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Performance Evaluation of Thermal Weeder for Weed Control in Greenhouses

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Abstract

An experiment was carried out in one of the greenhouses at the College of Agricultural Engineering Sciences –University of Baghdad /Al-Jadriyah during the Winter season of 2024. The experiment aimed to evaluate the performance of a thermal weeder for weed control in greenhouses. The experiment was designed using a randomized complete block design (RCBD) to study the effects of three factors: nozzle type at three levels (cone nozzle, flat nozzle, barbecue nozzle) exposure time at two levels (40 and 60 seconds), and nozzle height at two levels (2 and 12 cm). The study focused on several indicators, including the percentage of weed control, energy consumption rate, energy consumption costs, and productivity. Statistical analysis results showed significant differences in the three-way interaction between nozzle type, exposure time, and nozzle height. The first nozzle (N1) at the second exposure time (60 seconds) and the first height (2 cm) achieved the highest percentage of weed control at 82.50%. In contrast, the third nozzle (N3) at the first exposure time (40 seconds) and the second height (12 cm) recorded the lowest energy consumption rate at 1925.2 kWh. Regarding energy consumption costs, the lowest cost was recorded at the third nozzle, first exposure time and the second height, amounting to115,512 IQD. The highest productivity was achieved at the "third nozzle", second exposure time" (60 seconds) and" the second height: (12 cm), with a value of 0.000909 $ha.h^{-1}$ **.**

Keywords: Thermal Weeder, weed control percentage, energy consumption rate, energy consumption costs, productivity .

Introduction

Weed control is considered one of the most critical agricultural operations today [1]. Pesticides, despite their high efficiency and effectiveness, are one of the environmental pollutants used in fields and farms. Their impact on human and animal health has become evident, leading to carcinogenic diseases [2]. According to [3] thermal control methods are safer and more common alternatives to chemical control. When heat is applied repeatedly to combat harmful weeds in agricultural fields, it does not affect the soil or encourage the emergence of new waves of weeds. [4] stated that thermal control is a selective method in agriculture, as it targets specific areas where harmful weeds exist. It also improves soil properties by reducing the number of weed seeds that cause significant crop yield losses. Thermal control employs clean, environmentally friendly, and effective methods to control most surface weeds. [**5**] compared the steam method with hot air methods for weed control and concluded that hot air is superior, offering several benefits, including a 10%-20% reduction in energy usage. Thermal weed control technologies rely on direct contact with plant tissue, where temperatures of around 100°C are applied for short periods, causing water inside the cells to expand and rupture cell membranes [6]. [7] found that using a hot air thermal weeder at three different speeds demonstrated that the first speed (0.222 m/s) was the most effective, achieving an 81.78% weed control rate due to the longer exposure time of plants to thermal treatment compared to other speeds **.** Energy consumption is a vital aspect of modern life, and understanding how to measure and manage electricity consumption is essential for reducing and optimizing energy usage in any electrical device, based on the power rate and time. Energy consumption of electrically powered agricultural machinery has been studied, revealing that modern technologies improve performance during operations and reduce costs associated with electricity use. Energy requirements for agricultural tasks are estimated while considering predetermined pathways and environmental conditions [8].

Productivity refers to the amount of work a machine or equipment can perform within a unit of time, based on the design working width and speed during agricultural operations without losses [9]. [10] found that speed significantly affects productivity, as higher speeds result in increased productivity due to reduced time required to complete agricultural tasks. [11] compared energy consumption costs among chemical, mechanical, and thermal weed control techniques. They found that thermal control consumes significantly more energy than mechanical methods, with energy requirements for thermal techniques increasing by 100 to 1000 times compared to other methods **.**

Material and methods

A field experiment was conducted during the winter season of 2024 in a greenhouse at the Al-Jadriya complex, affiliated with the College of Agricultural Engineering Sciences. Study objective aimed to evaluate the performance of a thermal weeder for weed control in greenhouses. Data were analyzed using a factorial experiment within a randomized complete block design (RCBD). The experiment included three factors: nozzle type three levels (cone nozzle, flat nozzle and barbecue nozzle), nozzle height two levels (2cm, 12cm), and exposure time **.**two levels (40 sec ,60 sec) witch each treatment replicated three times.

Thermal Weeder

The thermal weeder FUV 2000 A1, locally modified, was used as shown in Figure (1). It comprises the following The device consists of a manual handle (1), a pressure reducer, a power cord, an on/off switch, an air inlet opening, a clamp, a casing containing a heating element, a ventilation fan, and a heat protective shield. It also features a structure made of cast iron (2) with dimensions of (65 cm × 20 cm), and includes a device holder equipped with ground wheels (6) for easy movement and transportation in all directions during the operation. To adjust the height of the nozzle above the plant, the structure is perforated with equally spaced holes (4), with a distance of (5 cm) between each hole. A nut is used to fix (3) the selected height at the desired position during the operation. to be installed to combat types of nozzles (5) which are a flat nozzle, a horn nozzle and a barbecue nozzle. When the device is turned on the on/off switch, the temperature is reached completely after about one minute from the start of operation noting that the temperature of the air coming out the weeder reaches 240°C .

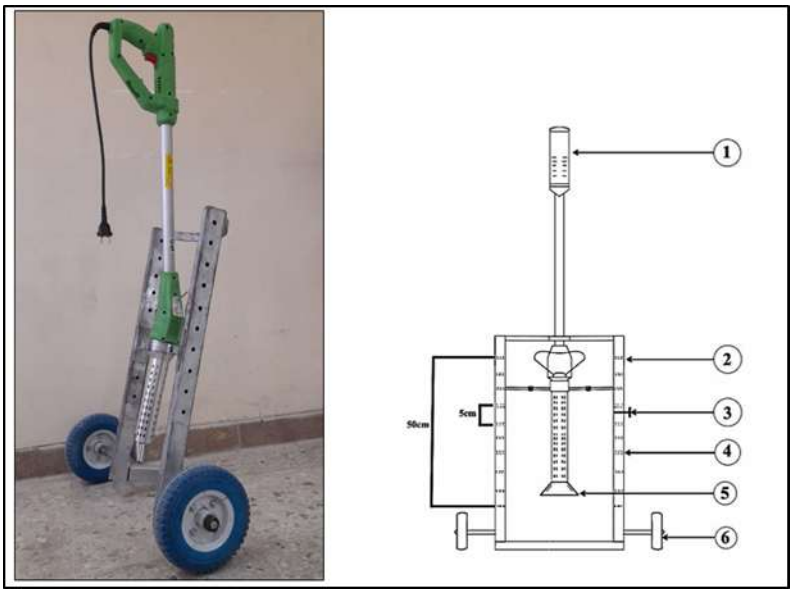

Figure (1): Thermal Weeder

Experiment Setup

The experiment was conducted during the winter of 2024. Weed samples were collected by cutting them at soil level and at regular intervals from the experimental field using a wooden frame (30 × 30 cm). The collected weeds were identified and counted for each type at each sampling site (Table 1). The weed samples were placed in perforated paper bags and dried in an electric oven at 70°C for 48 hours until a constant dry weight was achieved . The first nozzle was used for weed control, with the initial height set at 2 cm above the soil surface and an exposure time of 40 seconds. The same nozzle was then used with the second height (12 cm) and exposure time (60 seconds). This process was repeated for the second and third nozzles under the same heights and exposure times. A power consumption measurement device was installed and connected to the thermal weeder to measure the energy consumption rate .

Studied Traits :

1- Weed Control Percentage (%)

The percentage of weed control was calculated based on the number of weeds in the experimental unit before and after the control process. The following formula [12] was used:

W.C **(%)** = (A-B /A) ×100 (1)

Where **:**

W.C: Weed control percentage **(%)**

A: weed density in the comparison treatment

B: weed density in the control treatment

2- Energy Consumption Rate (Kw.h)

An electrical energy measurement device was installed, and the necessary cables were connected to integrate the device with the machine's electrical system. Energy consumption was calculated using the following formula [13].

EC = P×T (2)

Where **:**

EC: Energy consumption rate (Kw.h)

P: Electrical power (Kw)

T: Time (h)

3. Productivity (ha.h^{-1})

Al-Tahhan [14] indicated that field productivity is expressed as the ratio of area to time (hectares/hour, dunums/hour, or acres/hour). The most commonly used expression for estimating machine productivity is **:**

FC =0.0001 × $\frac{A}{T}$ (3)

Where **:**

FC: Productivity (ha.h^{-1})

A: Area (m^2)

T: Time taken to complete the task (h)

4. Energy Consumption Costs (IQD)

The costs of energy consumption were calculated using the following formula [15].

EE= EC*Price (4)

Where **:**

EE: Electricity costs (IQD)

EC: Energy consumption **(** Kw.h)

Price: Agricultural electricity rate (60 IQD)

Statistical Analysis :

Data were analyzed using the SAS (Statistical Analysis System) software. Significant differences among means were determined using the Least Significant Difference (LSD) test at a probability level of 0.05 **.**

Table (1): Types of Weeds in the Study Field

English name	Scientific name	Type	Life cycle
Mallow	*Malva rotundifolia L.*	Malvaceae	Annual
London rocket	*Sisymbrium septulatum Dc.*	Cruciferae	Annual
Lambs quarter	*Chenopodium album L.*	Chenopodiacea	Annual
Field bind weed	*Convolvolus arvensis L.*	Convolvulacea	Perennial
Wild radish	*Raphanus raphanistrum L.*	Brasicaceae	Annual
Prickly lettuce	*Lactuca serriola L.*	Astraceae	Annual
Sweet clover	*Melilotus indicus L.*	Fabaceae	Annual
Milk thistle	*Silybum marianum(L) Gaertn*	Campositeae	Annual
Pers	*Cynodon dactylon L.*	Gramineae	Perennial
Wild carrot	*Daucus carota L.*	Umbiliferae	Annual

Results and Discussion

1- Weed Control Percentage (%)

Table (2) shows the effect of nozzle type, exposure time, nozzle height, and their interactions on the percentage of weed control. Statistical analysis results revealed significant differences due to nozzle type on the weed control percentage. The first nozzle (conical) was the most effective, achieving the highest weed control percentage of 63.52%, followed by the second nozzle (flat) at 54.98%, while the third nozzle (grill) recorded the lowest percentage at 41.24%. This variation is attributed to differences in the shape and design of the nozzles, as the conical nozzle covers a larger exposure area during weed control compared to the other nozzles **.**The results also indicated no significant differences due to exposure time on the weed control percentage. However, nozzle height significantly affected the weed control percentage, with the first height achieving the highest value of 73.90%, compared to 32.60% for the second height. The superiority of the first height is attributed to the increased exposure time to thermal control, and this agree with the results of Sirvydas et al. [16] **.**The statistical analysis results in the table (2) indicate significant differences in the two-way interaction between nozzle type and exposure time for the weed control percentage.

The highest weed control with the interaction of the first nozzle (conical) and the second exposure time, percentage was observed reaching 64.94% .Regarding the interaction between nozzle type and nozzle height, the highest weed control percentage was recorded for the interaction of the first nozzle with the first height, amounting to 82.01%. As for the interaction between nozzle height and exposure time, the results showed the highest weed control percentage at the interaction of the first height with the second exposure time, achieving 75.98% .

The table also shows significant differences in the three-way interaction between nozzle type, exposure time, and nozzle height for the weed control percentage. The highest percentage was recorded with the interaction of the first nozzle, the first height, and the second exposure time, reaching 82.50% .

Table 2. The effect of nozzle type (N), exposure time (T), nozzle height (H), and their interactions on weed control percentage(%)

Nozzle type (N)	Exposure Time (T)	Nozzle Height (H)		N*T	Average-N
		H: 2	H: 12		
N1	T: 40	81.50	48.37	62.11	63.52
	T: 60	82.50	41.71	64.94	
N2	T: 40	69.56	35.04	52.31	54.98
	T: 60	75.50	39.83	57.67	
N3	T: 40	64.39	9.49	36.94	41.24
	T: 60	69.94	21.16	45.55	
Value LSD		LSD: N*T*H = 14.734 *		LSD: N*T=	LSD: N= 7.367
H x N					---
N1		82.01	45.04	LSD: N*H = 13.02 *	
N2		72.53	37.44		
N3		67.16	15.32		
H x T				Average T	
T: 40		71.82	30.96	51.39	
T: 60		75.98	34.23	55.11	
Value LSD		LSD: T*H = 10.172 *		LSD: T = 6.015 NS	
Average H	---	73.90	32.60	---	
Value LSD		LSD: H = 6.015 *			
*P≤0.05 ،(NS :No significant)					

2- Energy Consumption Rate (Kw.h)

Table (3) illustrates the effect of nozzle type, exposure time, nozzle height, and their interactions on the energy consumption rate. The statistical analysis revealed significant differences in energy consumption rates based on nozzle type. The second nozzle (flat) recorded the highest value at 2635.7 Kw.h, while the first nozzle (conical) recorded 2337.7 Kw.h. The third nozzle (grill) had the lowest energy consumption rate, at 2039.8 kWh .The analysis also showed no significant differences due to exposure time on the energy consumption rate. However, significant differences were observed for nozzle height, where the first height recorded the highest value at 2566. 92Kw.h, while the second height recorded 2108.54 Kw.h . It is evident from the statistical analysis results table (3) that there are significant differences in the interaction between nozzle type and exposure time regarding energy consumption rate. The highest energy consumption rate was observed with the interaction of the second nozzle (flat) and the second exposure time, with a value of 2658.6 Kw.h. the highest energy consumption rate occurred with the interaction of the first height and the second nozzle, with a value of 2979.5 Kw.h. Additionally, the results showed the highest weed control efficiency with the interaction of the first height and the second exposure time, with a value of 2719.7 Kw.h. The table also highlights significant differences in the three-way interaction among nozzle type, exposure time, and nozzle height regarding energy consumption rate. The highest energy consumption rate was recorded with the interaction of the second nozzle, the second exposure time, and the first height, with a value of 3025.3 Kw.h.

Table 3: The Effect of Nozzle Type (N), Exposure Time (T), Nozzle Height (H), and Their Interactions on Energy Consumption Rate (Kw.h)

Nozzle Type (N)	Exposure Time (T)	Nozzle Height (H)		N*T	Average-N
		H: 2	H: 12		
N1	T: 40	2200.2	2016.9	2108.5	2337.7
	T: 60	2842.0	2291.9	2566.9	
N2	T: 40	2933.6	2291.9	2612.8	2635.7
	T: 60	3025.3	2291.9	2658.6	
N3	T: 40	2108.5	1925.2	2016.9	2039.8
	T: 60	2291.9	2066.9	2062.7	
Value LSD		LSD: N*T*H = 506.28 *		LSD: N*T=	LSD: N=253.14
H x N					---
N1		2521.1	2154.4	LSD: N*H = 372.21 *	
N2		2979.5	2291.9		
N3		2200.2	1879.4		
H x T				Average T	
T: 40		2414.1	2078.0	2246.06	
T: 60		2719.7	2139.1	2429.41	
Value LSD		LSD: T*H = 281.33 *		LSD: T = 206.69 NS	
AverageH	---	2566.92	2108.54	---	
Value LSD		LSD: H = 206.69 *			
*P≤0.05 ،(NS :No significant)					

3- Energy Consumption Costs (IQD)

Table (4) demonstrates the effect of nozzle type, exposure time, nozzle height, and their interactions on energy consumption costs. The statistical analysis results indicate significant differences in nozzle type concerning energy consumption costs. The third nozzle (barbecue) was the best, recording the less value of 122,387 IQD, followed by the first nozzle (conical) with a value of 140,264 IQD, while the third nozzle (grill-type) had the lowest weed control cost, amounting to 122,387 IQD. This variation is attributed to the differences in the shape and design of the nozzles used .The statistical analysis results also indicate no significant differences for exposure time concerning energy consumption costs. However, significant differences were observed in nozzle height, with the first height recording the highest value of 154,015 IQD, while the second height recorded the lowest value of 126,513 IQD. The statistical analysis results table (4) reveals significant differences in the two-way interaction between nozzle type and exposure time regarding energy consumption costs. The highest costs were observed with the interaction of the second nozzle (flat) and the second exposure time, amounting to 159,516 IQD. As for the interaction between nozzle type and height, the highest weed control costs were recorded with the interaction of the first height and the second nozzle (flat), amounting to 178,768 IQD. Regarding nozzle height and exposure time, the results showed the highest costs with the interaction of the first height and the second exposure time, amounting to 163,183 IQD, as increased exposure time leads to higher energy consumption, and consequently, higher weeds control costs [17]. Additionally, the table indicates significant differences in the three-way interaction among nozzle type, exposure time, and nozzle height concerning energy consumption costs. The highest costs were recorded with the interaction of the second nozzle, the second exposure time, and the first height, amounting to 181,518 IQD.

Table 4: The Effect of Nozzle Type (N), Exposure Time (T), Nozzle Height (H), and Their Interactions on Energy Consumption Costs (IQD)

Nozzle Type (N)	Exposure Time (T)	Nozzle Height (H)		N*T	AverageN
		H: 2	H: 12		
N1	T: 40	132013	121012	126513	140264
	T: 60	170517	137514	154015	
N2	T: 40	176018	137514	156766	158141
	T: 60	181518	137514	159516	
N3	T: 40	126513	115512	121012	122387
	T: 60	137514	124610	123762	
Value LSD		LSD: N*T*H = 30377 *		LSD: N*T=	LSD: N=15188
H x N					---
N1		151265	129263	LSD: N*H = 24681 *	
N2		178768	137514		
N3		132013	112761		
H x T				Average T	
T: 40		144848	124679	134763	
T: 60		163183	128346	145765	
Value LSD		LSD: T*H = 22880 *		LSD: T = 12401 NS	
Average H	---	154015	126513	---	
Value LSD		LSD: H = 12401 *			
*P≤0.05 ،(NS : No significant)					

4- Productivity ($ha.h^{-1}$)

Table (5) illustrates the effect of nozzle type, exposure time, nozzle height, and their interactions on productivity. The statistical analysis results showed significant differences in nozzle type regarding productivity. The third nozzle (grill-type) recorded the highest value of 0.000821 $ha.h^{-1}$, while the first nozzle (conical) recorded a value of 0.000724 $ha.h^{-1}$. The statistical analysis revealed no significant differences for exposure time concerning productivity. However, significant differences were observed for nozzle height, with the second height recording the highest value of 0.000799 $ha.h^{-1}$. This can be attributed to the fact that as the nozzle height increases, the coverage area increases, and the time decreases and less heat reaches the weed cells to disrupt them [18]. The statistical analysis results table (5) indicates significant differences in the two-way interaction between nozzle type and exposure time concerning productivity. The highest productivity value was observed with the interaction of the third nozzle (grill-type) and the first exposure time, amounting to 0.000828 $ha.h^{-1}$ .Regarding the interaction between nozzle height and nozzle type, the highest productivity was recorded with the second height and the third nozzle (grill-type), with a value of 0.00088 $ha.h^{-1}$ .As for the interaction $ha.h^{-1}$. between height and exposure time, the highest value was recorded with the interaction of the second height and the first exposure time, amounting to 0.000810 $ha.h^{-1}$. Furthermore, the table (5) reveals significant differences in the three-way interaction among nozzle type, exposure time, and nozzle height concerning productivity. The highest productivity value was recorded with the interaction of the third nozzle, the second exposure time, and the second height, amounting to 0.000906ha.h^{-1}.

Table 5: The Effect of Nozzle Type (N), Exposure Time (T), Nozzle Height (H), and Their Interactions on Productivity (ha.h⁻ ¹)

Nozzle Type (N)	Exposure Time (T)	Nozzle Height (H)		N*T	Average-N
		H: 2	H: 12		
N1	T: 40	0.000760	0.000823	0.000791	0.000724
	T: 60	0.000590	0.000723	0.000656	
N2	T: 40	0.000583	0.000736	0.000660	0.000651
	T: 60	0.000550	0.000736	0.000643	
N3	T: 40	0.000786	0.000870	0.000828	0.000821
	T: 60	0.000723	0.000906	0.000815	
Value LSD		LSD: N*T*H = 0.00019 *		LSD: N*T=	LSD: N=0.0001
H x N					---
N1		0.000675	0.000773	LSD: N*H = 0.00014 *	
N2		0.000566	0.000736		
N3		0.000755	0.000888		
H x T				Average T	
T: 40		0.000710	0.000810	0.000760	
T: 60		0.000621	0.000788	0.000705	
Value LSD		LSD: T*H = 0.00012 *		LSD: T = 0.000075 NS	
Average H	---	0.000665	0.000799	---	
Value LSD		LSD: H = 0.000075 *			
*P≤0.05 ،(NS :No significant)					

The Conclusions

The flat nozzle used in the weed control process resulted in a significant increase in the percentage of weed control and a significant decrease in the energy consumption rate.

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