Dynamic performance test of auger-type metering device for Variable Rate Fertilizer Applicator (VRFA)

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Abstract. The auger-type metering device for variable rate fertilizer applicator (VRFA) was designed and considered to have a better performance compared to other types of metering device. Static performance testing has been done with very good performance results. The system can follow each dose instruction given both step response and stair-step response testing. The objectives of this study were to do dynamic performance tests and analysis of the auger-type metering device which was controlled using a proportional–integral–derivative (PID) controller. In this test, the variable rate fertilizer was mounted to a transplanter machine. A DC motor rotated the auger, and the motor speed was controlled using a PID controller. The step response test was conducted to get a dynamic calibration equation by measuring the fertilizer discharge at a particular set-point of DC motor speed. The results obtained showed that fertilizer discharge has a linear relationship with the motor speed ($R^2 = 0.984$). Fertilizer distribution testing was conducted using a stair-step response. These test results showed that the fertilizer was uniformly distributed to the track. Similarly, the increase in the DC motor speed is correlated with the amount of fertilizer was distributed to the track.

1. Introduction
The system of fertilizing lowland rice in Indonesia has developed very rapidly, ranging from subsistence agriculture to integrated agriculture. The evolution of rice crop fertilization systems is divided into four periods, namely the green pre-revolutionary period, the beginning of the green revolution, balanced fertilization, and the location-specific nutrient management period [1]. In the balanced fertilization phase in 1985 - 2000, the government promoted a balanced dose of fertilizing lowland rice. However, most farmers use inorganic fertilizers excessively resulting in a decline in the growth rate of national rice production from 3.15 % in 1985-1990 to 1.49 % in 1990-2000 [2,3]. Application of fertilizer with a greater than recommended dosage results in damage to soil chemical properties (soil pH decreases), soil physical properties (soil BD increases), and soil biological properties (population of soil organisms decreases) [1]. Some impact of the use of inorganic fertilizers for the long term and continuously with
incorrect doses is disturbing the balance of soil nutrients because inorganic fertilizers can reduce soil pH and cause nutrient disorders due to accumulation of P and K nutrients in the soil [1,3,4], environmental pollution [5].

Application of variable fertilization or variable rate fertilizer applicator (VRFA), which in precision farming systems is one of the technologies that can provide the right fertilizer application according to land conditions and crop requirements [6]. The right application of fertilization includes three aspects, namely the right dose, the right location and the right time. The right dosage treatment is giving fertilizer dosage according to what is needed by the plant, and the right location implies that fertilization with the right dosage is given at the right location, while on time is fertilizing time-based on the plant growth phase. According to [7], Precision agriculture is a sustainable technology through an information technology approach (GIS, GPS, and VRT) to produce food.

Variable Rate (VRT) technology for fertilizer application with controlled doses has been carried out and has been tested, both static and dynamic testing. VRT is made using an auger type metering device that ration fertilizer output from the hopper. Fertilizer dosage control is done by controlling the rotation speed of the motor connected to the shaft metering device.

2. Methodology

Dynamic VRT testing is done by coupling the applicator on a transplanter. The tool is operated at a speed of 0.4 m/s. The test is carried out using three stages, namely dynamic calibration, fertilizer distribution with the step response method and the stair-step response. The step response method is carried out by running VRT at one particular motor speed, then the fertilizer released is collected in a plastic container then weighed using a digital scale. In this method, motor speed varies at speeds of 800, 1100, 1400, 1700 and 2000 rpm (equivalent to 110, 148, 187, 22, and 265 kg/ha) for 20 minutes for each treatment. Fertilizer Distribution Testing The Step Response Method is performed with the same speed setpoint treatment as the calibration method. But in this method, the fertilizer released will be distributed to the PVC gutters. The goal is to see the distribution of fertilizer during the test.

Testing with the stair-step response method is done by a method that is almost the same as the step response method. This test also uses the same speed setpoint as the step response method. However, changes in the speed of each treatment change automatically and continuously. Motor speed data for the two test methods are recorded automatically with a sampling period of 2 ms and transferred automatically to the laptop device via TeraTerm software.

3. Results and discussion

3.1. Step response dynamic calibration method

VRT dynamic calibration is carried out to determine the effect of tool movement on fertilizer output. The influence of the movement of the tool in the form of vibrations originating from machine vibrations and vibrations from the movement of the wheels when passing. The results of the dynamic calibration are shown in figure 1. Figures 1 (a), 1 (b), and 1 (c) are the results of dynamic calibration metering devices I, II, and III, respectively. The three dynamic calibration results show that DC motor speed or auger rotation speed is linearly correlated with the mass or dose of fertilizer coming out of the metering device, with the correlation equation and the coefficient of determination \( y = 7.667x - 77.81 \) (R2 = 0.984); \( y = 7.674x - 37.19 \) (R2 = 0.984); and \( y = y = 8.027x + 101.4 \) (R2 = 0.992). Third, the dynamic metering device calibration results give very good results with a high coefficient of determination. It also shows that the performance of the three metering devices is very good at controlling fertilizer rations. The third correlation equation can also be used as a reference in determining the dose of fertilization in the application of control in the field.
Figure 1. Graphic of VRT dynamic calibration results by the step response method

3.2. Fertilizer distribution testing by step response method

Fertilizer distribution testing is carried out to see the uniformity of fertilizer rations by the metering device and the distribution pattern of the fertilizer produced (table 1). The test results can also represent the continuity of allotment results.

| Table 1. Distribution of fertilizer spread from three metering devices along the track. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| g/m | g/m | g/m | g/m | g/m | g/m | g/m | g/m | g/m |
| 2.1 | 3.2 | 3.9 | 4.8 | 5.4 | 3.0 | 3.5 | 4.6 | 5.8 |
| 4.4 | 4.0 | 2.6 | 3.2 | 3.4 | 4.6 | 3.2 | 4.2 | 4.2 |
| 2.8 | 4.2 | 5.4 | 4.0 | 10.0 | 2.4 | 5.4 | 4.4 | 5.8 |
| 3.0 | 4.0 | 8.6 | 5.8 | 5.2 | 2.2 | 6.2 | 7.4 | 6.8 |
| 3.6 | 6.0 | 6.0 | 5.0 | 7.0 | 2.2 | 5.0 | 4.6 | 6.8 |
| 3.0 | 4.6 | 5.0 | 5.8 | 5.8 | 2.4 | 5.4 | 5.4 | 6.7 |
| 5.2 | 3.8 | 5.6 | 5.6 | 6.0 | 4.0 | 5.0 | 4.4 | 6.8 |
| 3.2 | 3.8 | 4.2 | 5.2 | 6.4 | 3.2 | 3.6 | 5.6 | 5.7 |
| 2.6 | 4.2 | 3.2 | 6.6 | 5.8 | 3.6 | 4.2 | 5.8 | 6.8 |
| 2.6 | 4.2 | 4.6 | 5.4 | 6.2 | 3.2 | 6.0 | 4.6 | 5.4 |
| 3.0 | 4.4 | 4.8 | 5.8 | 6.2 | 4.0 | 4.2 | 3.6 | 6.4 |
| 2.0 | 5.4 | 3.4 | 4.6 | 5.0 | 3.0 | 6.0 | 5.0 | 5.9 |
| 1.8 | 3.8 | 3.4 | 4.4 | 5.0 | 2.2 | 5.5 | 4.8 | 5.8 |
| 1.2 | 4.8 | 5.8 | 4.6 | 6.0 | 3.2 | 4.4 | 5.2 | 6.2 |
| 0.6 | 2.2 | 5.6 | 6.4 | 4.4 | 2.8 | 4.8 | 4.8 | 4.2 |
| 0.0 | 0.0 | 5.2 | 4.2 | 5.6 | 0.2 | 2.2 | 6.4 | 5.6 |
| 0.0 | 0.0 | 0.0 | 2.8 | 0.0 | 0.0 | 2.8 | 0.0 | 2.6 |
| 0.0 | 0.0 | 0.0 | 0.0 | 4.8 | 0.0 | 0.0 | 0.0 | 4.8 |
The results of testing the distribution of fertilizer rations from the three metering devices with the step response method showed that the three were able to distribute fertilizer well and evenly to the track without any empty track sections. The highest yield of fertilizer rations was obtained from metering device III at 7.3 g/m and the lowest was obtained from the metering device I at 0.6 g/m.

Table 2 shows the results of the calculation of errors or distribution errors of fertilizer rationing of the three metering devices. The metering device I result in a distribution error of 5 % - 15 %. The lowest error occurred in the set-point treatment of 6.62 g/m and the highest error occurred in the set-point treatment of 4.58 g/m. Metering device II ration distribution errors ranged from 3 % - 27 %. Negative numbers indicate less than the desired distribution of rations, whereas the distribution error of Metering Device III ration ranges from 1 % - 9 %.

| Setpoint (g/m) | Metering device I | Metering device II | Metering device III |
|---------------|------------------|-------------------|-------------------|
| Actual | error | Actual | error | Actual | error |
| 2.97 | 2.44 | 14 % | 2.97 | 3.13 | -5 % | 2.71 | 2.55 | 7 % |
| 3.46 | 3.50 | 10 % | 3.46 | 4.77 | -27 % | 4.06 | 4.44 | -9 % |
| 4.58 | 4.55 | 15 % | 4.58 | 5.01 | -9 % | 4.80 | 4.77 | 1 % |
| 5.79 | 5.11 | 6 % | 5.79 | 5.68 | 2 % | 6.33 | 6.25 | 1 % |
| 6.62 | 5.63 | 5 % | 6.62 | 6.80 | -3 % | 7.38 | 7.18 | 3 % |

3.3. Fertilizer distribution testing by stair-step response method

The test results of the fertilizer step ladder distribution method are shown in table 3. The test results show that in the treatment of doses of 2.97 g/m to 6.62 g/m, the mass of fertilizer at the transition velocity changes (starting point) tends to be higher than the midpoint and end of taking the sample. That is caused at the point of transition from low to high; there is a higher overshoot causing the motor speed to be faster.

| Setpoint (g/m) | Starting point (g/m) | Middle point (g/m) | Endpoint (g/m) | Average (g/m) | Error (%) |
|---------------|----------------------|--------------------|----------------|---------------|-----------|
| 2.97 | 4 | 3.2 | 3.2 | 3.5 | 17 % |
| 3.46 | 5 | 4.8 | 4.8 | 4.9 | 41 % |
| 4.58 | 6.6 | 6 | 6 | 6.2 | 35 % |
| 5.79 | 8.4 | 7.4 | 7.6 | 7.8 | 35 % |
| 6.62 | 8.2 | 9 | 8.2 | 8.5 | 28 % |

4. Conclusion

The dynamic metering device test results have been done well. The calibration test obtained a linear correlation between the speed of the DC motor and the mass of fertilizer coming out of the metering device with the correlation equation and the coefficient of determination of each of the three metering devices, respectively $y = 7.667x - 77.81$ ($R^2 = 0.984$); $y = 7.674x - 37.19$ ($R^2 = 0.984$); and $y = 8.027x + 101.4$ ($R^2 = 0.992$). The results of testing the distribution of fertilizer ratios obtained distribution and
distribution patterns of fertilizer to the track quite evenly. Likewise, the increase in the speed of a DC motor correlates with the amount of fertilizer rationed to the track.

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