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Redesign and Performance Test of Liquid Fertilizer Based on Variable Rate Application on Chili Cultivation

Andi Muh. Saldan[1], Radi Radi[2,✉], Bambang Purwantana[2], Lilik Sutiarso[2]

[1] Master Program of Agricultural Engineering: Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, 55281 Yogyakarta, INDONESIA.

[2] Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, 55281 Yogyakarta, INDONESIA

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Corresponding Author:
✉ radi-tep@ugm.ac.id
(Radi Radi)

ABSTRACT

Liquid fertilizer applicator based on Variable Rate Application (VRA) is a technology that is used to fertilize in a controlled and precise manner. This study aims to improve the effectiveness and efficiency of the fertilization process of chili plants. The development carried out is esp32 cam which serves to detect chili plants that lack elements. The method used is input of the nutritional needs of chili plants, spray doses of each plant, and a microcontroller to control applicator components such as sprayer pumps, selenoid valve, and esp32 cam. In this liquid fertilizer applicator there are 2 pipes, each pipe has 4 nozzles. The results of laboratory tests show that the discharge of liquid fertilizer sprayed follows the input results of the nutritional needs of chili plants. The discharge released on the PWM sprayer motor varies from 40 to 100% resulting in very different discharge variations in each PWM spray. The efficiency of this VRA-based liquid fertilizer applicator reaches 87% or an increase of about 14.7% from the applicator before development. Regression analysis of dimmer level to spraying discharge showed a function $y = 6.3016x + 18.937$ *with an* R^2 *of 0.9921. While the regression analysis of the dimmer level of the applicator speed obtained the function* $y = 94.075x + 20.203$ *with an* R^2 *of 0.9936.*

1. INTRODUCTION

Precision farming can be defined as controlled, measurable, and precise farming. To realize the precision farming system, many aspects need to be considered, especially the aspect of adequate information related to technology. Precision farming is a revolution in information-based natural resource management. Precision farming is a technology used to allow more detailed treatment of each part of the land so that in addition to increasing productivity it can also reduce production costs and reduce environmental impact. Precision Farming is an appropriate solution to achieve sustainable, efficient agriculture and increase productivity (Putra, 2019). This can be achieved by precision farming through the creation of a Yield Map, Soil Map, Growth Map, Field Information Map, Variable Rate Application (VRA), Yield Sensor, making Variable Rate Application (VRA) and others (Prabawa, 2006).

Variable Rate Application (VRA) is one of the technologies used in precision farming. VRA is a technology in precision farming in the field of technology that focuses on automatically applying materials to certain landscapes. The system is based on data collected by sensors, maps, and a Global Positioning System (GPS) that typically includes things like fertilizers, chemicals, and seeds to help optimize crop production. VRA is a management approach to concentration in the field, which requires the right position on the land, the right information on the right location and operation on time, and where technology is needed. The equipment to perform VRA is called Variable Rate (Padmini *et al*., 2015). VRA uses application methods so that various input levels are in appropriate zones across the field. The goal of VRA is to maximize the profit to the maximum potential, creating efficiencies in input applications (Grisso *et al*., 2011).

The use of VRA system in the fertilization process is considered necessary due to levelling off and the increasing price of fertilizer is an encouragement to further improve the efficiency of the farming system, especially fertilization efficiency. Therefore, determining the right fertilizer dose with Variable Rate Application (VRA) technology is very important (Padmini *et al*., 2015). Theuse of the VRA system is important to do because when farmers fertilize, for example on chili plants, there are usually several garden trees that are exposed to fertilizer but not in accordance with the needs of chili plants. This can affect the productivity of chili farms. One chili tree can usually produce 1–1.2 kg of chili. Meanwhile, when the growth of chili garden is not optimal, the production of chili produced is less than 1 kg or even production does not exist at all. The mismatch of fertilization makes farmers usually refertilize some of these plant trees. Thus, farmers need additional time to refertilize, this causes farmers' work to be ineffective and efficient and can affect farmer productivity.

Please note that the need for N, P and K fertilizers in one chili plant tree is different from other chili trees. Fertilization based on soil Nitrogen (N), Phosphorus (P), and Potassium (K) content needs to be done so that fertilization is more efficient and plant fertility is maintained (Prabawa, 2006). With the use of VRA, fertilization can be well controlled and in accordance with what is needed by plants. So it can greatly help the work of farmers. The use of VRA, in addition to saving energy, is also predicted to save time, so that farmers' work can be done more efficiently and effectively, besides that it can also increase productivity.

Related research similar to this study is a study conducted by Fuadi *et al*. (2019) entitled Design of Liquid Fertilizer Applicators based on Variable Rate Application (VRA) in Soybean Plants. The research focused on designing a liquid fertilizer applicator that can be operated on soybean plants and the applicator has 8 nozzles. However, there are several shortcomings that need to be corrected, including the strengthening of the VRA system and the addition of a selenoid valve to the nozzle. Meanwhile, for efficiency in the study amounted to 72.27%. Referring to the study, the purpose of this study is to improve fertilization efficiency by doing several developments related to VRA-based liquid fertilizer applicators. In this study, there were several developments carried out including strengthening the VRA system by adding a camera sensor (esp32 cam) to detect the nutrients of chili plants. In addition, the use of 4 selenoid valves on 8 nozzles to control the type of fertilizer sprayed to suit the needs of plant nutrients. And the use of finned wheels to maximize liquid fertilizer applicators when used on varied fields.

2. RESEARCH METHODS

2.1. Location

This research was carried out in September 2022 February 2023 starting from tool design, tool testing to data analysis. Tool making was carried out at the Laboratory of Energy and Agricultural Machinery (EMP), Department of Agricultural Engineering and Biosystem, Faculty of Agricultural Technology, Gadjah Mada University, Sleman, DIY, Indonesia while the tool experiment was carried out on land owned by residents located in Wedomartani, Ngemplak, Sleman, DIY, Indonesia. The land area used in this study was 36 x 8 m 2, with a bed size of 1 m, bed height of 40 – 60 cm, distance between beds of 50 – 60 cm and planting distance of 65 x 50 cm (Suwandi, 2009).

2.2. Materials and Tools

The materials and tools used are SP-36 and KCl Urea fertilizer, chili seeds, ESP-32 cam sensors, pressure gauges, DC pump pumps, batteries, dimmers, gear boxes, nozzle, PE hoses, push buttons, 2 jerry cans of 10 liters, pneumatic, hose clamps, bolts, nuts, rings, iron wheels, tape measure, stopwatch, tool box, electric grinder, roll meter, drill, caliper and scale. This liquid fertilizer applicator is designed to be operated by one person as shown in Figure 1. The design of the applicator frame is adjusted to the width of the planting distance, light and strong weight and easy to control. The planting distance of 40 cm x 20 cm is the basis for designing the width of the fertilizer. The distance between the two rear wheels should not exceed 40 cm. When applying it, the applicator will run between plants that are 40 cm apart.

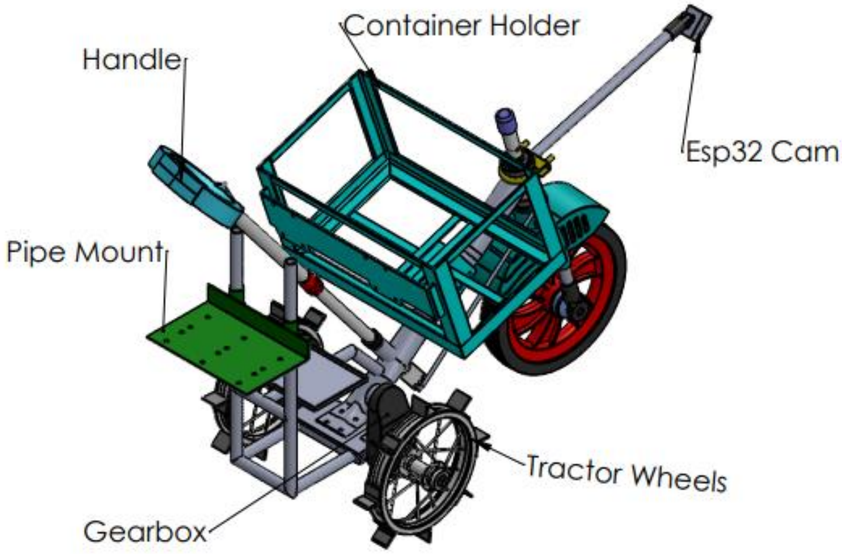


Figure 1. Liquid fertilizer applicator design

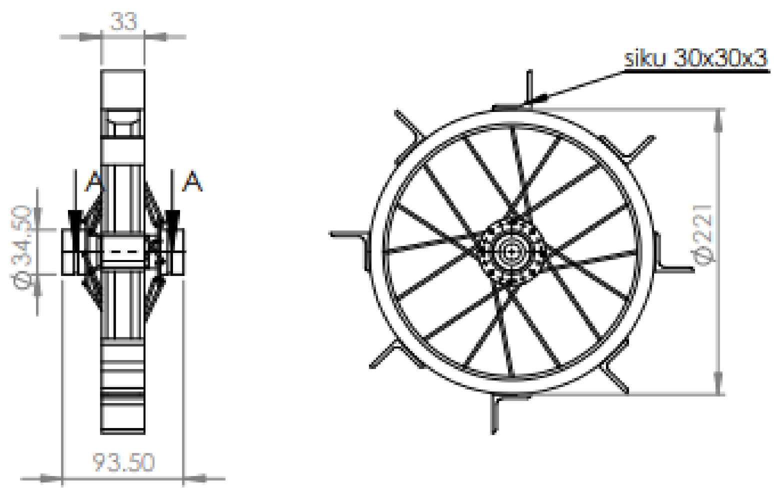


Figure 2. Wheel dimensions liquid fertilizer applicator

In this liquid fertilizer applicator, one of the things modified from previous research is the rear wheel of the applicator. The wheels on this applicator use finned wheels by modifying bicycle wheels that have a diameter of 22 cm then the use of elbow iron with a thickness of 4 mm and a width of 33 mm to be used as fins on the modified wheels. There are 8 fins on the wheel, this is to make it easier for the applicator to run on land that has uneven and loose soil contours. The applicator wheel can be seen in Figure 2.

In the design of the fertilizer pipe, it is adjusted to the distance between plants, which is 40 cm so that the distance between the nozzle is 40cm (Figure 3). The distance between the nozzles can be adjusted by sliding the nozzle pipe. The pipe is designed for 4 rows of plants for 1 type of fertilizer. On the applicator used 2 fertilizing pipes. The fertilization pipe consists of several components, namely the nozzle, knee ¼ inch, Tee 3/8inch, hose ½ inch, and pressure gauge. The pressure gauge is used to read the pressure exerted by the water pump.

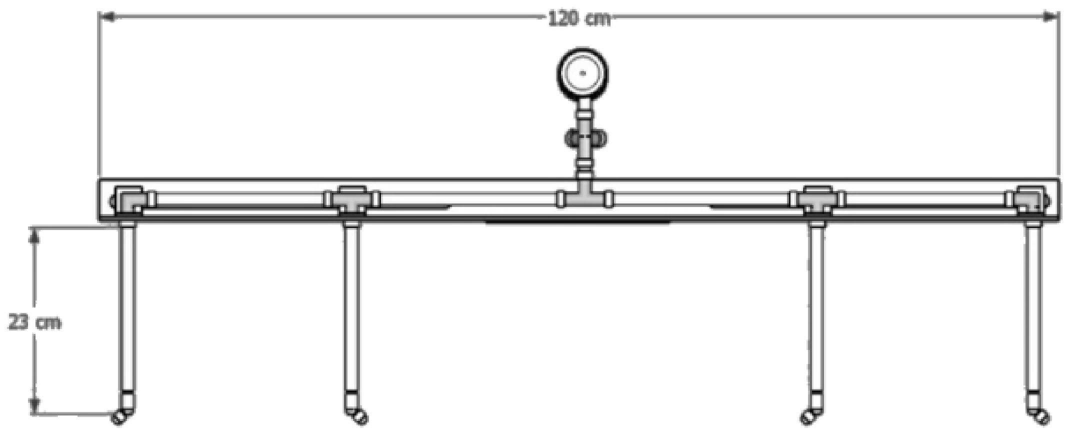


Figure 3. Fertilization pipe design

2.3. Fertilizer Performance Test

2.3.1. Functional testing of control performance

Functional tests are carried out on the component control system of liquid fertilizer to determine and ensure that each part can function properly (Rizal *et al*., 2016). The application of Variable Rate Application in the fertilization process aims to control the excessive use of liquid fertilizers so that plants get the appropriate nutrients. In the Variable rate application system in this study, the approach used is a sensor-based approach in the form of the use of camera sensors (esp32 cam). Esp32 cam is designed to detect plants that lack nutrients N, P and K, then the results of the esp32 cam analysis will enter the operator's smartphone, which will then give orders to Arduino to turn on the pump in accordance with the type of liquid fertilizer needed by plants detected on the esp32 cam

2.3.2. Test the performance of the tool in the laboratory

This test is carried out by testing the dimmer level recommendations on the motor sprayer and gearbox according to the results of previous tests. The laboratory test results obtained the discharge that can be achieved by the sprayer motor ranges from 192.08 – 734.17 ml/minute and the applicator speed ranges from 0.08 – 0.81 m/s. The combination of 0.2 m/s speed with the recommended dimmer level value of the motor sprayer obtained a coefficient of variation ranging from 4.54 – 6.45% for urea fertilizer and 2.71 – 4.45% for KCl fertilizer. The error value obtained is not more than 7.82% (Fuadi *et al*., 2021).

2.3.3. Test the performance of fertilizer tools in the field

The purpose of this test is to determine and evaluate the working ability of liquid fertilizer applicators to obtain work results with optimal conditions. Some of the parameters measured in this process are, calculating effective working width, effective field capacity, theoretical work speed, theoretical working width, actual work speed, total operating time, wheel slip measurement, measuring distance, calculating lost time during turning, time lost due to damage, ineffective working time, effective working time, cultivated land area and field efficiency as well as uniformity of CV and MAPE applications. Some calculation formulas were used for effective field capacity (KLE), theoretical field capacity (KLT), fertilization field efficiency (Ef) (Fuadi *et al*., 2021).

$$\mathrm{KLE} = \frac{\mathrm{A}}{\mathrm{t}} \quad (1)$$

$$\mathrm{KLT} = 3600 \times \mathrm{Wt} \times \mathrm{Vt} \quad (2)$$

$$\mathrm{Ef} = \frac{\mathrm{KLE}}{\mathrm{KLT}} \times 100\% \quad (3)$$

where KLE and KLT are presented in m^2/h, Ef is in %, A is area of fertilized land (m^2), *t* is time during operation (total free time) (h), Wt is theoretical working width of the fertilizing device (m), Vt is theoretical working speed (m/sec).

Statistical measures including standard deviation (SD), uniformity (CV) and MAPE were calculated as the following:

$$\bar{x} = \frac{\sqrt{\sum_{i=1}^{n} xi}}{n} \tag{4}$$

$$SD = \frac{\sqrt{\sum_{i=1}^{n} (xi-\bar{x})^2}}{n-1} \tag{5}$$

$$CV = \frac{\sqrt{\sum_{i=1}^{n} (xi-\bar{x})^2 / n-1}}{\bar{x}} \; x \tag{6}$$

$$MAPE = \frac{\sum \frac{|\text{debit observed} - \text{debit predicted}|}{\text{debit observed}} \; x\, 100}{n} \tag{7}$$

where xi is volume collected, $\bar{x}$ is average value of volume, *n* is number of data retrievals, SD is standard deviation from the droplet, and CV is coefficient of variation (%).

2.3.4. Soil N, P and K Content Testing

The land with 36m x 8m is divided into 6 plots with plot numbers 1 to 6. Soil sampling was carried out before planting to determine fertilizer dosage recommendations, and after fertilization 10 HST and 30 HST to determine soil NPK residues after fertilization. Figure 1 shows the fertilization scheme that will be used in liquid fertilizer applicator testing carried out in the field.

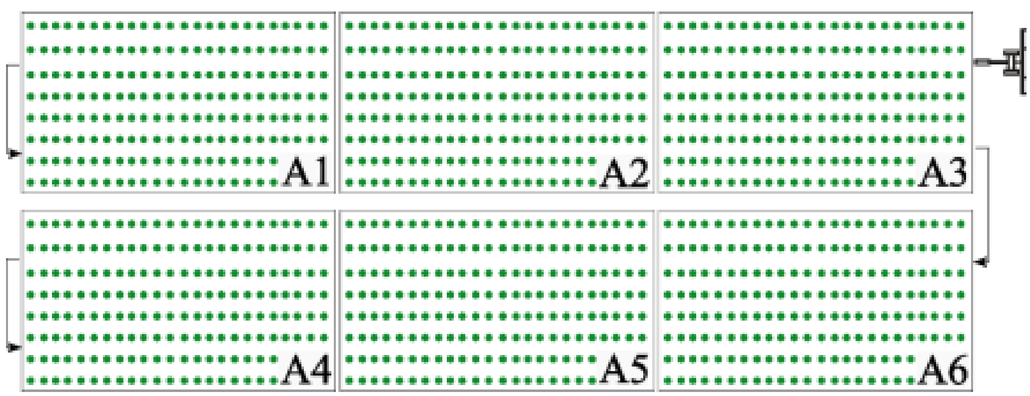


Figure 4. Fertilization scheme (Fuadi *et al*., 2021)

2.3.5. Red Chili Growth

The growth of red chili plants is observed in the high parts of the plant (Suherman *et al*., 2018), number of leaves, stem diameter, and leaf color. Plant height is measured from the base of the plant on the soil surface to the highest growing point. The number of leaves is calculated each week by counting all leaves from unifoliate leaves to leaves that have already opened. For color observation is carried out using the Esp32 cam. The advantage of esp32 is that it can be used as temporary storage (Fauzan, 2020), so that the data obtained is easier to observe. Color observation using a camera serves as a sensor to open the selenoid valve that regulates the function of watering plants. The following are the parameters used to determine the nutrient content of N, P and K plants based on the color of the leaves / stems owned by the plant (Suwandi, 2009). The following is a classification table of N, P and K content available in soil.

Table 1. Classification of N, P and K content available in soil

	Unit	Classification				Reference
		Low	Medium	Tall	Very high	
N	%	0.1 – 0.2	0.21 – 0.5	0.51 – 0.75	> 0.75	(Yamani, 2012)
P	ppm	< 10	10 – 25	25 – 50	> 50	(Langlois, 2015)
K	me/100g	< 0.4	0.4 – 0.6	0.6 – 2.0	> 2.0	(Langlois, 2015)

Table 2. Symptomatic characteristics of plants lack nutrients N, P and K.

Elements	**Deficiency Symptoms**
N	Leaf color yellowish-yellow
P	The color of the leaves is older, there is a purple tint on the stem
K	The color of the leaves is older and yellow appears on the edges of the leaves

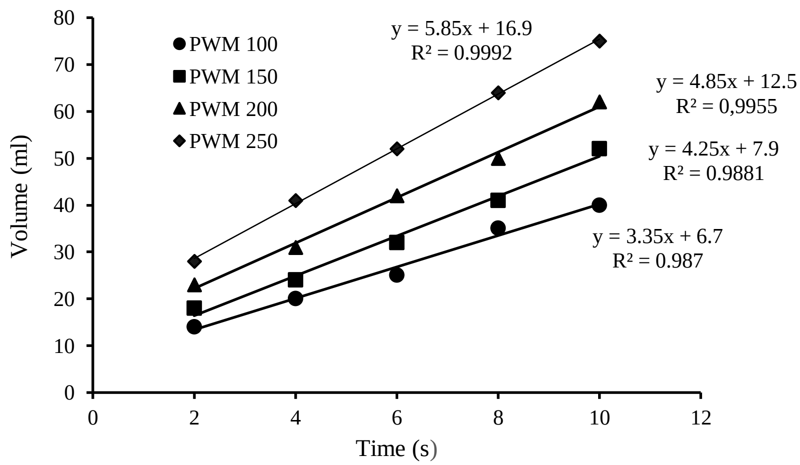


Figure 5. Spray conformity test results

3. RESULTS AND DISCUSSION

3.1. Test Results of the performance of the Fertilizer tool in the laboratory

The capacity of the control system on the fertilizer applicator at the rotational speed of the motor based on the Pulse Width Modulation (PWM) value from 100-250 obtained the minimum speed at PWM 100 and a maximum PWM 250. The average motor speed is 219 rpm and 570 rpm. The average spray yield volume of all PWMs is 38.45 ml with an average required time of 6 seconds. Motor speed testing is carried out under the condition that the applicator performs spraying. This is in accordance with the statement that the motor rotates at PWM 100-255 the speed change is not too large (Alghoffary, 2014).

Based on the fertilization applicator test conducted when all nozzles were open with PWM value settings, test results were obtained on PWM 100, 150, 200, and 250, namely the average spray volume at each PWM magnitude was 26.8 ml, 33.4 ml, 41.6 ml and 52 ml and the average spray duration was 6 seconds. The spraying result of the applicator is influenced by the magnitude of the PWM and the spraying time used at different sprayer motor speeds. The higher the PWM value used, the greater the spraying volume. Directly proportional to the relationship between time and spraying volume, the longer the time used, the greater the spraying volume. In accordance with the results of research (Arifin & Fathoni, 2014) which states that the higher the PWM value given, the greater the output voltage produced Based on the test results in Figure 5, the amount of PWM input and spraying time can be determined to achieve optimal spraying results on chili plants. This is in accordance with the statement that the liquid moving in the pipe is considered to be in a "steady state" state, or that water is assumed to have a constant velocity when flowing through a pipe that has the same diameter and produces the same amount of spray volume as the type of spray nozzle used is a "fine spray nozzle" (Triady & Triyanto, 2015).

Table 3. Discharge on various variations of dimmer level sprayer in all four nozzles

Dimmer level (%)	Discharge (ml/min)											Average Discharge (ml/s)
	Pipe 1				x1	Pipe 2				x1	x1,2	
	1	2	3	4		1	2	3	4			
40	205	202	200	197	201	178	179	190	198	186.3	193.63	3.227
50	287	289	270	288	283.5	276	296	297	280	287.3	285.38	4.756
60	398	400	380	406	396	400	400	398	397	398.8	397.38	6.623
70	497	500	513	502	503	498	499	500	503	500	501.5	8.358
80	600	604	575	589	592	600	590	603	600	598.3	595.13	9.919
90	695	700	689	698	695.5	687	687	698	685	689.3	692.38	11.54
100	743	733	750	744	742.5	734	745	735	720	733.5	738	12.3

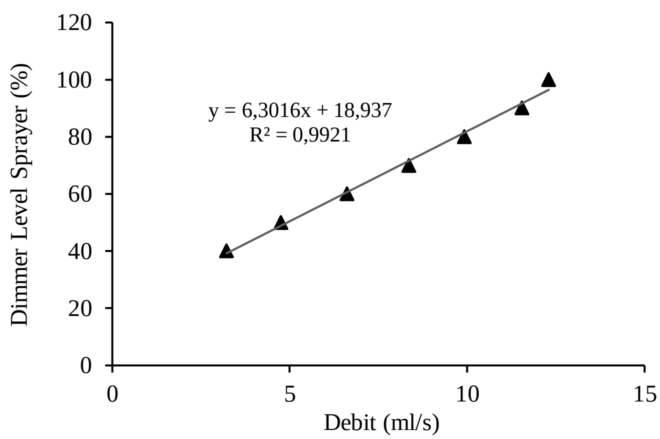


Figure 6. Relationship between discharge and dimmer level sprayer

Before the uniformity test is carried out, the nozzle openings are calibrated first so that the discharge on each nozzle is uniform. Uniformity testing was carried out on both nozzle pipes with each pipe consisting of 4 nozzles with dimmer level variations of 40 – 100%. The results of the uniformity test shown by Table 3, it is known that the discharge that can be achieved by the sprayer motor ranges from 3.227 – 12.300 ml / second. In Figure 6, showing the relationship between the dimmer level of the sprayer to the discharge produces a linear graph with a value of R^2 = 0.9921 so that it can be stated that the relationship between the dimmer lever sprayer and the spraying discharge has a relationship in a very strong category and obtained the discharge function as follows:
The above results show that the larger the dimmer level of the sprayer, the greater the spraying discharge produced by the liquid fertilizer applicator. This is in line with research conducted by (Dharmawan & Soekarno, 2020) which states that the greater the pressure exerted on pumping affects the amount of liquid sprayed. In this situation, Pascal's law applies, which states that the pressure exerted on a liquid in a closed space is continued by the liquid in all directions equally. Discharge is influenced by the speed of water flow, the greater the speed of water flow, the greater the resulting discharge, and vice versa.

Analysis of the test data is then carried out to find out the real difference between variables. Statistical analysis was carried out using SPSS 21 with the dependent variable being discharge, while the fixed variables were nozzle pipe, nozzle number and dimmer level sprayer. Based on Table 4, it can be seen that the significance value of the variation of the dimmer level sprayer to discharge has a value. The nozzle pipe variable and nozzle number show significance values of 0.216 and 0.933 so that the value is >0.05 so it can be concluded that the discharge produced in the four nozzles has no real difference or it can be said to be uniform and nozzle pipes 1 and 2 produce uniform discharge as well (Table 5).

Table 4. Anova test results between variations of dimmer level sprayer, nozzle pipe and nozzle number to discharge

Tests of Between-Subjects Effects					
Dependent Variable: Debit of Spraying					
Source	Type III Sum of Squares	Df	Mean Square	F	Itself.
Corrected Model	2,014,795.80	10	201,479.60	2704	0
Intercept	13,237,670.20	1	13,237,670.20	177,659.40	0
Dimmer Level Sprayer	2,014,646.50	6	335,774.40	4506.3	0
Number Nozzle	32.2	3	10.7	0.144	0.933
Pipe	117.2	1	117.2	1.57	0.216
Error	3353	45	74.5		
Total	15,255,819.00	56			
Corrected Total	2,018,148.80	55			
Adj R Squared = .998 (Adjusted R Squared = .998)					

Table 5. The relationship of dimmer level sprayer and dose on both pipes

Dimmer level sprayer (%)	Discharge (m/s)	
	Pipe 1	Pipe 2
40	3.35[a]	3.10[a]
50	4.73[b]	4.79[b]
60	6.60[c]	6.65[c]
70	8.38[d]	8.33[d]
80	9.87[e]	9.97[e]
90	11.59[f]	11.49[f]
100	12.38[g]	12.23[g]

The data shows that the greater the presentation of the dimmer sprayer variation, the greater the discharge produced by the liquid fertilizer spraying pipe both in pipe 1 and in the pipe 2, meaning that the greater the pump speed given, the greater the pipe output discharge produced by the liquid fertilizer applicator. The variable amount of pump pressure also affects the amount of water discharge produced. The greater the pump pressure given, the more water discharge produced (Siswadi, 2016). According to Mustakim (2015) the angular speed of the pump increases, the flow discharge will increase, this is because the rotation of the pump shaft that rotates the impeller rotates so high that more water is moved.

Applicator speeds have been tested with dimmer speed level variations from 30 to 100 % in fully filled tank conditions. Based on the results of the applicator speed test shown by Table 6, it is known that the applicator speed that can be reached ranges from 0.0838 – 0.8427 m/s. The relationship between the variation of the dimmer level of the sprayer to the speed of the applicator can be seen in Figure 7 which shows that a linear line with a coefficient of determination $R^2 = 0.9936$ so that it can be stated that the relationship between the dimmer lever sprayer and working time has a relationship in a very strong category and the following speed functions are obtained: $y = 94.075x + 20.203$ with $R^2 = 0.9936$.

Table 6. Applicator speed test results on speed level dimmer variations

Dimmer level Sprayer (%)	**Time(s)**				**in (m/s)**
	1	**2**	**3**	$\bar{x}$	
30	44.45	45.6	53.18	47.743	0.0838
40	20.34	21.21	19.01	20.187	0.1982
50	11.2	10.25	11.9	11.117	0.3598
60	9.34	8.99	9.1	9.143	0.4375
70	7.16	7.87	7.44	7.490	0.5340
80	6.27	6.87	6.3	6.480	0.6173
90	5.1	5.5	5.7	5.433	0.7362
100	4.34	5.01	4.89	4.747	0.8427

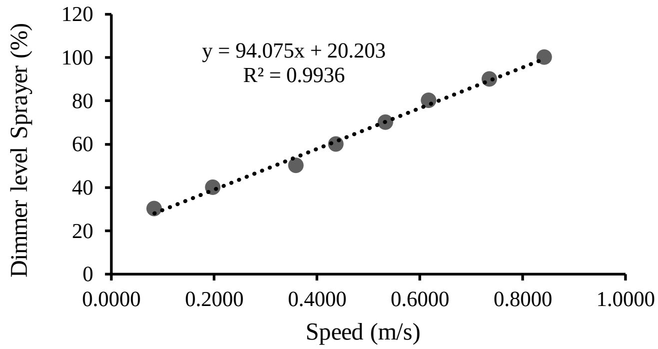


Figure 7. The relationship between speed and variation of the dimmer level sprayer

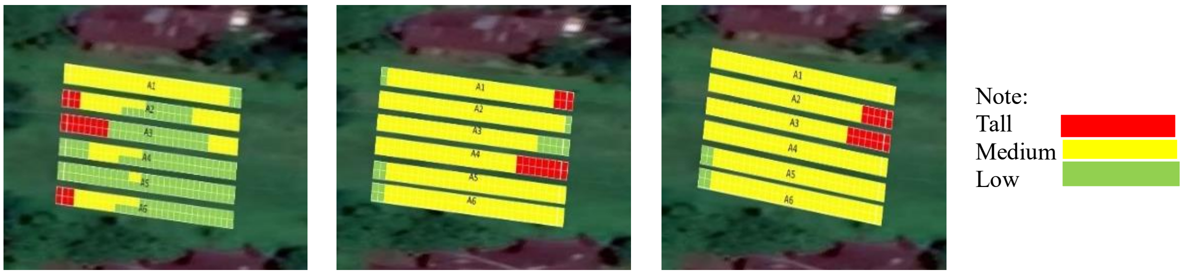
The relationship between speed and speed level dimmer variation in the test results shows that the greater the variation in the given dimmer level, the greater the speed given by the liquid fertilizer applicator. Speed in the process of using liquid fertilizer applicators is important to note, speed can affect spraying performance. This is as explained by (Dharmawan & Soekarno, 2020) that it is very important to keep the speed of an atomizer constant. A slower change in speed results in the volume of liquid sprayed.

Table 7. Test results of N, P and K samples

Plot	Chemical properties of soil		
	N (%)	P (ppm)	K (me/100 g)
A1	0.006	11.29	0.53
A2	0.008	16.43	1.08
A3	0.010	30.22	1.20
A4	0.007	10.43	0.54
A5	0.005	13.97	0.64
A6	0.008	38.02	0.63

3.2. Result Test the performance of fertilizer equipment in the field

Test The performance of fertilizer equipment in the field is based on the results of N, P and K tests before stacking. The N, P and K obtained are then classified into low, medium and high elemental content status categories according to Table 7. The results of the classification of N, P and K soils obtained in the test are shown in the table below. The results of the classification of classes N, P, and K soils are shown in Figure 8. In Figure 8 (a), it shows that the content of element N in all plots is relatively low even though on certain sides there are medium and high categories, while in Figure 8(b) shows that the content of element P shows that all plots are dominated by medium categories, and on certain sides there are high and low categories, and in Figure 8 (c) indicates that the K element in the entire plot is in the medium category, and there are high and low categories although not too many. This is due to differences in the ability of plants to absorb nutrients due to differences in land types (Masganti, 2011), besides that the type of soil texture on the land also affects the ability of the soil to absorb nutrients, which is caused by the absorption of nutrients that are not maximum, soil



(a) (b) (c)

Figure 8. Laboratory test results: (a) distribution of N content, (b) Distribution of P content, (c) Distribution of K content

(a) (b) (c)

Figure 9. Liquid fertilizer applicator product (a) front view (b) rear view (c) side view

Table 8. Summary of field test results

Testing/measurement	Unit	Value
Land area (A)	m^2	200
Theoretical free time (t)	hour	0.28
Theoretical Working Speed (Vt)	m/s	0.19
Working width (Wt)	m	1.2
Effective field capacity (KLE)	m^2/hour	714.3
Theoretical field capacity (KLT)	m^2/hour	820.8
Field efficiency (Ef)	%	87

texture dominated by sand, acidic soil, low organic matter content, and low KPK will result in reduced soil ability to absorb nutrients in the form of cation (Rahutomo & Ginting, 2018).

Based on the test results, liquid fertilizer applicators in the field provide field efficiency (Ef) of 87% as shown in Table 8. Field efficiency is determined by the working width and also the speed of the applicator during operation. In addition, conditions and vegetation in the field can affect the efficiency of the field, because if the soil form is uneven, it will affect the speed of the applicator so that it takes longer. Likewise, with vegetation found in the field, if the vegetation contained in the form of reeds and creepers will greatly interfere with the rotation of the applicator wheel so that the rate of the fertilizer applicator will be slower and the time needed will be longer (Kamal *et al*., 2021). Work efficiency depends on many factors such as, topography, operator expertise, maintenance and so on that concern the operation of the tool. In reality, it is difficult to determine the amount of work efficiency, but with experience can be determined work efficiency that is close to reality (Muis, 2007).

4. CONCLUSIONS

The results of the development of liquid fertilizer applicators based on Variable Rate Application (VRA) have an efficiency value of 87%, there is an increase of about 14.7% or more efficiency compared to liquid fertilizer applicators before development with an efficiency value of 72.27%. While testing liquid fertilizer applicators in the laboratory by testing the suitability of spraying, test results were obtained on PWM 100, 150, 200, and 250, namely the average spray volume in each PWM quantity was 26.8 ml, 33.4 ml, 41.6 ml and 52 ml and the average spray duration was 6 seconds, with each R^2 of 0.987, 0.9881, 0.9955, and 0.9992, respectively. As for the relationship between discharge and sprayer level dimmer obtained regression analysis y = 6.3016x + 18.937 with R^2 of 0.9921 and obtained the relationship between speed and variation of dimmer speed level obtained regression analysis y = 94.075x + 20.203 with R^2 of 0.9936. The test results of liquid fertilizer applicators in the field reveal an effective field capacity (KLE) of 714.3 m^2/h, and a theoretical field capacity (KLT) of 820.8 m^2/h.

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