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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.

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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 3 yr old. Experiments were terminated in October 2018 when weed control was no longer necessary due to the advanced growth of the palm trees. The objectives of this study 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. Few herbicides are registered for nursery use in Türkiye, thus weed control was performed mechanically using garden hoeing machines between rows and hand hoeing for intrarow strips. The most common and dense weeds were purple nutsedge, annual mercury, and common purslane in summer and autumn, and burning nettle in winter and spring. In 2014, weed densities were 100, 127, and 145 weeds m^{-2} for MWM, hand-weeding (HW), and nontreated (NT) plots, 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 that palm trees in the MWM treatment had approximately 84 leaves and a height of 210 cm by October 2018, compared with 54 leaves and a height of 136 cm for HW, and 40 leaves and 100 cm height 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. The research provides valuable insights for nursery managers and contributes to best practices for cultivating windmill palm trees in similar climatic regions.

Introduction

Palms are the primary commodity among outdoor ornamentals, accounting for approximately 70% of Türkiye's total floriculture production ([AIPH] International Association of Horticultural Producers, 2021). The windmill palm [*Trachycarpus fortunei* (Hook.) H. Wendl. (synonym *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] European & Mediterranean Plant Protection Organization, 2024; Feng et al. 2020; [IPNI] International Plant Names Index, 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 more than a century ago (Aguilar et al. 2017) and has adapted well to the cooler temperate zones of Europe (Campodonico et al. 2015). Compared to many other palm species it is tolerant to cold, wind, frost, salt, and alkali soils (Zhu et al. 2019), and therefore is highly desired by purchasers 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] World Trade Organization, 2024). The palm industry has been growing in Türkiye alongside other outdoor ornamentals ([SUSBIR] Turkish Ornamental Plant Growers Union, 2024). In 2023, more than 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 the plant's 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 be realistically determined with new leaf production (Inci and Uludag 2017; [SUSBIR] Turkish Ornamental Plant Growers Union, 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 increasingly more leaves until the palm stem reaches the maximal diameter—which can last several years, during which it does not grow vertically—and then it grows 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.

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 tend to grow the palm trees as tall as possible and refrain from selling young palms (M. Inci, personal communication). Under most circumstances, palm trees may need approximately 10 yr 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 among young palm seedlings delays growth by reducing light and resources available to them (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 a de facto zero-weed threshold (Stewart et al. 2017). This phenomenon is also necessary in field-grown palm trees because 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).

An absence of registered herbicides for use in palm nurseries present one of the biggest weed management challenges in Türkiye's palm production ([MAFT] Ministry of Agriculture & Forestry of Türkiye, 2024). Moreover, palm growers avoid using herbicides even at the edges of the nursery, or they 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 preemergence herbicides may appear up to 9 mo 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 in Türkiye relies heavily on continuous nonchemical weed management. We hypothesized that mechanical weed management (MWM) can control weeds that occur in windmill palm nurseries. Therefore, the objectives of this research were to determine the effects of MWM on the control of weeds and whether there are differences among hand-weeding (HW) and nontreated control (NT) 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. The research will therefore support 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 in Bursa, Türkiye (40.048339°N, 28.400167°E), for five growing seasons from April 2014 to October 2018. Owing to the long germination period and low germination rate, 3-yr-old windmill palm seedling were transplanted to nursery with 70 cm intrarow spacing and 130 cm between rows on April 23, 2014. The soil was classified as sandy-loam with 69 ppm N, 18 ppm P, 361 ppm K, 9 ppm Na, 8 meq 100 g^{-1} Ca, 11 meq 100 g^{-1} Mg, 20 meq 100 g^{-1} cation exchange capacity, 3% organic matter, and pH 6.6. The nursery was drip-irrigated, approximately at 5- to 7-d intervals when needed, and fertilized with each irrigation throughout the growing season. The fertilizers delivered annually included 350 kg ha^{-1} N, 100 kg ha^{-1} P, 130 kg ha^{-1} K, 125 kg ha^{-1} S, 17 kg ha^{-1} Ca, 4 kg ha^{-1} Fe, and 3 kg ha^{-1} humic-fulvic acid. 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 plots) was an experimental unit. Plots were precisely settled under an individual palm tree (Figure 1). Untreated palm trees were included as buffer among treatments. The same plots were used throughout the research to maintain consistency. Treatments included 1) MWM (mechanical hoeing of interrows with a 100-cm width followed by hand-hoeing of intrarows); 2) HW (HW the entire plot but with no tillage); and 3) an 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 interrows and hand-hoeing on intrarows based on an as-needed basis from 2014 to 2018 for five seasons (Figure 1). The decision to do 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). Plots were settled to cover a uniform soil surface on both interrows and intrarows with four replicates (MacLaren et al. 2019). Weed species were recorded, and individuals were counted for each species in each sampling plot. 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:

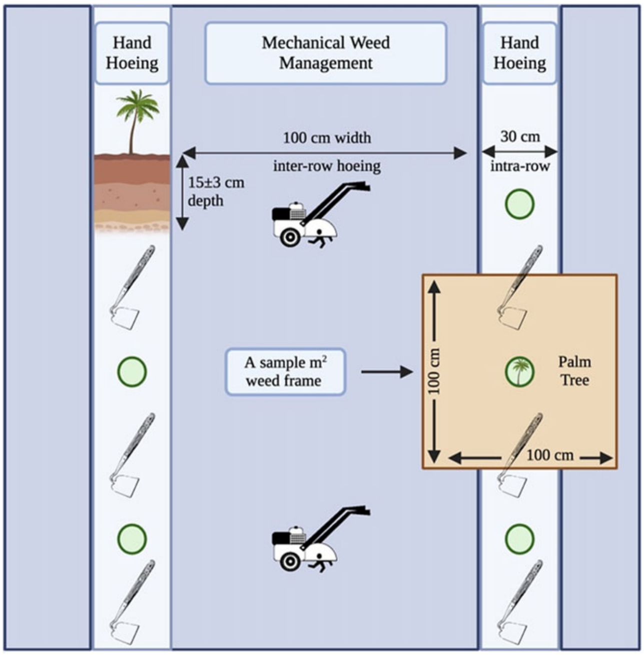

Figure 1. A representative diagram of a windmill palm nursery, where interrow mechanical hoeing is followed by intrarow hand-hoeing. Created with BioRender.com.

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

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 ANOVA using the AGRICOLAE (de Mendiburu 2024) and EMMEANS (Searle et al. 1980) packages with RStudio software (v. 2024.09.1+394; R Core Team 2024), and Tukey's honestly significant difference test were used at significance level of $\alpha = 0.05$ 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 with RStudio (Wickham et al. 2024). The statistical results are 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) in 2014 and 2015 compared with 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 plots, respectively. Similarly, in summer 2015, weed density was 107, 137, and 157 plants m^{-2} for the same treatments. As palm trees grew during the 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% in MWM, HW, and NT plots, 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. 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 recorded only during 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 was reduced to 42%, 45%, and 46% relative density in 2017 for MWM, HW, and NT plots, respectively (Supplementary Table S4). In 2018, CYPRO relative density in MWM treatment was reduced to 21% ($P \leq 0.05$), whereas the relative density of CYPRO in HW and NT treatments was 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, the relative density of MERAN was up to 19% in May 2015 (Supplementary Table S2), and stayed at approximately 20% in all treatments in 2016 and 2017 (Supplementary Tables S3, S4). In May 2018, MERAN relative density was reduced to 3% ($P \leq 0.05$) among MWM-treated palm trees, whereas relative density in the HW and NT plots were 21% and 20%, respectively (Supplementary Table S5). Moreover, the relative density of POROL was approximately 35% for all treatments during the 2015–2017 growing seasons, which was reduced to 3% ($P \leq 0.05$) and 31% for MWM and HW treatments in 2018 (Supplementary Table S5). Similarly, the relative density of URTUR ranged from 14% to 17% for all treatments during the 2015–2017 growing seasons and URTUR density was reduced below 4%, 5%, and 7% in the MWM, HW, and NT plots, respectively (Supplementary Table S5). This results in a harmony among CYPRO, MERAN, and POROL relative density trends that indicates the MWM treatment suppressed ($P \leq 0.05$) these weed species in the fifth season.

Leaf production among the treatments was different ($P \leq 0.05$) and indicated that MWM was the most effective treatment in affecting growth rate, with approximately 84 total leaves recorded

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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
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 are adopted (WFO 2024; WSSA 2024).
[b]The EPPO code is a harmonized coding system, formerly known as a BAYER code (EPPO 2024).
[c]Group: D, dicotyledon; M, monocotyledon; N/A, neither (USDA-NRCS 2024).
[d]Duration: A, annual; B, biennial; P, perennial.

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

Weed species observed in the palm nursery were similar to those found 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, as perennial and summer annuals, respectively, are common troublesome weeds in ornamental nurseries in Oregon. 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, only 4 URTUR plants and 1 MERAN plant per square meter were found during winter-spring (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 that weeds are the biggest problem in ornamental nurseries. Moreover, CYPRO, URTUR, and POROL were reported as problematic weeds of outdoor ornamental plant nurseries in northern Türkiye, with a density of approximately 3, 3, and 73 plants m^{-2}, 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

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

Year	Observation	Mechanical weed management		Hand-weeding		Nontreated	
		weeds m^{-2}					
2014	May 8	76	Aa	92	Ba	87	Ba
	June 5	67	Aa	75	Bb	100	Cb
	June 25	93	Abc	108	Bc	133	Cc
	July 18	100	Abcd	129	Bd	151	Cd
	August 5	101	Abd	130	Bd	145	Cde
	August 25	108	Ad	141	Be	153	Cd
	September 18	91	Ac	118	Bcf	136	Cce
	October 6	93	Abc	119	Bf	127	Cc
2015	April 1	80	Aa	102	Ba	118	Ca
	May 5	91	Ab	113	Bb	131	Cb
	May 25	95	Ac	122	Bc	141	Cc
	June 18	106	Ade	137	Bd	157	Cd
	July 5	106	Ade	135	Bd	153	Ce
	July 25	104	Ad	129	Be	150	Cf
	August 18	107	Ae	135	Bd	156	Cd
	September 5	105	Ade	129	Be	151	Cef
	September 25	95	Ac	120	Bc	141	Cc
	October 17	88	Af	108	Bf	125	Cg
2016	April 1	53	Aa	81	Ba	98	Ca
	April 17	59	Ab	90	Bb	108	Cb
	May 5	61	Abc	94	Bc	111	Cbc
	May 25	61	Abc	94	Bc	113	Ccde
	June 17	62	Abc	71	Bd	116	Cd
	July 5	62	Ac	93	Bc	112	Cce
	July 25	60	Abc	91	Bbc	115	Cde
	August 17	61	Abc	92	Bbc	114	Cde
	September 5	51	Aad	76	Be	99	Ca
	September 25	48	Ade	71	Bd	86	Cf
	October 17	47	Ae	65	Bf	78	Cg
2017	April 16	26	Aa	43	Ba	53	Ca
	May 5	24	Aa	43	Ba	54	Ca
	May 20	20	Ab	36	Bb	44	Cb
	June 6	18	Abc	32	Bc	37	Ccde
	June 21	17	Ac	37	Bb	40	Bc
	July 7	16	Ac	31	Bcd	39	Ccde
	July 22	17	Ac	30	Bde	36	Cd
	August 10	17	Ac	29	Bde	37	Ccde
	September 4	17	Ac	30	Bde	37	Cde
	September 19	18	Ac	30	Bde	37	Cde
	October 10	18	Ac	28	Be	39	Cce
2018	April 10	11	Aa	16	Aa	39	Ba
	April 26	11	Aa	13	Ab	31	Bb
	May 23	11	Aa	12	Abc	26	Bc
	June 9	11	Aa	12	Abc	21	Bd
	June 25	11	Aa	11	Acd	20	Bde
	July 10	12	Aa	11	Acd	20	Bde
	July 25	12	Aa	10	Acd	20	Bde
	August 10	12	Aa	10	Acd	20	Bde
	August 25	12	Aa	10	Acd	19	Bde
	September 11	11	Aa	10	Acd	20	Bde
	September 26	12	Aa	9	Ad	20	Bde
	October 26	11	Aa	10	Acd	19	Be

[a]Data were collected at 14 d 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.

obtain faster growth and avoid initial stand reduction (Simón et al. 2015). In the first year, there are fewer weeds 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 3 yr, there were fewer weeds in MWM plots ($P \leq 0.05$) than HW and NT plots. 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 resulted in ($P \leq 0.05$) a greater reduction in weed density than the NT plots throughout this research.

CYPRO was effectively controlled by MWM throughout the seasons. The percentage coverage of MERAN and POROL gradually decreased and became less dominant in 2018. URTUR was able to maintain its presence even after the crowns of the palm trees reached to each other, because *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. (nalta jute) (Adenawoola et al. 2005). Once palm trees have grown a trunk height of approximately 1 m, weeds may not be present in the nursery as densely as before because the palm crowns adequately reach to each other, thus blocking the sunlight and suppressing the weeds (Dilipkumar et al. 2017). This was observed in the third year in the current research.

Weeds are initially a more troublesome problem 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 HW (Gabelline and Scaramuzzi 2022). Particularly in container-grown nurseries, the cost of HW is estimated at approximately US$10,000 ha^{-1} around a 4-mo period (Case et al. 2005). At some nurseries, the cost of HW may constitute up to 90% of the total production costs (Nabb et al. 1995). However, growers cover the costs for HW because the profit is approximately $8,000 ha^{-1} (Case et al. 2005). In Türkiye, the biggest limiting factor in the management of weeds in ornamental tree production is the absence of herbicides registered for use on them. The common perspective among palm producers is that nonselective herbicides would not be desired even if they were registered for use in palm production due to the potential off-target movement (M. 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 aesthetics (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 improves 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 includes both prevention of future weed infestations and controlling existing weeds (Weller 2007). Therefore, the first step should be to prepare weed-free nurseries prior to palm transplanting, which will give palm trees an advantage to achieve establishment without resource competition with weeds. Moreover, starting nurseries with a weed-free environment is the most successful long-term weed management practice. Consequently, intensive and effective mechanical weed control without herbicide use is crucial for weed

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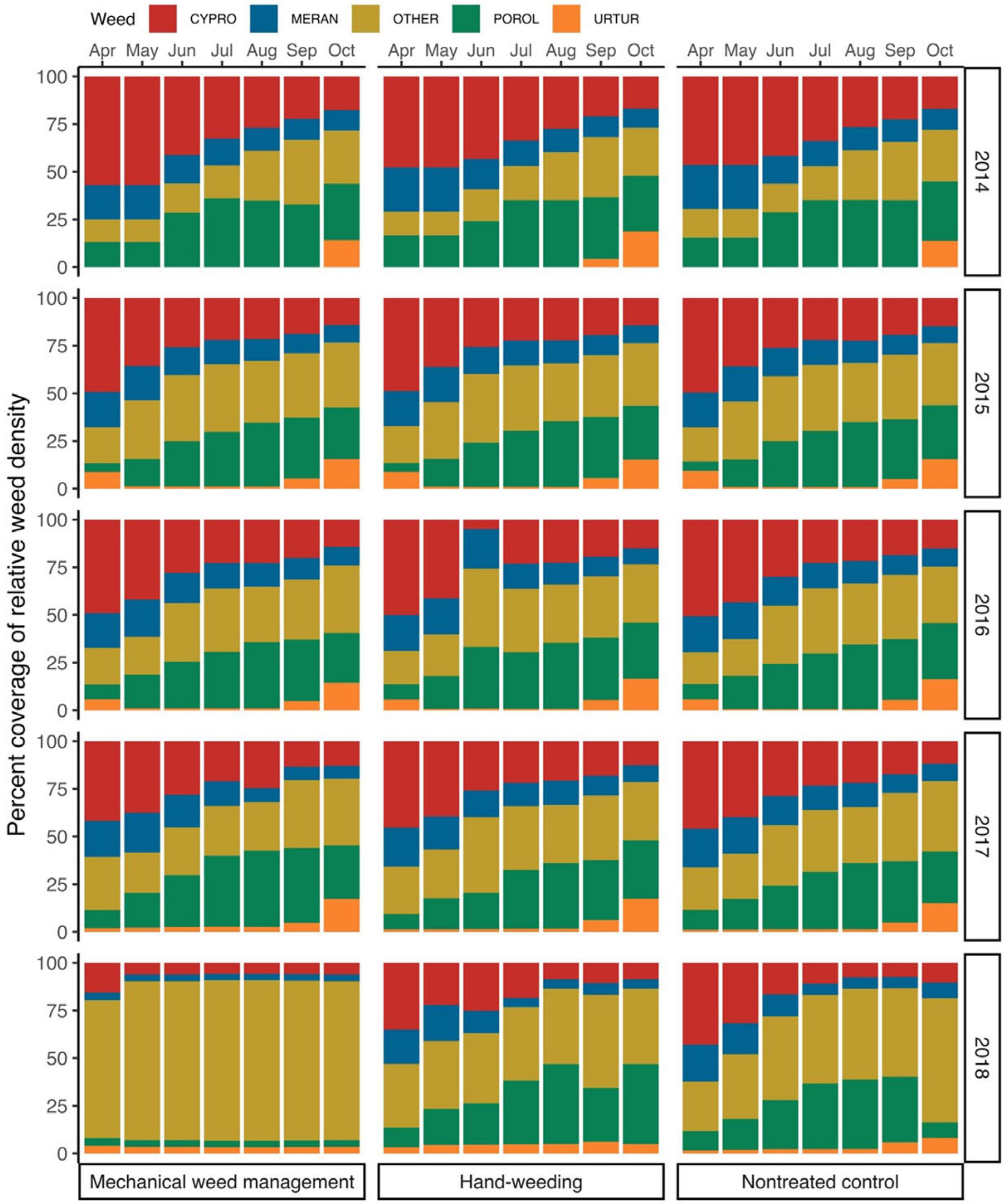

Figure 2. Percent of relative weed coverage in windmill palm nursery from 2014 to 2018. Abbreviations, Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October; CYPRO: *Cyperus rotundus*; MERAN: *Mercurialis annua*; POROL: *Portulaca oleracea*; URTUR: *Urtica urens*. Weeds less than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

management in windmill palm trees due to the significant adverse effects of weeds. Mechanical weed management with hand tools and soil tillage can be used to cultivate soil and hence control weeds. Therefore, MWM also avoids expensive and time-consuming hand-weeding (Marble et al. 2015a). This research has shown that weeds have inhibitory effects on the growth time of windmill palm trees unless the weeds are 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. MWM, which involves interrow hoeing and intrarow hand-hoeing, enhances palm growth compared to HW and no

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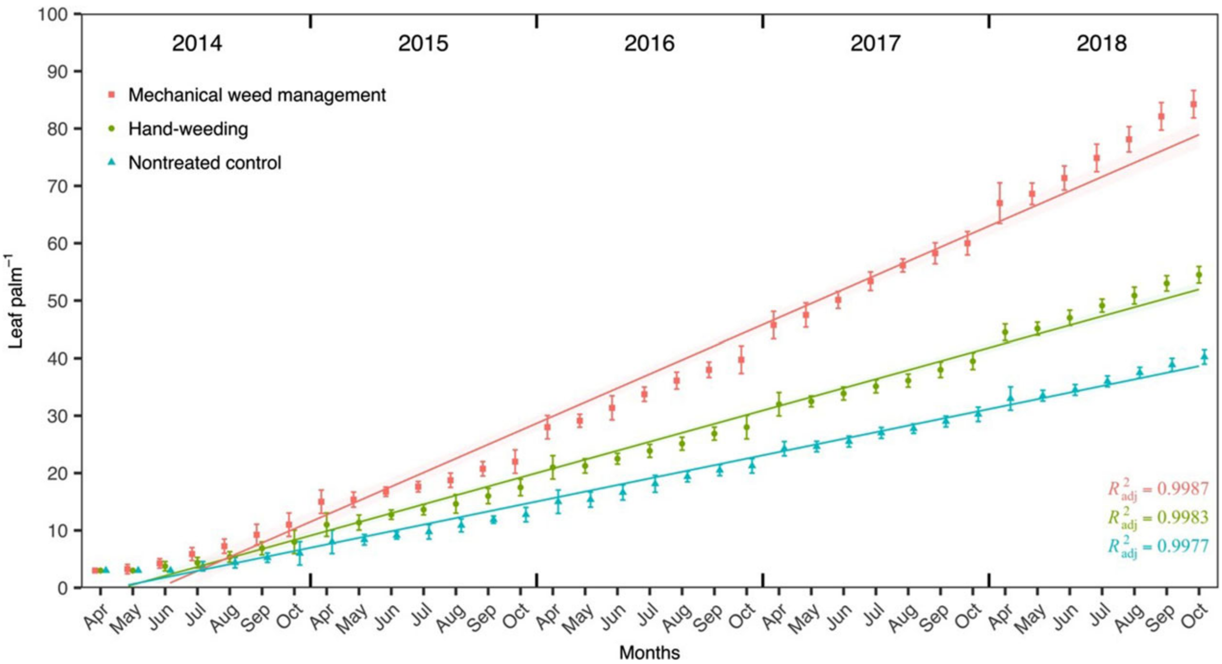

Figure 3. Effects of weed management treatments on total leaf production of windmill palm tree. Abbreviations, Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October. Numbers were rounded up to integers. Observations were made at 14 d after treatment and the data are shown monthly.

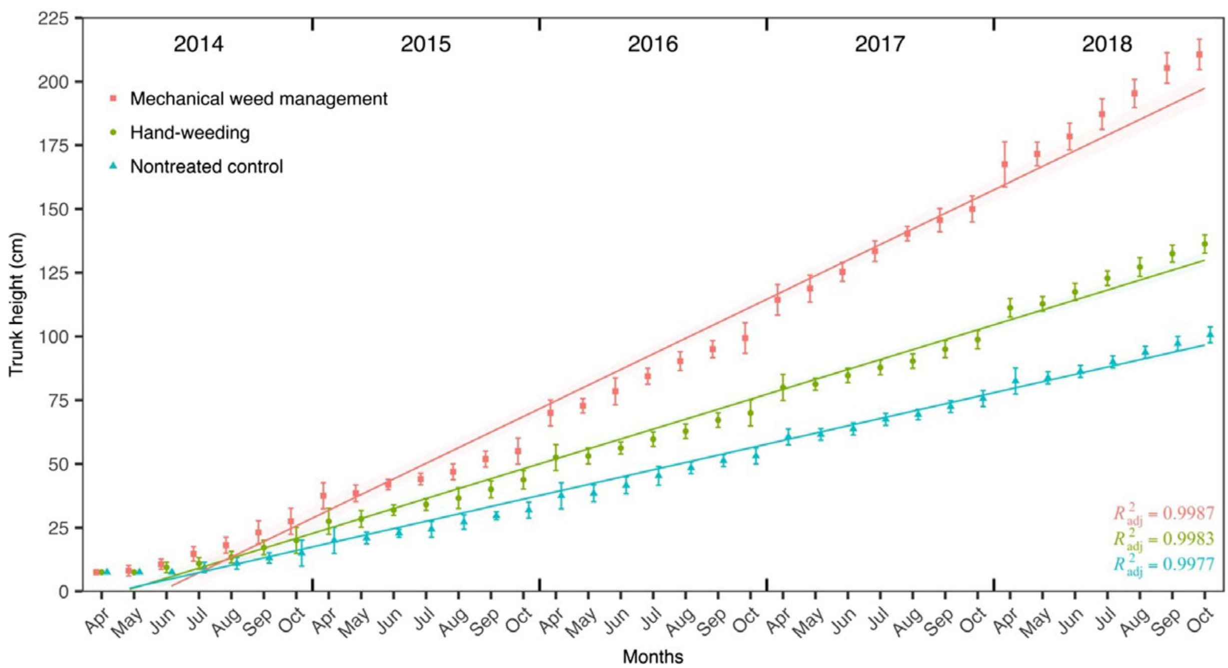

Figure 4. Effects of weed management treatments on windmill palm tree trunk height. Abbreviations, Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October. Numbers were rounded up to integers. Observations were made at 14 d after treatment and the data are shown monthly.

weed control. By October 2018, palm trees in the MWM treatment had approximately 84 leaves and a trunk height of 210 cm, whereas trees in plots that were hand-weeded and that received no weed control treatments had 54 leaves and 136 cm, and 40 leaves and 100 cm, respectively. Over 5 yr, 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 use on palm trees in Türkiye and the potential adverse effects of herbicides, this research underscores the need for nonchemical weed management approaches. Although MWM is initially labor-intensive, it is cost-effective because 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

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meet market standards for height and appearance more quickly, and thereby 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 interrow and intrarow 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 https://doi.org/10.1017/wet.2025.6

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