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Yellow Nutsedge (*Cyperus esculentus*) Management with Electrical Weed Control

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Abstract. **Yellow nutsedge (*Cyperus esculentus* L.) is an important perennial weed in horticultural crops that is difficult to manage due to its aggressive growth, prolific spread, and extensive tuber network, as well as its tolerance to a wide range of moisture and soil conditions. These characteristics make control especially challenging in organic farming systems. Electrical weed control (EWC) is an emerging nonchemical strategy that delivers electrical energy to plant tissues, disrupting cellular structures. This study evaluated EWC for *C. esculentus* control using tractor-powered systems in 2023 and 2024: an alternating-current unit (EH30 "Thor"; Zasso™ Group AG, Zug, Switzerland) and a direct-current unit (XPower XPS; Zasso™ Group). Treatments included EWC applied at different energy levels (24 to 518 kJ·m^{-2}) by varying operation speeds (0.5 to 3 km·h^{-1}), applied singly or sequentially, as well as mowing and combined mowing followed by EWC. In the 2023 Corvallis study (alternating current system), mowing and slow-speed EWC at 0.5 km·h^{-1} (144 kJ·m^{-2}) controlled *C. esculentus* shoots (88%) at 14 days after initial treatment (DAIT), but regrowth occurred over time. Sustained control was achieved with mowing followed by EWC (81%) and sequential EWC applications (80%) by 56 DAIT. Three passes at 3 km·h^{-1} (24 kJ·m^{-2} per application) provided 75% control at 80 DAIT. In greenhouse assays, field-treated tubers were evaluated for viability. Mowing followed by EWC reduced shoot emergence (38%) and shoot biomass by 42% compared with nontreated control. The 2024 study (direct current system) confirmed the advantage of sequential EWC: three passes at 3 km·h^{-1} (86 kJ·m^{-2}) achieved 93% control at 80 DAIT. Sequential and combined treatments (EWC two passes at 2 km·h^{-1}, EWC followed by mowing) reduced tuber density (52% to 57%) and weight (46% to 56%) compared with the nontreated control. EWC demonstrated strong potential for shoot suppression of *C. esculentus*, particularly when applied sequentially or combined with mowing. Importantly, treatment order was critical: mowing followed by EWC providing greater weed control (81%) compared with the reverse sequence (EWC followed by mowing, 61%).**

Yellow nutsedge (*Cyperus esculentus* L.) is a perennial sedge widely recognized for its invasive nature and adaptability. This species is distinguished by an extensive network of underground tubers, which form from the top 15 to 46 cm and serve as a reservoir for energy, facilitating rapid regeneration even after the aboveground portions are removed (Follak et al. 2016; Schippers et al. 1993). *C. esculentus* seed production, population persistence and spread, are driven primarily by vegetative propagation via tubers and rhizomes; seedling recruitment is considered a minor contributor (Mulligan and Junkins 1976; Stoller and Sweet 1987; Thullen and Keeley 1979). Its aggressive growth, combined with tolerance to varying moisture levels and diverse soil conditions, enables it to outcompete crop species for essential resources such as nutrients, water, and light (Keeley 1987; Morales-Payan et al. 2003). In the Pacific Northwest, *C. esculentus* poses a significant threat to specialty crops, including highbush blueberry (*Vaccinium corymbosum* L.), cranberry (*Vaccinium oxycoccus* L.), and vegetables, reducing yield and crop quality (Rojas-Sandoval and Acevedo-Rodríguez 2022).

Managing *C. esculentus* is particularly difficult in organic farming systems, in which the absence of systemic herbicides restricts the range of effective control strategies. Growers rely on methods such as mechanical removal, crop rotation, mulching, and cover crops to suppress growth (Bangarwa et al. 2008). Mowing, a commonly used method, often requires repeated treatments throughout the season for effective weed suppression and can disturb the soil surface and increase compaction depending on equipment weight, tire traffic, slope, and pass frequency (Patton 2025; Summerlin et al. 2000). However, the deeply positioned tubers and robust regenerative capabilities of *C. esculentus* often limit the effectiveness of methods consistent with organic principles, highlighting the need to explore innovative and integrated management strategies that target root systems.

Electrical weed control (EWC) is a technology that delivers electrical energy to plant tissues, disrupting cellular structures and leading to plant death. In an EWC system, an electrode transfers electric current directly into the weed and surrounding soil, damaging plant cells, reducing the ability to absorb water and nutrients, and limiting regrowth (Diprose and Benson 1984; Diprose et al. 1980). Modern tractor-mounted EWC equipment has been developed for commercial use in perennial horticultural systems, including orchards, vineyards, and berry crops, in which in-row weed management is particularly challenging and alternatives to herbicides are limited (Slaven et al. 2023). By damaging underground structures of the plants, EWC can reduce the regenerative capacity of perennial weeds, suggesting it may offer a sustainable alternative to mechanical practices such as mowing (Feys et al. 2023; Summerlin et al. 2000). Recent field studies confirm that EWC can drastically reduce shoot vitality in *C. esculentus*; however, a single treatment does not eliminate all vegetative propagules, emphasizing the need for repeated applications throughout the season to deplete underground tubers and stored resources (Feys et al. 2023).

Despite these promising results, limited research has directly compared EWC with organic practices such as mowing, particularly for *C. esculentus*. This study addresses this knowledge gap by evaluating the effectiveness of EWC on *C. esculentus*, comparing single versus sequential applications and different operating speeds against mowing. We further assess the combined effects of EWC and mowing on aboveground suppression and belowground tuber viability, providing practical insights for integrated weed management.

Materials and Methods

Site description. Two field studies were conducted in Oregon in 2023 and 2024 in areas with a natural high density of *C. esculentus*. The first study was conducted at the Lewis Brown research farm in Corvallis, OR (lat. 44.56°N, long. 123.22°W), in 2023, on a fallow field of Chehalis silty clay loam soil (0 to 20 cm: 20% sand, 49% silt, 31% clay). The studies commenced in Jun 2023 in an area where *C. esculentus* reached ∼20 to 25 cm in height at the Biologische Bundesanstalt, Bundessortenamt, and CHemical industry (BBCH) 19 stage. The second study was conducted on a commercial organic-certified highbush blueberry farm in Grants Pass, OR (lat. 42.23°N, long. 123.27°W), situated on Evans loam soil

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(0 to 20 cm: 44.3% sand, 40.7% silt, 15.0% clay). This field had a history of unsuccessful control of *C. esculentus* with plants measuring 15 to 20 cm in height in Jun 2024 at the BBCH 19 stage.

Treatment and equipment details. The experiments were arranged as a randomized complete block design with four replicates. Experimental units measured 3 × 6 m at both locations. All treatments at each site received an initial application on the same date (site-specific as presented in Table 1). Treatments requiring multiple passes then received sequential applications ~4 and 8 weeks after the initial application. The treatment structure comprised: a nontreated control (NTC); single application of mowing only; single or multiple application of EWC only, at tractor speeds of 0.5, 1, 2, or 3 $km \cdot h^{-1}$ (with site-specific energy doses); EWC followed by mowing [EWC at 1 $km \cdot h^{-1}$, then mowing 4 weeks after treatment (WAT)]; and mowing followed by EWC (mowing, then EWC at 1 $km \cdot h^{-1}$ 4 WAT).

Mowing operations executed by a walk-behind rotary mower (Premier 26; DR Power Equipment, Waukesha, WI, USA). EWC was performed using either alternating current (AC) or direct current (DC) tractor-mounted commercial units. The equipment selection was based on availability and dimensions that would be compatible with the cropping system. The Corvallis study used a 30-kW unit (EH-30 Thor; Zasso™ Group, Zug, Switzerland) connected to a 77-kW tractor (5100GN; John Deere, Moline, IL, USA). The electrical weeder consisted of an oil-cooled generator producing a peak power of 30 kW of AC at 180 V and 60 Hz that is mechanically powered by the tractor engine power take-off (PTO). For energy calculation, a power factor of 0.8 was assumed based on the manufacturer's recommendation. Electric current is transferred to a triphase transformer that can be configured to increase voltage from 3.5 to 12 kV. Cables transfer the high-voltage current to an applicator mounted on the front of the tractor. The applicator consists of metal electrodes arranged 1.2 m in width. The electrodes are the parts in contact with weed foliage and soil during operations (Fig. 1A-C).

The Grants Pass study used a Zasso™ XPower XPS system, a DC electrical weeding unit designed specifically for perennial cropping systems such as orchards and vineyards. The system was mounted on the rear of a 60-kW narrow tractor (T4.80; New Holland, New Holland, PA USA) and powered via the tractor's PTO, which mechanically drives the onboard generator. This generator produces DC and can deliver a peak power of 24 kW to the applicator. For energy calculation, a power factor of 0.9 was assumed based on the manufacturer's recommendation. The rear-mounted applicator, measuring ~30 cm in width and equipped with metallic electrodes, features a compact design that allows EWC application adjacent to the planting row (Fig. 1D-F). At Grants Pass, treatments were applied on both sides of the blueberry planting rows.

The nominal electric energy density per area applied was determined by the speed of operation using the following equation:

$$E(\mathrm{kJ \cdot m^{-2}}) = \mathrm{Power}\left(\frac{\mathrm{kJ}}{\mathrm{s}}\right) \times \mathrm{PF} \times \frac{1}{\mathrm{speed}\left(\frac{\mathrm{m}}{\mathrm{s}}\right)} \times \frac{1}{\mathrm{width(m)}} \qquad [1]$$

where E indicates applied energy ($kJ \cdot m^{-2}$), power indicates the generator power (kW = $kJ \cdot s^{-1}$), PF indicates power factor, speed indicates the speed of operation ($m \cdot s^{-1}$), and width indicates the width of the treated area (m).

Table 1. Application rates, timing, and dates of electrical weed control and mowing treatments for *C. esculentus* studies in Corvallis, OR, USA (2023), and Grants Pass, OR, USA (2024).

Treatment	Speed ($km \cdot h^{-1}$)[i]	Energy ($kJ \cdot m^{-2}$)	Number of applications	Application dates
Corvallis				
NTC	—		—	—
Mowing	—		1	29 Aug
EWC	0.5	144	1	29 Aug
EWC	1	72	1	29 Aug
EWC	2	36	2	29 Aug fb 9 Oct
EWC	3	24	3	29 Aug fb 9 Oct fb 30 Oct
EWC fb	1	72	2	29 Aug fb
Mowing	—			9 Oct
Mowing fb	—		2	29 Aug fb
EWC	1	72		9 Oct
Grants Pass				
NTC	—		—	25 Jul
Mowing	—		1	25 Jul
EWC	0.5	518	1	25 Jul
EWC	1	259	1	25 Jul
EWC	2	130	2	25 Jul fb 26 Aug
EWC	3	86	3	25 Jul fb 26 Aug fb 23 Sep
EWC fb	1	259	2	25 Jul fb
Mowing	—			26 Aug
Mowing fb	—		2	25 Jul fb
EWC	1	259		26 Aug

[i] Speed of operation of the tractor for EWC treatments.

— = not available; EWC = electrical weed control; fb = followed by another treatment application in 4 weeks; NTC = nontreated control.

Assessment timings differed slightly by site due to logistics and alignment with operational decision windows. At Corvallis (local site), we measured control of *C. esculentus* at 14, 56, and 80 d after initial treatment (DAIT), adding an early 14-DAIT rating to capture short-term responses. At Grants Pass, to accommodate travel time, budget, and grower scheduling, evaluations were conducted at 28, 56, and 80 DAIT. Weed control was visually assessed on a scale from 0% (no control) to 100% (complete control). At 80 DAIT, the aboveground biomass of *C. esculentus* was collected at the Grants Pass site from a randomly selected 0.25-m^2 quadrat/plot, then dried, and weighed. Biomass data were not collected in the Corvallis study.

Tuber density and viability. Tubers of *C. esculentus* were collected from experimental plots in Corvallis and Grants Pass, OR. For both locations, one soil sample per plot was collected to a depth of 20 cm. In the Corvallis study, sampling was performed by excavating an area of ~530 cm^2, resulting in a total soil volume of 10.6 dm^3. In the Grants Pass study, each sample consisted of 6 kg of soil and 5 dm^3. Collected soil was thoroughly washed, and tubers and roots were recovered in a 2-mm sieve. Tubers were then separated from the roots and remaining soil debris by a series of washes. Following recovery and cleaning, tubers were counted and gently dried with paper towel, and the fresh weight was recorded. Average tuber weight (g/tuber) was computed as the total fresh mass of tubers divided by the number of tubers (Corvallis: 100; Grants Pass: n). Tuber density was estimated by dividing the number of tubers recovered by the volume of soil sampled.

The *C. esculentus* tubers were planted in flats filled with a substrate composed of sphagnum peatmoss, perlite, pumice, dolomite, limestone, and a pH-adjusted Sunshine #4 Sungro® professional growing mix (Sun Gro Horticulture, Agawam, MA, USA). The flats were maintained in a greenhouse with daytime and nighttime temperatures of 24 and 15 °C, respectively. New shoot emergence (%) was recorded 4 weeks after planting as (number of emerged shoots ÷ number of tubers planted) × 100 for each plot flat. Emerged shoots were then clipped at the substrate surface, dried, and weighed. To standardize across sites, total fresh mass was also expressed on a per-tuber basis by dividing by the number of tubers planted for each plot.

Statistical analysis. All statistical analyses were performed in R (version 4.3.1; R Core Team, Vienna, Austria). Treatment was included as a fixed effect, and blocks were included as random effects. Weed control ratings were analyzed using generalized linear mixed models (GLMMs) with a β distribution implemented in the glmmTMB package (Brooks et al. 2017). Weed biomass, tuber weight, and dry weight of emerged plants were analyzed using linear mixed models (LMMs) with square-root transformation in the lme4 package (Bates et al. 2015). Tuber counts and plant emergence counts were analyzed using GLMMs with a negative binomial distribution to account for

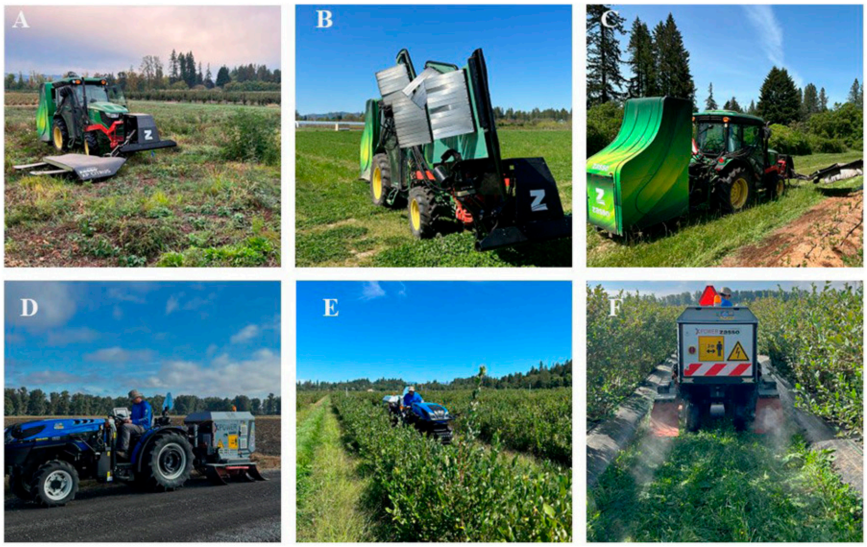

Fig. 1. Tractor-powered electrical weed control systems used in this study. (**A–C**) Zasso™ EH30 “Thor” (alternating current) mounted on a 77-kW tractor (5100GN; John Deere, USA). (**A**) Front overview in the field. (**B**) Close view of the front-mounted applicator head with metal electrodes (1.22-m working width). (**C**) Rear view showing the transformer cabinet mounted behind the tractor and driven via the power take-off. (**D–F**) Zasso™ XPower XPS (direct current) mounted on a 60-kW narrow orchard tractor (T4.80; New Holland, USA). (**D**) Front/lateral view of the unit. (**E**) Operation in blueberry field. (**F**) Rear view showing two rear-mounted applicators (0.30 m each) contacting the vegetation.

overdispersion (glmmTMB package). Model assumptions were checked before inference. For GLMMs, residual diagnostics were evaluated using DHARMa plots (Hartig 2022), and for LMMs, assumptions required for analysis of variance were verified through residual inspection. When significant treatment effects were detected, mean separation was performed using Fisher’s least significant difference test at $\alpha = 0.05$ with the agricolae package (Mendiburu 2023). Planned contrasts were conducted to further evaluate treatment effects on weed control at 80 DAIT and on biomass, comparing a single pass at 0.5 and 1 km·h^{-1} with the average of two sequential applications at 2 km·h^{-1} and three sequential applications at 3 km·h^{-1}. For weed control 80 DAIT only, contrasts were also used to test the sequence of integrated methods, comparing EWC followed by mowing with mowing followed by EWC.

Results

A significant effect of treatment ($\chi^2 = 78.39$, $P < 0.001$) and evaluation timing (DAIT; $\chi^2 = 64.57$, $P < 0.001$) was observed for *C. esculentus* control, with strong interactions among location, treatment, and DAIT ($\chi^2 = 26.16$, $P = 0.010$). Because energy levels and treatment responses varied by location and across evaluation timings, the data were analyzed and presented separately by location. Energy (kJ·m^{-2}) differed with equipment with EH30 at Corvallis (30 kW; 1.22-m width) and XPS at Grants Pass (24 kW; 0.30-m width), with the narrower applicator delivering a higher dose at the same speed.

Corvallis (2023, AC system). In Corvallis, both mowing and EWC treatments provided greater control of *C. esculentus* compared with the nontreated control (Tables 2 and 3). At 14 DAIT, mowing and EWC at 0.5 km·h^{-1} (144 kJ·m^{-2}) achieved the highest initial control (88%), although control from mowing alone declined to 26% by 80 DAIT. In

Table 2. Effect of electrical weed control and mowing on *C. esculentus* control in field studies conducted in Corvallis, OR, USA (2023), and Grants Pass, OR, USA (2024).

					C. esculentus control (%)[ii]				
Treatment	Speed[i]	En	Number of Applications	TE	14 DAIT	28 DAIT	56 DAIT	80 DAIT	Biomass (g·m^2)
Corvallis									
NTC	—		—		—	—	—	—	—
Mowing	—		1		88 a	56 b	41 e	26 e	—
EWC	0.5	144	1	144	88 a	70 a	52 de	36 de	—
EWC	1	72	1	72	70 b	51 ab	50 de	33 de	—
EWC	2	36	2	72	65 b	44 ab	62 cd	42 cd	—
EWC	3	24	3	72	59 b	37 c	80 ab	75 a	—
EWC fb mowing	1	72	2	72	69 b	48 ab	68 bc	50 bc	—
Mowing fb EWC	1	72	2	72	88 a	48 ab	81 a	57 b	—
Grants Pass									
NTC	—		—			—	—	—	435.3 a
Mow	—		1			36 a	35 d	37 d	36.5 b
EWC	0.5	518	1	518		28 ab	36 d	50 cd	51.1 b
EWC	1	259	1	259		26 ab	45 cd	52 c	29.3 b
EWC	2	130	2	260		20 b	70 a	70 b	19.6 b
EWC	3	86	3	258		18 b	63 ab	93 a	18.6 b
EWC fb mowing	1	259	2	259		19 b	59 ab	58 bc	14.3 b
Mowing fb EWC	1	259	2	259		38 a	57 cd	69 b	68.9 b

[i] Speed of operation of the tractor for EWC treatments in km·h^{-1}.

[ii] Means followed by the same letter within a column are not different based on Fisher’s least significant difference test ($\alpha = 0.05$).

— = not available; DAIT = days after initial treatment; En = energy applied in kJ·m^{-2}; EWC = electrical weed control; fb = followed by; NTC = nontreated control treatment; TE = total energy applied in kJ·m^{-2}.

Table 3. Effect of electrical weed control and mowing on *C. esculentus* control 80 DAIT in field studies conducted in Corvallis, OR, USA (2023), and Grants Pass, OR, USA (2024).

C. esculentus control 80 DAIT	Contrasts	Speed ($km \cdot h^{-1}$)	Mean difference	z ratio	*P* value
Control	Single vs. sequential app	0.5 − 1 vs. 2 − 3	+27%	−6.204	<0.0001
	EWC fb mowing vs. mowing fb EWC	1 vs. 1	−19.8	−2.586	0.0097
Biomass	Single vs. sequential app	0.5 − 1 vs. 2 − 3	−52%	1.015	0.3228

DAIT = days after initial treatment; EWC = electrical weed control; fb = followed by.

contrast, sequential EWC applications sustained greater suppression. Three passes at 3 $km \cdot h^{-1}$ (24 $kJ \cdot m^{-2}$ per pass; 72 $kJ \cdot m^{-2}$ total) provided 75% control at 80 DAIT, while mowing followed by EWC at 1 $km \cdot h^{-1}$ and EWC followed by mowing at 1 $km \cdot h^{-1}$ maintained 57% and 50% control, respectively.

Grants Pass (2024, DC system). At Grants Pass, both mowing and EWC treatments (0.5 to 3 $km \cdot h^{-1}$; 86 to 518 $kJ \cdot m^{-2}$) provided some control of *C. esculentus* at 28 DAIT (18% to 38%). Despite mowing treatments ranking highest, these levels were still insufficient (Tables 2 and 3). By 56 DAIT, control from mowing declined to 35%, while single EWC applications provided 45% weed control (the difference was not significant). At 56 DAIT, two sequential applications of EWC at 2 or 3 $km \cdot h^{-1}$ provided the higher control of *C. esculentus* (70% to 63%, respectively). Final evaluations at 80 DAIT, three-pass EWC at 3 $km \cdot h^{-1}$ (86 $kJ \cdot m^{-2}$ per pass; 258 $kJ \cdot m^{-2}$ total) provided the greatest control (93%; Fig. 2), followed by two-pass EWC at 2 $km \cdot h^{-1}$ (70%) and mowing followed by EWC at 1 $km \cdot h^{-1}$ (69%). All treatments reduced weed biomass compared with the nontreated control.

At 80 DAIT, planned contrasts confirmed that sequential applications were more effective than a single pass in both locations (Tables 2 and 3). Single applications at 0.5 and 1 $km \cdot h^{-1}$ provided significantly lower weed control than the average of two and three sequential applications, representing an improvement of 27 percentage points ($P < 0.001$). Contrast analysis also showed that the order of integration between methods influenced weed control outcomes. Mean control for EWC followed by mowing was 61%, which was significantly lower than mowing followed by EWC (81%), a difference of 19 percentage points

Fig. 2. Post-treatment symptoms of electrical weed control (EWC) in *C. esculentus.* Orange outlines and arrows indicate the width of treated area. The top left panel shows the nontreated control [28 days after initial treatment (DAIT)]. The bottom left panel shows a single EWC pass at 1 $km \cdot h^{-1}$ (28 DAIT). The right panel shows three EWC passes at 3 $km \cdot h^{-1}$ (80 DAIT).

($P = 0.009$).Weed biomass following a single application at 0.5 and 1 $km \cdot h^{-1}$ (40.2 $g \cdot m^{-2}$) did not differ from the average of two and three sequential applications (19.1 $g \cdot m^{-2}$, $P = 0.322$).

Tuber density and viability. In Corvallis (2023), average tuber weight did not differ significantly among treatments (128 to 167 mg/tuber; Table 4). However, greenhouse assays with tubers collected from field-treated plots revealed differences in regrowth potential. The mowing followed by EWC treatment resulted in the lowest shoot emergence (38%) and reduced shoot biomass (58 mg/shoot) to almost half of the emerged shoot weight in nontreated control. These results suggest that although tuber weight was not reduced, EWC, particularly when combined with mowing, can limit regrowth of new shoots by reducing new shoot emergence and aboveground biomass.

In Grants Pass (2024), tuber production was strongly affected by treatment (Table 4). The nontreated control averaged 69 tubers/dm^3 of soil with a mean weight of 260 mg/tuber. Single-pass EWC at 0.5 and 1 $km \cdot h^{-1}$ produced higher tuber counts (132 and 97 tubers/dm^3) compared with the control. In contrast, sequential and combined strategies presented lowest counts, with EWC followed by mowing (30 tubers/dm^3) and two-pass EWC at 2 $km \cdot h^{-1}$ (33 tubers/dm^3), although these mean differences were not statistically different from the nontreated control. Despite these decreases in tuber density and size, greenhouse assays did not detect significant differences in shoot emergence (4% to 13% of shoot emergence) or shoot biomass (12 to 31 mg) among treatments.

Discussion

This study demonstrates that EWC can effectively control shoots and, at the Corvallis site only, partially reduce tuber viability of *C. esculentus* in organic systems. These findings are particularly relevant for organic and specialty crop production, in which herbicide options are limited and perennial weeds with underground storage organs remain challenging to manage (Sosnoskie and Liu 2025). In our studies, EWC consistently controlled *C. esculentus* aboveground shoots, with performance strongly influenced by experimental site and number of applications. Sequential applications, particularly three passes, provided more sustained control than single treatments. When combined with mowing, EWC extended control for 80 DAIT, confirming the value of integrating weed control methods. However, greenhouse assays of recovered tubers showed reduced viability at Corvallis, indicating site-dependent effects on belowground propagules.

Previous research has shown that repeated mowing can temporarily limit regrowth of *C. esculentus* when performed in weekly or biweekly intervals at low cutting heights (Ryck et al. 2023; Summerlin et al. 2000). However, mowing alone only provides temporary suppression since tubers rapidly resprout, which aligns with reports that mechanical tactics such as cultivation, flaming, mulching, and solarization can suppress sedges and other perennial weeds aboveground but rarely eliminate tuber viability (Bangarwa et al. 2012; Horesh et al. 2019; Wada et al. 2024). Our results demonstrate that combining mowing with EWC extends suppression beyond what either tactic achieves alone, highlighting its role in integrated weed management. A limitation of our trials is the absence of repeated applications of mowing-only program. Nevertheless, repeated mowing is already the prevailing practice on many farms and has not prevented the continued spread of this perennial, which is why we emphasize testing combinations and sequences that might improve outcomes. Importantly, the sequence of operations also influenced outcomes. Applying mowing before EWC resulted in significantly higher weed control compared with the reverse order (EWC followed by mowing). This effect is consistent with reports that high weed density and tall biomass can shield smaller plants and reduce per-plant energy delivery during electrical treatments and that preliminary mowing can improve efficacy by lowering biomass and ensuring more uniform energy transfer (Slaven et al. 2023). The stronger efficacy observed in Grants Pass compared with Corvallis highlights the influence of environmental and operational factors and energy levels on EWC performance. Earlier applications in July under drier soil conditions, coupled with higher energy levels delivered by the DC system, likely enhanced energy transfer to underground structures compared with late-season treatments under wetter conditions in Corvallis. Previous research has emphasized the sensitivity of EWC efficacy to soil properties, moisture, and equipment configuration (Bauer et al. 2020; Vigneault and Benoît 2001; Vigneault et al. 1990), which may explain these site-specific differences.

EWC efficacy also varies among species. Annual broadleaf weeds such as *Amaranthus* spp., *Chenopodium album*, and *Ambrosia artemisiifolia* are often highly susceptible to a single application, with reported control levels ranging from 51% to 97% in *Amaranthus spp.* and 90% in *A. artemisiifolia*, and substantial reductions in seed viability when treated at reproductive stages (Schreier et al. 2022; Slaven et al. 2023). Greenhouse studies similarly showed that small broadleaf seedlings such as *C. album* and *Amaranthus* spp. are easily

Table 4. Tuber emergence and dry weight of aboveground shoots of *C. esculentus* in greenhouse studies evaluating electrical weed control and mowing treatments conducted in Corvallis, OR, USA (2023), and Grants Pass, OR, USA (2024).[i]

Treat	Speed ($km \cdot h^{-1}$)[ii]	Energy ($kJ \cdot m^2$)	Number of Applications	Field study: Tuber density ($count/dm^3$)	Field study: Avg tuber wt (mg/tuber)	Greenhouse study: New shoot emergence (%)	Greenhouse study: Weight of emerged shoots (mg/shoot)
Corvallis							
NTC	—		—	—	167	85 a	100 ab
Mowing	—		1	—	160	65 ab	75 bc
EWC	0.5	144	1	—	134	48 cd	72 bc
EWC	1	72	1	—	135	62 bc	70 bc
EWC	2	36	2	—	140	62 bc	80 abc
EWC	3	24	3	—	142	60 bc	67 bc
EWC fb mowing	1	72	2	—	155	74 ab	116 a
Mowing fb EWC	1	72	2	—	128	38 d	58 c
Grants Pass[ns]							
NTC	—		—	69 ab	260 a	4	12 c
Mowing	—		1	57 ab	135 b	6	12 c
EWC	0.5	518	1	132 b	200 ab	9	31 a
EWC	1	259	1	97 ab	122 b	13	24 ab
EWC	2	130	2	33 a	114 b	6	26 ab
EWC	3	86	3	42 ab	209 ab	5	29 ab
EWC fb mowing	1	259	2	30 a	140 b	6	13 c
Mowing fb EWC	1	259	2	96 ab	199 ab	6	16 bc

[i] Means followed by the same letter within a column are not different based on Fisher's least significant difference test ($\alpha = 0.05$).

[ii] Speed of operation of the tractor for EWC treatments.

EWC = electrical weed control applied at 57 $kJ \cdot m^2$ or 1 $km \cdot h^{-1}$; fb = followed by; ns = no significant difference based on Fisher's least significant difference test ($\alpha = 0.05$); NTC = nontreated control treatment.

controlled with low energy inputs, whereas grass weeds become more tolerant after tillering (Bloomer et al. 2022).

In contrast, perennial weeds such as Canada thistle (*Cirsium arvense*), field bindweed (*Convolvulus arvensis*), and yellow nutsedge (*C. esculentus*) are notoriously difficult to manage because of their extensive underground regenerative structures. Effective control of these species typically requires repeated or integrated management strategies, as single interventions rarely prevent regrowth. For example, Bongard et al. (2022) demonstrated that double or triple inter-row applications of electrical weeding, when combined with banded herbicides in sugar beet, achieved up to 94% control of *C. arvense* and *C. arvensis*, outperforming herbicides alone. Similarly, Lehnhoff et al. (2022) suppressed *C. arvensis* growth using continuous electrical exposure over several weeks. Nonchemical strategies such as repeated mowing and hoeing (Graglia et al. 2006) or integrated approaches combining cultural and chemical tactics (Davis et al. 2018) have also shown long-term reductions in perennial weed populations. Taken together, these findings suggest that, as with other management tactics, sustained suppression of perennial weeds with electrical weeding will likely depend on repeated applications and integration with complementary strategies, such as mowing, as we observed increased control (<75%).

Although tuber weight was not significantly reduced, greenhouse assays of tubers collected from Corvallis plots revealed reduced emergence and shoot biomass, particularly following sequential EWC and mowing–EWC combinations. This contrasts with Feys et al. (2023), who reported no impact on tuber viability but suggest that appropriate timing and number of applications can partially disrupt tuber regenerative capacity. In Grants Pass, the lack of response in tuber counts, weights, and greenhouse emergence is plausibly linked to site- and system-level differences: equipment configuration/width, higher initial tuber size/density, and soil texture–moisture conditions that change EC and shunt current through the soil rather than the plant. A deeper tuber depth distribution at this site would further buffer underground organs from lethal heating during passes. Interestingly, a single EWC pass increased the number of tubers relative to the untreated control, although tuber weights remained comparable across treatments. This compensatory response is consistent with disturbance-tolerance strategies in perennial weeds, where injury to shoots or underground organs can release dormant buds and stimulate vegetative propagation, often producing numerous but smaller propagules (Klimešová and Martínková 2022; Klimešová et al. 2017; Ott et al. 2019; Vesk and Westoby 2004). Notably, in Grants Pass, the mean tuber density in treated plots was 50% lower than the control, although this difference was not statistically significant. From a practical standpoint, growers should consider this magnitude of reduction when making management decisions, while also recognizing that single interventions may trigger resprouting and that repeated or integrated approaches are more likely to yield durable below-ground suppression.

The energy requirement for EWC in this study ranged from 24 to 518 $kJ \cdot m^{-2}$, depending on speed and number of applications. These requirements are similar to or lower than those reported for thermal methods such as propane flaming or saturated steam (365 to 740 $kJ \cdot m^{-2}$; Moretti and Pedroso 2023). Unlike other thermal control methods that are based on the indirect transfer of heating through steam or air, EWC transfers energy directly into the plants, moving it into underground structures like tubers. Literature reviews highlight that thermal systems such as flame, hot water, and steam typically require very high energy inputs (1000 to 4000 $MJ \cdot ha^{-1}$), whereas electrical weeding can operate at much lower ranges, 0.25 to 19 $MJ \cdot ha^{-1}$ depending on system configuration and plant size, making it one of the most energy-efficient nonchemical approaches currently available (Bloomer et al. 2024). Other emerging technologies, such as laser weeding or autonomous spot sprayers, may achieve lower per-plant energy requirements for small seedlings, but they remain less effective against perennial weeds with underground storage organs (Bloomer et al. 2024).

The findings presented here indicate that EWC is most effective in sequential applications or when combined with other nonchemical tactics. Mowing combined with EWC extended aboveground suppression and partially reduced tuber viability, offering stronger outcomes than either method alone, fitting well within the principles of integrated weed management. EWC proved capable of providing sustained control of *C. esculentus* shoots. Importantly, while tuber viability was only partially reduced, combined and repeated applications reduced regrowth more effectively than single passes. EWC can be incorporated into integrated weed management programs for organic and specialty crop systems, in which long-term suppression of perennial weeds like *C. esculentus* remains a critical challenge.

References Cited

Bangarwa SK, Norsworthy JK, Gbur EE. 2012. Effect of turnip soil amendment and yellow nutsedge (*Cyperus esculentus*) tuber densities on interference in polyethylene-mulched tomato. Weed Technol. 26(2):364–370. https://doi.org/10.1614/WT-D-11-00110.1.

Bangarwa SK, Norsworthy JK, Jha P, Malik M. 2008. Purple nutsedge (*Cyperus rotundus*) management in an organic production system. Weed Sci. 56(4):606–613. https://doi.org/10.1614/WS-07-187.1.

Bates D, Mächler M, Bolker B, Walker S. 2015. Fitting linear mixed-effects models using lme4. J Stat Softw. 67(1):1–48. https://doi.org/10.18637/jss.v067.i01.

Bauer M, Marx C, Bauer F, Flury D, Ripken T, Streit B. 2020. Thermal weed control technologies for conservation agriculture—A review. Weed Res. 60(4):241–250. https://doi.org/10.1111/wre.12418.

Bloomer DJ, Harrington KC, Ghanizadeh H, James TK. 2022. Micro electric shocks control broadleaved and grass weeds. Agronomy. 12(9):2039. https://doi.org/10.3390/agronomy12092039.

Bloomer DJ, Harrington KC, Ghanizadeh H, James TK. 2024. Robots and shocks: Emerging non-herbicide weed control options for vegetable and arable cropping. NZ J Agric Res. 67(1):81–103. https://doi.org/10.1080/00288233.2023.2252769.

Bongard M, Haberlah-Korr V, Koch M. 2022. Unkrautregulierung in Zuckerrüben–Überprüfung der Effizienz mechanischer und elektrischer Zwischenreihenbehandlung [Alternative weed control in sugar beet—verification of the efficiency of mechanical and electrical inter-row treatment], p 255–261. In: Proceedings of the 30th German Workshop on Questions of Weed Biology and Control. Julius Kühn Institute, Braunschweig, Germany.

Brooks ME, Kristensen K, Van Benthem KJ, Magnusson A, Berg CW, Nielsen A. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R. https://doi.org/10.32614/RJ-2017-066.

Davis S, Mangold J, Menalled F, Orloff N, Miller Z, Lehnhoff E. 2018. A meta-analysis of field bindweed (*Convolvulus arvensis*) management in annual and perennial systems. Weed Sci. 66(4):540–547. https://doi.org/10.1017/wsc.2018.25.

Diprose MF, Benson FA. 1984. Electrical methods of killing plants. J Agric Eng Res. 30:197–209. https://doi.org/10.1016/S0021-8634(84)80021-9.

Diprose MF, Benson FA, Hackam R. 1980. Electrothermal control of weed beet and bolting sugar beet. Weed Res. 20(5):311–322. https://doi.org/10.1111/j.1365-3180.1980.tb01625.x.

Feys J, De Cauwer B, Reheul D, Sciffer C, Clercx S, Palmans S. 2023. Impact of electrocution on shoot and tuber vitality of yellow nutsedge (*Cyperus esculentus*). Agriculture. 13(3):696. https://doi.org/10.3390/agriculture13030696.

Follak S, Belz RG, Bohren C, De Castro O, Del Guacchio E, Pascual-Seva N, Schwarz M, Verloove F, Essl F. 2016. Biological flora of Central Europe: *Cyperus esculentus* L. Perspect Plant Ecol Evol Syst. 23:33–51. https://doi.org/10.1016/j.ppees.2016.09.003.

Graglia E, Melander B, Jensen RK. 2006. Mechanical and cultural strategies to control *Cirsium arvense* in organic arable cropping systems. Weed Res. 46(4):304–312. https://doi.org/10.1111/j.1365-3180.2006.00514.x.

Hartig F. 2022. DHARMa: Residual diagnostics for hierarchical (multi-level/mixed) regression models. R package version. https://cran.r-project.org/web/packages/DHARMa/vignettes/DHARMa.html.

Horesh A, Goldwasser Y, Igbariya K, Peleg Z, Lati RN. 2019. Propane flaming as a new approach to control Mediterranean invasive weeds. Agronomy. 9(4):187. https://doi.org/10.3390/agronomy9040187.

Keeley PE. 1987. Interference and interaction of purple and yellow nutsedges (*Cyperus rotundus* and *C. esculentus*) with crops. Weed Technol. 1:74–81. https://doi.org/10.1017/S0890037X00029171.

Klimešová J, Martínková J. 2022. Clonal growth, resprouting, and vegetative propagation of weeds, p 200–218. In: Persistence strategies of weeds. Springer, Cham, Switzerland. https://doi.org/10.1002/9781119525622.ch11.

Klimešová J, Herben T, Martínková J. 2017. Disturbance is an important factor in the evolution and distribution of root-sprouting species. Evol Ecol. 31(3):387–399. https://doi.org/10.1007/s10682-016-9881-0.

Lehnhoff EA, Neher P, Indacochea A, Beck L. 2022. Electricity as an effective weed control tool in non-crop areas. Weed Res. 62(2):149–159. https://doi.org/10.1111/wre.12523.

Mendiburu F. 2023. agricolae: Statistical procedures for agricultural research. R package version 1.3-7. https://CRAN.R-project.org/package=agricolae. [accessed 10 Apr 2025].

Morales-Payan JP, Stall WM, Shilling DG, Charudattan R, Dusky JA, Bewick TA. 2003. Above- and belowground interference of purple and yellow nutsedge (*Cyperus* spp.) with tomato. Weed Sci. 51(2):181–185. https://doi.org/10.1614/0043-1745(2003)051[0181:AABIOP]2.0.CO;2].

Moretti ML, Pedroso RM. 2023. Weed control with saturated steam in organic highbush blueberry. Front Agron. 5:1297979. https://doi.org/10.3389/fagro.2023.1297979.

Mulligan GA, Junkins BE. 1976. The biology of Canadian weeds: 17. *Cyperus esculentus* L. Can J Plant Sci. 56(2):339–350. https://doi.org/10.4141/cjps76-052.

Ott JP, Klimešová J, Hartnett DC. 2019. The ecology and significance of belowground bud banks in plants. Ann Bot. 123(7):1099–1118. https://doi.org/10.1093/aob/mcz051.

Patton AJ. 2025. Why mow? A review of the resulting ecosystem services and disservices from mowing turfgrass. Crop Sci. 65(1):e21376. https://doi.org/10.1002/csc2.21376.

Rojas-Sandoval J, Acevedo-Rodríguez P. 2022. *Cyperus esculentus* (yellow nutsedge). In: CABI compendium. CAB International, Wallingford, UK. https://doi.org/10.1079/cabicompendium.17496.

Ryck S, Reheul D, De Cauwer B. 2023. Impact of regular mowing, mowing height, and grass competition on tuber number and tuber size of yellow nutsedge clonal populations (*Cyperus esculentus* L.). Weed Res. 63(6):371–381. https://doi.org/10.1111/wre.12600.

Schippers P, Borg S, van Groenendael J, Habekotte B. 1993. What makes *Cyperus esculentus* (yellow nutsedge) an invasive species? A spatial model approach, p 1319–1324. In: Proc Brighton Crop Prot Conf Weeds. British Crop Protection Council, Brighton, UK.

Schreier H, Bish M, Bradley KW. 2022. The impact of electrocution treatments on weed control and weed seed viability in soybean. Weed Technol. 36(4):481–489. https://doi.org/10.1017/wet.2022.56.

Slaven MJ, Koch M, Borger CPD. 2023. Exploring the potential of electric weed control: A review. Weed Sci. 71(5):403–421. https://doi.org/10.1017/wsc.2023.38.

Sosnoskie LM, Liu R. 2025. Editorial: Weed management in specialty crops. Front Agron. 7:1624103. https://doi.org/10.3389/fagro.2025.1624103.

Stoller EW, Sweet RD. 1987. Biology and life cycle of purple and yellow nutsedges (*Cyperus rotundus* and *C. esculentus*). Weed Technol. 1:66–73. https://doi.org/10.1017/S0890037X0002916X.

Summerlin JR, Coble HD, Yelverton FH. 2000. Effect of mowing on perennial sedges. Weed Sci. 48(4):501–507. https://doi.org/10.1614/0043-1745(2000)048[0501:EOMOPS]2.0.CO;2.

Thullen RJ, Keeley PE. 1979. Seed production and germination in *Cyperus esculentus* and *C. rotundus*. Weed Sci. 27(5):502–505. https://doi.org/10.1017/S0043174500044489.

Vesk PA, Westoby M. 2004. Sprouting ability across diverse disturbances and vegetation types worldwide. J Ecol. 92(2):310–320. https://doi.org/10.1111/j.0022-0477.2004.00871.x.

Vigneault C, Benoît DL. 2001. Electrical weed control: Theory and applications, p 896–898. In: Ascard J (ed). Thermal weed control. Marcel Dekker, New York, NY, USA.

Vigneault C, Benoît DL, McLaughlin NB. 1990. Energy aspects of weed electrocution. Rev Weed Sci. 5:15–26.

Wada N, Berry PA, Hill B, Mallory-Smith C, Parke JL. 2024. Soil solarization as a non-chemical weed control method in tree nursery production systems of the Pacific Northwest, USA. Front Agron. 5:1321372. https://doi.org/10.3389/fagro.2023.1321372.