Solar-Powered Plant Protection Equipment

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Solar photovoltaic (PV) devices present a positive approach to sustainable crop production by reducing crop loss in various ways. This might result in the extensive use of PV devices in the near future. PV-based plant protection equipment/devices are primarily utilized in protecting crops from birds, weeds, or insects. The utilization of PV systems for different applications constitutes a new era in agriculture, horticulture, and forest sectors. A PV system is a potential alternative, offering more opportunities in operating different types of electricity-based agricultural equipment. The development of devices with simple construction/operation for plant protection may work well on small-scale farms.

plant protection | pest control | solar energy gadgets

1. Applications of Solar Energy in Agriculture

Among the renewable energy sources, solar energy is closely associated with agriculture. Generally, the plant derives light energy from the sun for photosynthesis. In other words, plants produce their food by using water and CO_2 present in the atmosphere via photosynthesis in sunlight. Solar energy usage in agriculture is not a new technology in the post-harvest processing of agro produce. In earlier days, sunlight was directly used to dry different types of agro produce by spreading them in the open and then storing them for future use. In the case of solar thermal energy applications, conventional open-yard sun drying and solar drying are more popular among the farming community. The two forms of energy obtained from sun, light and thermal energy, can be tapped by using devices for various applications both at domestic and industrial levels in agriculture and agro/food processing sectors.

2. Solar Photovoltaic Technologies

Electricity production using solar energy is achieved either through photovoltaic technology or the concentration of solar power [1]. However, the solar photovoltaic (PV) system is mainly preferred for a mobile/stationary machine that requires low power inputs. Solar PV technology uses the photovoltaic effect for converting sunlight into electrical energy. The electrical load should be connected either directly to the PV system or battery. The added advantages of PV are the lack of moving parts, power production on any scale, reliable power production without toxic gas emissions, and long lifespan. The most common PV applications include remote site electrification, street lights, traffic signals, vehicle battery charging, water pumping, fencing, communications, satellite, and remote monitoring [2][3]. Several reviews are published on the different aspects of solar PV water pumping [4][5][6][7][8][9][10]

[11][12][13][14] and design aspects of solar pumping [15][16]. There is a broad scope for the successful implementation of solar-powered farm machinery/tools/implements in agriculture. Popular PV-powered farm gadgets used in crop production include solar water pumping, solar fencing, solar-operated sprayers, solar-operated dusters, solar bird scarers, solar insect traps, and solar PV–thermal hybrid drying systems. Standalone solar PV is unique and has several potential applications in agriculture. The present review briefly describes the role of solar powered plant protection equipment's in agriculture **(Figure 1)**.

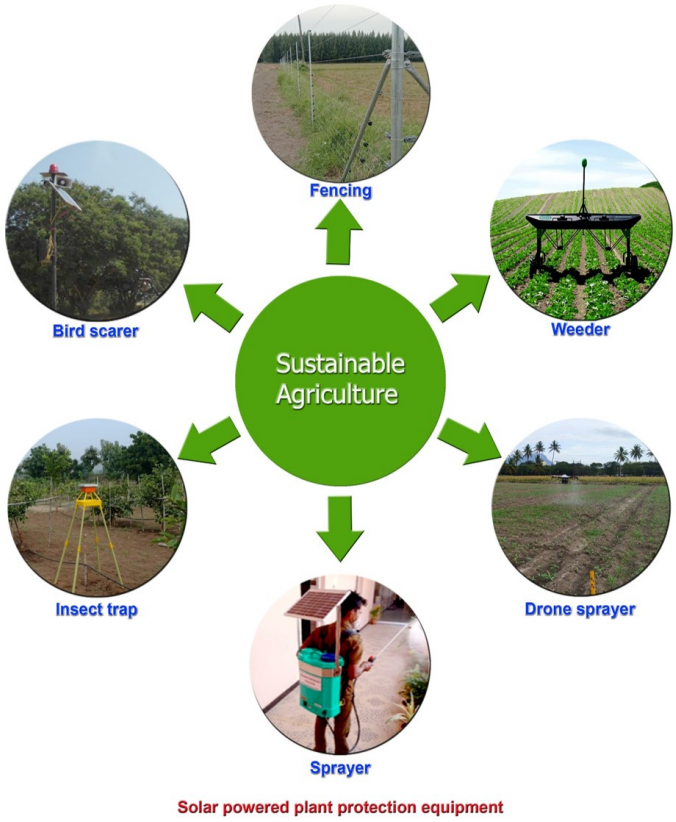

Figure 1. Solar powered plant protection equipment.

3. Solar-Powered Equipment for Weed Management

Weeds are usually eradicated by mechanical action or synthetic herbicides. Few herbicides are available with a specific mode of action, making it tedious to identify and achieve the expected management of weeds [17]. Mechanical weeding involves the repetitive actions of weeding tools (operated by man/machine) to make physical contact with weeds to uproot them [18]. Manual weeding is an energy- and labor-intensive process, and women laborers are primarily involved in manual weeding, which also increases the cost of operation. In order to reduce the drudgery and discomfort of the workers, long-handled weeders are available for both dry and wetlands. Presently, the utilization of human power has become expensive in developing countries such as India due to the non-availability of farm laborers or higher wage expectations. Developing fully or semi-automatic weeders is mandatory in farm mechanization to reduce the labor force. Solar-powered weeders are an excellent alternative to implement sustainable mechanization in agriculture due to increased fuel costs.

The components of solar weeders are a solar panel, a rechargeable battery, transport wheels, a motor, weed detectors (sensors/cameras), and a weeding mechanism. Generally, lead acid batteries are preferred for these types of equipment. The added advantages of lead acid batteries are that they are inexpensive, have a long life cycle, have a higher energy density, a higher surge current supply, and a lower energy to weight ratio than other battery types [19]. These batteries are a viable option for a DC motor with higher torque for electric vehicles [19].

Solar robotic weeders are also available, and they work a minimum of five hours continuously, which helps control weeds in time. Most solar weeders are robotic models, and their weeding operations are either mechanical or chemical spray types. DC motors are used in the weeder for movement and mechanical weeding purposes. The added advantages of these models are reduced human resources, no fuel requirement, more precision in weeding, light weight, and 24/7 operations. Furthermore, the solar panel is attached to the system, which helps recharge the battery, even during operations. Generally, 12 V rechargeable batteries are used in solar-powered mechanical weeders. The number of batteries may vary based on the power requirement for its operation.

The unmanned system (robot) is well suited for weeding operations, and it helps to minimize the required workforce and herbicide usage while weeding. Two solar-powered weeders, EcoRobot and AVO robot models, are developed by Ecorobotix, Switzerland. These models work more effectively in row crops based on the detection of weeds (>85%), and a micro-dose of herbicides is applied precisely on the weeds to destroy them. The solar power used in EcoRobot and AVO models is 380 W and 1150 W, respectively, and they have a working time of 8 and 12 h once fully charged by solar panels [20].

4. Solar-Powered Equipment for Pest Management

4.1. Solar Insect Traps

Candescent bulbs were used in light traps in earlier days, which consumed more power and generated heat during operation. The power consumption increased the operational cost to the farmer. Nowadays, mercury vapor lamps, gas lamps, fluorescent lamps, ultra-violet (UV) fluorescent lamps, UV light-emitting diodes (LED) lamps, LED garden lamps, and compact fluorescent lamps (CFL) are used in light traps. Among them, the first three are predominantly used for pest management purposes [21]. However, LED bulbs are preferred in solar insect traps due to many features such as less energy consumption, low cost per unit trapping time, higher energy efficiency, longer lifespan, etc. Moreover, the specific wavelengths available in LED bulbs for particular insect species improve trapping efficiency [22][23][24].

Recently, solar light traps have become more popular among the farming community as they are cost-effective (**Figure 2**). The main components of these traps are similar to other electrical light traps except the battery, timer, and solar panel. A solar insect trap unit is exposed to sunlight during the daytime to generate and store electrical energy in the battery. A timer is another critical component in the light trap for operation. A stand is used to hold all parts of the trap at different heights according to the nature of crops. Several researchers developed and tested the details of solar insect light traps. The energy required for the light source used in different solar insect traps ranges

from 3 to 20 W. Mostly, 12 V rechargeable lead acid batteries are used in these traps. The wavelength of the light source used in the traps is 315 to 590 nm to attract different insect species. Common traps used to attract the insects are a container filled with a soapy solution, net structures, and glue boards [25][26][27][28][29][30][31]. Plastic cups/aluminum funnel traps with pheromone lures also trap insects for taxonomic studies [32][33][34]. When monitoring insects over an extended period, these kinds of solar light traps help to reduce the labor requirement due to automatic timers [35]. Solar light traps effectively attract pests in vegetable crops [25]. Calderon et al. [30] reported a unique LED light trap for rice bugs with a solar panel made of polycrystalline solar cells (20 W).

Figure 2. Solar insect light trap.

4.2. Solar-Powered Sprayers

Spraying is an operation of spreading fine droplets of liquid chemicals over plant canopy to protect them from pests and diseases. For this purpose, many versions of manual or power-operated (engine, battery, tractor, and power tiller) spraying equipment are used. Backpack, trolley type, and wheel-supported solar-powered sprayers are used as alternatives to conventional sprayers. Solar PV sprayers consist of solar panels, rechargeable batteries, DC motors with a pump or a spinning disk, a chemical tank, wheels/support frame (based on types), a spray lance, and accessories. Solar panels are fitted in most of the sprayers for easy recharging. In the case of backpack sprayers, depending on the models, the power output from the solar panel varies in the range of 5 to 75 W. A solar-powered knapsack sprayer has a solar panel of 20 W, a 12 V and 7.5 Ah battery, a 12 V DC motor with a pump, a spraying tank, a frame, an adapter, and a connector output for multiple applications (radio, mobile charging, lighting, etc.). These kinds of sprayers are used for different crops such as cotton, red gram, and vegetables such as onion (**Figure 3**). The operation cost of solar-powered sprayers is INR 53.75, which is lower than battery-powered (INR 78.75) and manually operated (INR 102.5) sprayers.

Figure 3. Different types of solar-powered sprayers. (**a**) Solar-powered knapsack sprayer; (**b**) utilization of solar-powered knapsack sprayer in onion field; (**c**) utilization of solar-powered knapsack sprayer in cotton field; (**d**) utilization of bullock-drawn solar-powered high-clearance sprayer in cotton field; (**e**) utilization of solar-powered push-type sprayer in cotton field.

4.3. Solar PV Duster

A duster is a mechanical device used to apply solid chemicals in powder form to manage insect pests, weeds, and disease-causing pathogens in agro-horti ecosystems. The power source used for conventional dusters is either workforce or compression ignition engines. In a solar-powered duster, the main components are a solar panel, a rechargeable battery, and a dusting unit. Electricity generation and storage are similar to other types of solar PV gadgets. The solar panel is fitted in a supporting frame, and it can be carried above the head of the operator without any weight on the head. The approach has two advantages: it provides shade to the operator, and charges

the battery during operation. A battery-operated blower or a fan is used in the dusting unit to produce an air blast. The chemical powder from the hopper is sent to the blower outlet and carried by air to reach the exit point [36]. Furthermore, the device can be used for off-farm activities, such as lighting the house throughout the year when it is not in use as a duster/sprayer [37].

5. Solar-Powered Equipment for Non-Insect Pest Management

5.1. Solar Bird Scarer

A solar bird scarer consists of a PV panel, a lead acid battery, an audio oscillator, an amplifier, and speakers [38]. Birds are scared by sounds produced in these units with different frequencies and pitches. Pande [38] suggested a wide range of frequencies to scare the birds for an extended period. A solar-powered bird repelling system consists of a solar panel (7 W, 12 V), a charge controller, a 12 V rechargeable battery, an MP3 player, an amplifier, speakers (2 × 20 W), three sonar sensors or PIR sensors, and an Arduino UNO microcontroller [39]. The MP3 player is used to play different sounds to scare the birds. A similar study was carried by Koyuncu and Lule [40] to test a bird scarer using an MP3 player of domestic birds' predators' calls to scare the birds and found that falcon was a more aggressive sound than other predators. The results from Suryawanshi [41] confirmed the solar-powered audible bird scarer of Koyuncu and Lule [40]. Muminov et al. [39] also tested a solar-powered bird repelling system using bird scarer sounds. Another interesting study conducted by Siahaan et al. [42] using bird detectors and repellent via ultrasonic waves revealed that the frequency of 28–60 kHz could disturb bird activity on a farm.

5.2. Solar Fencing

In remote areas, electric fencing is a proven technology to protect and safeguard fields from animals. Farmers may fail to protect their farms from animal attacks mainly due to the non-availability of electricity/absence of power grids. A PV electric fence is an alternative to the existing electric fence system and is well suited for off-grid areas. It is the most effective and economical approach for long-term operations in unelectrified areas. Solar PV fencing systems can fulfill farmers' requirements to protect their crops (**Figure 4**). The components of the solar fencing system are solar panels, an energizer or a controller, a rechargeable battery, a main post, a fence wire supporting post, a t-post, a lightning diverter and choke kit, a super-earth kit, a super strain insulator, a permanent wire tightener, a chain wire strainer, tension springs, a double insulated lead-out cable, joint clamps, gateway and gates, cut out switches, electrified flood gates, live light, and a fence voltage alarm [43]. The current from the battery is supplied to the energizer to produce a high voltage with a low current in the fencing wires. Animals touching the fence wires experience a minimal electric shock which makes them leave the field. The fencing system would not cause any fatalities or injuries to animals/humans due to the low current supplied from the solar PV system. Kadam et al. [43] found that a combination of a solar panel (35 kW) and battery (12 V) was sufficient to effectively cover a 3.5 km fence line, which costs about USD 3300/km.

Figure 4. Solar fencing for agricultural field.

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