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Short title: Windmill palm weed management

Assessment of nonchemical weed management of windmill palm (*Trachycarpus fortunei*) nursery

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Abstract

The windmill palm is a distinctive outdoor ornamental palm adapted to cooler climates. Weeds pose significant challenges in palm nurseries, particularly during seedling and establishment stages. This research was conducted in a nursery with 5,500 windmill palm seedlings, starting in April 2014 when the palm trees were three years old. Experiments were terminated in October 2018 when weed control was no longer necessary due to the advanced growth stages of the palm trees. The objectives were to determine the weed composition and diversity, elucidate the effects of mechanical weed management (MWM) on growth rate of palm, and develop a sustainable program to maximize palm tree growth through effective weed management and soil tillage. Owing to the lack of registered nursery herbicides in Türkiye, weed control was performed mechanically using garden hoeing machines between rows and hand hoeing for intra-row strips. The most common and dense weeds were purple nutsedge, annual mercury, and common purslane in summer-autumn, and burning nettle in winter-spring. In 2014, weed densities were 100, 127, and 145 weeds m^{-2} for MWM, hand-weeding (HW), and nontreated (NT), respectively. Transplanted palm seedlings required at least two, ideally three growing seasons of intensive weed control until the palm tree crowns block sunlight and suppress weed growth. The research indicated palm trees in the MWM treatment had approximately 84 leaves and a height of 210 cm by October 2018, compared to 54 leaves and 136 cm for HW, and 40 leaves and 100 cm for NT. These results highlight the critical role of MWM in promoting optimal growth of Chinese windmill palms. Effective and sustainable weed management, combining MWM and HW, is essential for producing high-quality palm trees, which are valuable insights for nursery managers and contribute to best practices for cultivating windmill palm trees in similar climatic regions.

Nomenclature: Annual mercury, *Mercurialis annua* L. MERAN; burning nettle, *Urtica urens* L. URTUR; common purslane, *Portulaca oleracea* L. POROL; purple nutsedge, *Cyperus rotundus* L. CYPRO; Chinese windmill palm, *Trachycarpus fortunei* (Hook.) H.Wendl.

Keywords: hand-weeding; hoeing; leaf production; palm nursery; soil tillage; trunk height

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Introduction

Palms are the primary commodity among outdoor ornamentals accounting for approximately 70% of Türkiye's total floriculture production (AIPH 2021). The windmill palm [*Trachycarpus fortunei* (Hook.) H.Wendl. (Syn: *Chamaerops fortunei* Hook., formerly: *C. excelsa* Thunb.)] is a member of the Arecaceae (Palmae) family, also known as the Chinese windmill palm, Chusan palm, hemp palm, or mountain palm (Ahmed et al. 2017; EPPO 2024; Feng et al. 2020; IPNI 2024; Walther et al. 2007). Native to China, northern India, and Burma (Aguilar et al. 2017), windmill palm is the most widely distributed palm species along the latitudinal margin of its range (Li et al. 2020). The windmill palm was introduced to Europe over a century ago (Aguilar et al. 2017) and has adapted well to the cooler temperate zones of Europe (Campodonico et al. 2015). It is tolerant to cold, wind, frost, salt, and alkali soils compared to many other palm species (Zhu et al. 2019); therefore, highly desired in the Northern Hemisphere (Ahmad et al. 2020; Beaudoin-Ollivier et al. 2017; Cohen 2017).

Türkiye is an important producer and exporter of ornamental plants to the European Union and the United States (WTO 2024). The palm industry has been growing in Türkiye alongside other outdoor ornamentals (SUSBIR 2024). In 2023, over 0.5 billion palm trees were produced, accounting for approximately 25% of Türkiye's total ornamental production (TUIK 2024). Today, the windmill palm is the most widely produced and planted species in Türkiye due to cold tolerance, evergreen structure, and low pruning needs (SUSBIR 2024).

Palm tree height is the primary determinant of market value, as ornamental palm prices are directly tied to tree height. The amount and size of the leaves, often referred to as the apical canopy or crown, do not directly influence palm prices. However, new leaves contribute to the trunk's height as they are pruned and indicate a growth rate parameter. Therefore, the growth rate can realistically be determined with the new leaf production (Inci and Uludag 2017; SUSBIR 2024). A palm tree's life cycle can be divided into four growth stages: seedling, establishment, vegetative, and reproductive (Broschat et al. 2014; Cohen 2017). Palm trunk diameters increase during the establishment stage, growing more and more leaves until palm stem reaches the maximal diameter—which can last several years, the palm does not grow vertically—and then palms grow vertically to form a mature shape during the vegetative stage (Cohen 2017). Until a palm tree reaches the vegetative stage, the rate of new leaf emergence is mainly dependent on environmental conditions.

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Nearly all ornamental palm producers transplant new seedlings in their nurseries each year to maintain a continuous supply to the market. Owing to both domestic and international palm markets' standards, producers intend to grow the palm trees as tall as possible and refrain to sell young palms (Mustafa Inci, personal communication). Under most circumstances, palm trees may need approximately ten years or more following seedling emergence to reach a marketable size. Therefore, ornamental palm producers must develop feasible production strategies based on the palms' growth rate. Avoiding growth delays caused by weeds and shortening the production duration to reach marketable size is critical for windmill palm production.

Weeds are the primary challenge of palm production because they compete with palms, especially during the seedling and establishment stages (Dilipkumar et al. 2017). Weed competition in young palm seedlings delays growth by reducing light and utilizing resources (Burgos and Ortuoste 2018). Moreover, weeds can reduce the growth of ornamental plants by up to 80% in container-grown systems (Khamare et al. 2023), where weed-free production is also essential for the aesthetic demands of the market (Stewart et al. 2017). Regardless of aesthetic composition, ornamental plant customers strongly refrain from buying weed-infested, container-grown plants to prevent future weed infestations (Khamare et al. 2023), which sets de facto zero-weed threshold (Stewart et al. 2017). This phenomenon is also necessary in field-grown palm trees since palms are transplanted with their root ball to prospective lands. There is no consensus of the ideal root ball size for windmill palms; however, standard industry practices range from nearly no root ball to one as big as possible (Pittenger et al. 2005). Thus, effective and sustainable weed management is crucial in palm production to meet the desired market demands (Inci and Uludag 2017; Kuz et al. 2022).

Absence of registered herbicides in palm nurseries present one of the biggest weed management challenges in Türkiye's palm production (MAFT 2024). Moreover, palm growers avoid using herbicides even at the edges of the nursery or use them with excessive precautions due to possible adverse effects on palm tree growth (Kuz et al. 2022). The seedling and establishment growth stages of palms are more vulnerable to herbicide injury than established palms because younger plants are metabolically more active, making them more susceptible to herbicides (Inci 2019; Inci et al. 2019). Injury from pre-emergent herbicides may appear up to nine months after treatment (Broschat et al. 2014) and could result in palm death due to trees having a single apical meristem (Ahmad et al. 2020). Palm trees also are known for their susceptibility to sublethal doses of herbicides, which increases off-target herbicide movement concerns (Romney 1964). As a result, ornamental palm production heavily relies on continuous nonchemical weed management in Türkiye. We hypothesized that mechanical weed management can control weeds that occur in the windmill palm nurseries. Therefore, the objectives of this research were to determine the effects of mechanical weed management on the control of weeds and whether there are differences among hand-weeding and nontreated control treatments. The overall goal of this research was to develop a sustainable program to maximize windmill palm tree growth via effective weed management and soil tillage in Türkiye and Mediterranean climate basins. Therefore, support the weed management strategies aimed at reducing weeds and enhancing the growth rate of windmill palms and productivity of nurseries in ornamental palm production.

Materials and Methods

The research was conducted in a windmill palm nursery with 5,500 palm seedlings (40.048339°N, 28.400167°E) in Bursa, Türkiye, for five growing seasons from April 2014 to October 2018. Owing to the long germination period and low germination rate, three years old windmill palm seedling were transplanted to nursery with 70 cm intra-row spacing and 130 cm between rows on April 23, 2014. The soil was classified as sandy-loam with N 69 ppm, P 18 ppm, K 361 ppm, Na 9 ppm, Ca 8 meq 100 g^{-1}, Mg 11 meq 100 g^{-1}, cation exchange capacity 20 meq 100 g^{-1}, organic matter 3%, and pH 6.6 in April 2014. The nursery was drip-irrigated, approximately at 5–7-day intervals when needed, and fertilized with each irrigation throughout the growing season. The fertilizers delivered annually were N at 350 kg ha^{-1}, P at 100 kg ha^{-1}, K at 130 kg ha^{-1}, S at 125 kg ha^{-1}, Ca at 17 kg ha^{-1}, Fe at 4 kg ha^{-1}, and humic-fulvic acid at 3 kg ha^{-1}, respectively. Standard commercial practices were implemented to avoid disease and insect infestations.

Experiments were set up in a randomized complete block design with four replications, where 1- by 1-m quadrat [hereinafter refer to as plot(s)] was an experimental unit. Plots were precisely settled under an individual palm tree (Figure 1). Untreated palm trees were included as buffer among treatments. Same plots were used throughout the research to maintain consistency. Treatments were 1) Mechanical Weed Management (MWM): mechanical hoeing on inter-rows with a 100-cm width followed by hand hoeing on intra-rows; 2) hand-weeding (HW): hand-weeding the whole plot but no-tillage; and a 3) nontreated control (NT). The MWM was performed with a garden hoeing machine at a depth of 15 cm (Bertolini rotary tiller 218, Reggio Emilia, Italy) from April to October on inter-rows and hand hoeing on intra-rows based on an as-needed basis from 2014 to 2018 for five seasons, respectively (Figure 1). The decision on mechanical hoeing between rows was made based on the weed coverage between rows and when weeds were ≤ 18 cm tall, which was the maximum cutting depth of the rotary tiller. Weeding was performed simultaneously, as mentioned above, in both MWM and HW plots as needed.

Weeds were counted and manually removed from the plots at 14 d after treatment (Figure 1). Quadrats were settled to cover a uniform soil surface on both inter-rows and intra-rows with four replicates (MacLaren et al. 2019). Weed species were recorded, and individuals were counted for each species in each sampling quadrat. Species with less than 1% cover were eliminated from the assessments. The relative contribution of different weeds to the weed vegetation was calculated as follows:

$$Relative\ density\ of\ a\ species = \frac{Absolute\ density\ of\ a\ species}{Total\ density\ of\ all\ species} \times 100$$

The time among new leaves present on the same palm is the most explicit expression of the growth rate for a short-term evaluation (Simón et al. 2015). The growth rate of windmill palm was determined by the number of new leaves and trunk height, determined by the trunk's absolute height, excluding leaves and petioles.

Weed density and relative weed coverage were subjected to analysis of variance (ANOVA) using the AGRICOLAE (de Mendiburu 2024) and EMMEANS (Searle et al. 1980) packages in RStudio software (v. 2024.09.1+394; R Core Team 2024), and Tukey's honestly significant difference (HSD) test were used at significance level of α = 0.05 to separate means using the MULTCOMP (Bretz et al. 2010) package when applicable. Assumptions of ANOVA were tested with normal quantile-quantile plots of residuals and Shapiro-Wilk tests for normality, residuals versus fits plots and Levene's tests for homogeneity of variances, and randomly sampled experimental plots with individual trees were used to ensure independent sampling. No data transformation was implemented. Leaf production and trunk height data were analyzed with analysis of covariance (ANCOVA) using RStudio (Ritz et al. 2015). Aforementioned ANOVA assumptions for both ANCOVA were used with no data transformation. Weed management treatments and year were considered fixed factors, while blocks and replication were considered random factors. Visual illustration was generated using GGPLOT2 package version 3.5.1 in RStudio (Wickham et al. 2024). The statistical results were primarily included in the supplementary material to enhance readability.

Results and Discussion

Treatment by year interactions were observed; therefore, these data were analyzed and presented individually by year. In total, 42 weed species (Table 1) were observed as irregularly spread over the nursery during the observations. The total weed density was higher ($P \leq 0.05$) during summers (June, July, and August) of the 2014 and 2015 compared to other growing seasons (Table 2). The average weed density was recorded after treatments for the summer of 2014 as 108, 141, and 153 plants m^{-2} for MWM, HW, and NT, respectively. Similarly, in the summer of 2015, weed density was 107, 137, and 157 plants m^{-2} for the same treatments. As palm trees grew during 2016–2018 growing seasons, the total weed density gradually decreased. In 2018, total weed density was less than 13, 17, and 40 plants m^{-2} for MWM, HW, and NT treatments, respectively (Table 2).

The densest weed species were purple nutsedge [*Cyperus rotundus* L. (CYPRO)], annual mercury [*Mercurialis annua* L. (MERAN)], and common purslane [*Portulaca oleracea* L. (POROL)] during the summer-autumn and burning nettle [*Urtica urens* L. (URTUR)] during the winter-spring throughout the five growing seasons (Figure 2). In May 2014, relative density of CYPRO was 57%, 47%, and 46% for MWM, HW, and NT, respectively, and then gradually decreased throughout the growing season, being recorded as 17% for all treatments in October 2014 (Supplementary Table S1). Similarly, MERAN relative density was recorded as 18%, 23%, and 23% in May 2014, decreasing to 10%, 10%, and 11% in October for MWM, HW, and NT treatments, respectively. The POROL showed a trend of 13%, 16%, and 15% relative density in May 2014, gradually increasing to 33%, 32%, and 35% in September for MWM, HW, and NT treatments. Finally, URTUR was only recorded in October 2014 with 14%, 18%, and 14% density for MWM, HW, and NT, respectively. Similar trends were observed for CYPRO, MERAN, POROL, and URTUR species during the five growing seasons (Supplementary Tables S2, S3, S4, S5).

The CYPRO relative density was approximately 50% for all treatments in 2015 and 2016 growing seasons (Supplementary Tables S2, S3) and reduced to 42%, 45%, and 46% relative density in 2017 for MWM, HW, and NT, respectively (Supplementary Table S4). In 2018, CYPRO relative density for MWM treatment was reduced to 21% ($P \leq 0.05$) whereas HW and NT were 41% and 45%, respectively (Supplementary Table S5). This density shifts were mostly due to the larger growth stages of palm trees in MWM treatments that suppress CYPRO plants.

Likewise, MERAN relative density were up to 19% in May 2015 (Supplementary Table S2), and stayed ~20% for all treatments in 2016 and 2017 (Supplementary Tables S3, S4). In May 2018, MERAN relative density was reduced to 3% ($P \leq 0.05$) in MWM treated palm trees whereas HW and NT were 21% and 20%, respectively (Supplementary Table S5). Moreover, POROL relative density was ~35% for all treatments during 2015–2017 growing seasons, which reduced to 3% ($P \leq 0.05$) and 31% for MWM and HW treatments in 2018 (Supplementary Table S5). Similarly, URTUR relative density ranged among 14–17% for all treatments during 2015–2017 growing seasons and URTUR density reduced below 4%, 5%, and 7% for MWM, HW, and NT, respectively (Supplementary Table S5). This results in harmony with CYPRO, MERAN, and POROL relative density trends that indicates MWM treatment has suppressed ($P \leq 0.05$) these weed species in the fifth season.

The leaf production among the treatments were different ($P \leq 0.05$) and indicated that MWM was the most effective treatment in growth rate with approximately 84 total leaves recorded at the last observation on 10 October 2018, whereas HW had approximately 54, and NT had approximately 40 total leaves produced (Figure 3; Supplementary Table S6). The commercial standards of new leaf production for windmill palm trees are approximately 16–20 leaves per year in Mediterranean climates such as California (Pittenger et al. 2009). The MWM treatment as the cumulative leaf production of 4 years indicated a better growth rate than the industry standards. As a result of the new leaf production, the height of palm trees varied among the treatments. At the end of the fifth growing season (2018), palm trees were recorded as approximately 210 cm, 136 cm, and 100 cm for MWM, HW, and NT treatments, respectively (Figure 4; Supplementary Table S7). Palm seedling growth parameters showed ($P \leq 0.0001$) the greatest growth increases for the MWM treatment compared to HW and NT.

Weed species observed in the palm nursery were similar to those in other ornamental plant nurseries (Kucuk et al. 2020; Kuz et al. 2022; Ogut 2007; Owston and Abrahamson 1984; Yu and Marble 2022). Owston and Abrahamson (1984) reported that CYPRO and POROL are common troublesome weeds in Oregon ornamental nurseries as perennial and summer annual,

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respectively. Ogut (2007) found CYPRO and POROL were the densest weed species in fig nurseries during summer-autumn with approximately 39 and 32 plants m^{-2}, respectively. On the other hand, URTUR and MERAN were found approximately 4 and 1 plants m^{-2} during winter-spring, respectively (Ogut 2007). Kuz et al. (2022) reported that CYPRO and POROL were among the most common weed species in ornamental plant nurseries in Mediterranean basins of Türkiye where 13% of growers stated weeds are the biggest problem of ornamental nurseries. Moreover, CYPRO, URTUR, and POROL were reported as problematic weeds of outdoor ornamental plant nurseries in northern Türkiye, with approximately 3, 3, and 73 plants m^{-2} density, respectively (Kucuk et al. 2020). Likewise, Yu and Marble (2022) found CYPRO and POROL were among the most common weeds in ornamental nurseries and fields worldwide.

Nearly all palm seedlings are transplanted to nurseries from germination pots in the beginning of the third or fourth year to obtain faster growth and avoid initial stand reduction (Simón et al. 2015). In the first year, weeds were fewer than in the second year, likely due to field preparation before transplanting young seedlings and burying weed seeds that were in the top levels of soil. The highest weed density in the second year probably occurred due to the lack of shade from small palm seedlings and continuous fertilization and irrigation. In the first three years, MWM decreased weeds more ($P \leq 0.05$) than HW and NT. In the fourth year, weed density differences in MWM and HW treatments did not differ ($P > 0.05$). In the fifth year, HW became less effective due to the mature shape of palm trees and the weed reduction was similar to MWM. However, both MWM and HW treatments caused ($P \leq 0.05$) reduction in weed density than the NT throughout this research.

The CYPRO was controlled effectively by MWM throughout the seasons. The percent coverage of MERAN and POROL gradually decreased and became less dominant in 2018. The URTUR was able to maintain its presence even after palm trees' crowns reached to each other, as *Urtica* L. species prefer moderate shade over full sun (Taylor 2009). Weed competition was an inhibiting factor in the growth of palm trees, which was confirmed by previous research on ornamentals and *Corchorus olitorius* L. (Adenawoola et al. 2005). Once palm trees have grown to an approximately one-meter trunk height, weeds may not be present in the nursery as densely as before since the palm crowns adequately reach to each other, thus blocking the sunlight and suppressing the weeds (Dilipkumar et al. 2017) as observed from the third year in the current research.

Weeds are a more troublesome problem initially in palm nurseries and gradually decrease after palms become taller and larger. Yet, mechanical weed management continues to encourage faster palm growth. Ornamental plant consumers in Europe are willing to pay higher prices for better palm quality; therefore, palm growers prioritize aesthetic appearance and are willing to increase production costs such as hand-weeding (Gabelline and Scaramuzzi 2022). Particularly in the container-grown nurseries, hand-weeding cost is estimated at approximately \$10,000 ha^{-1} around a four-month period (Case et al. 2005). At some nurseries, hand-weeding cost may constitute up to 90% of the total production costs (Nabb et al. 1995). However, growers cover the costs for hand-weeding because there is a ~\$8,000 ha^{-1} profit (Case et al. 2005). In Türkiye, the biggest limiting factor in the weed management of ornamental production is the absence of herbicides registered for ornamentals. The common perspective among palm producers is especially non-selective herbicides would not be desired even if they were registered for palms due to the potential off-target movement (Mustafa Inci, personal communication). Some nurseries in the United States reported ornamental stock injury and losses by using glyphosate as part of their weed management, even with extreme care, such as a windproof spray shield, low spray pressure, and volume (Case et al. 2005). Herbicides can result in injury to ornamental plants (Marble et al. 2015a) or reduce the marketability of ornamentals due to aesthetic purposes (Marble et al. 2015b). As a result, there is an inherent zero tolerance for any phytotoxicity caused by herbicides (Marble et al. 2015a, 2015b).

Besides controlling weeds, soil tillage can enhance water infiltration, help warm cold soils, improve root growth through better aeration, reduced bulk density, and lower soil resistance to root penetration which ultimately improve ornamental plant productivity (Mohler 2004). To maintain a long-term weed management in ornamental palm nurseries, an integrated weed management approach should be followed that should include both prevention future weed infestations and controlling present weeds (Weller 2007). Therefore, the first step should be preparing weed-free nurseries prior to palm transplanting, which will give an advantage to palm trees to achieve an easy stand establishing without resource competition with weeds. Moreover, starting nurseries with a weed-free environment is the most successful long-term weed management. Consequently, intensive and effective mechanical weed control without herbicide use is crucial for weed management in windmill palm trees due to the significant adverse effects of weeds. Mechanical weed management through hand tools such as garden or hand hoeing and

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soil tillage can be used to cultivate soil hence control weeds. Therefore, MWM also avoids expensive and time-consuming hand-weeding applications (Marble et al. 2015a). This research showed that weeds have inhibitory effects on the growth time of windmill palm trees unless effectively and sustainably controlled through mechanical methods. A combination of mechanical and hand hoeing over at least three consecutive seasons resulted in faster growth and higher quality palms (Weller 2007).

Practical Implications

The results of this research provide useful information to ornamental palm nurseries about long-term nonchemical weed management. Mechanical weed management (MWM), involving inter-row hoeing and intra-row hand hoeing, enhances palm growth compared to hand-weeding and no weed control. By October 2018, palm trees in the MWM treatment had approximately 84 leaves and a trunk height of 210 cm, whereas those in hand-weeding and no weed control treatments had 54 leaves and 136 cm, and 40 leaves and 100 cm, respectively. Over five years, total weed density in MWM plots decreased from approximately 100 weeds m^{-2} in 2014 to about 12 weeds m^{-2} (an 88% reduction) by October 2018. This reduction in weed density led to decreased competition for resources, making subsequent seasons less labor-intensive and more cost-effective. Given the lack of registered herbicides for palm trees in Türkiye and the potential adverse effects of herbicides, this research underscores the need for nonchemical weed management approaches. Although initially labor-intensive, MWM is cost-effective as it reduces the need for frequent hand-weeding and minimizes economic losses from weed infestations. The enhanced growth rates from MWM enable palm trees to meet market standards for height and appearance faster, commanding higher market prices. Nursery managers are advised to start with a weed-free environment before transplanting palms, maintain rigorous MWM during the initial growth years, and combine inter-row and intra-row hoeing for effective weed control. Continuous monitoring and adjustments based on seasonal weed densities and growth stages can further improve the effectiveness, providing a sustainable and efficient weed management approach that enhances productivity and profitability in windmill palm nurseries.

Supplementary material. To view supplementary material for this article, please visit the assigned DOI link.

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Table 1. Weed species present at the windmill palm nursery from 2014 to 2018.

Weed species[a]	Common name	EPPO code[b]	Group[c]	Family	Duration[d]
Alopecurus myosuroides Huds.	blackgrass	ALOMY	M	Poaceae	A
Amaranthus albus L.	tumble pigweed	AMAAL	D	Amaranthaceae	A
Amaranthus retroflexus L.	redroot pigweed	AMARE	D	Amaranthaceae	A
Amaranthus spinosus L.	spiny amaranth	AMASP	D	Amaranthaceae	A
Avena fatua L.	wild oat	AVEFA	M	Poaceae	A
Avena sterilis L.	sterile oat	AVEST	M	Poaceae	A
Capsella bursa-pastoris (L.) Medik.	shepherds purse	CAPBP	D	Brassicaceae	A
Chenopodium album L.	common lambsquarters	CHEAL	D	Chenopodiaceae	A
Cirsium arvense (L.) Scop.	Canada thistle	CIRAR	D	Asteraceae	P
Convolvulus arvensis L.	field bindweed	CONAR	D	Convolvulaceae	P
Cynodon dactylon (L.) Pers.	bermudagrass	CYNDA	M	Poaceae	P
Cyperus rotundus L.	purple nutsedge	CYPRO	M	Cyperaceae	P
Datura stramonium L.	jimsonweed	DATST	D	Solanaceae	A
Digitaria sanguinalis (L.) Scop.	large crabgrass	DIGSA	M	Poaceae	A
Echinochloa crus-galli (L.) P.Beauv.	barnyardgrass	ECHCG	M	Poaceae	A
Equisetum arvense L.	field horsetail	EQUAR	N/A	Equisetaceae	P
Erigeron canadensis L.	horseweed	ERICA	D	Asteraceae	A/B
Euphorbia helioscopia L.	sun spurge	EPHHE	D	Euphorbiaceae	A
Euphorbia peplus L.	petty spurge	EPHPE	D	Euphorbiaceae	A
Galium aparine L.	catchweed bedstraw	GALAP	D	Rubiaceae	A
Hordeum murinum L.	mouse barley	HORMU	M	Poaceae	A
Jacobaea vulgaris L.	tansy ragwort	SENJA	D	Asteraceae	P
Lactuca serriola L.	prickly lettuce	LACSE	D	Asteraceae	A/B
Lamium purpureum L.	purple deadnettle	LAMPU	D	Lamiaceae	A
Malva parviflora L.	little mallow	MALPA	D	Malvaceae	A/B/P
Malva sylvestris L.	high mallow	MALSI	D	Malvaceae	A/B/P
Mercurialis annua L.	annual mercury	MERAN	D	Euphorbiaceae	A
Oxalis corniculata L.	creeping woodsorrel	OXACO	D	Oxalidaceae	A/P

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Physalis angulata L.	cutleaf groundcherry	PHYAN	D	Solanaceae	A
Plantago lagopus L.	Mediterranean plantain	PLALG	D	Plantaginaceae	A/P
Portulaca oleracea L.	common purslane	POROL	D	Portulacaceae	A
Reichardia tingitana (L.) Roth.	false sowthistle	REITI	D	Asteraceae	A/P
Setaria verticillata (L.) Beauv.	bristly foxtail	SETVE	M	Poaceae	A
Silybum marianum (L.) Gaertn.	blessed milkthistle	SLYMA	D	Asteraceae	A/B
Sinapis arvensis L.	wild mustard	SINAR	D	Brassicaceae	A
Solanum nigrum L.	black nightshade	SOLNI	D	Solanaceae	A/P
Sonchus oleraceus L.	annual sowthistle	SONOL	D	Asteraceae	A
Sorghum halepense (L.) Pers.	johnsongrass	SORHA	M	Poaceae	P
Taraxacum officinale F.H.Wigg.	dandelion	TAROF	D	Asteraceae	P
Urtica dioica L.	stinging nettle	URTDI	D	Urticaceae	P
Urtica urens L.	burning nettle	URTUR	D	Urticaceae	A
Xanthium strumarium L.	common cocklebur	XANST	D	Asteraceae	A

[a] Scientific and common name of species and families adopted (WFO 2024; WSSA 2024).

[b] EPPO code: a harmonized coding system, formerly known BAYER code (EPPO 2024).

[c] Group: D: Dicotyledon, M: Monocotyledon, N/A: Neither (USDA 2024).

[d] Duration: A: Annual, B: Biennial, P: Perennial.

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Table 2. Total weed density at the windmill palm nursery from 2014 to 2018.[a]

Year	Observation	Mechanical weed management		Hand-weeding		Nontreated	
		———weeds m^{-2}———					
2014	8 May	76	Aa[b]	92	Ba	87	Ba
	5 June	67	Aa	75	Bb	100	Cb
	25 June	93	Abc	108	Bc	133	Cc
	18 July	100	Abcd	129	Bd	151	Cd
	5 August	101	Abd	130	Bd	145	Cde
	25 August	108	Ad	141	Be	153	Cd
	18 September	91	Ac	118	Bcf	136	Cce
	6 October	93	Abc	119	Bf	127	Cc
2015	1 April	80	Aa	102	Ba	118	Ca
	5 May	91	Ab	113	Bb	131	Cb
	25 May	95	Ac	122	Bc	141	Cc
	18 June	106	Ade	137	Bd	157	Cd
	5 July	106	Ade	135	Bd	153	Ce
	25 July	104	Ad	129	Be	150	Cf
	18 August	107	Ae	135	Bd	156	Cd
	5 September	105	Ade	129	Be	151	Cef
	25 September	95	Ac	120	Bc	141	Cc
	17	88	Af	108	Bf	125	Cg

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	October						
2016	1 April	53	Aa	81	Ba	98	Ca
	17 April	59	Ab	90	Bb	108	Cb
	5 May	61	Abc	94	Bc	111	Cbc
	25 May	61	Abc	94	Bc	113	Ccde
	17 June	62	Abc	71	Bd	116	Cd
	5 July	62	Ac	93	Bc	112	Cce
	25 July	60	Abc	91	Bbc	115	Cde
	17 August	61	Abc	92	Bbc	114	Cde
	5 September	51	Aad	76	Be	99	Ca
	25 September	48	Ade	71	Bd	86	Cf
	17 October	47	Ae	65	Bf	78	Cg
2017	16 April	26	Aa	43	Ba	53	Ca
	5 May	24	Aa	43	Ba	54	Ca
	20 May	20	Ab	36	Bb	44	Cb
	6 June	18	Abc	32	Bc	37	Ccde
	21 June	17	Ac	37	Bb	40	Bc
	7 July	16	Ac	31	Bcd	39	Ccde
	22 July	17	Ac	30	Bde	36	Cd
	10 August	17	Ac	29	Bde	37	Ccde
	4 September	17	Ac	30	Bde	37	Cde
	19	18	Ac	30	Bde	37	Cde

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	September						
	10 October	18	Ac	28	Be	39	Cce
2018	10 April	11	Aa	16	Aa	39	Ba
	26 April	11	Aa	13	Ab	31	Bb
	23 May	11	Aa	12	Abc	26	Bc
	9 June	11	Aa	12	Abc	21	Bd
	25 June	11	Aa	11	Acd	20	Bde
	10 July	12	Aa	11	Acd	20	Bde
	25 July	12	Aa	10	Acd	20	Bde
	10 August	12	Aa	10	Acd	20	Bde
	25 August	12	Aa	10	Acd	19	Bde
	11 September	11	Aa	10	Acd	20	Bde
	26 September	12	Aa	9	Ad	20	Bde
	26 October	11	Aa	10	Acd	19	Be

[a]Data were collected at 14 days after treatment. Numbers were rounded up to integers.

[b]Means within rows followed by the same uppercase letter and within columns followed by the same lowercase letter are not statistically different at α=0.05 within the same year as determined by Tukey's honestly significant difference test, when applicable.

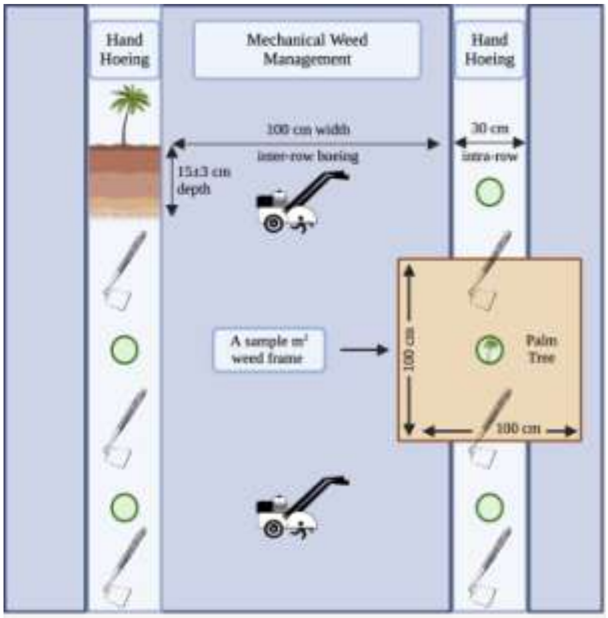

Figure 1. A representative diagram of a windmill palm nursery, where inter-row mechanical hoeing is followed by intra-row hand hoeing. Created with BioRender.com.

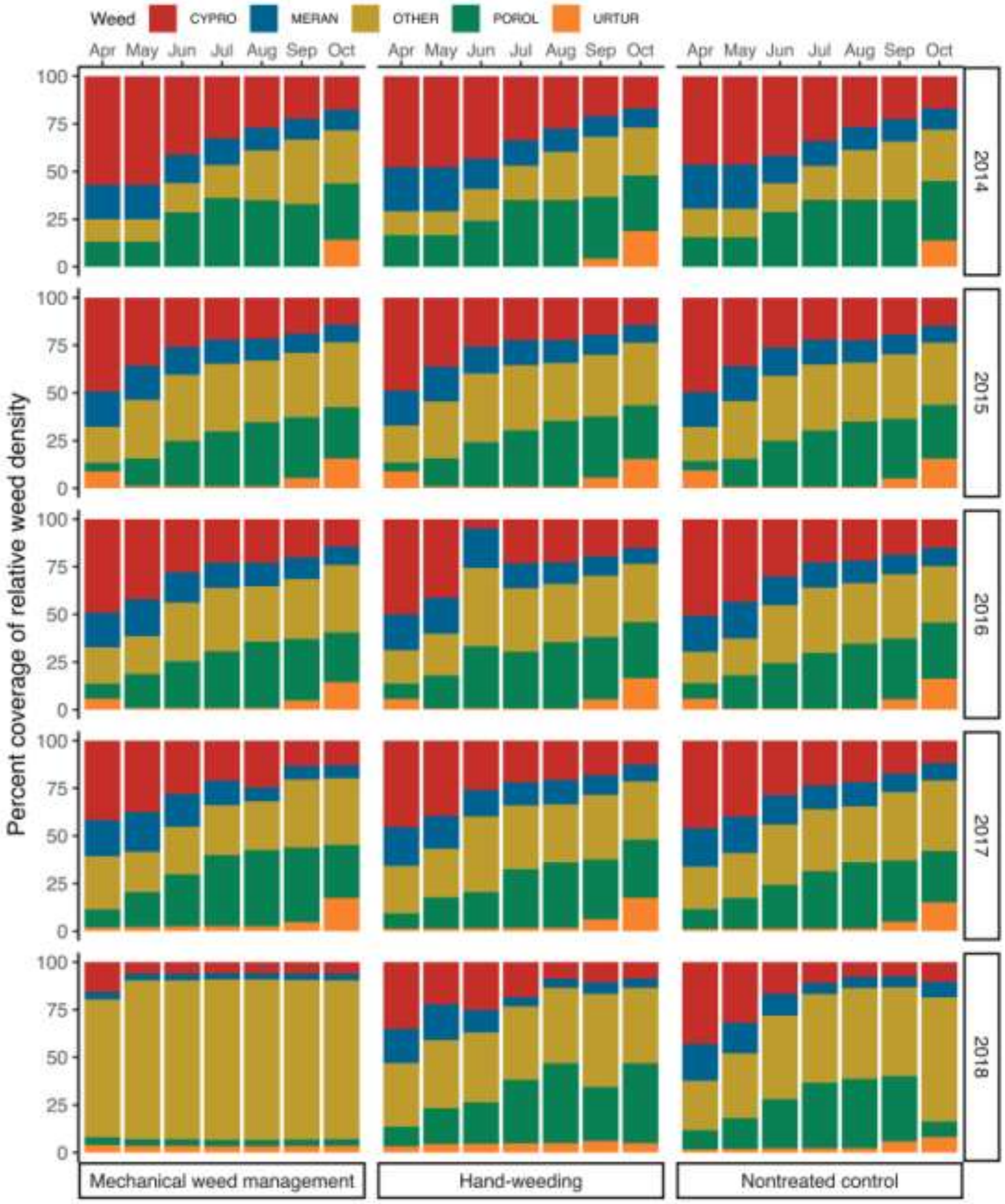

Figure 2. Percent of relative weed coverage in windmill palm nursery from 2014 to 2018. Abbreviations, Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October; CYPRO: *Cyperus rotundus*; MERAN: *Mercurialis annua*; POROL: *Portulaca oleracea*; URTUR: *Urtica urens*. Weeds less than 5% coverage are combined under the name OTHER. Observations were made at 14 days after treatment and the data is shown monthly.

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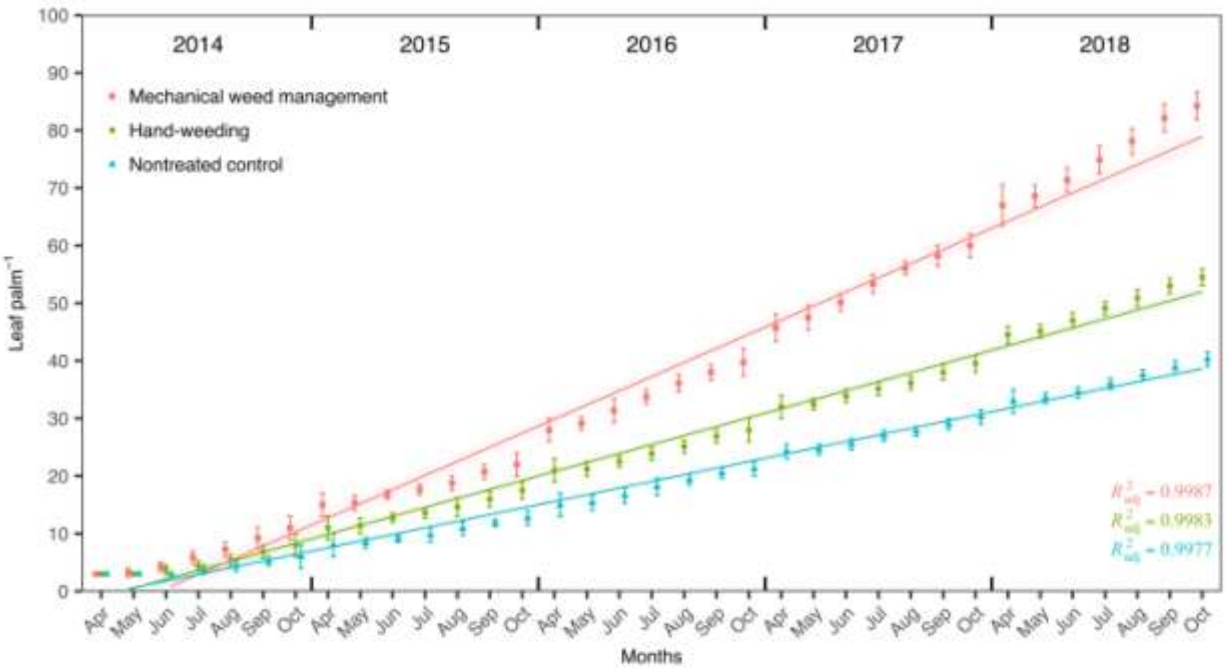

Figure 3. Effects of weed management treatments on total leaf production of windmill palm tree. Abbreviations, Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October. Numbers were rounded up to integers. Observations were made at 14 days after treatment and the data is shown monthly.

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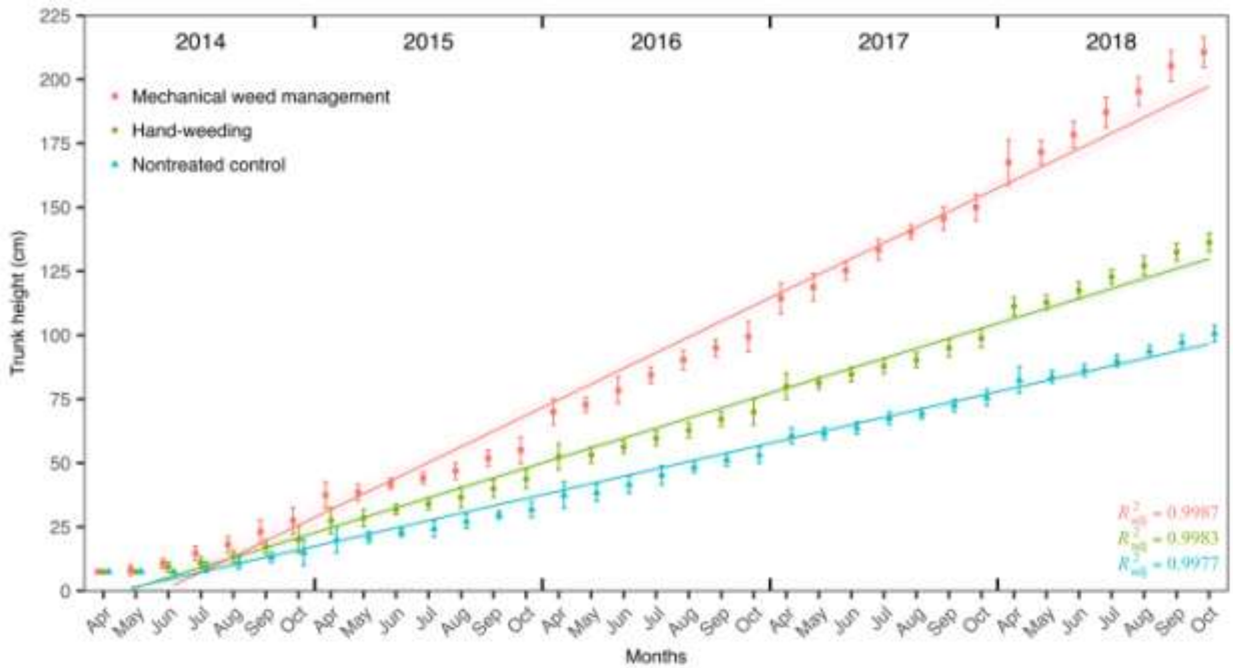

Figure 4. Effects of weed management treatments on windmill palm tree trunk height. Abbreviations, Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October. Numbers were rounded up to integers. Observations were made at 14 days after treatment and the data is shown monthly.

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Supplemental Materials

Supplementary Table S1. Percent of relative weed density of windmill palm, *Trachycarpus fortunei*, nursery in 2014 growing season.

Supplementary Table S2. Percent of relative weed density of windmill palm, *Trachycarpus fortunei*, nursery in 2015 growing season.

Supplementary Table S3. Percent of relative weed density of windmill palm, *Trachycarpus fortunei*, nursery in 2016 growing season.

Supplementary Table S4. Percent of relative weed density of windmill palm, *Trachycarpus fortunei*, nursery in 2017 growing season.

Supplementary Table S5. Percent of relative weed density of windmill palm, *Trachycarpus fortunei*, nursery in 2018 growing season.

Supplementary Table S6. Effects of treatments on total leaf production of windmill palm, *Trachycarpus fortunei*.

Supplementary Table S7. Effects of treatments on trunk height of windmill palm, *Trachycarpus fortunei*.

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