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Analysis on Fertilizer Application Uniformity of Centrifugal Fertilizer Distributor

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Abstract

Purpose: Chemical fertilizers contribute to agricultural productivity. Annually, 450,000 tons of chemical fertilizers are used in Korea, which is 268 kg per hectare (MAFRA, 2016). However, excessive use causes problems such as environmental pollution and soil acidification. This study proposes use conditions for a fertilizer distributor that can reduce excessive fertilization by analyzing distribution patterns. **Methods:** This study analyzed fertilizer application uniformity according to the number of blades on a centrifugal fertilizer distributor (three or four blades), orifice gate open ratio (50 or 100%), and blade rotation speed (400, 500, or 600 rpm). **Results:** When using four blades, the coefficient of variation (CV) was lower than when using three by 11-13% points, and the CV using the 50% open ratio was 10-30% points lower than using the 100% open ratio. The CV at 500 rpm blade rotating speed was 9-12% points lower than that for 400 and 600 rpm. **Conclusions:** The CV with four blades, 50% orifice gate open ratio, and 500 rpm of blade rotating speed was 18.4%, which provided the most uniform fertilization.

Keywords: Disc granule distribution, Fertilizer distributor, Spray pattern, Uniform spray

Introduction

Fertilizers are indispensable agricultural materials in agricultural production and significantly contribute to the increase in agricultural productivity. The increase factors of crops are normally fertilizers (50%), species improvement (30%), and other factors including disease and insect pest control (20%) (RDA, 2006). Among these, the use of chemical fertilizers significantly affects agricultural production. However, the excessive use of pesticides and chemical fertilizers for the increase in agricultural production has caused environmental pollution (Kim et al., 2006). Consumers preference for safe and high-quality agricultural products has increased in recent years. In addition, the eco-friendly agricultural product market has increased from 3.1927 trillion KRW in 2008 to 3.9678 trillion KRW in 2010, and the eco-friendly cultivation area has rapidly expanded. To cope with the increased demand for eco-friendly high-quality agricultural products and to reduce environmental pollution caused by the indiscriminate use of pesticides and chemical fertilizers, it is necessary to solve the excessive chemical fertilization problem (Hong et al., 2013). The Gyeongsangnam-do Agricultural Research Service investigated soil chemical property variations in paddy field soils in Gyeongsangnam-do and revealed that regions with excessive available phosphates have increased from 36% in 2001 to 43% in 2017, and regions with excessive levels of exchangeable calcium have also increased sharply from 47% in 2001 to 79% in 2017 (GNARES, 2016). If chemical fertilizers are used excessively as described above, they increase the concentration of soil

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salts, thereby increasing the inhibition of germination and plant growth imbalance, and hindering moisture and mineral nutrient absorption due to the osmotic pressure phenomenon, resulting in crop quality degradation. Furthermore, fertilizer ingredients that remain in soils are introduced to underground water and streams, polluting water resources (Uhm et al., 2012). Fertilizers are sprayed mostly using a disc granular fertilizer spreader, which has advantages of low maintenance cost, high durability, low price, and a large spread area, and can be used for various purposes such as basal fertilization and seed spray. However, it has a problem that the spray is not uniform (Kweon et al., 2009).

Han et al. (2016) improved a disc granular fertilizer spreader via the installation of inner blades at the rotating disk to have the falling fertilizer around the rotating axis forcibly moved to the adjustment device wall side in the outlet direction by the centrifugal force. They analyzed the granular behavior over the disk for the uniform spray of granular fertilizer spreader. Results showed that although variations of spray pattern due to changes in amount of applied fertilizers were reduced, falling particles around the rotating axis were increasingly forcibly moved to the wall of the adjustment device in the outlet direction as the amount of applied fertilizers increased, entailing the problem of those forcibly moved particles not being sprayed. Fulton et al. (2001) studied the spray pattern of centrifugal fertilizer distributors. In accordance with the ASABE S341.2 standard method, they studied a spray pattern by spraying 56-168 kg/ha of fertilizer. A desirable Gaussian-shape spray pattern was exhibited when the fertilization amount was small, an M-shape spray pattern was revealed when the fertilization amount was large, and a W-shape spray pattern was revealed as the fertilization amount increased. No uniform spray could be achieved with M and W shapes when fertilization overlapped in the tractor driving gap. Molin et al. (2002) analyzed the uniformity of distribution by changing a spray amount and width in the test where the spray amount was 50, 150, and 250 kg/ha and the spray width was 18, 21, and 24 m. The test result showed that as the spray amount increased, CV was reduced, and the highest CV was found at 21 m spray width, while a similar trend was exhibited at 18-m and 24 m spray widths.

Thus, this study aimed to identify the optimal conditions for uniform spray while using the centrifugal fertilizer distributor by analyzing the fertilizer application uniformity according to changes in blade rotating speed, orifice gate open ratio, and the number of blades

Materials and Methods

Material used

The chemical fertilizer used in this study was a low-phosphorus compound fertilizer (Heuk sarang, Namhae Chemical Co., Jeollanam-do, Rep. Korea). The standard quantity was 20-50 kg/10a, and the particle size was 2-4 mm. The fertilizer distributor (CH-600TS, Cheong Song Agri Machinery Co., Daegu, Rep. Korea) used in this study was a centrifugal fertilizer distributor that was 1.5 m long, 1.5 m wide, and 1 m high, and the work width was 4-12 m. As shown in Figure 1, a frame was attached to the distributor and a three-phase induction motor (BG-355, Bokuk Co., Daegu, Rep. Korea) was attached to the frame's upper end. The axis of the bland was connected to the motor and the rotating speed was controlled by a controller.

Application uniformity test

The tests were conducted five times iteratively in accordance with the standard specifications (ASAE, 2004) to analyze the fertilizer application uniformity. The blade rotating speed of the fertilizer distributor was 400, 500, 600 rpm, and the number of blades was three or four, as shown in Figure 2(a). The test was conducted at 1/3, 2/3, and 3/3 orifice gate open ratio, and the test results showed that a problem of unsprayed fertilizer occurred

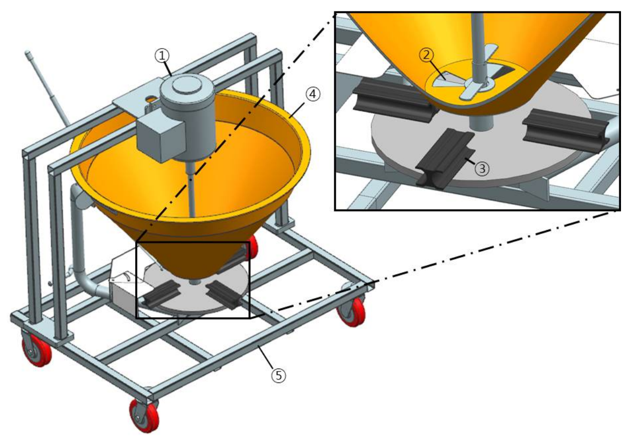

Figure 1. Schematic diagram of the centrifugal fertilizer distributor (1. squirrel cage induction motor, 2. orifice gate, 3. blade, 4. hopper, 5. frame).

at the 1/3 orifice gate open ratio. Thus, the test was conducted only at two levels, 50% and 100%, as shown in Figure 2(b). The tray used in the tests was a 34 cm long, 24 cm wide, and 20 cm high plastic box that was divided into 12 cells, each 8.5 cm long and 8 cm wide; 99 trays were used in total.

Figure 3 shows the layout of the fertilizer collection trays, in which 99 trays were arranged at 1 m intervals up to 7 m (effective spray distance) from the fertilizer distributor. From the fertilizer distributor, -2~0 m was Zone A, 1~2 m was Zone B, 3~4 m was Zone C, and 5~7 m was Zone D to measure the fertilizer spray pattern and amounts. The spray duration was one minute.

After the spray test, the amounts of fertilizer in the trays were measured and the CV was calculated using equation (1), where S represents the standard deviation of the measurements and $\overline{Y}$ represents the mean of the measurements. Equation (2) calculates the measurement of sprayed fertilizer amount per unit area, in which R represents the fertilizer quantity per unit area, K is the unit conversion constant 100,000, W is the amount of fertilizer contained in the fertilizer collection tray, A is a bottom area of the fertilizer tray (cm^2), and E is the number of fertilizer collection trays.

$$CV(\%) = \frac{S}{\overline{Y}} \times 100 \quad (1)$$

$$\mathrm{R}(kg/ha) = \frac{K \times W}{A \times E} \quad (2)$$

Results and Discussion

Table 1 presents the maximum, minimum, and mean fertilizer quantities per zone and the CV results according to each condition. The most uniform spray conditions at

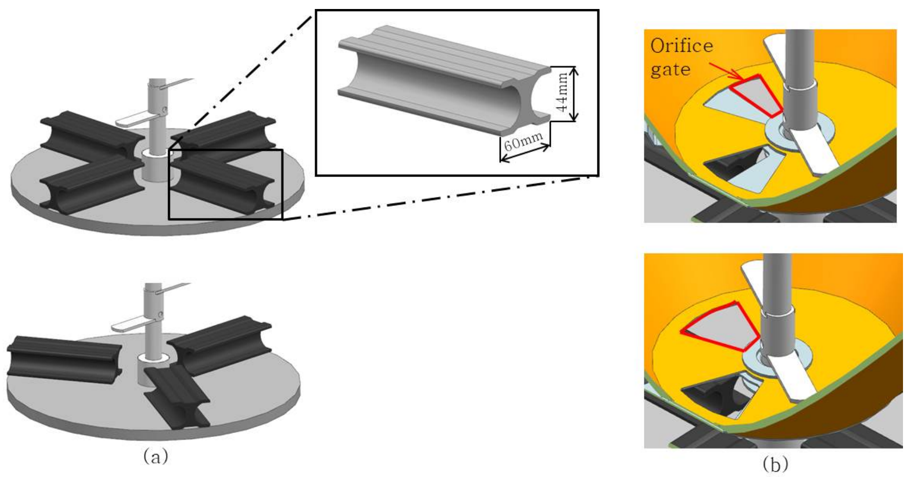

Figure 2. Schematic diagrams of the (a) blade type and (b) orifice gate open ratio.

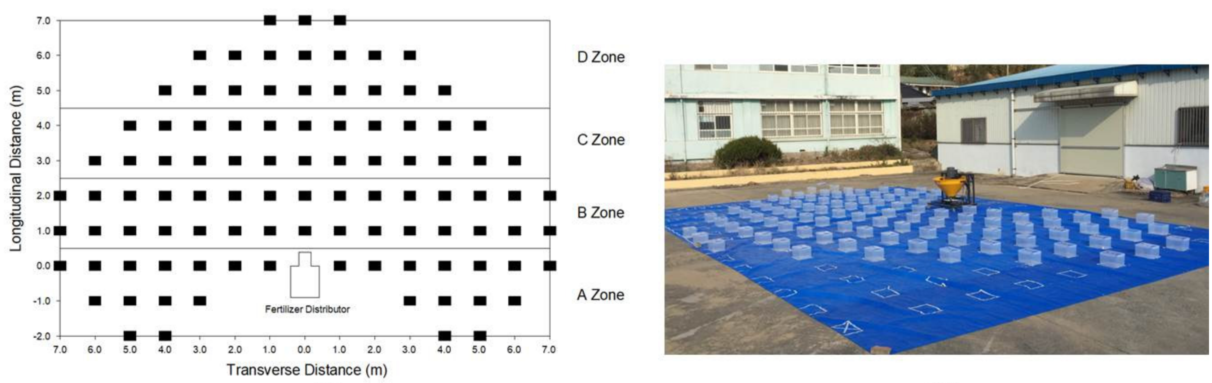

Figure 3. Fertilizer collection tray (a) schematic diagram and (b) layout photo.

Table 1. Fertilizer amount by conditions

RPM	Orifice gate open ratio (%)	Blades	Fertilizer quantity (g)				CV (%)
			Zone	Max.	Min.	Avg.	
400	50	4	A	99.49	49.62	78.96	31.1
			B	140.78	52.71	98.21	
			C	142.78	72.53	98.21	
			D	99.49	49.62	78.96	
		3	A	178.29	46.06	80.07	43.1
			B	174.21	47.96	101.03	
			C	181.48	66.72	116.26	
			D	97.50	47.63	74.37	
	100	4	A	279.32	55.47	109.96	56.3
			B	267.88	60.61	138.69	
			C	282.20	90.26	169.71	
			D	138.29	60.04	104.14	
		3	A	259.16	52.95	105.24	54.5
			B	259.16	57.98	131.83	
			C	273.56	87.10	163.76	
			D	129.33	59.54	100.24	
500	50	4	A	121.19	58.52	72.08	18.4
			B	115.98	64.58	85.26	
			C	121.68	75.01	93.98	
			D	82.93	78.49	72.08	
		3	A	150.27	53.83	70.71	29.8
			B	143.81	60.53	85.26	
			C	154.14	68.25	99.73	
			D	81.69	71.42	76.44	
	100	4	A	238.74	57.62	95.42	47.2
			B	228.48	67.18	119.24	
			C	226.32	91.04	150.15	
			D	112.86	91.04	102.22	
		3	A	218.14	65.58	91.87	43.5
			B	208.76	68.84	115.23	
			C	214.15	86.33	142.28	
			D	106.4	86.33	97.44	
600	50	4	A	142.98	49.98	72.37	28.5
			B	132.83	59.78	83.86	
			C	133.84	59.26	94.34	
			D	98.48	57.58	82.84	
		3	A	145.21	45.79	70.24	41.7
			B	164.70	55.41	85.43	
			C	179.34	54.51	100.07	
			D	93.55	56.42	77.94	
	100	4	A	222.01	57.62	99.38	57.7
			B	230.27	78.31	125.55	
			C	258.31	81.19	155.89	
			D	129.00	74.84	105.06	
		3	A	216.01	57.10	95.67	55.8
			B	217.48	73.61	119.81	
			C	254.29	77.03	150.53	
			D	128.02	71.39	102.24	

400 rpm of blade rotating speed in the fertilizer distributor were 50% orifice gate open ratio and with four blades, for which the CV was 31.1%. The fertilizer quantity and CV according to changes in the orifice gate open ratio showed that the sprayed fertilizer at 100% open ratio sprayed 2.8-fold more fertilizer than at 50% open ratio, and CV was increased more by 25.2% points, indicating that a more uniform spray could be achieved at the 50% orifice gate open ratio than at the 100% open ratio. The application uniformity according to the number of blades showed that at the 50% open ratio, the four-blade application uniformity was better than that of three blades. However, there was no significant difference in CV between four and three blades at the 100% open ratio due to the excessive input of fertilizer, indicating that three and four blades had similar application uniformity.

The most uniform spray conditions at 500 rpm blade-rotating speed in the fertilizer distributor were 50% open ratio and four blades, which had 18.4% CV. The fertilizer quantity and CV according to the orifice gate open ratio showed that the fertilizer quantity and CV at the 100% open ratio was increased by up to 1.9-fold and 28.8% points, respectively, indicating that the application uniformity at the 50% open ratio was better than at 100%. The application uniformity according to the number of blades showed that the application uniformity for three blades was superior to when using four blades, and there was no significant difference in application uniformity between three and four blades at 100% open ratio.

The most uniform spray conditions at 600 rpm in the fertilizer distributor were 50% open ratio and four blades, which had 28.5% CV. The fertilizer quantity and CV according to the open ratio showed that the maximum quantity of fertilizer at the 100% open ratio was 1.9-fold more than that for 50% and the CV was increased more, by up to 29.2% points. The CV results according to the number of blades showed that the CV at the 50% open ratio was 13.2% point higher when using three blades than when using four blades, and at the 100% open ratio there was no significant difference in the CV results according to the number of blades, the same as shown at 400 and 500 rpm, resulting in a similar uniformity level. The fertilizer quantities measured for all test conditions satisfied the standard quantity.

The minimum CVs at 400, 500, and 600 rpm blade rotating speeds were 31.1, 18.4, and 28.5%, respectively, when the open ratio was 50% and there were three blades. Figure 4 shows the best spray pattern of the spray conditions at each rotating speed, in which the fertilizer tended to be concentrated in the 1~2 m zone at 400 rpm. This was due to the slower blade rotating speed compared to the fertilizer quantity sprayed. At 500 rpm, the concentrated fertilizer spray was not wider, and a more uniform spray was shown than that for either 400 rpm or 600 rpm. At 600 rpm, the fertilizer was crushed and became powder due to the fast blade rotating speed, and the fertilizer spray tended to be concentrated at near 8 m distance. The above results can be summarized as follows: the optimum fertilizer spray conditions for the centrifugal fertilizer distributor were 500 rpm blade rotating speed, four blades, and 50% orifice gate open ratio. The factors that affected the application uniformity were orifice gate open ratio, blade rotating speed, and the number of blades. However, since these factors affected the application uniformity in a complex manner, it was difficult to identify which factor was the dominant factor.

Conclusions

This study analyzed the application uniformity and spray patterns according to spray conditions (number of blades, orifice gate open ratio, and blade rotating speed) of a centrifugal fertilizer distributor to solve environmental problems and economic loss due to excessive fertilization. The optimum conditions for the use of a fertilizer distributor were identified. Regarding the number of blades, four blades had a better fertilizer scattering effect than three blades, resulting in a more spray uniformity. However, at 100% orifice gate open ratio, there was no significant difference in application uniformity according to the number of blades due to the excessive supply amount of fertilizer to the spray blades. The fertilizer spray pattern according to the blade rotation speed showed that 500 rpm was determined as the optimum blading speed condition, showing a more uniform spray distribution than for 400 or 600 rpm. This study proposes

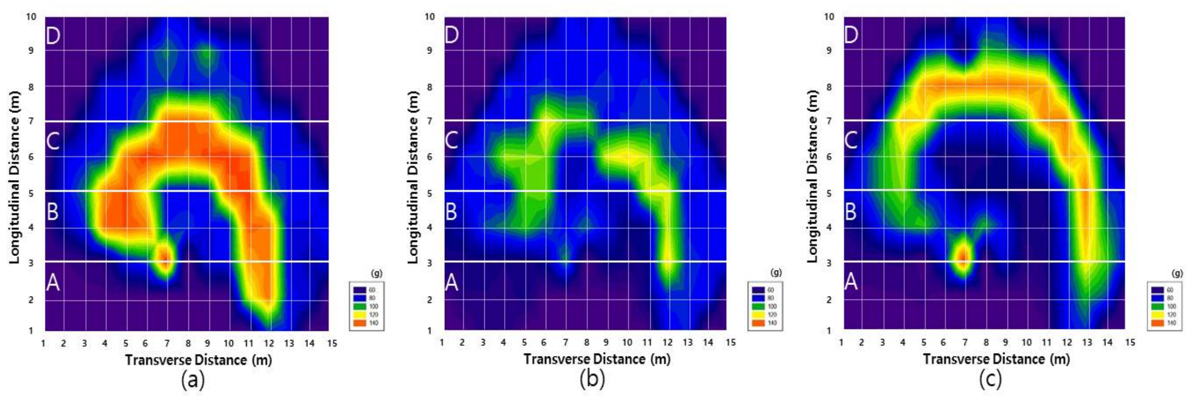

Figure 4. Spray pattern at the optimum spray conditions by 400 rpm (a), 500 rpm (b) and 600 rpm (c).

the optimum use conditions for a centrifugal fertilizer distributor to ensure a uniform spray through application uniformity analysis according to spray conditions.

In a future study, driving tests will be conducted after attaching the distributor to the tractor to identify the conditions of uniform application pattern, and distribution patterns at the fixed state will be compared and analyzed to analyze the distribution patterns according to various fertilizer application conditions.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgment

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