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A Simple Electrostatic Apparatus for Controlling Weeds on Slopes without Causing Soil Erosion

Yoshinori Matsuda[1,*], Koji Kakutani[2], Hideyoshi Toyoda[3]

[1]Laboratory of Phytoprotection Science and Technology, Faculty of Agriculture, Kindai University, Nara 631-8505, Japan
[2]Pharmaceutical Research and Technology Institute, and Anti-Aging Centers, Kindai University, Osaka 577-8502, Japan
[3]Research Association of Electric Field Screen Supporters, Nara 631-8505, Japan
*Corresponding author: ymatsuda@nara.kinda.ac.jp

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Abstract The objective of this study was to create a straightforward electric soil covering method for controlling weed seedlings on slopes, in response to the request of a road construction association. The main requirements for this weeding approach were twofold: the first was to inhibit weed growth, which shaded solar panels on the slope, and the second to prevent soil erosion on the slopes after the weeding process. To address both of these needs simultaneously, we developed a system using a pulse-charged metal net with spacers of 60-mm height (PC-MN60). The PC-MN60 generated an arcing region in the surrounding air, with a 5 mm radius around the net. The apparatus, placed on the slope, emitted spark discharges to weed seedlings that emerged from the ground beneath the net when they reached the boundary of the arcing region. A spacer was attached to the bottom surface of the net, creating a 60 mm gap between the net and the ground. Underneath the PC-MN60, weed seedlings grew with green foliage until they reached the arcing region. Even after the top part of the seedling was disrupted by the spark exposure in the arcing region, they continue to enlarge leaves. This spark exposure effectively prevented the seedlings from growing through the net. These seedlings under the PC-MN60 also helped to prevent soil erosion on the slope faces, thanks to their extended root system in the rhizosphere. One noteworthy feature of this device was its simplicity, which enabled regular workers to create it inexpensively using common materials without requiring specialized construction skills. Furthermore, the device was pulse-charged by a voltage generator connected to a solar panel-equipped storage battery, eliminating the need for electrical wiring. As a result, this work offers a straightforward and cost-effective electric method for weeding on slopes, ensuring no soil erosion after the weeding operation.

Keywords: *Electric weeder, pulse-charged metal net, spark exposure*

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1. Introduction

Our organization, the Research Association of Electric Field Screen Supporters [1], is a private institute dedicated to developing innovative electrostatic devices that effectively manage both biotic and abiotic environmental nuisances. We have done this in response to requests from individuals and various organizations. Some of our notable past achievements include: The development of a bamboo blind-type electric field screen for preventing the entry of flying insect pests into a greenhouse [2]. The creation of a phototactic electrostatic insect trap [3] and the design of an unattended electrostatic trap [4] for controlling flying insect pests in greenhouses. The construction of an unmanned aerial vehicle for monitoring flying pests outdoors [5]. The development of a pulsed arc discharge exposer for deterring fence-climbing vine weeds [6]. The creation of an unattended electric weeder for controlling ground-level weeds in orchard greenhouses [7]. The design of an electrostatic precipitator for trapping atomized droplets containing viruses in enclosed living spaces [8]. Our current project involves developing a straightforward electric soil cover (ESC) to manage weed growth on the sloped surfaces, where solar photovoltaic panels are installed along roads, without causing soil erosion.

The most commonly used method for effectively managing weeds on slopes is the application of non-selective systemic herbicides like glyphosate. These herbicides work by killing the entire plant, spreading throughout its vascular system from the leaves down to the roots [9]. However, this approach poses an increased risk of soil erosion on the slope's surface, which can lead to dangerous landslides [10]. Alternative methods include using non-selective herbicides that have a partially systemic mode of action or employing manual mowing by workers. Both of these approaches leave living roots in the soil, which helps to prevent soil erosion but also encourages new shoot growth from the weeds. This situation necessitates frequent herbicide applications or the physically demanding task of repeatedly mowing the slope. The present ESC is a unique device to solve these problems.

The ESC was designed as a pulse-charged metal net (PC-MN) to emit electric discharges, creating sparks to target and eliminate weed seedlings emerging from the soil beneath it. The concept of using spark-based weeding was initially introduced by Wilson and Anderson [11], and it was subsequently adopted by other researchers [12-17]. The key idea behind this method involves charging a conductor with high voltages to generate an arcing spark, which is directed towards a grounded conductor (the weeds) to electrocute them. In earlier studies, a continuous-charging type voltage generator was employed. While it provided high charging power output, it posed a constant risk of electric shock due to the charged conductor. Matsuda et al. [18] took a different approach by using a pulse-charging type voltage generator, commonly employed in electric fences to safely deter wild animals. They used this generator to produce pulsed arcing exposure for weed control. In the present study, a metal net was also charged using a pulse-charging type voltage generator for safety purposes.

The main objective of this study is to determine the extent of the arcing region created by a pulse-charged metal net. When weed seedlings growing on the ground, which serve as grounded biological conductors, reach the lower part of the arcing zone, they are exposed to pulsed sparks emitted from the charged metal net [18]. The primary focus of our investigation is to establish the optimal distance between the charged metal net and the ground surface. This distance should allow weed seedlings to thrive with green foliage beneath the net while preventing them from growing through the metal net laid on the ground. Based on our findings, we will evaluate the practicality of the designed soil covering net for weed control.

2. Materials and Methods

2.1. Plant Species

We obtained seeds of common wild oat (*Avena fatua* L.) and white clover (*Trifolium repens* L.) from Takii Seed (Kyoto, Japan). These seeds were used as typical monocotyledonous (wild oat) and dicotyledonous (white clover) weed species in our study. We planted these seeds in plastic trays filled with soil, and once they grew into elongated seedlings, we used them for our laboratory spark-exposure experiment.

2.2. Construction of the PC-MN and Determination of Arcing Region

To create the PC-MN, we connected a solar cell-powered pulse-type negative voltage generator (pulse interval, 1 sec; usable voltage, 10 kV) (Suematsu Denshi, Kumamoto, Japan) (Figure 1A) to an expanded stainless-steel net (30 × 30 cm2; 4-mm strand width) (Okutani Wire Netting Manufacturing Co., Ltd., Kobe, Japan) (Figure 1B). This net had two identical polyvinyl chloride tubes (insulators) (30-cm length, 20-, 40-, 60-, and 70-mm outer diameter) on its bottom surface, to maintain different distances between the net and the ground.

The PC-MN generates an arc discharge in the surrounding space. The range of this discharge can be observed by bringing a grounded conductor closer to the PC-MN. To conduct this experiment, we used wet soil as the grounded conductor. Specifically, the PC-MN produces a spark when the soil surface comes into contact with the lower boundary of the discharge range. Figure 1C shows an experimental system. In this experiment, the PC-MN was held horizontally in place using a plastic clamp. We positioned a polypropylene tray (insulator), filled with wet soil, on a horizontal platform attached to a laboratory jack-scissor stand beneath the PC-MN. A grounded wire was inserted from the side of the tray to ensure the soil was grounded. We then raised the tray to a height at which the initial spark occurred. This distance between the PC-MN and the soil surface was considered the arcing distance of the PC-MN.

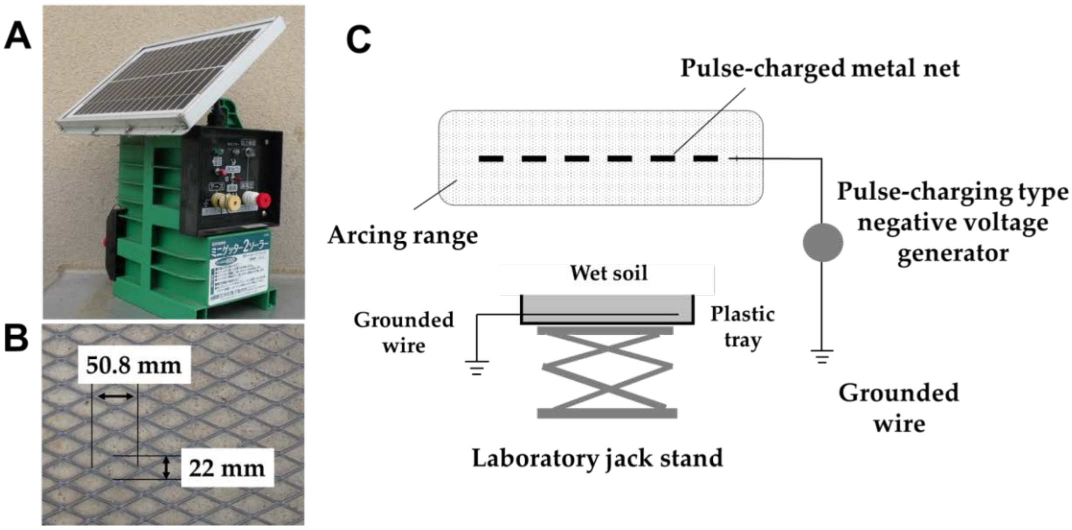

Figure 1. (A) Pulse-type voltage generator equipped with a solar panel and storage battery, connected to a metal net and a grounded wire. (B) Expanded stainless-steel net with diamond-shaped net. (C) Configuration of the instrumental system to examine the extent of an arcing range formed by a pulse-charged metal net (PC-MN). The PC-MN was maintained in a horizontal position, while the wet soil in the tray was placed on the horizontal platform of a laboratory jack stand beneath the net. The tray was raised the height at which the initial spark, from the PC-MN toward the soil surface, occurred

2.3. Effect of Seedling Heights on Successful Arcing

In order to create sparks on weed seedlings within a certain range, it is crucial to establish a ground-to-ground circuit for the movement of negative charge. A negative voltage generator collects negative charge (free electrons) from the ground (Figure 2A1) and delivers it to a metal net connected to the voltage generator (Figure 2A2). The negative charge accumulates on the surface of the charged metal net and is transferred to the seedlings through an arc discharge in the air when the seedlings reach a specific distance (Figure 2A3). The negative charge then travels through the seedlings (Figure 2A4) to the ground via the grounded soil and wire (Figure 2A5 and 6). The most challenging aspect in this process is maintaining a continuous current flow through the seedlings.

As the seedlings grow taller, the conductivity of their bodies decreases [6]. Eventually, the further growth of the seedlings disrupts the current flow through their bodies, resulting in the failure to generate sparks from the charged metal net. In our experiment, we used four pulse-charged metal nets (PC-MNs) with spacers of 20 mm, 40 mm, 60 mm, and 70 mm (created using polypropylene tubes) to determine the height at which seedlings would no longer be affected by the PC-MN (Figure 2B). These metal nets with spacers were named PC-MN20, PC-MN40, PC-MN60, and PC-MN70, respectively. We planted single seeds of common wild oat and white clover in a tray filled with the grounded soil, positioning the tray underneath the PC-MN. For the experiment, we used seedlings with heights ranging from 10-19 mm, 20-39 mm, 40-59 mm, and 60-69 mm for the PC-MN20 (Figure 2B1), PC-MN40 (B2), PC-MN60 (B3), and PC-MN70 (B4), respectively. In each height group for each weed species and each PC-MN, we used twenty seedlings and recorded whether or not sparking occurred.

2.4. Survival of Weed Seedlings Exposed to Sparks

In this experiment, we utilized three types of PC-MNs: PC-MN20, PC-MN40, and PC-MN60. The objective was to compare the survival rates of seedlings, specifically common wild oats and white clover, when exposed to sparks generated by these PC-MNs. We planted twenty seeds of each weed species in a tray and positioned the tray beneath the respective PC-MN within a greenhouse. In each tray, we recorded the number of seedlings appeared before they were exposed to arcing. After two and three weeks, we examined all the seedlings to determine whether they were still alive or had perished. Simultaneously, we conducted a similar experiment as a control, using non-charged metal nets with spacers of the same height. These experiments were repeated five times for statistical analysis.

2.5. Practical Application of the PC-MN60 to Control Weeds on Slopes

For practical purposes, we created larger PC-MN60s (1 × 1 m2), connected them to each other with electric wires, and placed them in 20 randomly selected locations on five slopes. Experiments were carried out for three months each year between April and October for three consecutive years (2021-2023), with the test sites changing annually. Before commencing the experiments, all weeds were manually removed from the test sites, and the PC-MN60s were operated for three months. At the end of the experiments, we observed that weeds grew with green foliage beneath the net, and no weeds grew through it. Simultaneously, we conducted an ecological survey to identify the weed species that appeared in the region adjacent to the area covered by the apparatuses, using the on-line plant identification application [19].

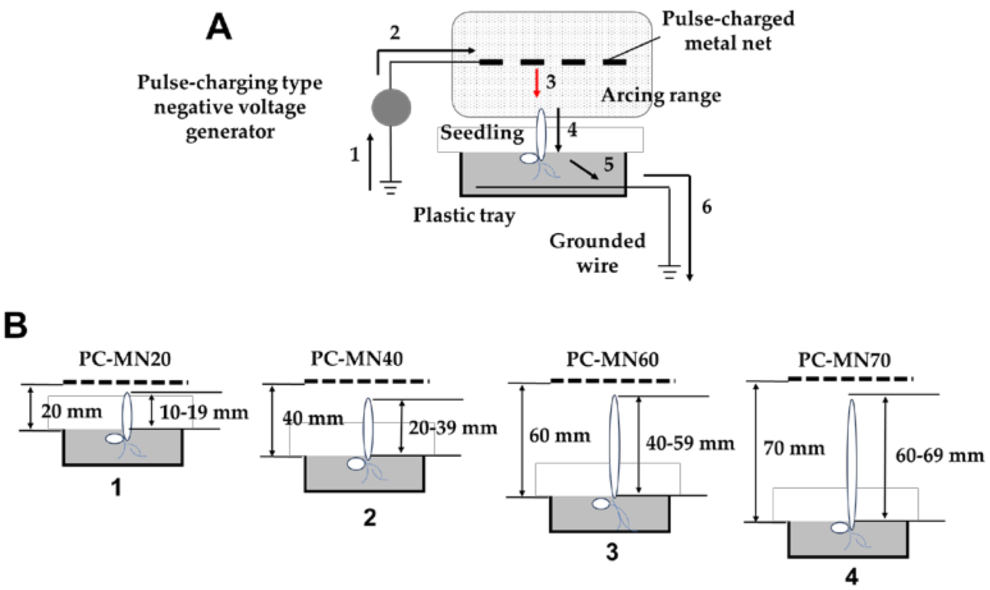

Figure 2. (A) A ground-to-ground circuit for the movement of negative charge. The circuit involves five steps: 1) the ground to a voltage generator, 2) the voltage generator to a metal net, 3) the metal net to a seedling via arc (spark) discharge (red arrow), 4-6) current flows through the seedling (4), soil (5) and a grounded wire (6). (B) Heights of weed seedlings placed under the pulse-charged metal nets (PC-MNs). The PC-MN20-70 shows the metal net with spacers of 20-70 mm in height, respectively

2.6. Statistical analysis

All experiments were repeated five times, and all data are presented as mean and standard deviation. Tukey's test was performed using EZR software (ver. 1.54; Jichi Medical University, Saitama, Japan) [20] to detect differences among the various conditions. A P-value < 0.05 was considered significant.

3. Results and Discussion

3.1. Key Factors for Generating Sparks Using Arc Discharge

The purpose of this study is to present a practical method for generating sparks via arc discharge specifically targeted at weeds growing on the ground. To create sparks, certain conditions must be met, including establishing an electric circuit for the flow of negative charges, ensuring an air gap for arcing within the circuit, and supplying the necessary voltage to initiate the breakdown of air, resulting in arcing in the surrounding air. Figure 2A illustrates the ground-to-ground circuit employed in our experimental system. Using voltage generated by the voltage source, negative charges flow through this circuit, emitting sparks to a grounded conductor (a seedling growing in a tray with wet soil) within the air space of the circuit.

The objective of the initial experiment was to determine the extent of the arcing region produced by the PC-MN. The arcing region represents the distance that the spark can travel, which is crucial for ascertaining the reachable height of ground-based weed seedlings that can be affected by the PC-MN when used as a soil cover. The extent of the arcing region was determined by gradually bringing a grounded conductor closer to the PC-MN. In this experiment, a tray with wet soil acted as the recipient of the negative charge discharged from the PC-MN through the arc. Matsuda et al. [21] demonstrated that wet soil is an effective conductor, as water within the soil facilitates the flow of negative charges. Ultimately, we found that the arcing region extended within a 5 mm radius from the PC-MN. This method proved effective in targeting weed seedlings growing in the grounded wet soil. In fact, sparks were emitted to the seedlings when their top part reached the 5 mm distance from the PC-MN.

The main problem in our experimental setup is the height of weed seedlings. When some of these seedlings exceed a certain height, their conductivity is compromised, leading to a disruption in the flow of electrical current through their bodies [6]. This disruption causes the arc discharge on the PC-MN to cease. In our second experiment, we investigated the correlation between the height of the seedlings and the occurrence of arcing. We used four types of PC-MNs (PC-PN20, PC-MN40, PC-MN60, and PC-MN70), which had varying distances (20-70 mm) between the net and the soil surface of the tray, allowing us to work with seedlings of different heights that grew in grounded wet soil in a tray. Figure 3 illustrates the distribution of seedlings that were either exposed to sparks or not, depending on the type of the PC-MN. In the cases of PC-MN20, PC-MN40, and PC-MN60, all seedlings that reached the arcing zone were exposed to sparks. However, seedlings located beneath the PC-MN70 did not experience exposure to sparks, even when they reached the arcing region. These results indicate that seedlings with a height of 59 mm or lower are conductive enough to allow electric current to pass through their bodies.

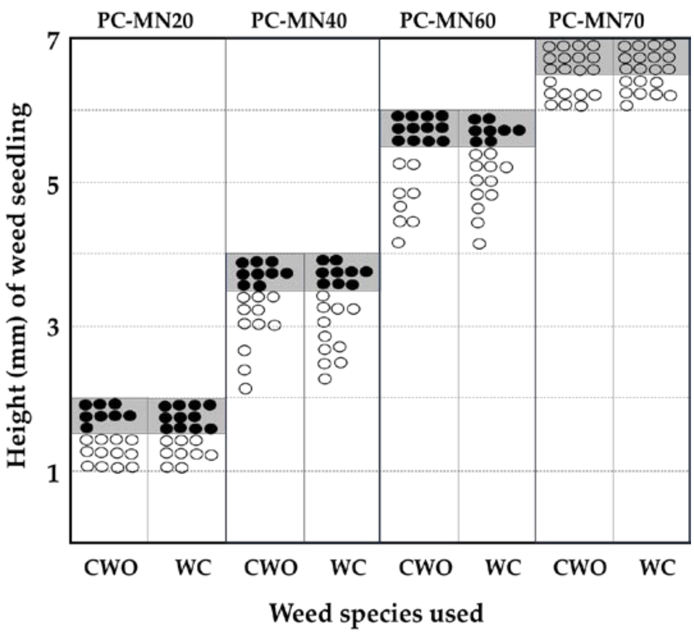

Figure 3. Exposure of weed seedlings of common wild oat (CWO) and white clover (WC) to arc discharge-mediated sparks generated by a pulse-charged metal net (PC-MN). Twenty seedlings of different heights were placed beneath the PC-MN20, PC-MN40, PC-MN60 and PC-MN70 with 20-, 40-, 60- 70-mm spacers, respectively. Open and closed circles indicates individual seedlings exposed to sparks and those not exposed, respectively. The gray zone in each column shows the area where sparks occurred for each PC-MN

3.2. Effects of Spark Exposure on Survival of Weed Seedlings

The current study demonstrates that three types of the PC-MNs (PC-MN20, PC-MN40, and PC-MN60) were able to produce sparks via arc discharge upon contact with seedlings in their vicinity. Prior research [6,18] had already shown that exposing young shoots or elongating weed seedlings to pulsed sparks is an effective way to inhibit their growth. However, the aim of this present study was not to eliminate weed seedlings by spark exposure, but rather to utilize this technique to impede the unwanted upward growth of these seedlings. This experimental setup allowed weed seedlings to develop robust leaves beneath the PC-MN, which subsequently facilitated root growth in the soil.

In the third experiment, a tray containing twenty seeds of common wild oat and white clover was placed beneath the three types of PC-MNs, and the emerging seedlings were observed for three weeks. Table 1 displays the proportion of seedlings that were either killed or allowed to grow leaves after exposure to sparks. Under the greenhouse conditions of this study, both weed species typically emerged 3-6 days after sowing, with a germination rate of approximately 93%. The most significant outcome was that all three PC-MNs prevented seedlings of both species from penetrating the net. In contrast, in the non-charged control group, nearly all seedlings grew through the net. In the case of PC-MN20, the majority of seedlings were killed by the spark exposure, preventing any from passing through the net. However, PC-MN40 proved insufficient to eliminate all seedlings. In fact, about half of the seedlings developed their first leaves before being exposed to sparks and continued to grow after the upper part was disrupted by the exposure. Consequently, this disruption proved effective in preventing them from passing through the net. The other half of the seedlings were killed by the spark exposure before developing leaves. PC-MN60 was the most effective in allowing seedlings to grow with primary leaves and disrupting the upper portion of the growing seedlings through spark exposure. As a result, all seedlings thrived with green foliage beneath the net, without passing through it.

3.3. Practical Application of the PC-MN60 to Manage Weeds on Slopes

The PC-MN20 proved highly effective in eliminating weed seedlings because it could target and kill newly born seedlings located under the net. In contrast, the PC-MN60 allowed seedlings a safe space of 55 mm to grow until they reached the arcing region, enabling them to develop primary leaves. Seedlings growing beneath the PC-MN60 were beneficial in preventing soil erosion on sloped surfaces. From this perspective, the PC-MN60 was well-suited for the goals of our study.

The most crucial feature of the PC-MN60 was its ability to generate an arc discharge directed at the seedling nearest to the PC-MN. This meant that arcing happened at a specific point on the charged metal net, regardless of the net's size or the number of seedlings in the arcing region. This characteristic made it feasible to scale up the size of the charged metal net for practical applications. In fact, we easily connected ten PC-MN60 units by linking their metal nets to each other and to a voltage generator using electric wires (see Figure 4A).

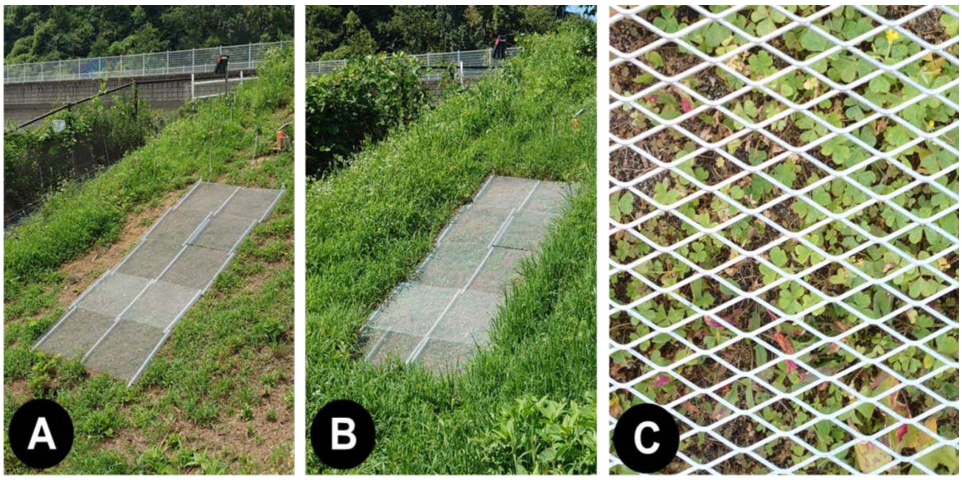

Figure 4. Photograph showing the successful use of a pulse-charged metal net with 60-mm spacer (PC-MN60) for managing weed seedlings on a slope. At the start of the experiment (A) and after 3 months (B), you can see weed seedlings thriving beneath the nets, but none grew through the net. C is an enlarged view of image B

The voltage generator produced 60 arcs per minute, equivalent to 86,400 arcs per day. Theoretically, this implies that the PC-MN60s could emit sparks affecting approximately 85,000 seedlings. In our initial survey, we found an average weed density of 313.96 ± 66.7 weeds per square meter, indicating that the voltage generator could effectively treat weeds in an area ranging from 50 to 280 square meters. These preliminary calculations encouraged us to consider the application of the PC-MN60 for weed control.

We conducted slope experiments to demonstrate the practicality of our device. The results showed that the PC-MN60 consistently worked well during the experiments. In fact, it effectively prevented the emergence of weed seedlings over the net in all 20 locations where we used 10 of these devices to cover various areas. Figure 4 provides an example of a successful application. In Figure 4A and B, you can see the 10 PC-MN60 units placed on the slope, initially and after 3 months, respectively. The results indicate that the PC-MN60 completely suppressed the growth of seedlings over the net. Figure 4C shows that weed seedlings of both weed species grew vigorously under the net. In conclusion, we found that the PC-MN60 is a promising tool for managing weed seedlings on slopes without causing soil erosion.

Table 1. Exposure of weed seedlings of common wild oat (CWO) and white clover (WC) to arc discharge-mediated sparks generated by three types of pulse-charged metal nets (PC-MNs)

Types of PC-MN[1]	Pulse-charging (10 kV)	Weed species[2]	Percentage of weed seedlings classified into A-E[3]								
			Day 14					Day 21			
			A	B	C	D	E	B	C	D	E
PC-MN20	yes	CWO	3.5 ± 0.8	93.5 ± 0.8	2.8 ± 0.2	0 a	0	96.5 ± 0.8	0	0 a	0
		WC	2.6 ± 0.6	95.5 ± 0.7	1.3 ± 0.9	0 a	0	97.4 ± 0.7	1.3 ± 0.9	0 a	0
	no (control)	CWO	3.4 ± 0.2	1.2 ± 0.2	1.5 ± 0.2	3.5 ± 0.8	90.5 ± 0.4	1.2 ± 0.2	0	0	95.5 ± 0.4
		WC	3.8 ± 0.3	2.8 ± 0.6	0	3.8 ± 0.3	89.5 ± 0.7	2.8 ± 0.6	0	0	89.5 ± 0.7
PC-MN40	yes	CWO	2.9 ± 0.1	49.5 ± 0.8	3.5 ± 0.8	43.5 ± 0.8 b	0	49.5 ± 0.8	0	47.5 ± 0.8 d	0
		WC	3.1 ± 0.8	51.4 ± 0.2	1.5 ± 0.1	40.5 ± 0.7 b	0	51.4 ± 0.2	0	48.5 ± 0.7 d	0
	no (control)	CWO	2.1 ± 0.5	1.4 ± 0.3	3.5 ± 0.6	27.3 ± 0.5	68.2 ± 0.4	1.4 ± 0.3	0	0	96.2 ± 0.4
		WC	3.3 ± 0.7	1.0 ± 0.8	3.8 ± 0.2	23.5 ± 0.8	70.5 ± 0.8	1.0 ± 0.8	0	0	94.9 ± 0.8
PC-MN60	yes	CWO	2.3 ± 0.5	1.2 ± 0.2	0	97.5 ± 0.2 c	0	1.2 ± 0.2	0	97.5 ± 0.2 c	0
		WC	3.0 ± 0.9	0	2.5 ± 0.8	94.5 ± 0.7 c	0	0	0	96.8 ± 0.7c	0
	no (control)	CWO	3.3 ± 0.4	0	0	60.5 ± 0.6	37.2 ± 0.4	0	0	0	93.7 ± 0.4
		WC	2.5 ± 0.6	1.1 ± 0.3	0	67.8 ± 0.7	30.5 ± 0.9	1.1 ± 0.3	0	0	96.5 ± 0.9

[1] PC-MN20, PC-MN40 and PC-MN60 were the pulse-charged metal nets with 20-, 40- and 60-mm spacers, respectively.
[2] Twenty seeds of weed species were sown in a grounded wet soil of a tray and placed beneath each PC-MN for three weeks.
[3] A, seedlings that did not appeared because of failure of seed germination; B, seedlings were killed by spark exposure; C, seedlings developed coleoptiles or cotyledons, but not formed leaves; D, seedlings developed leaves, but not passed through the net; E, seedlings developed leaves and passed through the net. The means and standard deviations were calculated from five repetitions of the experiments. The letters (a-c) on the means in a vertical column indicate significant differences ($p < 0.05$) according to Tukey's method.

Table 2. List of identified weeds [a]

Dicotyledons		Monocotyledons	
Common name	Scientific name	Common name	Scientific name
chickweed	*Stellaria media* (L.) Vill.	green bristlegrass	*Setaria viridis*（L.）P. Beauv
narrow-leaved vetch	*Vicia sativa* subsp. *nigra* (L.) Ehrh.	Southern crabgrass	*Digitaria ciliaris* (Retz.) Koel
Philadelphia fleabane	*Erigeron philadelphicus* L.	Indian goosegrass	*Eleusine indica* (L.) Gaertn
white clover	*Trifolium repens* L.	annual bluegrass	*Poa annua* L.
Spotted spurge	*Euphorbia supina* Rafin.	Shortawn foxtail	*Alopecurus aequalis* Sobol.
Chinese yarrow	*Achillea alpina L.*	wild oat	*Avena fatua* L.
Common dandelion	*Taraxacum officinale* Weber	Blady grass	*Imperata cylindrica* (L.) Beauv
Commonfield speedwell	*Veronica persica* Poir.	Asiatic dayflower	*Commelina communis* L.
common henbit	*Lamium amplexicaule* L.	clavate bent	*Agrostis clavata* Trin.
Mugwort	*Artemisia princeps* Pampanin	Italian ryegrass	*Elymus tsukushiensis* Honda var. transiens (Hack.) Osada
Wood sorrel	*Oxalis corniculata* L.	orchard grass	*Dactylis glomerata* L.
lawn pennywort	*Hydrocotyle sibthorpioides* Lam.	broomsedge bluestem	*Andropogon virginicus* L.
Chinese Plantain	*Plantago asiatica* L.	dallisgrass	*Paspalum dilatatum* Poir.
Tall goldenrod	*Solidago altissima* L.	Yellow nutsedge	*Cyperus esculentus* L.
indian lettuce	*Lactuca indica* L.	smooth crabgrass	*Digitaria ischaemum* (schreb.) Muhlenb.
Common sowthistle	*Sonchus oleraceus* L.	short-stem sedge	*Carex breviculmis* R. Brown
cleavers	*Galium aparine* L.		
oriental false hawksbeard	*Youngia japonica* (L.) DC.		
annual fleabane	*Erigeron annuus* (L.) Pers.		
smooth hawksbeard	*Crepis capillaris* Wallr.		
cobbler's pegs	*Bidens pilosa* L.		
white goosefoot	*Chenopodium album* L.		
Common Purslane	*Portulaca oleracea* L.		
curly dock	*Rumex crispus* L.		
Common Yellow Woodsorrel	*Oxalis dillenii* Jacq.		
aisy fleabane	*Erigeron strigosus* Muhl.		
Hairy crabweed	*Fatoua villosa* (Thunb.) Nakai		
common evening primrose	*Oenothera biennis* L.		
Sumatran fleabane	*Conyza sumatrensis* (Retz.) E.Walker		
mugwort	*Artemisia vulgaris* L.		

[a] Weeds growing on the area adjacent to the test places that were covered with the pulse-charged metal nets with spacer of 60-mm height (PC-MN60s).

In our ecological survey, we were unable to analyze the weeds that grew beneath the net (as shown in Figure 4C). To address this issue, we made assumptions about the types of seedlings that were suppressed, based on a survey of weeds near the test location where we used the PC-MN60. Our survey revealed that a variety of weed species appeared seasonally during the experimental period, including 30 types of dicotyledonous weeds and 16 monocotyledonous species (Table 2). It's likely that these weeds grew under the device and could be expected to prevent the occurrence of soil erosion on slope surfaces.

We have introduced a unique electrostatic weeder. Thanks to its simple design, it can be manufactured inexpensively using common materials, without requiring any specialized construction skills. We reduced the overall production cost by using a pulse-charging voltage generator, which is typically used for electric fences to deter wild animals. The voltage generator was powered by a solar panel-equipped storage battery, eliminating the need for electrical wiring. This cost-effective equipment should be suitable for many users as a weed management tool. Additionally, the device is weatherproof, making it suitable for outdoor operation over extended periods.

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