Design, construction and evaluation of a sprayer drift measurement system

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Abstract: Spray drift study for reducing environmental hazards and protecting crops is of high importance as the pesticides used today are more active and many are non-selective. The aim of this research was to design, construct and assess an intelligent system to measure the level of the spraying drift. The main parts of the system were liquid supply mechanism, pipes and nozzles, wind tunnel and electronic panel. A controlled pneumatic system was used to pressurize the liquid. The nozzle was displaced by a moving system connected to the controlling panel. The wind tunnel was constructed to provide and control the wind flow. To assess the performance of sprayer and drift of droplets, water sensitive papers were placed in different distances from the nozzle considering different environmental conditions. Experiments were performed in the wind speed of 12 km/h, three spraying pressure levels (3, 4 and 5 bar) and three nozzle heights (0.35, 0.5 and 0.6 m). The evaluation results showed that the drift was increased with increasing of sparing pressure and nozzle height. The fewest amount of drift, 0.36%, was obtained at pressure and height of 3 bar and 35 cm, respectively. The largest droplet sizes were observed in the lowest spraying pressures and heights. According to the results spray technology plays an important role to optimize the spraying parameters, minimize the spraying drift and reduce the level of environmental pollutions.

Keywords: sprayer, wind tunnel, drift, droplet size

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1 Introduction

Taking into account the rapid growth of the world population, the need for agricultural productions and nutrients is continuously rising in the world, while at the same time, nearly 25%–35% of the entire agricultural productions of the world are decayed by insects, and botanical pathogen factors. In case of not struggling, this decay may reach 80% of the whole production (Mansouri-Rad, 2007). The use of sprays for fighting with pests and herbaceous diseases shows itself faster than other methods. Thus, pesticide applications have been significantly increased. It is well-known that reducing the use of sprays and reducing the traffic of agricultural machineries as a result, should be specially taken into consideration. Achieving this goal not only leads to reduce environmental pollution, but also causes to decrease the resistance of the pests and diseases to the sprays (Cheah et al., 2010).

The nozzle is the most important part of the sprayers. They have an important role in the model and the pattern of spraying and therefore reaching spray to the target (Friedrich, 1996). Most of the sprayers are equipped with the conical and blowing nozzles. The size of the spray droplets is highly changing and it is impossible to control and regulate accurately (Hewitt et al., 2009).

The factors influenced the homogeneity of spraying of the boom-sprayer were determined and evaluated. It was known that nozzles model of Even had better spraying pattern (Gil et al., 2014). The effects of three

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factors including nozzle type, diameter of nozzle orifice and spraying pressure of the pesticide solution on the droplet spraying rate were assessed and obtained direct relationship between them (Nuyttens et al., 2007). The homogeneity of spraying pattern has been taken into account by many researchers. After testing and evaluating, it was distinguished that the blowing flat nozzles was the best. The main problem of spraying, especially when using blowing nozzles, is the risk of drifting droplets to an untargeted place (Bayat and Bozdogan, 2005). Many studies aimed to control or optimize overarching drift causes (Fritz et al., 2012; Sehsah and Herbst, 2010; Van de Zande et al., 2008). Anthonis et al. (2005) studied the optimization of the dynamics of a vertical suspension for a 39 m wide boom on a John Deere crop sprayer. Their study was based on a mathematical model leading the objective function which was achieved by minimization of the standard deviation of the absolute boom rotation around the horizontal axis while applying the tracks. Nuyttens et al. (2007) investigated the effect of nozzle type, size and spraying pressure on spray droplet properties. They measured the droplet sizes velocities based on light-scattering principles. Their research confirmed that reference nozzles were required to classify sprays due to the remarkable variation of absolute results depending on settings and type of measuring equipment. In another study, an orchard sprayer prototype running a variable-rate algorithm was designed, implemented and validated for adapting the volume application rate on a real-time and continuous basis (Escolà et al., 2013). They reported that the prototype was developed to close the actual application coefficients as much as possible near to the objective.

Regarding the mentioned problems, the aims of this study are:

1- Evaluating the nozzle type.

2- Determining the diameter of droplets.

3- Spray drift in different conditions of spraying application.

4- Design, construct and evaluate a system for determining the drift and assessing and optimizing these conditions.

2 Materials and methods

The design and constructing of the system for determining the spraying drift was done through a series of primary experiments in the Instrumentation Laboratory of Biosystems Engineering Department at Ilam University, Ilam, Iran. First of all the measuring instrument was developed and tested. Then, all of the experiments were carried out in summer, 2014. The main parts of the system were chassis, compressor, liquid container, nozzle moving mechanism and wind tunnel. Through this system, it was possible to simulate the factors affecting spraying operation and evaluating nozzle including the tractor/nozzle speed, the nozzle height, spraying pressure with the least cast, time and energy. Regarding performed calculation and the obtained data, designing of the intelligent system for determining the drift of the sprayer was done using CATIA software.

2.1 Chassis

In order to assemble all parts of the system, a chassis was designed to keep and balance the power transfer mechanism and control the panel. To enhance the safety coefficient, the legs of the chassis were fixed on a foundation through appropriate junctures. The designed chassis had the dimensions of 170 cm ×40 cm ×70 cm for length, width and height, respectively.

2.2 Solution container

The solution container (Qingdao Turbo Machinery Co. Ltd, Howo 20L, China) was selected in a way to be sufficiently stable and at the same time be resistant to chemical materials. The container used had the quality certificate of ISO-9001 standard. Pure water was used as the spray solution in all experiments (Escolà et al., 2013).

2.3 Compressor

The pressure losses in the system related to the pipes and junctions was determined by the Equations (1) and (2).

$$\mathrm{HL} = 10.64 \times L \times \left(\frac{\mathrm{Q}}{\mathrm{Cp}}\right)^{1.85} \times \mathrm{Dp}^{-4.78} \quad (1)$$

$$\mathrm{HL} = k\left(\frac{V^2}{2g}\right) \quad (2)$$

where,

HL is the pressure loss in the pipe (Pa)

L is the pipe length (m)

Q is the flow rate (m^3/s)

Dp is the pipe diameter (m)

V is the liquid velocity (m/s)

g is the acceleration gravity (m/s^2)

Cp is the constant coefficient

K is a constant coefficient

In the system, two plastic pipes, each having one meter length with the inside diameter of 1 cm, a two-way control valve, a pressure gage, three pipe joint and three pressure reducing control valves transferred the solution from the container to the nozzle. The constant coefficient of Cp for metal and smooth pipes was suggested for designing problems from 100 to 110. In addition, the velocity of the liquid in the system, V, was calculated having the spray flow rate, Q, divided by the pipe cross section, A (Shigley, 2011):

$$Q = A \times V \quad (3)$$

Considering the maximum flow rate of 1.37 L/min and the pipe inside diameter of 0.01 m, the velocity of the solution was calculated as 0.075 m/s. To calculate the system pressure loss, the constant coefficient of Cp was considered as 100, the values of coefficient K were considered to be 20, 108, 105, 10, 0.42, and 5.5 for two-way controlling valve, pressure gage, pipe joints, pressure reducing valves, sudden reducing of the pipe cross section and the nozzle output, respectively (Nourbakhsh, 2008).

2.4 The nozzle moving mechanism

The mechanism of nozzle moving included a plate carrier, chain-sprocket, ball-bearing, electromotor and controlling panel. To test and evaluate the instrumentation, an 11003 flat fan nozzle (TeeJet, US) was used.

In order to simulate the tractor movement, a steal galvanized rectangular plate with the dimensions of 38.5 cm and the thickness of 0.5 cm was used. The moving mechanism of the carrier was performed through ball-bearings reciprocating and the needed power was provided through an electromotor with the chain-sprocket mechanism.

In order to have smoothly reciprocating movement of the carrier, four ball bearings under the carrier to bear its weight and four ball bearings in each side of the carrier were used for reducing the friction with the edges of the chassis rail. The ball bearings had a simple structure and needed a low operating torque. The downward weight force on the bearings under the carrier was 5 kg (49.5 N). So, the redial force (Fr) on each bearing was equal to 12.262 N. With regard to the slight vibration of the rail, the axial force on each bearing was measured as 6 N. Considering the rotation of the external ring of the bearings, the coefficient of rotation of the ring in Equation(4), V, based on the standard of the Timken Company was considered to be 1.2. Through Equation(5), the static loading rate of the bearing, C_0, was obtained (Timken, 2015). Having the coefficient M of 511 mm, n_b the number of balls of the bearing and d_b as the diameter of the balls by mm, the static loading rate of the bearing was calculated as 67 kN. According to Equation (6), the proportion of axial load to the static loading rate of the bearing e was calculated to be 0.287. Based on Equation (7), the radial force was obtained.

In this equation, X_i and Y_i are constant coefficients according to the standards of Timken Company standard (Timken, 2015). As value of $\frac{F_a}{VF_r}$ (Equation (4)) was higher than e (Equation (6)), and i in Equation (7) was considered as 2. With regard to Equation (8), equivalent coefficient, α_f as 1.2, and the fact that the bearing is of rolling type (a=10/3), $60L_Rn_R$ was considered as 10^6 and L_Dn_D as the total work-hours.

$$\frac{F_a}{VF_r} \quad (4)$$

$$C_0 = Mn_b d_b^2 \quad (5)$$

$$e = \frac{F_a}{C_0} \quad (6)$$

$$F_e = X_i V F_r + Y_i F_a \quad (7)$$

$$C_{10} = \alpha_f F_e \left(\frac{60L_D n_D}{60L_R n_R}\right)^{\frac{1}{a}} \quad (8)$$

where,

Fr is the redial force (N)

L_Dn_D is the total work-hours (h)

F_a is the axial force (N)

d_b is the diameter of the balls (mm)

n_b is the number of balls of the bearing

$60L_Rn_R$ was considered as 10^6

X_i and Y_i are constant coefficients according to the standards of Timken Company

F_e is the equivalent of radial and axial forces (N)

C_{10} is the testing lifetime (h)

α_f is the equivalent coefficient as 1.2

e is the proportion of axial load to the static loading rate

i is the speed ratio

In order to transfer and synchronize rotation motion between an axis to another one far from each other and also having high efficiency, the chain-sprocket mechanism was used. In this mechanism, two sprockets with different diameters, a gearbox, chain and two ball bearings were used. The speed ratio of the mechanism was calculated by the following equation as 2.28.

$$i = \frac{n_d}{n_D} \quad (9)$$

where:

n_d is the speed of the small sprocket (50 rpm)

n_D is the speed of the bigger sprocket (22 rpm)

Z_D is the bigger sprocket, 57 teeth

Z_d is the small sprocket, 25 teeth

he selected sprockets were simple type with number of M 30×1 (ACS Crossfire, California, the US) and the chain was rolling type, single row, with number of 10B-1 and the pitch of 15.875. The rate power of the selected chain was 0.57 kW. The modified rate power of the chain was obtained by Equation (10).

$$P_{rm} = P_r \times K_z \quad (10)$$

Where P_{rm} is the modified rate power, P_r is the rate power and of chain and K_z is the modification coefficient of the teeth number. Considering K_z equals to 1.3, the modified power was obtained as 0.741 kW.

In order to select an electromotor for providing the required power of the system, after calculating the modified rate power, the desired power was calculated by Equation (11) (Shigley, 2011):

$$P_D = P_T \times K_S \quad (11)$$

Where P_T is the required power for the chain-sprocket system (P_T=P_{rm} = 0.741 kW), K_S is the constant coefficient that for 24-hour working was considered as 1.3 (Shigley, 2011), and P_D is the design power that obtained as 0.963 kW.

The required power for the system was provided from the city electricity thorough a controlling panel. It was composed of two parts which were power and controlling circuit. The power circuit included a rotary switch for either connecting or disconnecting of the flow of electricity, two conductors (model: LA_1-D_{22}) and the controlling circuit included two micros-switches (model: ME-8111), an on-off switch and a single-phase inverter (model: SV0081 C5–1 F). The inverter was used to regulate the movement speed of the carrier and also the nozzle. Two micro-switches (model: ME-8771) were installed at the beginning and end of the chassis to intelligent control the carrier and nozzle movement, so that the horizontal reciprocating of the nozzle was intelligently changed when the carrier reached to the each end of chassis.

2.5 Wind tunnel

The aim of providing the wind tunnel was to simulate the air flow in laboratory conditions as compared to real farm windy conditions. The tunnel included a channel, axial fan and honeycomb and grid network. The dimension of the channel was $50 \times 65 \times 115$ cm^3 for length, width and height, respectively.

Of the most determining factors in selecting or designing the blower are the air flow rate and the pressure inside the tunnel. Considering the highest required wind speed in the tunnel, the air flow rate was calculated be Equation (3) (Cook, 1999). After that, an axial blower with the dimensions of 50×50 cm^2 was used. Of other determining parameters in selecting the type of the blower, is the direction of the flow that in the axial one both entrance and entrance air are collinear (Bleier, 1998). Based on the catalogue, the highest rotation speed of the blower was 1400 rpm and pressure of 300 Pa.

A Hexagonal honeycomb network was used to avoid separation of the boundary layer in the cross section of the tunnel and also reduce the eddy currents and lateral disturbances, two square grid networks were used to reduce the axial disturbances. The eddy currents are broken in honeycomb network and disappeared before passing from grid network (Pereira, 2011). In addition, for reducing axial disturbances, the grids reduce the thickness of the boundary layer, severity of disturbances and modify the flow lines within the wind tunnel. A dimer was used to achieve different electric powers to highest amount of 0-0.37 kW. For measuring instantaneous velocity of the wind in the tunnel, a digital air flow meter (AM-4206, Letron Company, Taiwan) was used.

2.6 Experiments

The components of the system for determining the drift of the sprayer were chassis, a compressor, a liquid container, a moving mechanism of the nozzle and a wind tunnel. Figure1 showed the designed system by CATIA Software. In addition, the designed system can test and evaluate all of the nozzles used in spraying operation with high accuracy and according to Iran national standard 5885. Taking into consideration all of the spraying conditions, the different components of the desired system were designed and constructed. After different tests, technical parameters and the optimal dimensions of the system for determining and evaluating the drift were known.

The system was evaluated considering different spray pressure (3, 4 and 5 bar) and spraying height (0.35, 0.5 and 0.6 m) with wind speed of 12 km/h. After each pass of the nozzle on the water sensitive paper cards 4 m far from the nozzle, they were collected and dried. Then the papers corresponding to each experiment were separately scanned by Canon Scanner (LIDE 110, Vietnam) with the resolution of 600 dpi. After collecting the pictures and reading by the MATLAB 2010 Software, the gray scale images were obtained and then they were converted to black and white (binary) images (Figure2). In the end, the evaluated parameters including Vd50 and SC showed mean volume diameter and coverage area, respectively, were calculated.

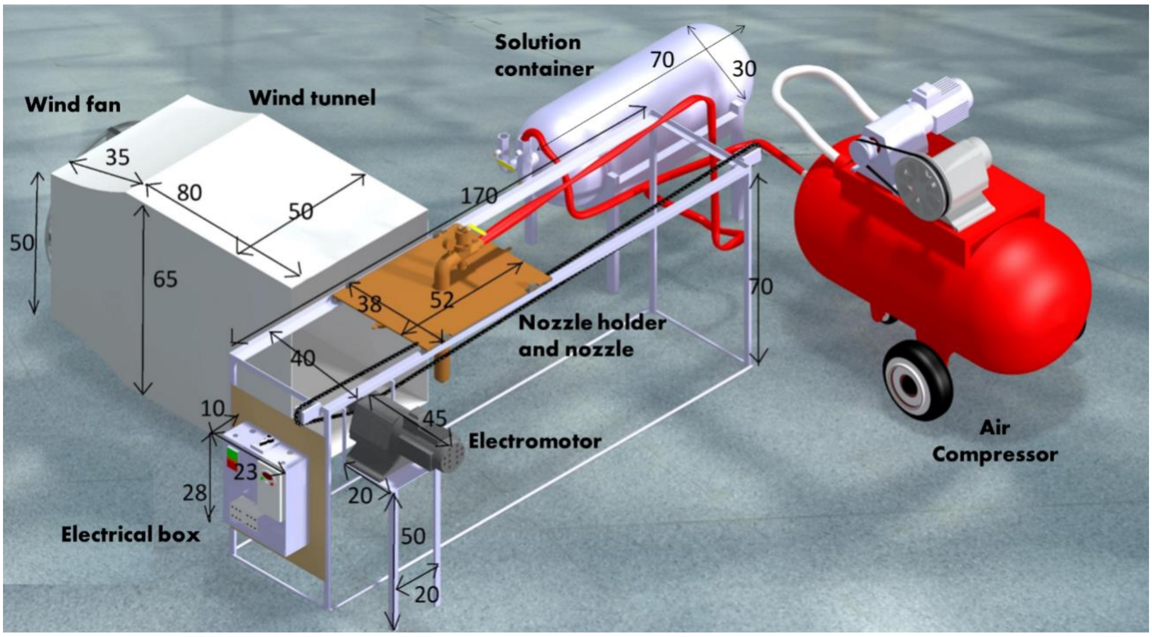

Figure 1The designed system (dimensions are in cm)

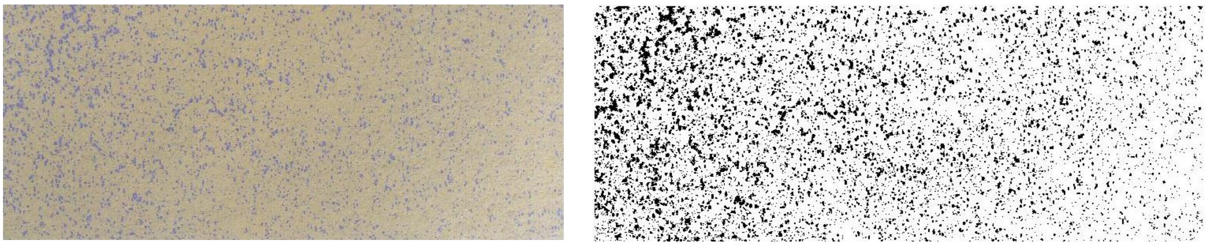

Figure 2 A water sensitive card before processing (left) and the same card after processing (right)

3 Results and discussion

In this research, a system was designed, constructed and evaluated for determining the drift of the sprayer. The total pressure loss in the system, including junctions and pipes, was determined to be 12.3 m or 1.2 bar. Considering the maximum six bar pressure in the system, a single phase compressor with highest capacity of 10 bar (MK 101, Finy Company, Italy) was selected.

Considering the designing power rate of 0.963 kW, an electromotor, squirrel cage rotor, under the standard of IEC-34, protection degree of IP-54, ventilation method of IC–41, with cooling fan and rotor blades with heat class of F, suitable for permanent work, with the power of 1.1 kW (CRS90 L4A, Motojen Company, Tabriz, Iran) was selected. Also the flow rate of the wind tunnel (Q) was calculated to be 1.09 m/s^3; for that, a Khazar fan with six blades was opted.

The results of the mean volume diameter in a place with four meters horizontal distance from the nozzle and the drift in the wind speed of 12 km/h and different spraying pressures and heights has been illustrated in the Figures 3 and 4.

Figure 3 showed that the diameter of the droplets had a reverse relationship with the spraying pressure and height. Increasing of the pressure (3, 4 and 5 bar) in all different spraying heights has led to the decreases of droplets diameter (31.14, 22.6 and 11.8 μm). Also, the more height of spraying, the smaller droplets sizes were observed. Thus, as Figure 3 illustrates, the smallest droplets diameters were resulted in the highest pressure (5 bar) for all three heights of nozzle, and for all spraying pressures, the smallest diameters were observed in the highest distance of nozzle orifice from the ground. Therefore, with increasing of the spraying height (35, 50 and 60 cm), a sharp decrease in the diameter of the droplets was observed. When spraying height, spraying pressure and wind speed were 35 cm, 3 bar and 12 Km/h, respectively, the mean volume diameter (Vd50) had the largest amount of 31.14 µm. The smallest droplet diameter, amounting to 2.2 µm, was observed in the pressure and height of 5 bar and 60 cm, respectively. Bayat and Bozdogan (2005) investigated the drift phenomenon and droplets diameters in different wind speeds. Results of the study showed that the average deposits were higher for smaller droplets (85 µm in diameter) than larger droplets (210 µm in diameter). In general, they reported that the speed of the air, diameter of droplets, and their cross relationship significantly affected on the drift (Bayat and Bozdogan, 2005; Jamaret al., 2010).

Figure 4 gives information about Volume Median Diameter (Nd50) of droplets in various spray conditions and wind speed of 12 km/h. As the figure shows, there were no remarkable difference between Nd50 based on different spraying pressures and heights. So, the distribution of droplets sizes in all of spraying conditions had the same result. Based on the figure, it can be noted that along with increasing in height of spraying, the droplets sizes decreased. Also, a slight decrease occurred in droplets sizes with rising in spraying pressure.

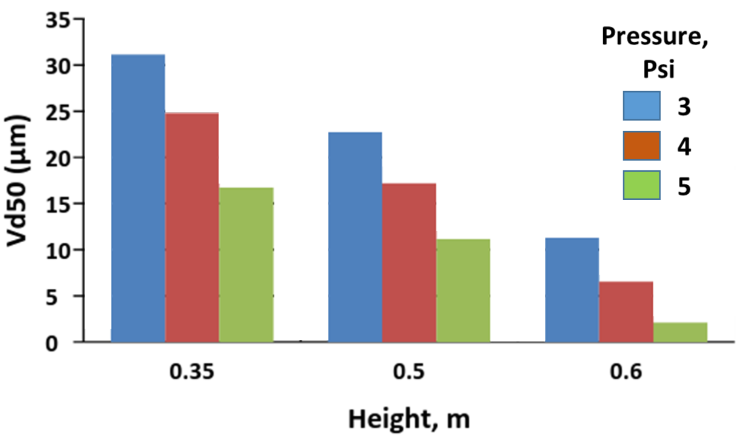

Figure 3 The mean volume diameter (Vd50) at wind speed of 12 km/h and different spraying pressures and heights

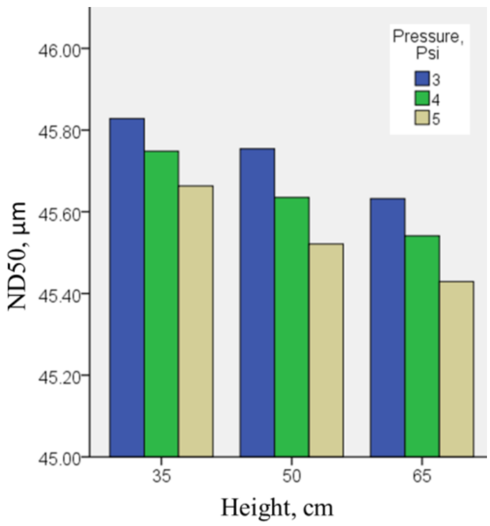

Figure 4 Nd50 at 12 km/h wind speed and different spraying pressures and heights

As Figure 5 indicates, the drift was 0.47% when the spraying height was 35 cm and the spraying pressure was 5 bar. Drift had a direct significant relationship with the spraying height and pressure. It was observed that the increasing of the spraying height (35, 50 and 60 cm) has led to increasing of the drift (0.36, 0.377 and 0.4%). Moreover, the changes in the spraying pressure had a significant effect on the drift. In all heights of spraying, rising spraying pressure has increased the drift of droplets. The effects of spraying pressure and height on drift have been investigated in various studies, all of which reporting similar results (Balsari et al., 2007; De Schampheleire et al., 2008; Sehsah and Herbst, 2010).

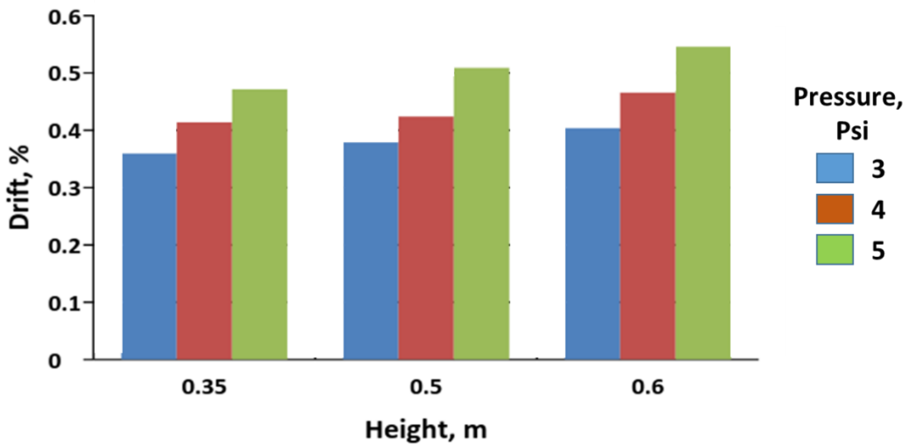

Figure 5 Drift at wind speed of 12 km/h and different spraying pressures and heights

4 Conclusions

In this research, a system was designed, constructed and evaluated for measuring the spraying drift. It was included a chassis, a compressor, a liquid container, a nozzle movement mechanism and a wind tunnel. The results showed that the diameters of the droplets had a converse significant relationship whereas, the drift had a direct relationship with the spraying height and pressure. The largest droplets diameter was observed in the spraying pressure and height of 3 bar and 35 cm, respectively. The lowest amount of drift was obtained in spraying pressure and height of 3 bar and 35 cm, respectively.

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