



RESEARCH ARTICLE

Herbicidal management of stem hemiparasitic weed *Dendrophthoe* spp. in mango orchards

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Abstract

Dendrophthoe falcata is a stem hemiparasitic weed infesting tree crops. Manual removal of this parasitic weed is the common practice, often involving cutting the infested tree branches. However, it is labour-intensive and requires repeated removal due to regrowth. Even herbicidal sprays for selective control are unavailable and the use of conventional spraying methods often results in host toxicity. Hence, there is a need to develop targeted spraying methods. Therefore, a study was carried out during 2024–25 in a mango orchard at the College of Agriculture, Thrissur, in a completely randomized design (CRD), replicated thrice. The efficacy of various herbicides, application methods and sprayer types for controlling parasitic weed *Dendrophthoe* spp. on mango trees was studied. Treatments included foliar sprays of 2,4-dichlorophenoxyacetic acid (2,4-D) Sodium (Na) salt 80 wettable powder (WP) (5 g L⁻¹), 2,4-D amine 58 soluble liquid (SL) (10 mL L⁻¹), 2,4-D Na salt 80 WP (5 g L⁻¹) + copper sulfate (CuSO₄) (20 g L⁻¹), glufosinate ammonium 13.5 SL (10 mL L⁻¹), metribuzin 70 WP (5 g L⁻¹), ethrel 39 SL (25 mL L⁻¹) and metsulfuron methyl 20 WP (0.4 g L⁻¹); 2,4-D Na salt (2 %) and metribuzin (2 %) as padding at host-parasite junction, physical removal and untreated check. Ethrel induced complete defoliation within 2–3 days, followed by 2,4-D + CuSO₄, glufosinate ammonium, metribuzin and metsulfuron methyl. Defoliation was completed by 3–4 weeks in 2,4-D spray. Padding treatments were ineffective and no visual symptoms of phytotoxicity or reduction in physiological parameters were observed. Herbicide sprays reduced soluble sugars, protein, relative leaf water content, membrane stability, chlorophyll and nitrogen, phosphorus, potassium (NPK) content of *Dendrophthoe*. Foliar sprays of 2,4-D Na salt or 2,4-D amine provided sustained control without regrowth, whereas other herbicides provided only temporary suppression. Herbicide deposition rate, spray coverage and weed control efficacy varied with sprayer type. Compared to battery-powered hydraulic, backpack manually operated and air-assisted sprayers, the electrostatic sprayer recorded the highest spray deposition rate (30.5 µL cm⁻²) and lowest spray volume, but was ineffective. Though the deposition rate was low (10 µL cm⁻²), the battery-powered hydraulic sprayer provided superior canopy wetting with high volume spray and complete control. Targeted foliar application of 2,4-D with optimised sprayer technology provided effective control of *Dendrophthoe* in mango orchards, without host phytotoxicity. The study revealed a significant role of spray volume in herbicide efficacy, despite the electrostatic sprayers being highly efficient for disease and pest management.

Keywords: air-assisted sprayer; droplet deposition; electrostatic sprayer; *Loranthus* control; parasitic weed; sprayer types

Introduction

Dendrophthoe spp., belonging to the family Loranthaceae, are stem parasites. There are around 30 species of *Dendrophthoe* found in tropical Africa, Asia and Australia. Seven of these species are common in India. Two of them are commonly found: var. *falcata*, also called Honeysuckle Mistletoe, which is recognisable by its white flowers and var. *coccinea*, often called Red Honeysuckle Mistletoe, which is distinguished by its pink flowers. More than 300 plants have been identified as hosts for this parasitic perennial plant (1).

Dendrophthoe produces small berry-like fruits that stick to host tree trunks with a sticky substance called viscin, or “bird glue”. The seeds germinate on the host under ideal climatic conditions,

form a haustorium, a specialised structure that penetrates the host tissue to absorb water and nutrients, leading to a severe reduction in host vigour and yield.

The infestation of *Dendrophthoe falcata* is a concern in tree crops such as mango and other economically important species, significantly affecting yield. While manual removal by severing the infested branches is a widely practised method of control, but it is often impractical. Most often, the removal of the penetrated subepidermal haustoria from the host is incomplete and the parasite can re-emerge from any leftover portions (2, 3). 2,4-D was used to control *Loranthus* using the base banding technique (4), but a more effective approach was needed due to practical limitations. *Loranthus* can be controlled with ethrel spray at 25 mL L⁻¹ (5), but this practice is not widely adopted.

The application of herbicides is an efficient method, but only if it is done with precision to avoid environmental contamination and harm to host trees. The introduction of precision low-volume sprayers represents a game-changing solution for this problem, offering targeted, efficient and environmentally responsible herbicidal management. Hence, the study was undertaken to develop an effective herbicidal management strategy and to enable targeted herbicide application to minimise adverse effects on host trees.

Materials and Methods

The study was carried out at the mango orchard of the College of Agriculture, Thrissur of Kerala Agricultural University from October 2024 to September 2025. The mango trees in the orchard were about 20–25 years old and in a single tree, many branches were infested with *Dendrophthoe* and the trees were under infestation for about 8–10 years. Almost uniformly sized *Dendrophthoe* clusters (2 m² surface area) were selected for spraying. Three trees were selected for each treatment and a minimum of 3 clusters were sprayed per tree. Treatment details are furnished below. Herbicides were foliar-sprayed except in T₈ and T₉. The treatment details are elaborated in Table 1.

Table 1. Treatment details

Treatments		Trade name	Product - Quantity per litre of water
T ₁	2,4-D Na salt	Kilharb 80 % WP	5 g L ⁻¹
T ₂	2,4-D amine	Jerico 58 % SL	10 mL L ⁻¹
T ₃	2,4-D Na salt + CuSO ₄	Kilharb 80 % WP + Commonly available CuSO ₄	5 g L ⁻¹ + 20 g L ⁻¹
T ₄	Glufosinate ammonium	Ferio 13.5 % SL	10 mL L ⁻¹
T ₅	Metribuzin	Sencor 70 % WP	5 g L ⁻¹
T ₆	Ethrel	Tagpon 39 % SL	25 mL L ⁻¹
T ₇	Metsulfuron methyl	Convo 20 % WP	0.4 g L ⁻¹
T ₈	2,4-D Na salt padding	Kilharb 80 % WP	20 g L ⁻¹
T ₉	Metribuzin padding	Sencor 70 % WP	20 g L ⁻¹
T ₁₀	Manual removal of parasite once in 3 months	With a sickle attached to pole	-
T ₁₁	Unsprayed check	-	-

Urea (50 g L⁻¹) and sticker (2 g L⁻¹) were tank-mixed in all treatments (except ethrel spray and padding) to enhance herbicide efficacy. Chemicals were sprayed using a battery-powered hydraulic sprayer calibrated to deliver 200 L per acre with a flood-jet nozzle. Padding (base banding) was done after making a fresh wound on the main stem of the parasite, near the main point of attachment and a cotton strip was soaked in the herbicide solution at a concentration of 2 % and banded (4,5).

Phytotoxicity symptoms, including browning, drying and leaf shedding of *Dendrophthoe* and the host, were periodically recorded at intervals of 1, 3, 5, 7, 14, 21 and 28 days after treatment (DAT). These symptoms were scored using a rating scale (6) ranging from 0–5 for *Dendrophthoe* (0- no control, 1- slight control, 2- moderate control, 3- good control, 4- very good control, 5- complete control) and for host (Rating scale: 0- no injury, 1- slight injury, 2- moderate injury, 3- severe injury, 4- very severe injury,

5- complete destruction). Regrowth of *Dendrophthoe* was also noted at periodic intervals up to 90 days and also at 1 year after treatment application.

Leaf samples were collected for analysis from each treatment before spraying and 7 days after spraying (DAS) (leaves retained on clusters). Samples were collected 1 day after ethrel application due to sudden defoliation. Total soluble sugar, protein, relative leaf water content, membrane stability and total chlorophyll content [dimethyl sulfoxide (DMSO) method] of the *Loranthus* leaves were estimated following standard procedures. Leaves were collected, cleaned, dried under shade and oven-dried at 60 ± 5 °C for plant NPK analysis.

The experiment evaluating different sprayers for enhancing the application efficacy of herbicides to *Dendrophthoe* on trees was conducted using a completely randomized design (CRD), with 3 replicates. Four sprayer types, namely battery-powered hydraulic sprayer (T₁), air-assisted sprayer (T₂), electrostatic sprayer (T₃) and an air-compression backpack sprayer as control (T₄), were evaluated for the application of 4 herbicides-2,4-D sodium salt, metribuzin, metsulfuron-methyl and ethrel-applied at varying concentrations and spray volumes. Sprayer performance and herbicidal efficiency were evaluated based on parameters such as droplet deposition, percentage weed control and spray volume requirement. The spray volume requirement was calibrated at 1.5 L m⁻² for high-volume spray and 0.3 L for air-assisted and electrostatic sprayers, which were low-volume sprayers. For a single cluster, the approximate surface area was estimated at 2 m².

In spray droplet deposition study, methylene blue (Sinopharm chemical reagent co., ltd., Shanghai, China) 1 mL L⁻¹ was used as a spray indicator. After spraying the solution onto the *Dendrophthoe* clusters, leaves were collected once the spray solution had completely dried and carefully transferred into plastic covers. In the laboratory, each leaf was washed with 10 mL of deionised water and sonicated for 3 min to elute the spray indicator. The absorbance of the eluent was measured using an ultraviolet-visible spectrophotometer and the deposition was calculated in accordance with the field deposition measurements specified in ISO 24253-1. Each spray solution was tested 3 times and the average values were calculated. The deposition rate per unit area was calculated as:

β_{dep} = 1000(A_{smp}l - A_{blk})P_{cal} · V_{dil} / (P_{spray} · S_{colok}) (Eqn.1)

where β_{dep} is the deposition amount per unit area (μL cm⁻²) and V_{dil} is the volume of deionised water used to elute the spray indicator on the leaf surface (mL). A_{smp}l is the absorbance of eluent, A_{blk} is the absorbance of the blank, P_{cal} is the relationship between eluent absorbance and spray indicator concentration (mg L⁻¹) and P_{spray} is the concentration of spray indicator (g L⁻¹). S_{colok} is the area of the *Dendrophthoe* leaf (cm²).

The experimental data were subjected to statistical analysis using the software general R-based analysis platform empowered by statistics (GRAPES) (7). The experiment was conducted in a CRD with 3 replications. Analysis of variance (ANOVA) was performed to determine the significance of treatment effects. Differences among treatment means were tested using an F-test at the 5 % significance level. When the F-test was significant, mean separation was carried out using Tukey's honestly significant difference (HSD) test (p ≤ 0.05).

Results and Discussion

Phytotoxicity to parasite and host

The efficacy of various herbicidal sprays was assessed by measuring phytotoxicity to *Dendrophthoe* and regrowth (Table 2). Ethrel spray induced rapid ethylene-mediated leaf abscission, which began within 24 hr of spraying. It is a common defoliant used in commercial fruit production and defoliation in 5–7 days was reported in sugar apple and pomegranate (8, 9). This was followed by 2,4-D Na salt + Copper sulfate (CuSO_4), glufosinate ammonium, metribuzin and metsulfuron methyl (14 DAT), while 2,4-D formulations acted more slowly (Fig. 1) and complete defoliation was observed in 21–28 DAT. Foliar sprays were more effective than padding as they facilitated better absorption and translocation through foliage.

Table 2. Phytotoxicity rating of *Dendrophthoe*

Tr.No.	Treatment	Days after treatment application						
		Day 1	Day 3	Day 5	Day 7	Day 14	Day 21	Day 28
T ₁	2,4-D Na salt	1	2	3	4	4	5	5
T ₂	2,4-D amine	1	1	2	3	4	4	5
T ₃	2,4-D Na salt + CuSO_4	1	3	4	5	5 *	5	5
T ₄	Glufosinate ammonium	0	2	4	5	5 *	5	5
T ₅	Metribuzin	0	2	4	4	5 *	5	5
T ₆	Ethrel	3	4	5	5	5	5	5**
T ₇	Metsulfuron methyl	1	3	4	5	5	5	5***
T ₈	2,4-D Na salt padding	0	0	0	0	0	0	1##
T ₉	Metribuzin padding	0	0	0	0	0	0	1##

(Rating scale: 0-none; 1-slight toxicity; 2-moderate; 3- good; 4-very good; 5- complete drying)

*Regrowth within 2 weeks; **Regrowth by 40 days of spraying;

***Regrowth by 70 days; ## Weed remained healthy.



Fig 1. Phytotoxic symptom of 2,4-D Na salt application 7 days after spraying.

The directed application of herbicides effectively managed *Dendrophthoe*. Even 1 year after application, no phytotoxic effects were observed on the host plant, either on existing leaves or on newly emerged flushes. The lack of distinct phloem prevented the movement of herbicide from parasite to host tissues. This anatomical peculiarity of the vascular bundles of *Loranthus* was earlier reported (10). This revealed that a targeted application of a suitable herbicide can selectively control the stem hemiparasitic plant *Dendrophthoe* without host injury. However, direct contact of herbicides with the host is injurious as it kills all the broad-leaved plants.

Effect of herbicides on total soluble sugar (TSS) content of *Dendrophthoe* leaves

Significant difference in total soluble sugar content of *Dendrophthoe* leaves was observed under herbicidal treatments (Table 3). Padding with 2,4-D Na salt and metribuzin maintained higher TSS levels comparable to the unsprayed control (33.94 mg g⁻¹), indicating minimal interference with carbohydrate metabolism. This response was due to limited herbicide translocation and the consequent maintenance of normal parasite metabolic activity in padding treatments. In contrast, foliar sprays markedly reduced TSS, with the lowest value observed with metsulfuron methyl (7.63 mg g⁻¹).

Effect of herbicides on protein content of *Dendrophthoe* leaves

Protein content in *Dendrophthoe* leaves showed significant variation due to herbicidal treatments (Table 3). Similar to TSS, padding with metribuzin (3.89 mg g⁻¹) and 2,4-D sodium salt (3.58 mg g⁻¹) maintained higher protein levels because poor herbicide movement limited their systemic toxicity. In contrast, foliar applications caused a marked decline, with the lowest levels in 2,4-D amine (1.79 mg g⁻¹), followed by 2,4-D Na salt and metsulfuron methyl (1.90 mg g⁻¹). Intermediate protein levels were observed with glufosinate ammonium, metribuzin, ethrel and 2,4-D Na salt + CuSO_4 (2.06–2.28 mg g⁻¹). The drastic reduction in protein under foliar-applied 2,4-D amine and metsulfuron methyl indicates severe metabolic disruption, as auxinic herbicides generate ROS, interfere with nucleic acid metabolism and impair ribosomal activity, ultimately suppressing protein synthesis (11).

Effect of herbicides on relative leaf water content of *Dendrophthoe* leaves

The relative leaf water content (RWC) of *Dendrophthoe* leaves declined significantly under herbicidal treatments (Table 3) and the trend was similar to that of TSS and protein. Foliar sprays caused severe reductions, with the lowest in 2,4-D Na salt + CuSO_4 (10.85 %), followed by metribuzin (18.20 %) and 2,4-D Na salt (22.56 %), which were statistically comparable. Padding treatments maintained a RWC of 59–60 %, which indicated slight stress compared to healthy leaves where RWC was 86.42 %. The pronounced decline under foliar sprays is attributed to herbicide-induced oxidative stress, membrane damage and ionic imbalance, impairing water regulation, consistent with reports of similar effects of 2,4-D on ROS, antioxidant activity and ion transport in plants (12).

Effect of herbicides on membrane stability index of *Dendrophthoe* leaves

As in the case of RWC, the membrane stability index (MSI) of *Dendrophthoe* leaves varied significantly among herbicidal treatments (Table 3). Comparing the effect of various herbicidal treatments, higher MSI was maintained in padding treatments with metribuzin (81.14 %) and 2,4-D Na salt (75 %). Foliar sprays caused a

Table 3. Effect of herbicides on total soluble sugar, protein, relative leaf water content, membrane stability index and total chlorophyll content of *Dendrophthoe* leaves

Tr. No.	Treatment	TSS (mg g ⁻¹)	Protein (mg g ⁻¹)	Relative leaf water (%)	Membrane stability index (%)	Total chlorophyll (mg g ⁻¹)
T ₁	2,4-D Na salt	11.79 ^{bc}	1.90 ^e	22.56 ^f	26.40 ^f	1.39 ^{bc}
T ₂	2,4-D amine	11.78 ^{bc}	1.79 ^e	29.10 ^e	32.51 ^e	1.56 ^{bc}
T ₃	2,4-D Na salt + CuSO ₄	15.26 ^b	2.22 ^d	10.85 ^g	55.26 ^d	1.50 ^{bc}
T ₄	Glufosinate ammonium	14.90 ^b	2.28 ^d	29.53 ^e	55.10 ^d	1.45 ^{bc}
T ₅	Metribuzin	14.47 ^b	2.06 ^{de}	18.20 ^f	55.85 ^d	1.17 ^{cd}
T ₆	Ethrel	13.22 ^b	2.20 ^d	50.00 ^c	52.31 ^d	0.92 ^d
T ₇	Metsulfuron methyl	7.63 ^c	1.90 ^e	45.37 ^d	54.92 ^d	1.64 ^b
T ₈	2,4-D Na salt padding	29.24 ^a	3.58 ^c	60.00 ^b	75.00 ^c	3.57 ^a
T ₉	Metribuzin padding	29.05 ^a	3.89 ^b	59.33 ^b	81.14 ^b	3.64 ^a
T ₁₀	Unsprayed check	33.94 ^a	4.2 ^a	86.42 ^a	90.46 ^a	3.83 ^a

The values followed by common alphabets do not differ significantly at 5 % level as per Tukey's HSD test.

severe reduction, the lowest in 2,4-D Na salt (26.40 %), followed by 2,4-D amine (32.51 %). Intermediate MSI levels (52–56 %) were observed with glufosinate ammonium, metribuzin, metsulfuron methyl and 2,4-D Na salt + CuSO₄.

Effect of herbicides on total chlorophyll content of *Dendrophthoe* leaves

Total chlorophyll content in *Dendrophthoe* leaves showed significant variations (Table 3). Padding with 2,4-D Na salt (3.64 mg g⁻¹) and metribuzin (3.57 mg g⁻¹) maintained higher pigment levels, comparable to the unsprayed check (3.83 mg g⁻¹), due to poor translocation of herbicides. In contrast, foliar sprays caused severe chlorophyll degradation, with the lowest levels in ethrel (0.92 mg g⁻¹) and metribuzin (1.17 mg g⁻¹). Intermediate chlorophyll content (1.39–1.64 mg g⁻¹) was recorded with 2,4-D Na salt, 2,4-D amine, 2,4-D Na salt + CuSO₄, glufosinate ammonium and metsulfuron methyl. Similar responses have been reported in fodder radish, where glyphosate reduced chlorophyll, fluorescence and membrane stability, highlighting plant sensitivity to herbicide-induced oxidative stress (13).

Overall, the data clearly indicated that the padding of 2,4-D Na salt and metribuzin was not effective and was comparable to the unsprayed check in maintaining higher TSS, protein, RWC, MSI and chlorophyll content, highlighting their reduced phytotoxic effect. In contrast, foliar-applied herbicides, particularly auxinic compounds (2,4-D Na salt and 2,4-D amine), severely disrupted metabolic and physiological processes, as evidenced by sharp decline in various physiological parameters. Hence, it is clear that the foliar application induced significant stress in *Dendrophthoe* spp. leading to metabolic dysfunction, cellular injury and reduced photosynthesis.

Effect of herbicides on N, P and K content of *Dendrophthoe* leaves

In healthy *Loranthus* leaves, the average N content was 2.26 %. Phosphorus (P) and potassium (K) were 0.12 and 3.6 %, respectively. Variations in nutrient content were observed in most herbicidal sprays, as urea 5 % was tank mixed, this also contributed to the nitrogen (N) content of leaves (Table 4). Reduction in N content was significant in padding treatments though urea was not used. The 2,4-D padding, metribuzin padding, 2,4-D amine and metsulfuron methyl spray showed significantly lower N content (1.66–1.14 %), while other treatments recorded higher values (2.15–1.81 %), comparable to the unsprayed check (2.26 %). Phosphorus content in

healthy leaves was 0.012 %, but all sprayed and padded treatments showed significant reductions (0.002–0.005 %). Potassium content in healthy leaves was 3.6 %, which decreased under treatments with ethrel, padding with metribuzin and 2,4-D Na salt, metsulfuron methyl, metribuzin, glufosinate ammonium and 2,4-D amine (1.3–2.3 %), while 2,4-D Na salt and 2,4-D Na salt + CuSO₄ also recorded higher values comparable to the check. These nutrient reductions align with the findings that in soybean herbicide sprays significantly reduced P concentration and nodulation, highlighting the broader impact of herbicides on plant nutrient status due to impaired metabolic pathways (14).

Table 4. Effect of herbicides on nitrogen, phosphorus and potassium content of *Dendrophthoe* leaves

Tr. No.	Treatment	Nitrogen (%)	Phosphorous (%)	Potassium (%)
T ₁	2,4-D Na salt	2.15 ^{ab}	0.005 ^b	2.50 ^b
T ₂	2,4-D amine	1.45 ^{cde}	0.002 ^b	1.93 ^{bcd}
T ₃	2,4-D Na salt + CuSO ₄	2.12 ^{ab}	0.003 ^b	2.3 ^{bc}
T ₄	Glufosinate ammonium	1.75 ^{abcd}	0.004 ^b	2.16 ^{bcd}
T ₅	Metribuzin	1.98 ^{abc}	0.004 ^b	1.5 ^{bcd}
T ₆	Ethrel	1.81 ^{abcd}	0.004 ^b	1.30 ^d
T ₇	Metsulfuron methyl	1.66 ^{bcd}	0.002 ^b	1.99 ^{bcd}
T ₈	2,4-D Na salt padding	1.14 ^e	0.002 ^b	2.28 ^{bcd}
T ₉	Metribuzin padding	1.36 ^{de}	0.002 ^b	1.4 ^{cd}
T ₁₀	Unsprayed check	2.26 ^a	0.012 ^a	3.6 ^a

The values followed by common alphabets do not differ significantly at 5 % level as per Tukey's HSD test.

Regrowth of *Dendrophthoe*

Regrowth of *Dendrophthoe* was observed in many treatments reflecting the differences among herbicides in tissue penetration, translocation and mode of action. Regrowth appeared earliest at 11 DAS in 2,4-D Na salt + CuSO₄, followed by glufosinate ammonium and metribuzin at 13 DAS (Fig. 2, 3). Ethrel treated clusters regrew at 40 DAS and in manually removed, by 60 DAS. Metsulfuron methyl suppressed regrowth up to 2 months and later sprouts were seen by 70th DAS. 2,4-D Na salt and 2,4-D amine provided the most effective and sustained control, with no regrowth even after 1 year. In contrast, metribuzin offered only temporary suppression due to poor uptake and limited

translocation. Ethrel spray, although it led to rapid defoliation, failed to kill the parasite. This may be due to the limited herbicidal activity of this plant hormone. It can cause defoliation or yellowing as a side effect of high ethylene release. It is reported that even sequential applications of ethrel are not effective and conventional mechanical removal led to 77 % re-emergence of *Loranthus* within 3 months, emphasising the need for interventions that eradicate the parasite without harming the host (4). The poor efficacy of mixture of 2,4 D + copper sulphate can be due to poor translocation of this mixture to parasite's tissues. It is clear from the phytotoxicity rating that faster leaf fall in 3–5 days (Table 2) was observed with the addition of heavy metal copper, resulting in enhanced toxicity, which in turn prevented the further transport of herbicide to twigs/branches of *Dendrophthoe*. In 2,4 D sole application, it took 21–28 days for complete defoliation and hence sufficient time was available for effective systemic toxicity. Additionally, the coagulation of 2,4-D and CuSO_4 mixture indicated the incompatibility of these chemicals in tankmix. This also might have contributed to the poor efficacy of 2,4-D in the mixture. The herbicide 2, 4-D is absorbed through leaves and translocated through phloem and xylem to actively growing points where it disrupts normal growth and metabolism, eventually leading to the death of broad-leaved plants.



Fig 2. No regrowth after 2,4-D Na salt application (1 year after application).



Fig 3. New sprouts emerging in glufosinate ammonium treated plants at 13 days after spraying.

Evaluation of different sprayers for enhancing the application of herbicides to *Dendrophthoe* on trees

Spray deposition rate ($\mu\text{L cm}^{-2}$)

Herbicide deposition on foliage varied significantly with sprayer types (Fig. 4), with the electrostatic sprayer registering the highest deposition ($30.5 \mu\text{L cm}^{-2}$), followed by air-assisted ($12.63 \mu\text{L cm}^{-2}$) and battery-powered hydraulic sprayer ($10.0 \mu\text{L cm}^{-2}$), while the backpack manually operated sprayer recorded the lowest ($7.23 \mu\text{L cm}^{-2}$). These results highlight the decisive influence of sprayer type on deposition efficiency, as supported by reports that electrostatic pesticide spraying yields greater droplet density and leaf coverage than conventional sprayers, thereby enhancing bio-efficacy (15). The higher deposition rate of the electrostatic sprayer is attributed to the charged spray droplets, which enhance their adhesion to the leaf surface, minimising drift and ensuring uniformity in deposition.

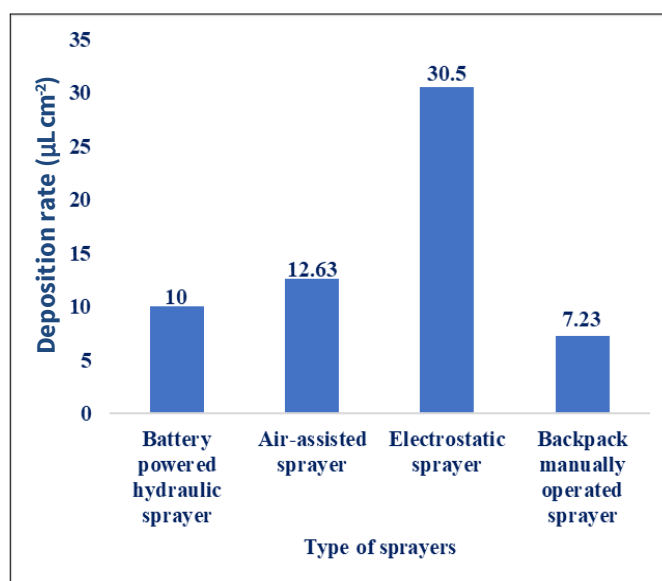


Fig. 4. Spray deposition rate ($\mu\text{L cm}^{-2}$).

Percentage control of *Dendrophthoe*

Weed control of *Dendrophthoe* varied with sprayer type, herbicide and spray volume (Table 5, Fig. 5). A battery-powered hydraulic sprayer provided the highest long-term control with the systemic herbicide (2,4-D) due to its coarse droplets, higher spray volume and better canopy penetration, which enhanced absorption and translocation. In contrast, air-assisted and electrostatic sprayers were less effective, as fine droplets limited retention and uptake and reduced spray volumes further hindered systemic action. Ethrel (ethephon) achieved high short-term control among all sprayers through contact-based action, but regrowth was observed by 40 DAS. While fine droplets may improve retention, coarse droplets significantly enhance absorption and systemic movement to active sink tissues, emphasising that herbicide efficacy depends not only on retention but also on effective uptake and translocation (16). The study indicates that long-term control of *Dendrophthoe* is possible with systemic herbicides applied via high-volume, coarse-droplet sprays, whereas contact herbicides provide only short-term suppression.

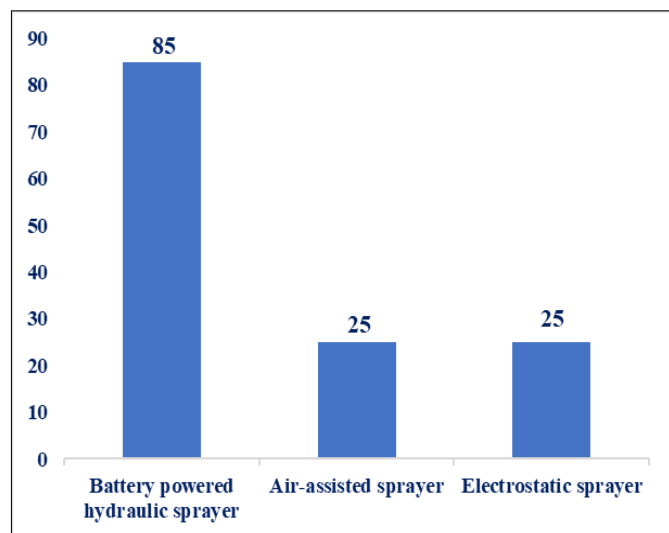
Spray volume requirement

Although electrostatic and air-assisted sprayers are generally considered superior in conventional pest management because of reduced chemical use, minimal residues and higher energy

Table 5. Percentage control of *Dendrophthoe* in different herbicidal treatments with different types of sprayers at 21 days after spraying

Herbicide	Sprayer type					
	Battery-powered hydraulic sprayer	Percentage control (Visual)	Air-assisted sprayer	Percentage control (Visual)	Electrostatic sprayer	Percentage control (Visual)
2,4-D Na salt	5 g L ⁻¹	>80 %	5 g L ⁻¹	25 % *	5 g L ⁻¹	25 % *
					5 g 0.5 L ⁻¹	20 % *
Metribuzin	5 g L ⁻¹	>80 % *	5 g L ⁻¹	45 % *	5 g L ⁻¹	25 % *
					5 g 0.5 L ⁻¹	20 % *
Metsulfuron methyl	0.4 g L ⁻¹	>80 % *	0.4 g L ⁻¹	40 % *	0.4 g L ⁻¹	50 % *
					0.4 g 0.5 L ⁻¹	20 % *
Ethrel	25 mL L ⁻¹	>90 % *	25 mL L ⁻¹	35 % *	25 mL L ⁻¹	>70 % *

Rating scale: (0–20 % Slight toxicity; 20–40 % Moderate; 40–60 % Good; 60–80 % Very good; 80–100 % Complete drying) *Regrowth observed.

**Fig. 5.** Percentage control of *Dendrophthoe* after 2,4-D Na salt spray.

efficiency (17), their performance in *Loranthus* control was limited in this study. Air-assisted and electrostatic sprayers achieved complete visual coverage of *Loranthus* clusters using only 0.3 L 2 m⁻², whereas the battery-powered hydraulic sprayer required a much higher spray volume (3.0 L 2 m⁻²) to attain similar coverage. However, the ultra-fine droplets produced by the electrostatic sprayer dried rapidly in the field and the low spray volume was insufficient to maintain prolonged wetness on the foliar surface of the parasitic weed, thereby restricting herbicide retention and absorption. In contrast, the battery-operated high-volume sprayer, provided longer surface wetting and better spray-target contact due to the higher spray volume, resulting in a comparatively improved biological response in *Loranthus* management. This shows the importance of spray volume in achieving effective translocation of active ingredient into the plant system for its action. A comparison made by including the same herbicide load of 2,4-D (5 g) in the reduced spray volume of 0.5 L, which proved that spray volume has a decisive role in herbicide efficacy, as it gave only 20 % control of the parasite. However, electrostatic sprayers are superior, generating ultra-fine, charged droplets that achieve “wrap-around” coverage even in dense canopies, reducing chemical use by 25–80 % without compromising efficacy in insect and disease control (18). Future studies should focus on integrating herbicide mode of action, plant surface properties and sprayer engineering to ensure compatibility of technology with weed and crop biology for optimal results.

Conclusion

Foliar application of 2,4-D Na salt and 2,4-D amine tank mixed with urea and sticker, provided the most effective and sustained control of *Dendrophthoe*, without adversely affecting the host. Directed herbicide application using optimised sprayer technology is a reliable strategy for the sustainable management of *Dendrophthoe* in mango orchards. Future research should focus on varying herbicide doses and advanced spraying technologies for precision application.

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Authors' contributions

PP and SA conceived and designed the herbicidal experiment, while DD and BP planned the second part on spraying technology. RC conducted the literature review, carried out the experiment and wrote the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflicts of interest to declare.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to correct sentences and grammar. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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