ABSTRACT

A self-propelled electric variable-rate electrostatic sprayer (EVRES) was developed to overcome the issues associated with traditional ways of spraying in small or fragmented land such as non-uniformity in spraying, drift losses, non-selective spraying, low field capacity, high operator exposure to pesticides and manpower requirement. It comprised four air-assisted electrostatic spraying (ESS) units, a hydraulic spraying system, a spray tank, a VRS unit, a propelling unit and a guiding unit. The ESS unit was designed and developed using a hollow-cone nozzle for liquid atomization and a copper induction electrode maintained at high DC potential to charge the droplets. A laboratory setup employing the conductive plate method was used to measure the spray current of droplets emerging from the ESS unit. The operating parameters such as electrode diameter, voltage applied, position of electrode and target distance were optimized to achieve the CMR in the range of 5 to 10 mC kg^{-1} and the values were found to be 30 mm, 2000 V, 0 mm and 400 mm, respectively, yielding a CMR of 6.11 mC kg^{-1}. A pre-trained YOLOv8-n model was fine-tuned on a custom groundnut foliar disease dataset, achieving an F1 score of 0.85 at a confidence threshold of 0.623 and an mAP@0.5 of 0.931 for healthy and diseased leaves. A variable-rate spraying (VRS) strategy was implemented, wherein ESP32-CAM modules were used for real-time leaf image acquisition and also served as microcontrollers to generate control signals. The disease incidence percentage, estimated by the model, was converted to duty cycles of solenoid valves through a predefined control logic, thereby regulating the quantity of pesticide applied to the crop.

Based on the optimized electrostatic induction parameters obtained from the laboratory studies and the developed VRS system, a field prototype of the sprayer for groundnut crop with overall dimensions 1250×800×860 mm and total weight 105 kg was developed. A 24 V, 650 W DC motor, powered by two 12 V, 18 A-h lead-acid batteries connected in series, transmitted power to the wheels through a chain–sprocket system and a worm gearbox. Camera modules were mounted on an MS angle positioned 30 cm ahead of the ESS units to capture images of crop leaves during operation. Dedicated battery units were provided for operating the relay channels and solenoid valves, spray pump and charging unit, and blowers integrated into the ESS units.

EVRES was tested for carrying out spraying in groundnut crop at an average forward speed of 1.2 km h^{-1}. The actual field capacity, field efficiency, turning radius, turning time, swath and application rate of the EVRES were 0.18 ha h^{-1}, 70%, 1.01 m, 17 s, 2.2 m, and 416.82 L ha^{-1}, respectively. Compared to uncharged spraying, electrostatically charged spraying reduced the volume median diameter, number median diameter, uniformity coefficient, and relative span by 3.31 to7.75%, 4.40 to13.64%, 5.58 to 15.00%, and 3.40 to 9.72%, respectively. In contrast, droplet density and area covered increased by 15.05 to 54.71% and 29.41 to 40%, respectively. The average power consumption for propelling, spraying and charging operation, blower, and VRS units was measured to be 207.83 W, 51.33 W, 48.94 W, and 17.79 W, respectively. With the selected battery configuration, once charged, the sprayer was operated continuously for 75 minutes. The total response time of VRS from image acquisition to solenoid valve actuation was 0.30 to 0.37 s. Detection accuracy for healthy and diseased leaves ranged from 62.5 to 83.3% and 62.5 to 80%, respectively. The VRS strategy resulted in pesticide savings of 31.25 to 100% compared to continuous spraying. For the developed sprayer, the daily exposure of hand vibration (A (8)), the noise level at ear of operator as well as at bystanders' position were measured to be 2.11 m s^{-2}, 76 dB(A) and 56 dB(A), respectively. Compared to continuous spraying under severe disease conditions, the EVRES reduced cost of spraying up to 67.46% in healthy and less disease-severity areas. When compared with manual knapsack spraying, the developed sprayer reduced the total cost of spraying by 29.47% to 77.05%, depending on the level of disease severity. The break-even point of the EVRES ranged from 3.81 to 9.97 ha year^{-1}, from no spraying to continuous spraying, demonstrating its economic viability under varying disease conditions.

Keywords: Electrostatic spraying; Optimization of electrostatic induction parameter; Deep-learning; Variable-rate spraying; Battery power; Droplet size and distribution; Power consumption; Field efficiency