MANAGEMENT OF AUTOMATIC AND CONVENTIONAL SPRAYING TECHNIQUES IN GREENHOUSES, A COMPARATIVE STUDY

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ABSTRACT

This study aimed to used automated spraying inside greenhouses using automated sprayers and compare it with traditional spraying. An experiment was conducted in one of the greenhouses at the Research Center of the College of Agricultural Engineering Sciences, University of Baghdad / Jadriyah, during the summer season on the cucumber crop cultivar CADIAR F1. The techniques used in the spraying process included a locally-made automated sprayer to spray pesticides inside the greenhouses horizontally and a knapsack sprayer. Two types of nozzles were used: universal flat fan nozzle (120-02C) and (120-04C), with three different pressures (1.8, 3, 5) bar, using a constant speed of 2 km h^{-1}. This was to study the spray quality characteristics and the amount of waste resulting from using both methods. The experiment results indicated the automated sprayers' success in achieving good spray quality with less waste compared to the backpack sprayer. The automated sprayer achieved good results in increasing the spray penetration rate into the foliage and reducing the waste rate of pesticides by (34.3%) and (2.42%) respectively, compared to the backpack sprayer, which achieved (14.46%) and (18.42%) respectively.

Keywords: control, cucumber, monitoring, nozzle, pesticides, technology,

إدارة تقنيات الرش الالي والتقليدي في البيوت المحمية دراسة مقارنة

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المستخلص

هدفت هذه الدراسة الى استخدام الرش الالي داخل البيوت المحمية باستعمال مرشات الية ومقارنتها بالرش التقليدي وقد اجريت تجربة في احد البيوت المحمية التابعة لكلية علوم الهندسة الزراعية جامعة بغداد /الجادرية الموسم الصيفي على محصول الخيار صنف (CADIAR F1). التقنيات المستخدمة في عملية الرش هي مرشة الية محلية الصنع تعمل على رش المبيدات داخل البيوت المحمية وبشكل افقي ومرشة ظهرية. تم استخدام نوعين من الفوهات اذ كان الاول universal flat fan nozzle (120-02C) والثاني (120-04C) مع ثلاث انواع من الضغوط (5,3,1.8) بار بتطبيق تجربة عاملية باستخدام تصميم تام التعشية CRD وبثلاث مكررات باستخدام سرعة ثابته 2 كم/ سا لدراسة صفات جودة الرش وكمية الضائعات الناتجة من استخدام الطريقتين, وكانت نتائج التجربة نجاح المرشة الالية في الحصول على جودة رش جيدة وبأقل الضائعات من المرشة الظهرية, اذ حققت المرشة الالية نتائج جيدة في زيادة معدل اختراق الرذاذ للمجموع الخضري وتقليل معدل الضائعات من المبيدات وبنسب (34.3) و(2.42) % على التوالي مقارنة بالمرشة الظهرية التي حققت (14.46) و(18.42) %.

الكلمات المفتاحية: إدارة المرشات، التكنلوجيا، السيطرة والمراقبة الفوهات ، المبيدات، محصول الخيار.

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INTRODUCTION

Cucumber ranks among the top ten vegetable crops worldwide and is widely cultivated due to its high nutritional value. It provides essential nutrients such as potassium, magnesium, calcium, vitamins, and antioxidants. With a water content of approximately 90%, cucumber is also low in calories and has alkaline properties, making it a valuable component of a healthy diet. Cucumber thrives in temperatures between 20°C and 25°C, with reduced productivity at temperatures below 16°C. While it is traditionally grown in open fields, increasing market demand has led to widespread adoption of greenhouse cultivation to ensure higher yields and consistent quality (18). Furthermore, changing climate conditions and water scarcity have prompted farmers to focus on agricultural management and technologies to improve efficiency, yield, and sustainability (3,4). Integrating modern agricultural techniques and innovations such as greenhouse automation help optimize growing conditions and reduce resource wastage (6, 23). Protected cultivation is one of the most important agricultural programs worldwide, having a clear impact on providing agricultural products throughout the year (7). However, it is evident that this type of farming requires exceptional care due to the environmental conditions inside greenhouses, which create a suitable climate for the growth of diseases and agricultural pests (22). This necessitates regular and continuous control measures, in addition to the application of fertilizers and growth regulators (8, 16, 17), to ensure continuous growth of the foliage with high productivity, free from undesirable residues such as agricultural pesticides (15, 19). Previously, pest control mainly relied on backpack and handheld sprayers due to the inability to use plant protection equipment inside greenhouses because of the small space and dense vegetation. Additionally, these sprayers were inexpensive and easy to use (7, 10, 14). However, this type of equipment has many drawbacks, including inconsistent and uneven spraying, high labor requirements, and the inability to control the amount of sprayed material. These results in significant pesticide waste, economic loss, and environmental pollution (7). Studies have shown that modern technology in agriculture has a significant impact on increasing production (12). Sustainable agriculture and agricultural operations like spraying management are strongly closely connected (12, 20). Efficient spraying methods are essential for promoting the sustainability of farming systems (3,4). At present, many sprayers have been developed for pesticide application, particularly in fields and orchards (9, 14). However, there is a pressing need to develop automated sprayers for pesticide application inside greenhouses. Despite the expansion of protected agriculture, many unresolved issues related to the machinery used for pesticide spraying in greenhouses still exist (10). This study aims to develop innovative pesticide spraying techniques for practical adoption, focusing on effectiveness, cost, speed, ease of use, and maintenance. Special emphasis is placed on addressing the challenges posed by the ongoing decline in agricultural labor. Additionally, the study aims to enhance and improve the level of mechanization in plant protection activities. Most importantly, it seeks to ensure the environmental sustainability of agriculture (14, 15) by using these techniques inside greenhouses to achieve high-quality spraying with minimal waste compared to traditional spraying methods with the right nozzle selection.

MATERIALS AND METHODS

An experiment for pesticide spraying was conducted in a plastic greenhouse belonging to the Research Center of the College of Agricultural Engineering Sciences, University of Baghdad / Jadriyah, during the summer season. The greenhouse was planted with cucumber saplings of the type CADIAR F1. The dimensions of the greenhouse were 9 meters in width, 35 meters in length, and 3 meters in height. The crop was planted inside the greenhouse in alternating double rows, with single rows planted on both sides near the edge of the greenhouse. The distance between each plot was 1 meter, the width of each plot was 1 meter, and the distance between each sapling was 40 cm. The average height of the plants at the time of the experiment was 2 meters. Two types of sprayers were used for the experiment:

1- Traditional Backpack Sprayers are equipped with a pressure gauge to measure the pressure generated by the sprayer during operation, which was 1.8 bars, as shown in Figure (1). The second type of sprayer used was an automated sprayer, locally manufactured for horizontal pesticide application. It moves automatically with the help of the greenhouse structure. A 35-meter-long rail was installed, which matches the greenhouse length at which the experiment was conducted. The sprayer is mounted on a cart that moves along the rail with the help of four wheels. The pesticide or solutions are delivered to the sprayer via a flexible plastic tube connected to a tank placed at the beginning of the greenhouse, equipped with a centrifugal pump that helps to push the liquid to the sprayer, as illustrated in Figure (2).

Figure 1. Locally Manufactured Sprayer

Figure 2. Traditional Backpack Sprayer

2- Two types of flat fan nozzles were used: (120-04C and 120-02C), as shown in Table (1). These nozzles are from pl.agroplast

3- Water-sensitive paper was used to study spray quality. In this experiment, Kromekote cards or glossy photo paper measuring (7.5*2.5) cm² were used (1, 17).

4- A food dye with a brilliant blue color (Brilliant Blue Sivi Karisimi) was used. This dye is harmless to plants and can be used at a ratio of 300 ml per 30 liters of water. It is easy to prepare and spray. The dye was added to give the water a blue color, aiding in the study of spray quality after attaching the water-sensitive paper to the plant leaves.

5- The Deposit Scan program was used to calculate spray quality. This program quickly and accurately assesses spray deposits on Kromekote paper, providing results on droplet size, percentage coverage, amount of deposited material, and the number of droplets prone to drift (15). The area on the Kromekote paper to measure spray characteristics was specified, ensuring equal area for all characteristics. Notably, the larger the area, the more accurate the results (18).

Table1. Shows the specifications of the nozzles

KOLOR	COD PRODUCT	(bar)			ROZSTAW ROZPYLACZY-50 L/ hectare							
				L/min	6 km/h	8 km/h	10 km/h	12 km/h	14 km/h	16 km/h	18 km/h	20 km/h
Yellow	AP12002	2	D	0.65	129	97	77	65	55	48	43	39
		3	D	0.79	158	119	95	79	68	59	53	47
		4	D	0.91	182	137	109	91	78	68	61	55
		5	BF	1.00	200	150	120	100	68	75	67	60
		6	BD	1.09	218	164	131	109	93	82	73	65
Red	AP12004	2	S'	1.30	260	195	156	130	111	97	87	78
		3	D	1.59	318	239	191	159	136	119	106	95
		4	D	1.84	367	275	220	184	157	138	122	110
		5	D	2.05	411	308	246	205	176	154	137	123
		6	D	2.25	450	337	270	225	193	169	150	135

Studied Characteristics

1. The amount of spray reaching the plant parts: The deposited material on the test leaves is calculated using the Deposit Scan program in µL cm^{-2}, representing the volume deposited per square centimeter.

2. Penetration Spray (%) : This measures the extent of spray penetration into the foliage. It is calculated by comparing the average percentage coverage values on the plant's leaf surface, represented by the symbol F, with the coverage values on the test paper inside the plant, represented by the symbol H. This is the percentage resulting from dividing the coverage value inside the plant by the coverage value on the plant's surface, multiplied by 100%, according to the following equation:

$$Penetration\% = \frac{H}{H+F}\ \%.... (1)$$

Where:

- Penetration: Spray penetration into the foliage
- H: Coverage value of the spray on the test paper inside the plant
- F: Coverage value of the spray on the test paper on the surface of the plant

3. Spraying Losses (%): This is the amount of spray that falls onto the ground between the plant rows. This characteristic is calculated using Kromekote test papers distributed along the planting line between the plants for each experimental unit. It represents the percentage coverage on the sensitive papers, which is then analyzed using image processing software to assess the spray quality on the Kromekote papers, as shown in Figure (3).

Figure 3. Represents spray loss test papers

Methodology

The test paper was attached to the plant leaves, with four leaves on each plant (heart, face, down, up), as shown in Figure (4). The plastic greenhouse was divided into two sections: the right side was used to test the automated sprayer with 27 experimental units, with three replicates for each unit, and the left side was used for the backpack sprayer, divided into 18 experimental units, also with three replicates. The least significant differences (L.S.D) were employed to compare the means of treatments at a significance level of 0.05. Two types of nozzles were used: universal flat fan nozzle (120-02C) and (120-04C), with three different pressures (1.8, 3, 5) bar, using a constant speed of 2 km h^{-1}. The statistical analysis was conducted using the GenStat12.1 software. to analyze the data using both one-way ANOVA and two-way ANOVA methods

Figure 4. Illustrates the distribution of the sensitive paper on the plant parts

RESULTS AND DISCUSSION

The following are the results of the statistical analysis related to the use of the locally manufactured sprayer:

1. **The Amount of Spray Reaching the Plant Parts (μL/cm²):** The statistical analysis results, shown in Table (2) and Chart (2), regarding the amount of spray reaching the plant parts, indicated a significant impact of the nozzle type and the pressures used on the amount of spray reaching the plant leaves. The results showed that the flat fan nozzle (120-04C) achieved the highest amount of spray reaching the plant parts (deposited material) with an average of 6.17 μL cm^{-2}, while the flat fan nozzle (120-02C) achieved an average of 5.26 μL cm-². This is attributed to the amount of spray emitted from the nozzle and the discharge rate, with the flat fan nozzle (120-04C) having a higher discharge rate compared to the flat fan nozzle (120-02C). Regarding the effect of pressure on the amount of spray reaching the plant, the third pressure (5 bars) achieved the highest amount with an average of 8.34 μL cm-², while the first pressure (1.8 bar) resulted in the lowest amount of spray reaching the plant with an average of 2.66 μL cm-². This means that increasing the pressure produces smaller droplets, which increases the coverage rate and thus increases the amount of deposited material on the plant parts (2). Using the optimal pressure for the nozzle improves the delivery of spray to the plant parts with minimal loss. Concerning the interaction between nozzle type and pressure, the results showed that the highest amount of deposited material was at the third pressure (5 bar) with the flat fan nozzle (120-04C), reaching 8.72 μL cm-², while the first pressure (1.8 bar) with the flat fan nozzle (120-04C) achieved the lowest amount of spray reaching the plant parts, with 2.3 μL cm-².

Table 2. Effect of nozzle type and pressure on the amount of droplets reaching the plant parts (μL cm⁻²)

The amount of spray reaching the plant parts μL cm⁻²				
Type nozzle	Pressure			Mean nozzle
	1.8 bar	3 bar	5 bar	
Flat fan nozzle (120-02C)	3.01	4.82	7.96	5.26
Flat fan nozzle (120-04C)	2.3	7.48	8.72	6.17
LSD		1.347		0.778
Mean pressure	2.66	6.15	8.34	
LSD		0.953		

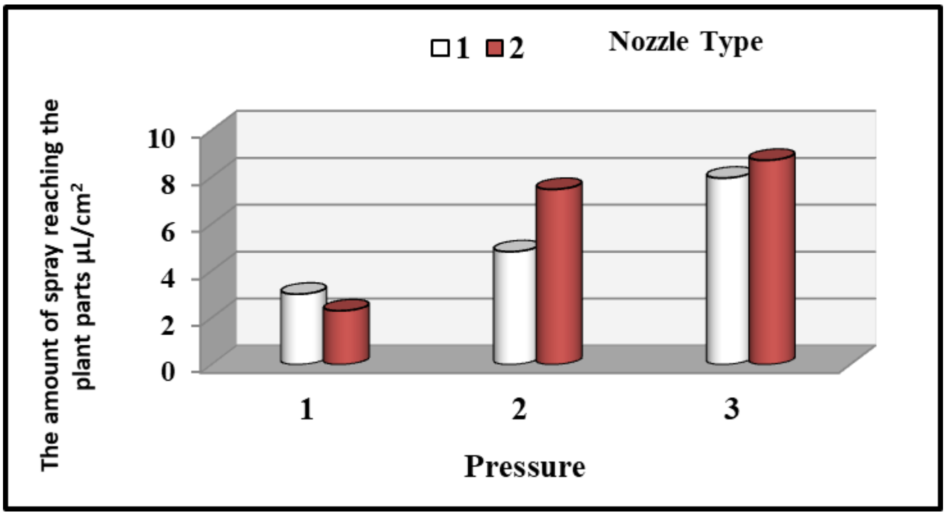

Chart 2. Effect of nozzle type and pressure on the amount of droplets reaching the plant parts (μL cm⁻²)

1. Penetration Spray (%):

The statistical analysis results in Table (3) and Chart (3) related to the penetration spray (%) indicated a significant effect of nozzle type and pressure on this trait when using the locally manufactured sprayer. The results showed a significant effect of the flat fan nozzle (120-02C) on the penetration attribute, with an average spray penetration of 38.05%. In contrast, the flat fan nozzle (120-04C) achieved a penetration rate of 30.62%. This means that using nozzles with smaller orifice sizes produces larger droplets, thereby increasing the spray penetration rate into the foliage compared to nozzles with larger orifices. The statistical analysis also showed a significant effect of pressure on the penetration attribute, with the first pressure (1.8 bars) achieving the highest penetration rate at 43.41%, while the penetration rate decreased to 22.57% at the third pressure (5 bars). This indicates that using lower pressure produces larger droplets, which are less sensitive to the effects of wind movement, thus achieving better penetration. This finding agreed with (5). Regarding the interaction between the spray nozzle and pressure, the results showed a significant effect on the penetration attribute. The interaction of the first pressure (1.8 bars) with the flat fan nozzle (120-02C) achieved the highest penetration rate at 49.25%. This does not agree with (5), which indicated that the best pesticide penetration into the foliage is achieved by combining high pressure with a coarse atomization nozzle, which increases the speed of the spray droplets and thus achieves good penetration.

Table 3. Effect of nozzle type and pressure on penetration (%)

Type nozzle	Penetration spray % Pressure 1.8 bar	3 bar	5 bar	Mean nozzle
Flat fan (120-02C)	49.25	42.87	22.02	38.05
Flat fan (120-04C)	37.57	31.17	23.12	30.62
LSD		5.688		3.284
Mean pressure	43.41	37.02	22.57	
LSD		4.022		

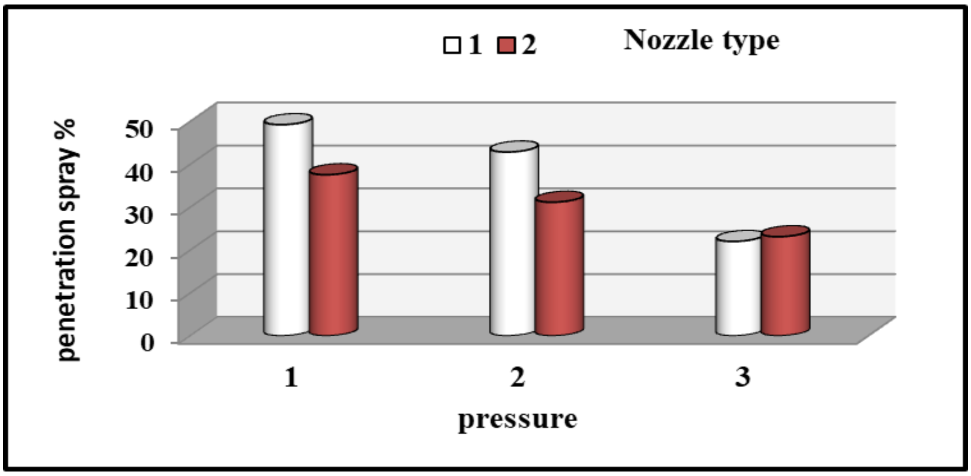

Chart 3. Effect of nozzle type and pressure on penetration (%)

3. Spray Losses (%)

The statistical analysis results in Table (4) and Chart (4) indicated a significant effect of nozzle type and pressure on the spray losses. The flat fan nozzle (120-04C) had the lowest loss rate at 1.53%, while the flat fan nozzle (120-02C) had a loss rate of 3.32%. This variation in loss rates between the two nozzles is not substantial, and there is no significant pesticide wastage thanks to the locally manufactured sprayer, which operates horizontally from top to bottom uniformly and at a constant speed without obstacles during movement. As for the effect of pressure on the loss rate, the first pressure (1.8 bar) had the lowest loss rate at 0.61%, followed by the 3 bar and 5 bar pressures with loss rates of 2.26% and 4.4%, respectively. The variation in the loss rate between the three pressures was minimal, indicating that higher pressure produces smaller spray droplets that are more prone to drift away from the target. These results consistent with (5). Regarding the interaction between nozzle type and pressure, the combination of 1.8 bar pressure with the flat fan nozzle (120-04C) achieved the lowest loss rate at 0.56%.

Table 4. Effect of nozzle type and pressure on spray losses (%)

Type nozzle	Spray losses Pressure 1.8 bar	3 bar	5 bar	Mean nozzle
Flat fan (120-02C)	0.67	3.03	6.27	3.32
Flat fan (120-04C)	0.56	1.49	2.53	1.53
LSD		0.906		0.523
Mean pressure	0.61	2.26	4.4	
LSD		0.641		

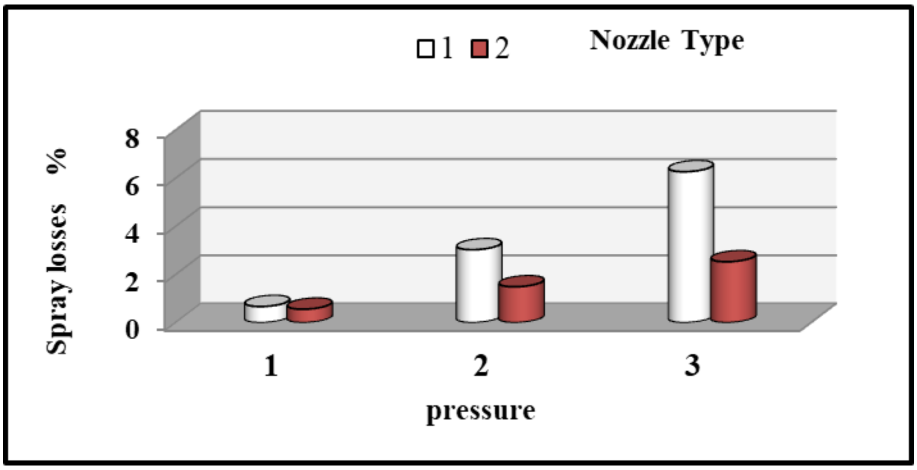

Chart 4. Effect of nozzle type and pressure on spray losses (%)

Comparison between the locally manufactured sprayer and the traditional sprayer: The statistical analysis results indicated significant differences when using the two sprayers in some of the spray quality attributes studied in this research. The locally manufactured sprayer achieved the highest rate of pesticide penetration into the foliage and the lowest percentage of losses, with averages of 34.3% and 2.42%, respectively. In contrast, the traditional sprayer achieved a penetration rate of 14.46% and a loss rate of 18.42%. This is consistent with previous studies (7, 8, 9). Meanwhile, neither sprayer had a significant impact on the amount of deposited material (the amount of spray reaching the plant), although there were numerical differences between them, with averages of 5.72 µL cm^{-2} and 4.36 µL cm^{-2} In addition, the amount of losses on the ground was higher for the traditional sprinkler.

Table 5. Effect of sprayer type on studied characters

Adjective	Sprinkler type: Automatic sprinkler	Conventional sprinkler	S
The amount of spray reaching the plant parts µL/cm^2	5.72	4.36	N.S
% spray penetration	34.30	14.46	**
% Spray Losses	2.42	18.42	**

Conclusion

Under the conditions of the experiment and based on the results obtained from statistical analysis, an automated sprayer was designed and manufactured for applying pesticides and other solutions in greenhouses. It was tested and achieved good spray quality results compared to the traditional sprayer as follows:

a- The automated sprayer achieved good results in increasing the spray penetration rate into the foliage, with a percentage of 34.3% compared to the backpack sprayer, which achieved a penetration rate of 14.46%.=

b- The automated sprayer achieved good results in reducing the rate of pesticide spray losses falling on the ground, with a percentage of 2.42% compared to the backpack sprayer, which had a loss rate of 18.42%.

c- Optimal use of pressures that achieve effective spraying with minimal losses can be achieved using spraying equipment equipped with a gauge to determine the appropriate spraying pressure, along with selecting a suitable spray nozzle.

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