Study of Optimization of Liquid Fertilizing on Red Spinach Cultivation in A Greenhouse

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Abstract. The objective of the research is to determine optimum liquid fertilizing on red spinach cultivation in a greenhouse. The research was conducted from March to April 2019 at the Sprayer Laboratory and in a greenhouse to determine parameters of droplet diameter, droplet density, effective spraying width, effective spraying debit, and harvested biomass weight. Spraying tools and material are SWAN F16 electric sprayer, air blower, and liquid fertilizer. Results of the research showed that the use of the electric sprayer and the use of the electric sprayer and the air blower produced minimum droplet diameter, maximum droplet density, maximum effective spraying width, and minimum effective spraying debit were 311 micron meter, 706 droplet cm⁻², 56 cm, and 1.99 litre min⁻¹ and 405.14 micron meter, 361 droplet cm⁻², 72 cm, and 2.21 litre min⁻¹ in average respectively. The use of the electric sprayer has produced maximum harvested biomass weight of 7.17 g/plant in average on walking speed of 0.9 m/s with 1.97 litre ha⁻¹ liquid fertilizer dosage. The use of the electric sprayer and the air blower have produced maximum harvested biomass weight of 4.55 g/plant in average on walking speed of 0.5 m s⁻¹ with 3 litre ha⁻¹ liquid fertilizer dosage.

1. Introduction
Formerly, spinach was known as adorned plant, however it has been developed as food source of protein, vitamin, and mineral of calcium, phosphor, and iron. One of the spinach plants is red spinach (Alternanthera amoena Voss). Spinach contained complete nutrient i.e. protein, vitamin A, vitamin C, vitamin E, carbohydrate, mineral, fat, and substances of iron, magnesium, mangaan, calcium, and calcium [1].

Low productivity of red spinach was caused by several cases i.e. the uses of non-proper variety, kind and fertilizer dosage, and fertilizing time and frequency. One of the efforts to raise growing and spinach production is fertilizing. Good fertilizing will increase good and balance of macronutrient and micronutrient in soil [2].

Hanolo [3] reported that liquid organic fertilizer application to leaves caused better growth and yield just than applied it in soil. Rizqiani et al. [4] also reported that liquid organic fertilizer was generally contains sufficient complete macronutrient and micronutrient, and also it was easy dissolved in water so that it was fast and easy to absorb by plant. This was a good characteristic of liquid organic fertilizer that applied to leaves because of its fast impact.

Liquid fertilizer application to leaves was become easy to inside leaves stomata if it was in form of liquid fertilizer droplet utilized sprayer. Effective liquid fertilizing is determined by droplet size (droplet
diameter) and droplet density. Liquid fertilizing by using a sprayer will be more effective with finer droplet diameter and higher droplet density. Smaller droplet diameter and higher droplet density make this condition met so that the effectiveness of liquid fertilizing by using a sprayer will be achieved.

Efficient liquid fertilizing is also important in order to save time and money. This can be achieved with quick and cheap liquid fertilizer application. In order to achieve it, no repeated application is advised, droplet distribution during the application time is done once only, and the volume of droplets applied is not excessive. This condition is met if the effective spraying width (ESW) is high and effective spraying debit (ESD) is low (economical). In other words, liquid fertilizing will be more efficient (short application time and economical application cost) if ESW is high and ESD is low. Optimum liquid fertilizing is achieved when the droplet spraying produce effective and efficient liquid fertilizing.

Liquid fertilizer is applied in the form of droplet utilized a sprayer which is sprayed onto the stomata of red spinach leaves. In a greenhouse, it is suitable that spraying utilized an electric sprayer because it is non-pollutant sprayer i.e. smoke and noise. Therefore, this research aimed to determine optimum liquid fertilizing on red spinach cultivation in a greenhouse utilized an electric sprayer.

2. Materials and methods
The research was conducted from March to May 2019 at the Protection Machinery and Equipment Laboratory, Leuwikopo, IPB University Darmaga Campus, Bogor and in a greenhouse to determine parameters i.e. droplet diameter, droplet density, effective spraying width, effective spraying debit, and harvested biomass weight of red spinach plants. The materials that be used in this research were liquid fertilizer and clean water. Measuring instruments and machines that be used were patternator, protractor, scanner, measuring cup, stopwatch, concord papers, computer, SWAN F-16 electric sprayer and air blower as seen on Figure 1. Determination of optimum liquid fertilizing performance was based on the ability of the sprayer to produce minimum droplet diameter, maximum droplet density, maximum effective spraying width, and minimum effective spraying debit.

![Figure 1. A knapsack electric sprayer and an air blower that be used in this research.](image)

Determination of spraying effectiveness and efficiency parameters of liquid fertilizing is important to do before it is applied in a greenhouse. In principle, liquid fertilizing is filling all leaves stomata with liquid fertilizer droplet to fill nutrient inside stomata.

Determination of optimum (effective and efficient) liquid fertilizing was based on the most effective and the most efficient spraying results. The flow chart of this analysis is shown in figure 2.
Figure 2. An analytic chart for determining optimum liquid fertilizing using sprayer.

It was shown that determination of optimum (effective and efficient) liquid fertilizing was based on minimum droplet diameter, maximum droplet density, maximum effective spraying width (ESW), and minimum effective spraying debit (ESD). These four parameters of liquid fertilizing effectiveness and efficiency can be measured at the Laboratory of Protection Machinery and Equipment, Leuwikopo, IPB Darmaga Campus, Bogor as shown in figure 3.

Figure 3. Sample activity in determination of optimum liquid fertilizing
Determination of the four parameters was based on the droplet spreading on a patternator. Liquid volume accommodated in each measuring cup, spraying angle, and spraying time were measured to determine effective spraying width (ESW) and effective spraying debit (ESD) as seen on Figure 4. Determination of spraying angle and effective spraying width (ESW) will produce effective spraying distance. Based on the value of the effective spraying distance, it can be used to determine droplet diameter and droplet density using concord papers, a scanner, and a computer.

**Figure 4.** Determination of the four parameters in the Laboratory of Protection Machinery and Equipment.

Effective spraying width (ESW) was determined by replacing an original spraying pattern on several overlapping pattern. ESW was determined by calculating coefficient of variation (CV) of each overlapping pattern. Finally, ESW can be calculated by determining minimum CV and measure distance from both two cross sections as seen on figure 5.

**Figure 5.** An example of effective spraying width determination.
Effective spraying debit (ESD) was determined by calculating total volume accommodated in each measuring cup on the range of effective spraying width (ESW). ESD can be calculated by calculating the volume accommodated divided by spraying time as expressed on equation 1.

\[ Q = \frac{V}{t} \]  

(1)

Where

- \( Q \) = effective spraying debit, litre min\(^{-1}\)
- \( V \) = total volume accommodated on the range of effective spraying width, litre
- \( t \) = spraying time

Droplet diameter and droplet density were determined by using an image processing program, which be made using “C-Language” of SharpDevelop 4.3 software. Its determination process can be seen on Figure 6.

**Figure 6.** Determination process of droplet diameter and droplet density.

First, the liquid fertilizer solution mixed with dark ink, and then it be sprayed onto concord paper surface perpendicular with droplet spraying direction from nozzle on its effective spraying distance. Scan and crop the 10 cm x 10 cm droplet picture, then conduct major binary of it to determine total area of paper and total area of droplet. Conduct minor binary to determine area of one droplet. Output data from the program is an area in unit of pixel. Next, the output data are processed to determine droplet diameter (unit: micron meter) and droplet density (unit: droplet cm\(^{-2}\)).

Before measure the four parameters of spraying effectiveness and efficiency, it is conducted to choose the best nozzle of the electric sprayer. The nozzle choosing was based on its performance that can produce minimum droplet diameter, maximum droplet density, maximum effective spraying width (ESW), and minimum effective spraying debit (ESD). The best nozzle will be used for liquid fertilizing utilized an electric sprayer in a greenhouse.

Another spraying method of liquid fertilizing is air blowing by replacing the nozzle with an air blower. So, there are two spraying methods that be applied in a greenhouse i.e. Method A (using an electric sprayer with the best nozzle) and Method B (using an electric sprayer with an air blower).
In the greenhouse, red spinach plants were transplanted on pots that arranged in a stack like a vertical culture cultivation system as seen on figure 7. Each pot was irrigated using drip irrigation system. There is no nutrient added on the drip irrigation system.

When the two spraying methods are applied in the greenhouse, there are two treatments are applied during conduct liquid fertilizing i.e. three forward walking speed of spraying and three dosages of liquid fertilizer solution as seen on table 1. Optimum liquid fertilizing can be obtained by conducting the two treatments. Recommended application dosage for red spinach plants is 3 liters ha$^{-1}$. Concentration of the liquid fertilizer solution is 0.3% (3 ml of liquid fertilizer in 1 liter of water). Liquid fertilizing will be applied on 14 days after transplantation and next regularly conduct liquid fertilizing for every 5 days until 2 days or 3 days before harvesting.

![Image](image_url)

**Figure 7.** Sample installation of red spinach plants on pots in the greenhouse.

| Spraying method     | Forward walking speed (m s$^{-1}$) | Application dosage of liquid fertilizer (l ha$^{-1}$) | Note for the application dosage of liquid fertilizer |
|---------------------|-----------------------------------|------------------------------------------------------|---------------------------------------------------|
| Method A (electric spraying with best nozzle) | A1 0.90 | 1.97 | Less than the recommended application dosage |
|                     | A2 0.60 | 3.00 | Equal with the recommended application dosage |
|                     | A3 0.30 | 5.92 | More than the recommended application dosage |
| Method B (electric spraying with an air blower)  | B1 0.75 | 2.03 | Less than the recommended application dosage |
|                     | B2 0.50 | 3.00 | Equal with the recommended application dosage |
|                     | B3 0.25 | 6.12 | More than the recommended application dosage |

Red spinach growing i.e. plants high, leaves number, and leaves area were measured on 14 days, 21 days, 28 days, 35 days, and 42 days after transplanting. Finally, harvested biomass weight of red spinach plants was measured on the same time of harvesting (42 days after transplanting).
3. Results and discussion

There are four nozzle types available in the electric sprayer box. Best nozzle of the electric sprayer was determined using weighing method. Weighing value for choosing best nozzle was based on the value of spraying effectiveness and spraying efficiency i.e. minimum droplet diameter, maximum droplet density, maximum effective spraying width (ESW), and minimum effective spraying debit (ESD), so that proportion for each parameter are 40% for droplet diameter, 30% for droplet density, 20% for effective spraying width (ESW), and 10% for effective spraying debit (ESD). Result of the analysis showed that the straight 4-holes solid cone nozzle is the best nozzle for liquid fertilizing utilized the electric sprayer because it has largest total weighing value. It can be seen on table 2.

Table 2. Result of the choosing best nozzle of the electric sprayer.

| Parameters      | Unit   | Single solid cone nozzle | Double flat fan type nozzle | Straight 4-holes solid cone nozzle | Angled 4-holes solid cone nozzle |
|-----------------|--------|--------------------------|-----------------------------|-----------------------------------|---------------------------------|
| Droplet diameter| micron meter | 509.47                   | 564.87                      | 459.36                            | 637.32                          |
| Droplet density | droplet cm$^2$    | 89                       | 96                          | 284                               | 205                             |
| ESW             | cm     | 88                       | 56                          | 72                                | 48                              |
| ESD             | litre min$^{-1}$ | 1.27                     | 1.15                        | 1.95                              | 1.87                            |

Weighing value of the parameters

| Parameters      | Weighing value |
|-----------------|----------------|
| Droplet diameter| 1.2 0.4 1.6 0.8 |
| Droplet density | 0.3 0.6 1.2 0.9 |
| ESW             | 0.8 0.4 0.6 0.2 |
| ESD             | 0.3 0.4 0.1 0.2 |
| Total weighing value | 2.6 1.8 3.5 2.1 |

Performance test of the two spraying methods in the Laboratory of Protection Machinery and Equipment showed different value of the four parameters. Values of the four parameters were in average. It can be seen on table 3.

Table 3. Performance test results of the two methods

| Spraying method | Value of the parameters (in average) |
|-----------------|--------------------------------------|
|                 | Droplet diameter (micron meter)      | Droplet density (droplet cm$^2$) | Effective spraying width (cm) | Effective spraying debit (litre min$^{-1}$) |
| Method A $^a$   | 311                                  | 706                                | 56                           | 1.99                                  |
| Method B $^b$   | 405.14                               | 361                                | 72                           | 2.21                                  |

$^a$ electric spraying with the straight 4-holes solid cone nozzle
$^b$ electric spraying with the air blower

Table 3 showed that Method A had better result in spraying method than Method B because it had value of droplet density was smaller than Method B, value of droplet density was larger than
Method B, and value of effective spraying debit (ESD) was smaller than Method B. It would result in different red spinach plant growing. More and more smaller (finer) droplet diameter and more and more larger droplet density would result in ease in many liquid fertilizer droplets enter to red spinach stomata. As a consequence of that results so liquid fertilizing using Method A will produce higher plant high and leaf number than Method B as seen on figure 8 and figure 9. Finally, liquid fertilizing using Method A will produce higher harvested biomass weight of the red spinach plants than Method B. It can be seen on figure 10.

Figure 8. Average plant high of the red spinach plants using Method A and Method B.

Figure 9. Average leaf number of the red spinach plants using Method A and Method B.

Figure 10. Average harvested biomass weight of the red spinach plants using Method A and Method B.
Method B had larger effective spraying width and effective spraying debit than Method A. It may result in excessive liquid fertilizer droplet application that too many liquid fertilizer droplets, which it did not enter to stomata, so that it would result in dissipation droplet outside stomata.

Difference in that result above (table 3, figure 8, figure 9 and figure 10) is caused by the difference in spraying mechanism between the two methods i.e. Method A (electric spraying with the straight 4-holes solid cone nozzle) and Method B (electric spraying with the air blower). Method A described that the liquid is exited from liquid tank that caused by a high-pressure liquid from a liquid pump, which it resourced from a battery, so that when it passed the nozzle it will be formed droplet. Method B described that the liquid is exited from liquid tank that caused by a high-pressure liquid from a liquid pump, which it resourced from a battery, but furthermore the high-pressure liquid from the liquid pump will be sucked and blown by a blower of air blower, and then it be directed by air blower nozzle in the form of droplet toward a sprayed area. It can be seen on figure 11.

![Figure 11. A schematic spraying mechanism of Method A (a) and Method B (b).](image)

Difference in that spraying mechanism of the two methods (figure 11) has resulted in droplet performance i.e. droplet diameter and droplet density. A high blowing by the air blower of Method B would resulted in domination of air in the droplet formation, so that it caused bigger size of droplet diameter and smaller droplet density as seen on figure 12.

![Figure 12. An example of droplet pattern formed by Method A and Method B.](image)
4. Conclusion
Results of the research showed that the use of the electric sprayer with the straight 4-holes solid cone nozzle and the electric sprayer with the air blower produced minimum droplet diameter, maximum droplet density, maximum effective spraying width, and minimum effective spraying debit were 311-micron meter, 706 droplet cm², 56 cm, and 1.99 litre min⁻¹ and 405.14-micron meter, 361 droplet cm², 72 cm, and 2.21 litre min⁻¹ in average respectively. The use of the electric sprayer has produced maximum harvested biomass weight of 7.17 g/plant in average on walking speed of 0.9 m/s with 1.97 litre ha⁻¹ liquid fertilizer dosage. The use of the electric sprayer and the air blower have produced maximum harvested biomass weight of 4.55 g/plant in average on walking speed of 0.5 m s⁻¹ with 3 litre ha⁻¹ liquid fertilizer dosage.

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