Design of liquid fertilizer applicator based on Variable Rate Application (VRA) for Soybean

M Fuadi¹, L Sutiarso¹, Radi¹, S Virgawati¹ and P H T Nugraheni¹

¹Universitas Gadjah Mada, Yogyakarta, Indonesia

E-mail: mirajfuadi@gmail.com

Abstract. The process of fertilization is one of the phases that is very important in improving the quality and quantity of crops. The needs of plants nutrient on one stretch of the fact that not entirely uniform. In addition the use of chemical fertilizer continuously with the doses increasing each year can upset the balance lands nutrient therefore it is necessary variable-rate liquid fertilizer applicator to set a dose of fertilizer required by the plant. This study attempts to design and test the performance of variable-rate liquid fertilizer applicator and soil nutrient test. The applicator can be used to 4 line the soybean plant with distance cropping 40x20 cm. This applicator can control travel speed and dosage of fertilizers that were out of 4 Nozzle. Evaluation and its performance tested in the laboratorium. Discharge that was issued on PWM motor sprayer variations 40 to 100% produce discharge markedly dissimilar variations on each of the PWM sprayer. In application uniformity evaluations use the coefficient of variation (CV). The coefficient of variation of the discharge range 2.71-12.37% and there is a diversity of N, P and K soil contents in each land tested although the changes are not too different.

1. Introductions
Fertilizers are needed when the soil lacks nutrients for plants. Sandy plants will lack nutrients more quickly when exposed to rainwater and provide irrigation water, while clay is relatively slower to lose nutrients. The type of fertilizer given to the soil includes manure, granular fertilizer, and liquid fertilizer. The variety of types of fertilizers available will cause differences in applicator used. For example liquid fertilizer is given to plants by spraying onto plants. How to spray liquid fertilizer also varies, therefore according to fertilizers will be more complicated due to the non-uniformity of the fertilizer [1].

Precision agriculture has very diverse designations and definitions. There are three aspects in precision agriculture, that (1) finding out what happened on the land, (2) deciding what was done for it, and (3) giving treatment to the area according to the decisions made [2]. The aim is to match the application of resources and agricultural cultivation activities to soil conditions and crop needs based on site-specific characteristics in the land. In figure 1. show activities in precision agriculture, namely livestock management, plant management, machine management, and workforce management that contribute to the sustainability of agriculture.
A fertilizer applicator should have good application performance and show high accuracy, short response time, and uniform application patterns. In application uniformity evaluations, the coefficient of variation (CV) is widely used. Fulton et al. [5] characterized distribution patterns at varying rates for different granular applicators: two spinner-disc spreaders and two pneumatic applicators. To evaluate application uniformity, they used a CV of 20% as an acceptable level of uniformity. Kim et al [6] tested fertiliser application performance of a variable-rate pneumatic granular applicator and CV values ranged from 11.2% to 13.1% regardless of the working speed. Chen et al [7] tested a fixed-amount and variable-rate fertilizer applicator based on pulse width modulation. It was uniform and ranged little at the same level of amount of the distributed fertilizer. And the CV values were both less than 13%. Sun et al [8] tested performance and parameter optimization of variable spraying liquid fertilizer machine and the coefficient of variation of the droplet distribution is 0.8421.

The main nutrients that are needed by many plants but the amount of availability is often lacking or insufficient in the soil are N, P, and K. Therefore these three elements are added in the form of fertilizer. Excessive application of chemical fertilizers can cause a decrease in soil and water quality [9]. In soybean cultivation the application of fertilizer is still based on general recommendations that is 25-75 kg Urea / ha + 50-100 kg SP-36 / ha + 50-100 kg KCL / ha [10]. Continuous use of chemical fertilizers with doses that increase each year can actually cause the soil to become hard and the balance of soil nutrients is disrupted [11]. This situation will occur symptoms of disguised nutrient (hidden hunger) because there is no suggestion of soybean fertilization in those who experience these symptoms [12].

Table 1. Nitrogen, Phosphorus and Potassium (NPK) recommendation fertilizing for soybeans in each soil status class [4]

| Soil Nutrient | Class Category | Fertilizing Dose (kg/ha) | Application Schedule |
|---------------|----------------|-------------------------|----------------------|
|               |                |                         | 10 DAF   | 30 DAF   |
| N (Urea)      | Low            | 174                     | 70%     | 30%     |
|               | Medium         | 152                     | 70%     | 30%     |
|               | High           | 117                     | 70%     | 30%     |
|               | Low            | 104                     | 100%    | -       |
| P (SP-36)     | Medium         | 80                      | 100%    | -       |
|               | High           | 40                      | 100%    | -       |
|               | Low            | 210                     | 70%     | 30%     |
| K (KCl)       | Medium         | 190                     | 70%     | 30%     |
|               | High           | 150                     | 70%     | 30%     |
This can be anticipated using a precision farming system. Therefore, there is a need for further research regarding the soil nutrient content and fertilizers that adopt precision agriculture.

2. Materials and Methods

2.1 Overall design
The design of a liquid fertilizer applicator based on a variable rate applicator was developed in three dimensional models with Sketch up 2018. This applicator is designed to be operated by one person as shown in figure 2. Applicator consists of support frame, wheel, control box, motor sprayer, travel motor, handle, 12 V battery, switch, pressure gauge, tank and tank bracket. The applicator is run using a 12V DC motor sprayer that is installed in the tank bracket section. The applicator speed and discharge of liquid fertilizer are regulated by the PWM controller rotation in the control box.

![Figure 2. Description of variable rate liquid fertilizer applicator](image)

2.1.1. Frame. The design of the applicator frame is adjusted to the width of the planting distance, the weight is light and strong and easily controlled. Based on research conducted by Srihartanto et al [13], spacing of 40 cm x 20 cm is the best spacing to increase soybean productivity in DI Yogyakarta. The spacing of 40 cm x 20 cm is the basis for designing the width of fertilizers. The distance between the two rear wheels must not exceed 40 cm. when applying it, the applicator will walk between soybeans within 40 cm.

In the design of the applicator frame (Figure 3) it can be seen that the distance of the two wheels is 33.5 cm. The design is in accordance with the terms of the distance between the two wheels which must not be from 40 cm (<40cm). Then the design of fertilizer support poles is adjusted to the height of soybean plants at the age of 30 DAF. Puspitasari and Elfarisna [14] conducted a study to see the growth response of grobogan varieties of soybeans by adding organic liquid fertilizer and inorganic fertilizers. From the results of the study, the height of soybean plants at the age of 4-5 weeks ranged from 39.2 cm - 49.55 cm. This is the basis for high-pressure fertilizer pipe so that when applied it does not damage the plants.
Figure 3. Dimensions of the fertilizer application applicator (a). Rear view (b). Side view

The height of the fertilizer pipe used in the design is the length of the support pole and radius of the rear wheel: 57 cm. The battery holder and control box are placed at the rear to facilitate the regulation of liquid fertilizer or dosage and to make it easier to replace the battery when it is soaked. The material used in the buffer pipe and control box holder is ½ inch iron pipe. While the battery holder uses an iron plate with 3 mm thick.

2.1.2. Motor DC. The design of this applicator is assisted by 4 DC motors that is two motor sprayer 12V DC and two motors that are installed in the gearbox. The motor sprayer is used to drain from the fertilizer tank to the nozzle expected to drain fertilizer with high pressure so that the fertilizer output will be uniform. While the motors in the gearbox is used as an applicator driving force to move the applicator and the fertilizing tank load is around 20 kg. In figure 4.a. You can see the gearbox installation scheme on the applicator wheel. Then the gearbox will be installed on the rear wheel of the applicator. While the two motor sprayer will be installed at the rear of the tank bracket (Figure 4.b.).

Figure 4. (a). Installation of gearboxes on wheels (b). Installation of motor sprayer on fertilizer tank bracket

2.1.3. Nozzle Pipe. In the design of fertilizing pipes adjusted to the distance between plants is 40 cm (Figure 5). This pipe is designed for 4 rows of soybean plants for 1 type of fertilizer. In the applicator 2 fertilizing pipes are used. Fertilizer pipe consists of several components, namely nozzle, knee ¼ inch, 3/8 inch tee, 1/2 inch hose, and pressure gauge. A pressure gauge is used to read the pressure given by the motor sprayer so that the pressure reading can be determined the discharge used during fertilization. Based on fertilizer recommendations, SP-36 fertilizer is only applied once, which is 10 DAF so that the applicator is designed to only accommodate 2 types of fertilizer.
2.1.4. **Control Box**. The speed of the motor dynamo on the gearbox and motor sprayer is regulated by the PWM Controller. All controllers are incorporated into one control box. In Figure 5 you can see the control box consists of 3 PWM Controllers to adjust the speed of two motor sprayer and a pair of gearboxes and one Voltampere meter to monitor battery capacity. The sprayer motor has a 12V 3A specification with a maximum pressure of 110 PSI, while the gearbox motor has a 12V 1A specification and the battery used is 12V 8ah.

![PWM Controller](image1)

**Figure 5.** Design of fertilizing pipes

2.2. **Labolatory test**

Three tests were carried out for this study, that is testing soil nutrient content for fertilizer uniformity testing. Testing of soil nutrient content was carried out to determine the diversity of soil properties. The second is travel test to measure maximum and minimum speed of applicator. The third test is to find out the uniformity of the release of fertilizers at various discharge rate and travel speeds.

2.2.1. **Soil nutrient test by laboratory**. Padmini et al [15] have research NPK soil mapping for variable rate application. Determination of NPK nutrients available in the soil was conducted by using a paddy soil test device (PUTS) developed by the Soil Research Institute. The test begins with taking soil samples on the land to find out the soil, N, P and K content. The tested land is located at the Agro-technology Innovation Center of Gadjah Mada University (PIAT-UGM) located in Berbah District, Sleman Regency, Yogyakarta. Used two fields with an area of 1000 m² each. Testing of soil samples using. In the preliminary research that has been carried out, 9 soil samples were taken on each plot measuring 30m x 40m. Each soil sample represents an area of 10m x 10m. Then the soil samples were tested in the labolatory.

| Soil Properties | Unit     | Classification       |
|-----------------|----------|----------------------|
| N               | %        | Very Low 0.1         |
| P₂O₅ HCl        | me/100 gr| 0.1-0.2 10-20        |
| K₂O HCl         | me/100 gr| 0.21-0.5 21-30        |
|                 |          | Medium 0.51-0.75     |
|                 |          | High > 0.75 31-60    |
|                 |          | Very High > 60       |

(Source: Soil Capability Survey LPPT-Bogor, 1983 [16])
2.2.2. Travel speed test. The travel speed test is measured by running the applicator in a condition ready to operate with implants without operation, noting the travel time at a 4 m track distance (Figure 7). A variation of the user set speed is carried out to determine the minimum and maximum speed that can be achieved by the applicator. The variation of PWM motor travel given by settings user set from 30 to 100% and repeat 3 times. Travel speed can be defined as following:

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

Where v is travel speed of applicator, s is distance and t is time

![Figure 7. Travel speed test[17]](image)

2.2.3. Uniformity test. The quality of spray is generally affected by many factors. One of the key indicators is the uniformity of spray. The application uniformity in this research was represented with CV. The uniformity of droplet distribution is affected by the type of nozzle, flow rate, spray pressure, and travel speed. CV can be defined as following:

\[ CV = \frac{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}}{\bar{x}} \times 100 \]  

\[ \bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \]  

\[ SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \]

Where CV(Coefficient of Variation) is the variation coefficient %. SD (standard deviation) is the standard deviation of droplet coverage. \( x_i \) is the weight of collected fertilizer, \( \bar{x} \) is the average value of droplet coverage, \( n \) is the number of sampling points

Testing the uniformity of fertilizer was carried out on both fertilizer pipes. The discharge at each nozzle is first set to uniform by turning the head nozzle and then given a variation of PWM motor sprayer. The water that comes out is stored in a container for 1 minute. Calculated the discharge at the four nozzles and repeat 3 times.

3. Result and discussion
The following are test results soil nutrient test, travel speed and uniformity test to assess the applicator.

3.1. Result of soil sample test
There are two land locations in PIAT UGM which are used as research sites as shown in Figure 8. Based on the results of testing the soil samples presented in Table 3, then the values are categorized based on nutrient status classes Low, Medium and High. From Table 4, there is a diversity of N, P and K soil contents in each land tested although the changes are not too different. Some soil properties are very stable, changing slightly by the time, such as texture and soil organic matter content [18] The results of this lab test indicate that on a single stretch of land there are various nutrient content. These results also form the basis for designing fertilizers that can be adjusted to doses based on soil requirements.

![Figure 8. Location of research field in PIAT UGM](image)

**Table 3. Results of testing soil samples in 2 different locations**

| Field | Soil Properties | Unit       | Soil Sample |
|-------|----------------|------------|-------------|
| B     | N              | %          | 0.03 0.03 0.02 0.02 0.03 0.03 0.03 0.03 0.02 |
| B     | P₂O₅ HCl       | me/100 gr  | 36.91 40.54 41.56 54.49 33.87 25.49 46.39 49.67 43.53 |
| B     | K₂O HCl        | me/100 gr  | 19.27 19.75 19.56 19.54 19.66 19.22 21.43 23.83 19.13 |

**Table 4. Classification of soil samples on Land B and D**

| Field | Soil Nutrient | Soil Sample |
|-------|---------------|-------------|
| B     | N             | L L L L L L L L |
| B     | P             | H H H H H M H H H |
| B     | K             | L L L L L L M M L |
| D     | P             | M M M M M M H H |
| D     | K             | M M M M H M M H H |

3.2. Result of Travel speeds
The travel speeds of applicator speed have tested with variation PWM motor travel. Variation of PWM motor travel from 30 to 100%. In Figure 9. shows the relationship between PWM motor travel and travel
speed. From the graph, the value of $R^2 = 0.9947$ and so the model was defined as follows: $y = 96.307x + 19.742$

Where $y$ is PWM motor travel (%) and $x$ is travel speed (m/s).

![Figure 9. Relationship between PWM motor travel and travel speed](image)

3.3. Result of application uniformity

After being calibrated, then it gives a variation of the discharge rate given by the motor sprayer regulated by the PWM controller. The given PWM motor sprayer from 40 to 100 for 1 minute and repetitions 3 times. In Figure 10, shows the relationship between the PWM motor sprayer and the resulting discharge of fertilizer. From the graph, the value of $R^2 = 0.9896$ and so the model was defined as follows: $y = 9.47624x - 176.96$

Where $y$ is the fertilizer discharge (ml / min) and $x$ is the PWM motor sprayer (%)

![Figure 10. Relationship between PWM motor sprayer and discharge rate](image)

Analysis of lab test data was carried out using SPSS 16 with the dependent variable is discharge rate and fixed factors is nozzle pipe, nozzle number and PWM motor sprayer. Based on Table 5. it can be seen that the significance value of the variation of PWM motor sprayer on the discharge has a value of $<0.05$ so that it can be concluded that there is a significant difference from the variation PWM motor sprayer on the discharge of water produced. Duncan test results (Table 6) it can be seen that the discharge of each variation of PWM sprayer is in a different subset. Based on Table 7. the coefficient of variation of the discharge is range value 2.71-12.37% so the Liquid Fertilizer Applicator met the design requirement for stability and consistency.
Table 5. Analysis of variance of discharge rate

| Source              | Type III Sum of Squares | df | Mean Square | F     | Sig.       |
|---------------------|-------------------------|----|-------------|-------|------------|
| Corrected Model     | 6.124E6a                | 55 | 111349.426  | 2.201E3 | 3.49 x 10^{-149} |
| PWM Motor_sprayer   | 6097997.619             | 6  | 1016332.937 | 2.009E4 | 2.57 x 10^{-167} |
| Nozzle number       | 11587.500               | 3  | 3862.500    | .104   | 5.9 x 10^{-1}   |
| Nozzle pipe         | 14.881                  | 1  | 14.881      | .294   | 5.9 x 10^{-1}   |
| Error               | 5666.667                | 112| 50.595      |        |             |
| Corrected Total     | 6129885.119             | 167|             |        |             |

R Squared = .999 (Adjusted R Squared = .999)

Table 6. Comparison of discharge from applicator with variation PWM motor sprayer

| PWM Motor Sprayer | Nozzle Pipe 1 (ml/min) | Nozzle Pipe 2 (ml/min) |
|-------------------|-------------------------|-------------------------|
| 40                | 199.17a                 | 185.5a                  |
| 50                | 282.5b                  | 282.5b                  |
| 60                | 396.67c                 | 403.33c                 |
| 70                | 495d                    | 505d                    |
| 80                | 601.67e                 | 597.5e                  |
| 90                | 695f                    | 697.5f                  |
| 100               | 732.5g                  | 735.83g                 |
4. Conclusions

The diversity of soil nutrients has been carried out through lab tests and the manufacture of variable rate application based liquid fertilizer applicators has been developed and tested laboratory to evaluate the uniformity and speed of the applicator. The following conclusions were drawn:

- In one stretch there is a diversity of soil nutrient content (N, P and K)
- Users can preset expected discharge and the variety of travel speeds can adjust by PWM controller. PWM motor travel variation give the model was defined as follows: $y = 96.307x + 19.742$ with the value of $R^2 = 0.9947$. The highest and lowest travel speeds is 0.81m/s and 0.08 m/s
- PWM motor sprayer and discharge variations show linear lines with functions $y = 9.47624x - 176.96$. The highest and lowest discharge rate is 734.17 ml/min and 192.08 ml/min
- The coefficient of variation of the discharge range 2.71-12.37%

Subsequent research will be looked at the influence of fertilization on plant development and its effect on the nutrient content of the soil after fertilization. Besides that, the development of applicators can analyze soil nutrient content in real time.

| Soil nutrient | Class Category | PWM motor sprayer (%) | Repetition | Discharge observation (ml/crop) | $\bar{x}$ | Discharge prediction (ml/crop) | SD | CV (%) |
|---------------|----------------|-----------------------|------------|-------------------------------|-------|-------------------------------|----|-------|
| N (Urea)      | Low            | 100                   | 1          | 12                            | 12.5  | 11.83                         | 12.83 | 0.76  | 6.45  |
|               |                | 2                     |            |                               | 11    |                               |      |       |       |
|               |                | 3                     |            |                               | 11.5  |                               |      |       |       |
|               | Medium         | 91                    | 2          | 10.5                          | 11    | 11.21                         | 0.5  | 4.54  |
|               |                | 3                     |            |                               | 11    |                               |      |       |       |
|               | High           | 75                    | 1          | 8                             | 8.5   | 8.63                          | 0.5  | 5.89  |
|               |                | 2                     |            |                               | 9     |                               |      |       |       |
|               |                | 3                     |            |                               | 8     |                               |      |       |       |
| P (SP-36)     | Low            | 69                    | 1          | 6.5                           | 6.66  | 7.73                          | 0.29 | 4.33  |
|               |                | 2                     |            |                               | 7     |                               |      |       |       |
|               |                | 3                     |            |                               | 6.5   |                               |      |       |       |
|               | Medium         | 60                    | 2          | 5.5                           | 5.75  | 6.39                          | 0.25 | 4.35  |
|               |                | 3                     |            |                               | 5.5   |                               |      |       |       |
|               | High           | 38                    | 1          | 2                             | 2.5   | 2.33                          | 0.29 | 12.37 |
|               |                | 2                     |            |                               | 2.5   |                               |      |       |       |
|               |                | 3                     |            |                               |       |                               |      |       |       |
| K (KCl)       | Low            | 96                    | 1          | 12                            | 11.5  | 11.91                         | 0.5  | 4.35  |
|               |                | 2                     |            |                               | 11    |                               |      |       |       |
|               |                | 3                     |            |                               | 10.5  |                               |      |       |       |
|               | Medium         | 88                    | 1          | 10.5                          | 10.66 | 10.78                         | 0.28 | 2.71  |
|               |                | 2                     |            |                               | 11    |                               |      |       |       |
|               |                | 3                     |            |                               | 10.5  |                               |      |       |       |
|               | High           | 74                    | 1          | 8.5                           | 8.25  | 8.51                          | 0.38 | 4.45  |
|               |                | 2                     |            |                               | 9     |                               |      |       |       |
|               |                | 3                     |            |                               | 8.25  |                               |      |       |       |
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