure. This will help assess the practical feasibility of using this device.

Using lightweight plastic materials like polypropylene or polystyrene instead of heavy metal conductors goes against traditional thinking when it comes to designing pest control devices. Applying a conductive paste to the inner surface of a soft polyvinyl chloride tube could charge it, replacing the need for a metal wire passing through the tube. This suggests the possibility of applying a conductive paste to the outer surface of a plastic material, enabling surface charging of a plastic insulator. When the material to be charged is plastic, the device can be molded to fit the shape of its installation area. Such discharge-generating weed control devices would be ideal for ridges formed into mounds for planting. Organic materials like reed, bamboo, and rattan trees show promise as alternatives for new conductors. These plant materials, when wet, conduct electric charge through their moist surfaces, acting as both a surface-charging conductor to generate electric discharge and a charge-receiving conductor when placed on the ground. Combining charged and grounded organic materials could create a new system of electric mulching capable of eliminating weeds on planting ridges through discharge exposure. Structures like bamboo-woven blinds could be used for this purpose. The challenge lies in maintaining the surface of these materials wet during discharge, as surface conductance is easily lost due to dryness (evaporation of surface water). If a method for maintaining optimal surface wetness (i.e., good conductance) is established, it could open up an innovative approach to weed control.

Moving forward, future research should focus on addressing the challenges associated with non-insulated conductors for outdoor use, exploring alternative materials or methods that could achieve similar effects through an easy production process at a lower cost. Additionally, optimizing the design and configuration of electrostatic pest control devices to enhance their effectiveness and efficiency remains an important area for further investigation.

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