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Study of the performance of a developed remotely controlled sprayer for weed control

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Abstract

Spraying pesticides is an important procedure to control weeds, fungi, insects, and diseases. The determination of the equipment used to achieve such a task depends initially on the area sprayed. For low-scale areas such as small fields or greenhouses the backpack sprayer is commonly preferred due to its ease and low cost. However, utilizing backpack sprayers causes serious health issues related to the contamination and the bad effect on the human skeletal system due to the weight of the sprayer filled with the sprayed solution. In this research, a remotely controlled sprayer was developed and the effect of three travel speeds, and two spraying heights on some spray parameters were estimated including the spray coverage, droplet size, and droplet density. The results expressed that the developed sprayer showed the expected trend of coverage and deposition on the target which decreased with increasing the travel speed and the spraying height. In relation to the droplet density, the developed sprayer achieved an increase in droplet density with the travel speed and the spraying height.

Key words: precision agriculture, weed control, labor safety, sustainable use of pesticide, spray quality

Introduction

Generally, pests negatively impact the quantity and quality of the desired crop [1]. Controlling pests by spraying pesticides is one of the most common and effective methods used nowadays [2], [3]. Spraying pesticides is usually performed using tractor-mount sprayers, air-borne sprayers, or backpack sprayers based on several considerations such as the area treated, the growth stage of main crop, the weed density, and the planting environment either in a field or a greenhouse.

Backpack sprayer is usually preferred to spray pesticide in greenhouses due to its low cost and small size. Backpack sprayers are available in two general types, namely hand-operated and electrically-operated backpack sprayers. However, using backpack sprayer involves serious risks such as the operator contamination [4], in addition to the health issues and tiredness resulted due to the weight of the filled sprayer which is mounted on the operator's body [5], [6].

[4] investigated the effect of operators' exposure to pesticides using two sprayers, namely a backpack and a stretched-mounted sprayers at different protective procedures. They found that the higher exposure occurred when using insufficient protective procedures and improper settings of spraying task. This result confirms the risky impacts on farmers which usually do not follow the safety requirements when applying pesticides.

[5] studied the impacts of vibration of the motorized backpack sprayer on four parts of the human body. They found that there were negative effects on the human body, and they recommended not to use such a sprayer for more than 1 hour.

Mosalanejad et al. (2021) developed a spraying robot that can navigate based on ultrasonic sensors and can detect the start and the end of each row based on an infrared sensor. They used a backpack sprayer, a microcontroller, sensors, drivers, and motors. They compared the developed spraying robot with the conventional backpack sprayer, and they found that the spraying robot achieved better spraying quality, less spraying time, and less spraying loss. However, they recommended using the speed of 0.84 $km\ h^{-1}$ which is considered low speed.

Hence, developing the backpack sprayer to be used remotely is a critical issue to mitigate the negative impacts of mounting the backpack sprayer and the exposure to the chemical used.

This study aimed at developing a remotely controlled sprayer for sustainable use to mitigate the bad impacts on the operator due to the pesticide exposure, to reduce the variability of the forward speed and spraying height that are expected when using the backpack sprayer manually by an operator which in turn affect the spraying quality by evaluating some spraying parameters.

Material and methods

The platform

A four-wheel small platform (Figure 1) was designed and manufactured from hollow steel bars of square and circular sections (length of 80 cm, width of 45 cm, and a clearance above the ground of 30 cm. These dimensions were adopted for the platform to be able to work in between the crop rows. The two rear wheels were the driving wheels with a diameter of 28 cm each had a DC gear motor (Table 1), while the two front wheels were caster wheels with a diameter of 20 cm that facilitate the process of steering.

This platform was designed to be controlled remotely by a wireless controller (MicroZone 2.4G 6CH MC6C Remote Controller) that covers up to 800 meters (Figure 2). The steering system of this platform was a skid-type that depends on the differential motion between the two rear driving wheels. A 12-volt battery was used as a power source, and an Arduino mega microcontroller board (Figure 3) as a control unit for controlling the speed and the steering of the platform via two pulse width modulation (PWM) motor drivers (Figure 4).

Table 1. The specifications of the sprayer pump, the Nozzle, PWM drivers, and the the motors

Pump specifications	
Max pressure	4.8 bar
Open flow	3.1 $l\ min^{-1}$
Voltage	12 V
Max current	2 A
Nozzle specifications	
Manufacturer	TeeJet
Model	XR11002-VP
Material	Polymer
Operating pressure	1- 4 bar
Flow rate @ 2 bar	0.65 $l\ min^{-1}$
Flow rate @ 3 bar	0.79 $l\ min^{-1}$
Spray angle	110°
Spraying type	Extended range
Motor specifications	
Model	DG-168A2
Unloading voltage	24 V
Unloading current	Up to 4.5 A
Unloading maximum speed	135 rpm
Output power	150 W
Gear ratio	26.25
Gear motor rated torque	11.3 N.m
Weight	4.63 kg
PWM driver board specifications	
Input voltage	6-27 V
Maximum current	43 A
Input level	3.3-5 V

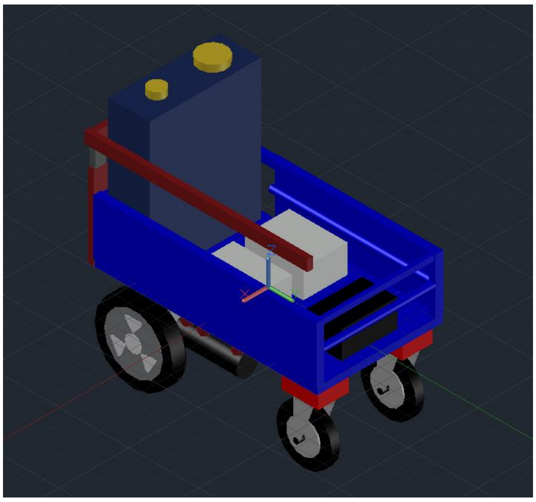

Figure 1. The scheme of the developed sprayer (drawn by AutoCAD 2017)

Figure 2. Microzone Controller

Spraying system

The spraying system consists of an electric backpack sprayer, an extended range flat spray nozzle whose installing angle is set to be vertical to the platform forward speed, a pressure gauge, filters, pipes, and fittings (see Table 1). Tap water was used as a spraying material in this experiment for safety considerations.

A boom (Figure 1) was designed and manufactured by two vertical rectangular hollow steel bar that were welded at the end of the platform within each of them another steel bar that slides up and down and can be fixed by bolt in order to control the spraying height. A horizontal bar was welded to the two sliding vertical bar and was connected to another horizontal bar that was slotted to make it easy to adjust the distance between nozzles and was designed to be foldable to facilitate transporting it out of the working times.

Control unit

The control unit composed from an Arduino Mega microcontroller board (Figure 3), and two PWM motor drivers (BTS7960 IBT2 40A) (Figure 4) whose specifications are shown in (Table 1). Each driver has a module with four ports: two for the input voltage from the power supply (B+ and B-), and the other two for the output voltage to the motor (M+ and M-). Moreover, each driver has a pin module that contains pins whose symbols and descriptions showed in (Table 2). An Arduino scratch was developed to control the speed and the steering of the platform.

Field experiment

The experiment was conducted in a paved courtyard in the college of Agricultural Engineering Sciences –

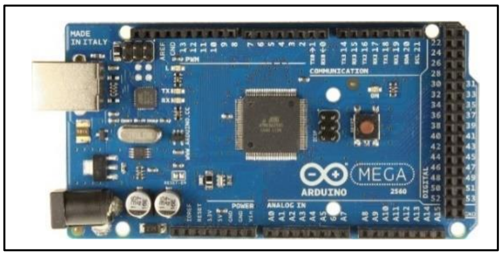

Figure 3. Arduino Mega microcontroller board

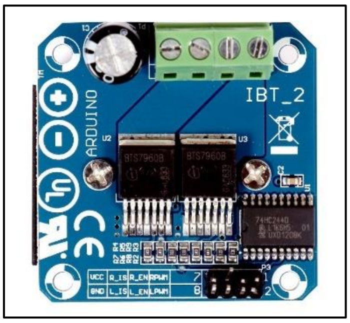

Figure 4. PWM driver board

Table 2. Positions, symbols, and the description of PWM driver's pins

Pin position		Pin symbol	Description
Row	Column		
1	1	VCC	Connected to the Arduino 5-volt pin.
1	2	R_IS	Not connected.
1	3	R_EN	Forward drive enable input (high-level enable, low level off).
1	4	RPWM	Connected to the Arduino pin that support PWM (~).
2	1	GND	Connected to the Arduino ground pin.
2	2	L_IS	Not connected.
2	3	L_EN	Reverse drive enable input (high-level enable, low level off).
2	4	LPWM	Connected to the Arduino pin that support PWM (~).

University of Baghdad in May 2023 from 7:00 am to 10:00 am. The temperature ranged from 25 to 31 °C, the relative humidity was 18%, and the wind was south-western with a speed ranged from 6 to 9 $km.h^{-1}$. This experiment studied the effect of three forward speeds, and two spraying heights above the target on the spray coverage (%), droplet density ($deposits\ cm^{-2}$), and deposition ($\mu l\ cm^{-2}$). Thus, this experiment represented a factorial design with six treatments and each treatment had eight samples. Each treatment was represented by a line of 1-liter nursery pots [8], [9] spaced at 50 cm in which green pepper seedlings at vegetative growth stage were implanted. This experiment was arranged as a completely randomized design (CRD). For each treatment eight water sensitive papers (SpotOn $25 \times 76\ mm$) were used as a sample collector. Each paper was fixed to a leave of a green pepper seedling by a staple and collected 1 minute after applying the treatment to allow them to be dried sufficiently, then they are placed in a transparent self-adhesive nylon bag which in turn was placed in a paper envelope.

The spraying speed was controlled by the Microzone wireless controller. Using different positions of the controller's stick that was programed to control the speed via the Arduino mega microcontroller board, different speeds can be obtained. The speed was estimated by fixing the stick into a position and measuring the time required to move for 10 meters, then the speed was calculated by dividing the distance (10 m) by the time required. Three speeds were adopted, namely $1, 2, and\ 3\ km\ h^{-1}$.

Finally, the spraying height was controlled using the aforementioned sliding bar by which the spray height can range from 65 to 90 cm above the ground (about 40 to 50 cm above the target).

Estimating spray parameters

The water sensitive papers (WSP) collected were scanned using a scanner (MFC-J480DW, Brother Corporation) at a resolution of 600 dpi [9], [10], [11], [12]. WSPs of each treatment were scanned once then a software DepositScan (USDA, Wooster, OH, USA) was used to estimate the spray parameters [9], [10], [12], [13], [14]. Then, the DepositScan results were collected in one excel sheet for further analysis.

Statistical analysis

Spray attributes acquired from the DepositScan software were analyzed via two-way analysis of variance (two-way ANOVA) using Origin software (Origin Pro, v2018. OriginLab Corporation, Northampton, MA, USA) to investigate the null hypothesis that the means of all groups in each speed, height, and their interactions are equal. If the null hypothesis was rejected, the Fisher's least significant difference test (LSD) was used as a multiple comparison test to estimate the least significant differences among means. All analyses were performed at the 0.05 level of significance.

Results and Discussion

Spray coverage

The results showed that the two-way interactions among the travel speeds, and the spraying heights did not significantly affect the spray coverage. However, the effect of speed was highly significant ($p < 10^{-5}$). Fisher LSD test revealed that the highest coverage of 48% was obtained through the slowest speed ($1\ km\ h^{-1}$), whereas the lowest coverage of 43% and 42%, were obtained by the speeds of 2 and $3\ km\ h^{-1}$ respectively which in turn did not differ significantly from each other (Figure 5).

These results confirmed that the spray coverage decreases with increasing the travel speed which agreed with the findings of [11], [12], [15], [16]. It is known that the application rate decreases with the travel speed at a specific operating pressure which may in turn cause a decrease in the spray coverage.

In relation to the effect of spraying height on the spray coverage (Figure 6), the results expressed that there was a highly significant effect ($p<10^{-7}$) on the spray coverage. The lowest height of 40 cm achieved the highest spray coverage of 48%, whereas the highest height of 50 cm achieved the lowest coverage of 41%. These results corresponded to the results of [15], [17]. The effect of the height on the coverage may be attributed to the fact that at a specific spray angle the spraying width increases with the spraying height which in turn makes the amount of the sprayed liquid distributed to a larger area with less coverage and vice versa [18]. Moreover, the possibility of losses due to drift and evaporation increases with increasing the spraying height [19].

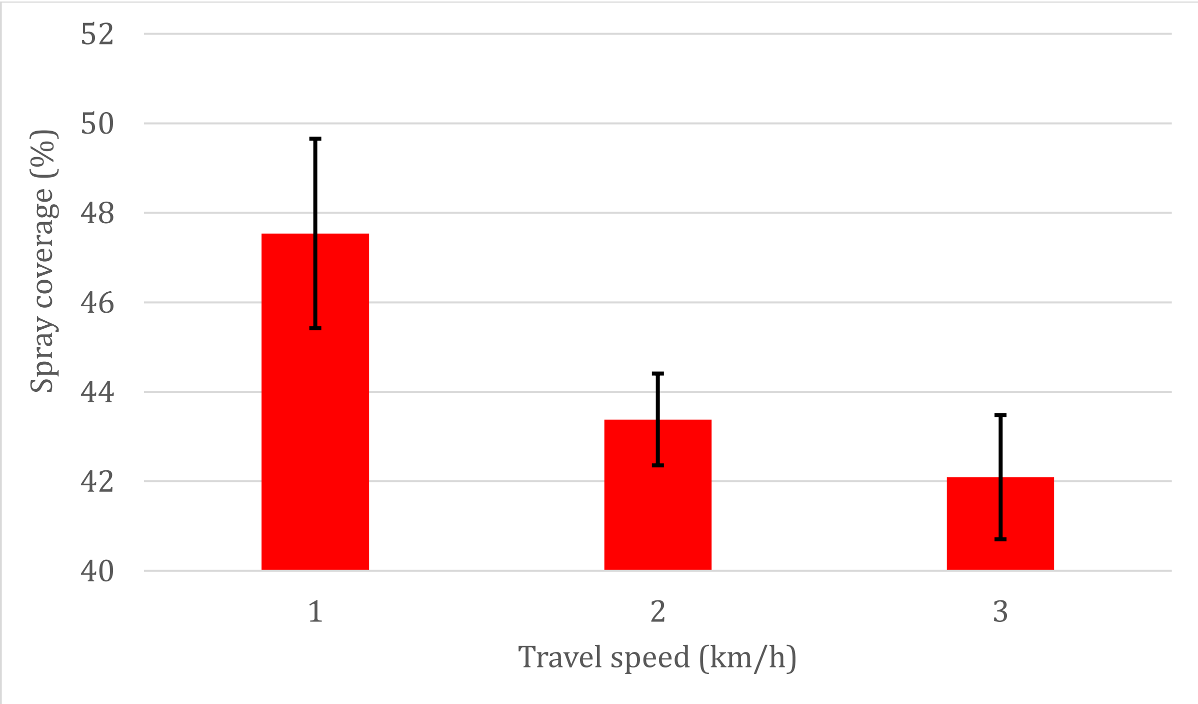

Figure 5. The effect of travel speed on the spray coverage (Means and standard errors)

Droplet density

The analysis of the droplet density revealed that the travel speed significantly affected the droplet density ($p<10^{-6}$) where the speed of $1\ km\ h^{-1}$ achieved $74\ deposits\ cm^{-2}$, whereas the $2\ and$ $3\ km\ h^{-1}$ achieved 116 and 136 $deposits\ cm^{-2}$, respectively (Figure 7). These results confirmed the findings of [11] that increasing the travel speed increases the droplet density. However, the results obtained contradicted that of [20] which found that decreasing the flight speed of an airborne sprayer increased the droplet density. This may be attributed to the fact that Muhammad et al. (2019) used an UAV with the minimum speed of 7 $km\,h^{-1}$ at a height of 2 m which in turn may make the spray more susceptible to drift [21] and evaporation at higher speed leading to lower droplet density.

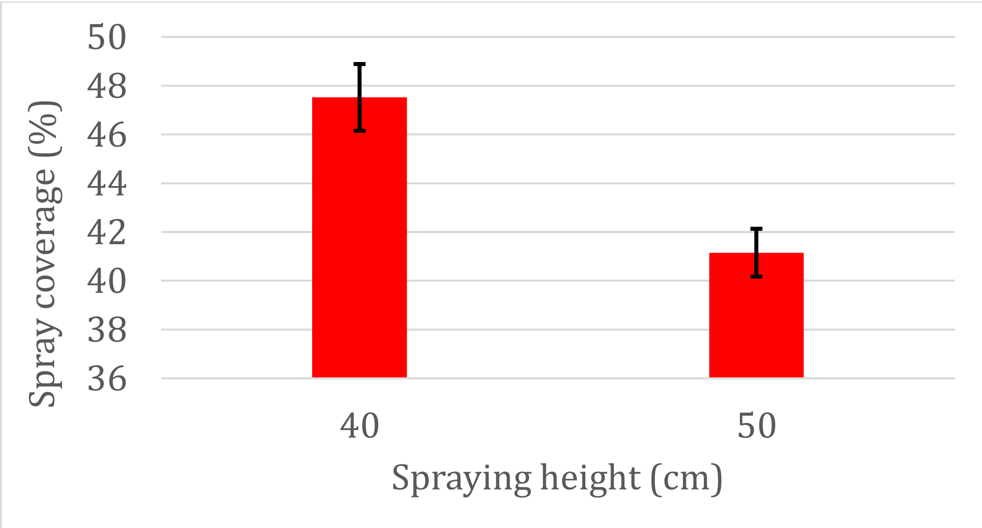

Figure 6. The effect of the spraying height on the spray coverage (Means and standard errors)

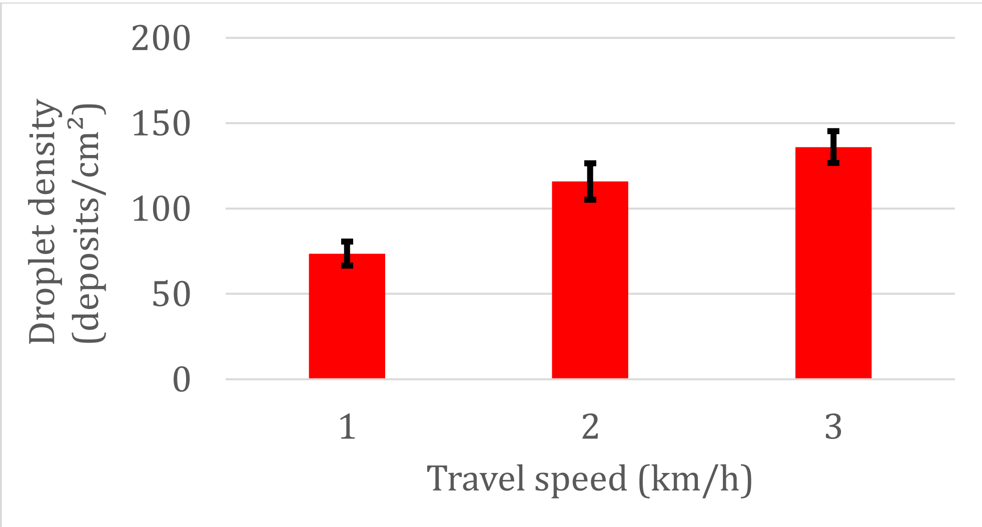

Figure 7. The effect of travel speed on the droplet density (Means and standard errors)

Whereas in our experiment the maximum speed and height were 3 $km\,h^{-1}$ and 50 cm, respectively, which makes the droplets less susceptible to the drift effect.

The spraying height showed a significant effect on the droplet density,

$88\ deposits\ cm^{-2}$, and the height of 50 cm achieved $129\ deposits\ cm^{-2}$ (Figure 8). These results agreed with [22] who found that increasing the spraying height increases the droplet density. However, our results contradicted with some of [17] results which studied the effect of 50 and 70 cm height above the target and they found a general decrease in the deposit density with increasing the spraying height.

Nevertheless, some types of nozzles in their experiment acted against that trend. This may reveal that the droplet density depends not only on the spraying height but also on the nozzle type.

It is worth mentioning that the interaction between the speed and the spraying height did not show a significant effect on the droplet density.

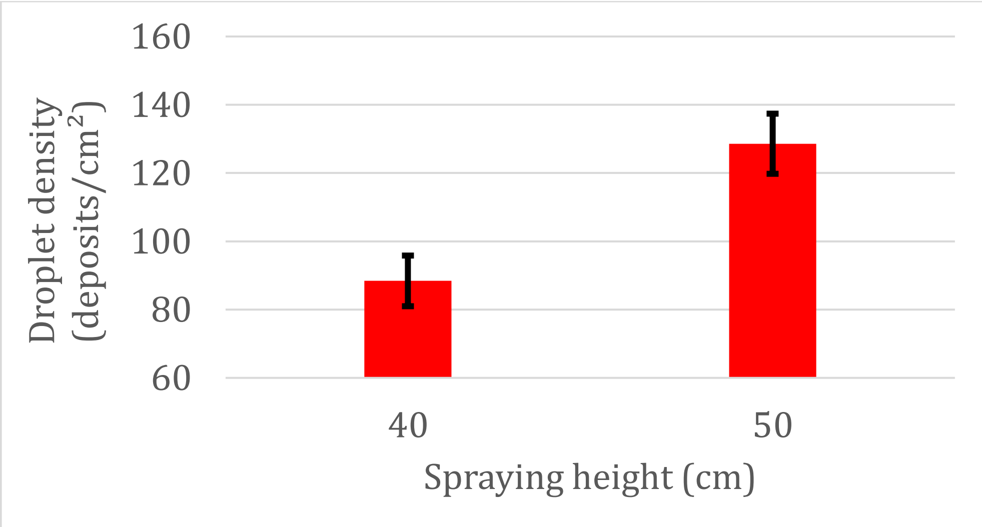

Figure 8. The effect of the spraying height on the droplet density (Means and standard errors)

Deposition on the target

The statistical analysis revealed that the travel speed significantly affected the deposition on the target (p<10^{-10}) (Figure 9). The deposition values obtained were $16.7, 6.8,\ and\ 6.6\ \mu l\ cm^{-2}$ at the speed of $1, 2, and\ 3\ km\ h^{-1}$, respectively.

The spraying height showed a significant effect on the deposition (Figure 10). The height of 40 cm achieved a deposition value of $12.06\ \mu l\ cm^{-2}$ which was higher than $8.06\ \mu l\ cm^{-2}$ which was achieved by the height of 50 cm.

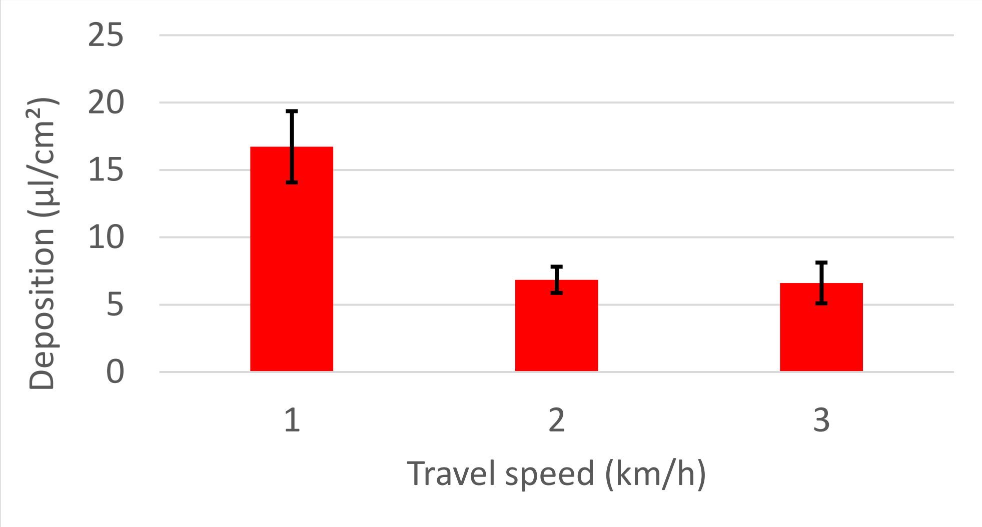

Figure 9. The effect of the travel speed on the deposition on the target

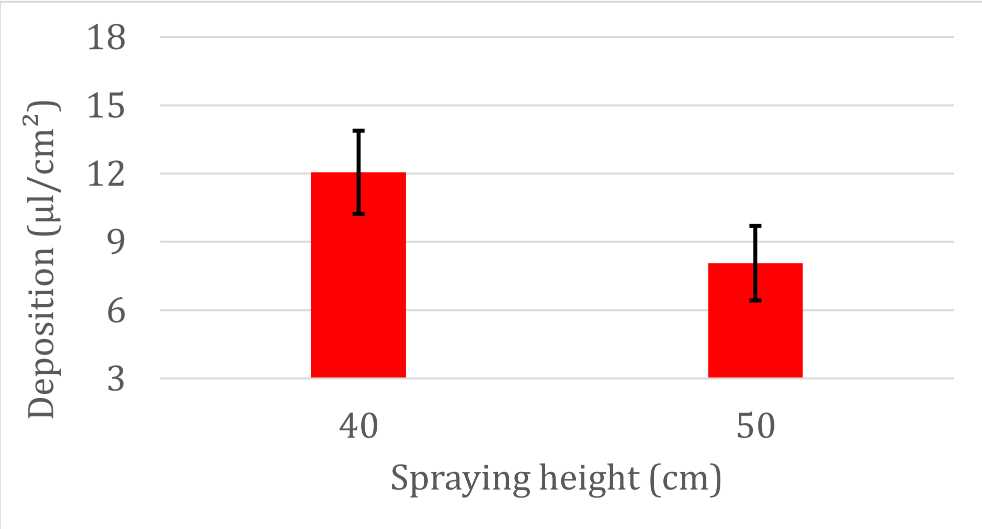

Figure 10. The effect of the spraying height on the deposition on the target

Conclusion

An experiment was conducted to investigate the effect of the travel speed and spraying height on some spraying characteristics using a newly developed remotely controlled sprayer. The results showed that the developed sprayer was able to control the speed and height reasonably, that was reflected from the results of coverage droplet density, and deposition at different speeds and heights. The coverage and the depositionon the target decreased with the travel speed and the spraying height as was expected from the previous studies. Moreover, the droplet density increased with the spraying speed and the spraying height.

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