Design of Automatic Spraying System for Liquid Pesticide Application on Cabbage Cultivation

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Abstract. This research was conducted to analyze the performance of Knapsack Electric Sprayer (KES) compared with KES controlled by an Automatic Control System (ACS). KES that is modified with ACS using Arduino Mega as the main controller equipped with a pressure sensor, solenoid valve, and PID control on the control system is able to produce almost constant flow pressure. The ACS was applied using a one-by-one spraying method toward cabbage plants. The performance test was conducted in Sprayer Test Laboratory to analyze two types of nozzles and determine Effective Spraying Debit (ESD), Effective Spraying Width (ESW), and droplet diameters. The results of the research showed that the performance of a 3-hole solid cone nozzle is better than a 4-hole solid cone nozzle at 4 bar pressure. Spraying with ACS using the 3-hole nozzle can produce 95% accuracy of spraying output volume. Using ACS, spray duration on each cabbage was controlled by the system based on input. The ACS type can be applied with high Forward Spraying Speed (FSS) than the sprayer without ACS. The FSS did not affect the output Application Dosage using ACS on the sprayer. The implementation of ACS for spraying cabbage can overcome inappropriate output application dosage.

1. Introduction
Pests attack in cabbage cultivation can reduce production and quantity of cabbage. Pest can spread to other plants quickly, so farmers must anticipate their attacks carefully. Farmers usually use pesticides by spraying all area of cabbage plantation, because they considered it as the fastest and effective way to repel the pest. The use of pesticides to protect these cabbages besides having a positive effect also has a negative effect for environment, such as environmental pollution that can harm humans and plants, and caused pest being resist [1]. This happens if the application is inappropriate.

The farmer usually spraying pesticide using knapsack sprayer, semi-automatic knapsack sprayer, and electric sprayer. The knapsack electric sprayer (KES) and semi-automatic electric sprayer has a control valve to control the spraying flow (open/close valve). The pressure on The Kes depends on electric pump voltage (can be set by potenio), but the pressure on Knapsack Sprayer and Semi-Automatic Knapsack Sprayer is depends on the number of pumping with the lever. The pressure will affect the droplet size and Spraying Discharge Rate. So that the spraying discharge rate will affect the Output Application Dosage. In the operation of spraying, spray duration on each cabbage and Forward Spraying Speed will affect the Output Application Dosage.

The application dosage (spraying output volume) is the amount of pesticide solution used to spray each unit area [2]. Spraying in cabbage cultivation is different with other commodity (in example spraying paddy), because the cabbage has long planting distance between cabbage plant (40-60cm). There are two method for spraying in cabbage cultivation. First method is the operator spraying
continuously and give spray duration on each cabbage while walking on the field, so the Forward Spraying Speed (FSS) and spray duration will affect the output application dosage. And the second method is the operator spraying by giving spray duration on each cabbage while walking on the field (not continuously spraying). This method can reduce wasted spray liquid. Both of method has disadvantage, it’s difficult to get correct spraying duration for each cabbage and constant forward speed (spraying continuously).

The purpose of this study is to design and test performance of pesticide sprayer with a control system that can spray automatically based on the application dosage. In further research, this automatic spraying control system will be applied to autonomous spraying robot.

2. Materials and methods
This research was conducted in Laboratory of Siswadhi Soepardjo and Laboratory of Spraying Test IPB University. The equipment used in this study is a SeeSa Sx-MD16I knapsack electric sprayer modified with the addition of system control components including Arduino mega, motor drivers, relays, solenoid valves, pressure sensors, keypads, and LCDs. The materials used were liquid pesticide, water, concord paper, and ink. The research method as seen in figure 1.

![Figure 1. Research method to determine performance of modified Knapsack Electric Sprayer with automatic system control](image)

The aim of spraying test is to get (1) droplet diameter, (2) effective spraying width (ESW), (3) effective spray debit (ESD), and (4) water pump voltage at each nozzle, the type of nozzle used on this research as shown in figure 2. Spraying test was done by using a Patternator as shown in figures 3. The graph on figure 4 used to determine the ESD and ESW based on spray liquid collected on glass. Two intersection point between original and overlapping graph used to determine the ESW and ESD,
this test based on Indonesian national standard for performance test of electric sprayer (SNI 02-4513.1-2008). Electrical pump voltage was tested to determine the voltage needed to obtain a certain spray pressure. The type of nozzle and spray pressure to be used for pesticide spraying are determined based on the results of the knapsack sprayer test. It also used as basis for designing automatic control systems for spraying pesticide precisely on cabbage cultivation.

**Figure 2.** Solid cone nozzle 3 holes (left) and 4 holes (right)

**Figure 3.** Spraying test on the Patternator in the sprayer test laboratory

**Figure 4.** Example of ESW measurements

The measurement of the droplet diameter was conducted by mixing the water and ink liquid with a ratio of 30 ml of ink and 1000 ml of water which is sprayed onto concord paper (figure 5) then scanned the paper, the spray drip results are analysed with ImageJ software to determine the diameter of the droplet in VMD (Volume Median Diameter) range.

In Automatic Control System (ACS) design, electronic components integrated with the control system algorithm, so it can work properly according to functional planning, the control system circuit scheme according to figure 6.
The operation of the prototype ACS is if the spray button is pressed the pump will automatically work based on the appropriate pressure while the solenoid valve open, then the nozzle will produce a spray in the form of droplet beads. Figure 7 shown the algorithm of Automatic Control System (ACS).

**Figure 5.** Example droplet sprayed on concord paper

**Figure 6.** Schematic control system

**Figure 7.** Automatic control system algorithm
The sprayer will work according to the duration that has been calculated based on the input of application dosage and width of spraying target. Application dosage calculations based on sprayer performance can be determined by the following equation [3].

\[ A_D = 166.7 \frac{E_{SD}}{F_{SS} \cdot E_{SW}} \]  

Because the method of spraying crops uses plant area, the equation can be simplified by following equation.

\[ A_D = 166.7 \frac{E_{SD}}{A} \cdot t \]  

So, the duration of spraying can be determined by the following equation.

\[ t = \frac{A_D}{(166.7 \frac{E_{SD}}{A})} \]  

Where,

- \( A_D \) = Application dose (L / Ha)
- \( E_{SD} \) = Effective spraying debit (L / min)
- \( F_{SS} \) = Forward spraying speed (m / sec)
- \( E_{SW} \) = Effective spraying width (m)
- \( A \) = Spraying area (m\(^2\))
- \( t \) = Spraying time (sec)

Spraying plants are conducted one-by-one with solid cone nozzle by giving spray duration on each cabbage while walking on the field (not continuously spraying) will produce different spraying pattern compare to spraying continuously as shown in figure 8.

![Figure 8](image)

**Figure 8.** (A) Spray pattern with spraying continuously  
(B) Spray pattern by spraying one-by-one plants

This research used the second method for spraying pesticide in cabbage cultivation. This method can reduce wasted spray liquid. The purpose of this method to ensuring spraying only on the plant, so it can avoid inaccuracies application, because the Forward Spraying Speed (FSS) will affect the Application Dose (AD).

3. Result and Discussion

The prototype of Automatic Control System (ACS) attached on Knapsack Electric Sprayer is shown on figure 9. The results of nozzle performance test can be seen in Table 1. Based on the measurement results, the higher spray pressure will produce a smaller droplet for both nozzles. The spray droplet produced between the two nozzles in the same pressure almost had similar size because both nozzles have the same output hole diameter.
Table 1. Results of 3-Hole (3-H) and 4-Hole (4-H) nozzle spray test with 1 mm diameter hole size

| Pressure (bar) | ESD (ml/s) | ESW (cm) | Droplet Size (µm) VMD |
|---------------|------------|----------|-----------------------|
|               | 3-H        | 4-H      | 3-H       | 4-H       | 3-H     | 4-H     |
| 1             | 7.07       | 10.44    | 56        | 50.67     | 573     | 608     |
| 2             | 14.03      | 15.92    | 64        | 56        | 478     | 451     |
| 3             | 16.59      | 18.82    | 66.67     | 64        | 331     | 382     |
| 4             | 17.77      | 21.76    | 69.33     | 66.67     | 270     | 297     |

Effective Spraying Debit (ESD) of 4-hole nozzle produce a higher debit than the 3-hole nozzle at the same spraying pressure. The 3-hole nozzle has a higher Effective Spraying Width (ESW) at each spray pressure compared to the 4-hole nozzle, because the construction of the 4-hole nozzle has a small funnel at the end of nozzle, so the spraying can be more focused.

3.1 Selection of the nozzle type and spray pressure

Based on Table 2, droplets produced by 3-hole nozzle and 4-hole nozzle are included in the classification of Medium spray granules and it’s suitable for spraying insecticides with diameter of droplets between 200 – 400 µm [2]. To produce 4-bar pressure on 4-hole nozzle requires 12.75 volts pump voltage while 3-hole nozzle is only 12.3 volts. Based on the test result we choose the 3-hole nozzle for the design.

Table 2. Classification of spray droplets (ASAE S572.1)

| Spray Quality     | Size Droplets µm (VMD range) |
|-------------------|-------------------------------|
| Extremely Fine    | <60                           |
| Very Fine         | 61-105                        |
| Fine              | 106-235                       |
| Medium            | 236-340                       |
| Coarse            | 341-403                       |
| Very Coarse       | 404-502                       |
| Extreme Coarse    | 503-665                       |
| Ultra Coarse      | >665                          |
3.2 Automatic control system test

By using an Automatic Control System (ACS) in spraying cabbage plants allows spraying conducted one-by-one plant with adjustable duration based on the application dosage and the width of the plant to be sprayed.

Calibrating pressure sensor was conducted to get the real pressure value on the pressure transducer. Data from the sensor will be converted into voltage value by the microcontroller, the results of this calibration are used as a reference in the microcontroller program. The results of the pressure transducer calibration sensor are shown in figure 10.

![Figure 10. Relation between pressure sensor voltage and pressure gauge](image)

The automatic control system is designed to keep the spray pressure constant by setting value of Pulse Width Module (PWM) to control rotation speed of water pump, so this design will be used PID (Proportional Integral Derivative) control. PID control used the "trial & error" method in getting constant values to produce the fastest settling time. The Constanta value of Kp=15, Ki=305, and Kd=0.5 testing at 4 bar set-point. The graph of pressure response on figure 11 shows the settling time at 4 bar set-point is 0.6 seconds, then for set-point 3 bar and 2 bar at 0.7 seconds, and set-point 1 bar at 0.9 seconds.

![Figure 11. Graph of pressure response for each set-point](image)
Setpoint at 1 bar produces a greater oscillation than others, this is influenced by the electric pump that used in two-sided diaphragm pump type. So, at low pressure the rotation speed of the water pump becomes low and consequently the water pump is unstable because it only has two sides of the pump diaphragm. Water pump in high rotation speed will produce high pressure and produce good stability, this can be seen at 2 bar, 3 bar, and 4 bar pressure.

Pressure stability testing was conducted under conditions of application dosage of 300 L / Ha and 0.5 m spraying width at 4 bar pressure, so resulting in 0.33 seconds duration for each spraying. Based on figure 12 the pressure response was drop as much as 3 bars when the duration of the spraying ended, because the mechanism of solenoid valve to shut-off the flow not only by the spring, but also by the fluid pressure. This happened when the time of closing the solenoid valve and electric pump stopped simultaneously. So, if the spraying time is too short it will be difficult to get set-point pressure.

**Figure 12.** Graph of the stability of the pressure response of the spraying solenoid condition closing and the pump motor stopping the same time

Because of that problem, so the solenoid valve was designed to close 55 ms faster than electric pump when the spray duration ends. With this condition the spray pressure only decreases 0.4 bar and overshoot only 0.3 bar from the 4-bar set-point, making it possible to spray with a shorter duration. The result of the pressure response graph shown in figure 13.

**Figure 13.** Graphs of pressure response spraying solenoid conditions close faster than electric pump
3.3 Spraying accuracy test
Spraying accuracy was obtained by comparing the spray output volume with the theoretical spray output volume, the test results are shown in Table 3. Spray duration for each cabbage plant will increase along with the application dosage (Ad). The tested output volume for each application dosage produced bigger value than theoretical output volume, because the control system difficult to get constant spray pressure in short spray duration.

The Effective Spraying Width (ESW) is the maximum width for spraying. Application dosage for spraying pests on annual crops commonly at 200-600 L/Ha [2] or depending on the instructions on the label of the pesticide.

Table 3. Test results for spraying volume accuracy of 3-hole nozzle at 4 bar pressure and 0.5 m spraying width (0.196 m² spray area per cabbage)

| AD (L/Ha) | Spray duration (sec) | Tested output vol. (ml) | Theoretical output vol. (ml) | Accuracy (%) |
|-----------|----------------------|-------------------------|-----------------------------|--------------|
| 300       | 0.331                | 6.22                    | 5.88                        | 94.53        |
| 400       | 0.442                | 8.14                    | 7.85                        | 96.45        |
| 500       | 0.552                | 10.3                    | 9.81                        | 95.21        |
| 600       | 0.663                | 12.5                    | 11.77                       | 94.19        |

3.4 Field capacity and output application dosage test
The experiment was conducted on 10 x 0.5 meter plot, the distance between plants and the width plant is simulated 0.5 meters with total of 21 plant points (one row). The test was conducted with three spraying methods: (1) Spraying with ACS in Low Speed (ACS LS), (2) Spraying with ACS in High Speed (ACS HS), (3) Spraying with Knapsack Electric Sprayer (KES).

The ACS can produce highest Forward Spraying Speed (FSS) because spray duration in ACS was controlled by the system, so operator can adjust their FSS to the highest speed without passing the plant as shown in figure 14. The FSS will influence the field capacity, high FSS produced high field capacity as shown in figure 15. The test result of output application dosage in spraying with ACS LS and spraying with ACS HS give same result at each application dosage. Spraying with KES produced high output application dosage as shown on figure 16, because KES just use operator feeling to giving spray duration on each cabbage.

Figure 14. Forward spraying speed on 3-hole nozzle with 4 bar pressure
Figure 15. Field capacity on 3-hole nozzle with 4 bar pressure

Figure 16. Comparison of Output application dosage on 3-hole nozzle with 4 bar pressure

4. Conclusions
Knapsack Electric Sprayer (KES) with Automatic Control System (ACS) has been designed and tested. The 3-hole spraying nozzle used in this research require lower electric pump voltage than 4-hole nozzle to produce 4 bar pressure and medium spray granules.

The application of PID control system on Knapsack Electric Sprayer (KES) can produce constant 4 bar pressure with settling time 0.6 s. Pressure drop after turning off the water pump was minimized into about 0.3 bar by closing the solenoid valve 55 ms faster than turning off the water pump. The spraying duration of the individual cabbage was calculated automatically based on the application dosage and the cabbage size.
The Knapsack Electric Sprayer (KES) with Automatic control system was able to apply pesticide solution with accuracy 95\% of volume. It was able to operate with higher forward spraying speed without changing the application dosage and without miss spraying of the cabbage plant.

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