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Spray Pattern Analysis for a Centrifugal Fertilizer Distributor with Two Shutter Holes

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두 개의 셔터 구멍이 적용된 원심식 비료 살포기의 살포패턴 분석

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ABSTRACT

In this study, the spray pattern of a centrifugal fertilizer distributor with two shutter holes was analyzed and an effective driving width that satisfies proper spray uniformity was derived. The centrifugal fertilizer distributor was mounted on a tractor with a rated power of 23.7 kW and static and dynamic spray pattern tests were performed according to the standard procedure proposed by the American Society of Agricultural and Biological Engineers Standard ASAE S341.5. The height of the fertilizer distributor was 80 cm from the ground and the PTO (power take-off) shaft speed of the tractor was fixed at 540 rpm. The fertilizer scattered in space was collected using 275 evenly spaced collectors at shutter opening ratios of 25%, 50%, 75%, and 100%. The spray pattern was analyzed via the amount of sprayed fertilizer at each collector location and the coefficient of variation was used as an indicator of spray uniformity. Using the analyzed spray pattern, the effective driving width that satisfied less than 15% of the coefficient of variation was derived for different tractor driving patterns (race track mode, back and forth mode). From the results, spray uniformity increased as the shutter opening ratio decreased. The largest effective driving width was 8 m at a shutter opening ratio of 25% for both driving patterns.

Keywords : Centrifugal Fertilizer Distributor(원심식 비료 살포기), Effective Driving Width(유효 살포폭), Uniformity of Spray(살포 균일도), Spray Pattern(살포 패턴)

1. Introduction

Spreading a fertilizer is an essential agricultural work to promote crop growth. After using the chemical fertilizer, the crop production rate has increased by sufficient nutrient supply and improved chemical properties of soil[1]. However, the use of excessive fertilizer caused problems such as environmental pollution[2]. As a solution to the

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problem, there is a growing interest in precision agriculture that has advantages of minimizing environmental pollution and maximizing high quality productions[3]. Precision agriculture can maximize crop yield while minimizing unnecessary fertilizer input by considering the growth status of crops and soil conditions for each location. Precision agriculture has been studied mainly in North America in the 1990s, and it is now in practical use in North America, Europe, and Australia[4]. In South Korea, although the needs for precision agriculture is increasing, the related researches are insufficient[5].

Fertilizer distributors that are widely used in South Korea adopt methods of blowing the fertilizer by high-speed air flow, dropping fertilizer by gravity, and scattering fertilizer by centrifugal force. Among them, blowing-type and dropping-type have restrictions on use when high-viscous fertilizers are used, because of clogging of fertilizer inlet. Therefore, scattering-type distributor by centrifugal force is most often used[6].

Centrifugal fertilizer distributor can be used in multipurpose such as scattering the fertilizer and sowing the seeds[7]. It has advantages of wide spraying area, simple design, high reliability and durability, and low price and maintenance cost. However, it has a disadvantage that the direction of the sprayed fertilizer is unilaterally biased due to it's operating mechanism[8].

Fulton et al. (2005) have analyzed the spray pattern according to the amount of fertilizer in various kinds of distributor. They evaluated the superiority of spray uniformity using 20% of coefficient of variation as a guide[9]. Kim and Lee (2007) analyzed spray uniformity and spray accuracy according to the spray rate and the travel speed in the field to evaluate the performance of the boom-type fertilizer distributor[10].

Han et al. (2014) analyzed the spray pattern of centrifugal fertilizer distributor with three shutter holes to develop uniform spraying system[11]. For the same distributor, Han et al. (2015; 2016) also experimentally investigated the movement of fertilizer particles on a disk by motion analysis using high-speed camera[12-13].

In South Korea, due to the high proportion of small and medium-sized field, compact tractors less than 30 kw of rated engine power have been released that are easy to work in a small area and cheap. Due to size constraints, only centrifugal fertilizer distributors with two shutter holes can be attached to the compact tractors. The two shutter-type centrifugal fertilizer distributor has spiral-shaped blades that differ from flat plate-type blades of the three shutter-type centrifugal fertilizer distributor. The blade shape and shutter hole size are important variables that affects spray pattern[14]. Therefore, spray pattern of two shutter-type distributor will be different from three shutter-type distributor.

In this study, as a preceding research to perform precision fertilization using a compact tractor, the spray pattern of the two shutter-type centrifugal fertilizer distributor was analyzed, and effective driving width to satisfy a proper spray uniformity was derived.

2. Materials and Methods

2.1 Test equipment

2.1.1 Tractor

Fig. 1 A view of the tractor used

Table 1 Specifications of the tractor used

Item	Specification
Model/Company/Nation	C320/Tongyang Moolsan/Korea
Weight (kN)	14.2
Weight distribution ratio (front axle : rear axle, %)	43.2 : 56.8
Length×Width×Height (mm)	3010×1390×2560
Minimum ground clearance (mm)	345
Rated Engine power (kW) /speed (rpm)	23.7/2600

The agricultural tractor was used in the test that has an engine rated power of 23.7 kW at rated rotational speed of 2600 rpm. The tractor has four main transmission gears (1, 2, 3, and 4), and three sub gears (L, M, and H). It is compact and has high minimum ground clearance compared with products of similar engine rated power. Fig. 1 and Table 1 show the shape and specifications of the tractor.

2.1.2 Centrifugal fertilizer distributor

The target centrifugal fertilizer distributor has two shutter holes. It is mounted on the 3-point hitch of the tractor and operated by the power transmitted from tractor's PTO shaft. The main components are a hopper to store fertilizers, two shutters to control the discharge rate of fertilizers, four blades to scatter fertilizers, and a distribution plate to put fertilizers. The operating procedure of the centrifugal fertilizer distributor is as follows: The stored fertilizers in the hopper falls freely on the distribution plate through the two shutter holes. The amount of fallen fertilizers can be adjusted by controlling the shutter opening ratio. The shutter can be rotated from 0° to 43° from its original location. The two holes are fully opened at the shutter rotational angle of 0°, while they are completely closed at shutter rotational angle of 43°.

Based on the hole area, the shutter opening ratios are 25%, 50%, 75% when the shutter rotational angles are 25.5°, 17° and 8°, respectively. The shapes and specifications of the centrifugal fertilizer distributor are shown in Fig. 2 and Table 2, respectively.

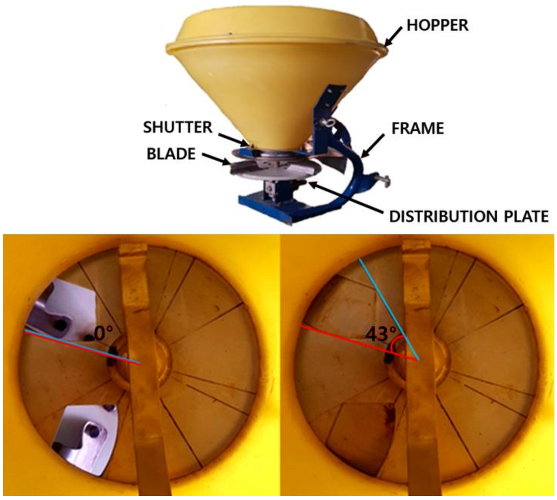


Fig. 2 A view of the centrifugal fertilizer distributor

Table 2 Specifications of the centrifugal fertilizer distributor

Item	Specification
Model/Company/Nation	DP-2000/Dae-Pung /Korea
Weight (kg)	53
Length×Width×Height (mm)	1060×1140×1030
Capacity of the hopper (kg)	140
Distribution range (m)	24

2.2 Test method

2.2.1 Static spray pattern test

Static spray pattern test was conducted to analyze the spray pattern of the centrifugal fertilizer distributor when the tractor was stopped. The test was conducted in accordance with the standard procedure proposed by the American Society of Agricultural Engineers (ASAE STANDARD S341.5)[15]. The shutter opening ratio of the two holes (25%, 50%, 75%,

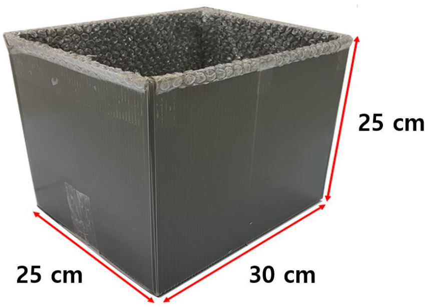


Fig. 3 A view of the collector used

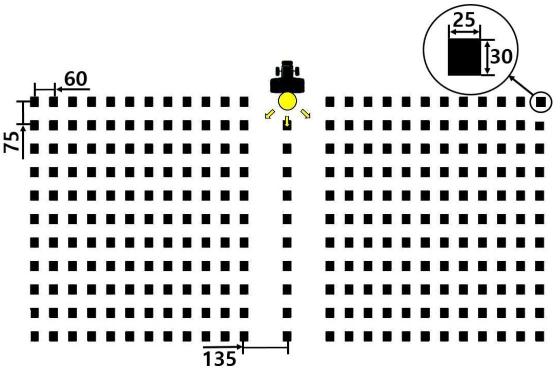


Fig. 4 Arrangement of the collectors in the static spray pattern test

100%) was set as the experimental factors. In each condition, the amount of fertilizer scattered in space was measured using evenly spaced collectors. The shape of the used collector is shown in Fig. 3. The height of the collector is 25 cm, and the width and length are 30 cm and 25 cm, respectively. The collector is made of plastic material and an air buffer was put inside to prevent the fertilizer from being thrown out. The collectors were arranged in 12 rows on each left and right side of the tractor in longitudinal direction with lateral interval of 60 cm. In addition, one row was added with the center line of the tractor. The collectors were arranged in 11 columns in lateral directions with longitudinal interval of 75 cm. Thus, total 275 collectors were used in the static spray pattern test (Fig. 4). The PTO shaft speed was fixed at 540 RPM and the spraying height was

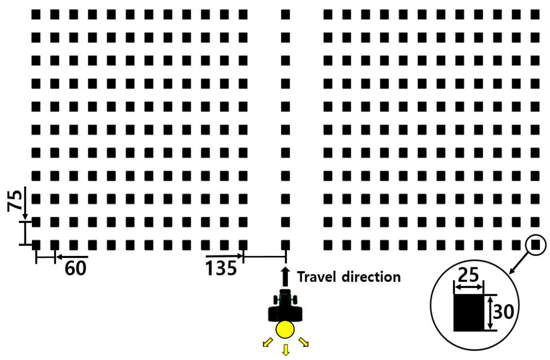


Fig. 5 Arrangement of the collectors in the dynamic spray pattern test

set to 80 cm from the ground. Test time was 30 seconds for each condition and the average value of three repeated tests was used for the representative value.

2.2.2 Dynamic spray pattern test

Dynamic spray pattern test was conducted to analyze the spray pattern of the centrifugal fertilizer distributor when the tractor was traveling. The dynamic test was conducted according to the same standard procedure as the static test. Also, the same experimental factors, spraying height, PTO shaft speed, collector shape, and collector arrangement as in the static test was applied (Fig. 5). Tractor travel speed was set to 1 m/s (transmission gear of L3), and the engine speed was fixed to the rated speed (2600 RPM). Test time was 30 seconds for each condition and the average value of three repeated tests was used for the representative value.

3. Results and Discussion

3.1 Static spray pattern test

Fig. 6 and Table 3 show measured application rate of fertilizer according to shutter opening ratio. The application rate was 533 g/s, 981 g/s, 2,134 g/s, and 3,275 g/s at 25%, 50%, 75%, and 100% of shutter

Table 3 Application rate of fertilizer according to opening ratio of shutter holes

Unit : g/s

Number of tests	Opening ratio of two shutter holes (%)			
	25	50	75	100
1st	523.2	960.0	2025.2	3239.4
2nd	533.8	999.6	2145.6	3296.2
3rd	542.2	982.7	2232.5	3289.4
Average	533.1	980.8	2134.4	3275.0

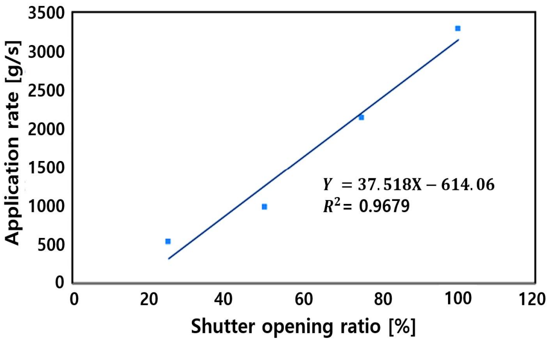


Fig. 6 Application rate according to shutter opening ratio in static condition

opening ratio, respectively (Table 3). The application rate tended to be proportional to the shutter opening ratio.

Fig. 7 and 8 show the amount of sprayed fertilizer at each longitudinal or lateral distance from the tractor center, under static condition. It was derived by adding the amount of fertilizer collected in same row or column of collectors that have a certain longitudinal or lateral distance from tractor center. In lateral application, based on the center of the tractor, the left direction has a negative sign and the right direction has a positive sign. The measured total spraying width was 1,590 cm. As shown in Fig. 8, the amount of sprayed fertilizer on the right side was higher than left side in all shutter opening ratios (25%, 50%, 75%, 100%). This is considered to be due to the clockwise rotation of the distribution plate and blades.

The amount ratio of applied fertilizer between left and right side from tractor center is defined as a R/L ratio (Fig. 9). The R/L ratio were 1.57, 1.42, 1.54, and 1.56 at 25%, 50%, 75%, and 100% of shutter opening ratio, respectively.

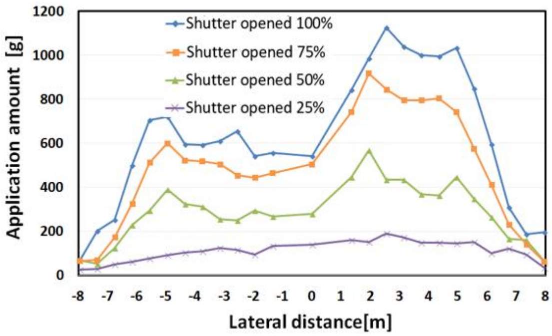


Fig. 8 The amount of sprayed fertilizer in lateral direction according to shutter opening ratio in static condition

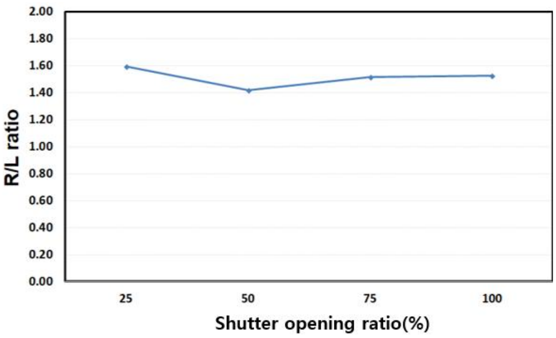
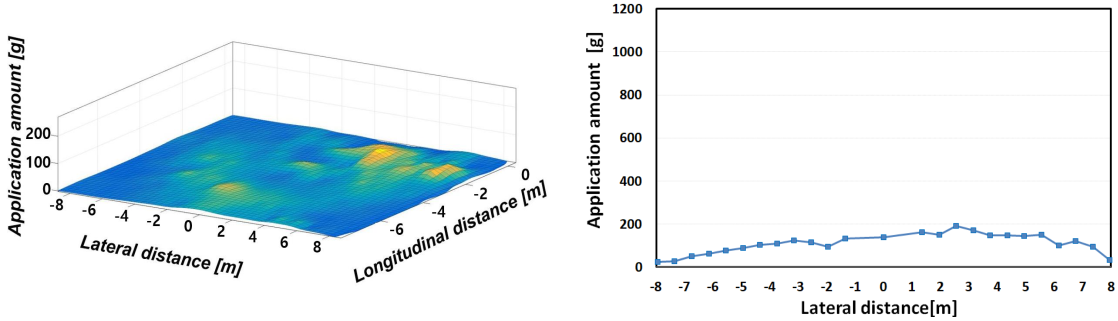
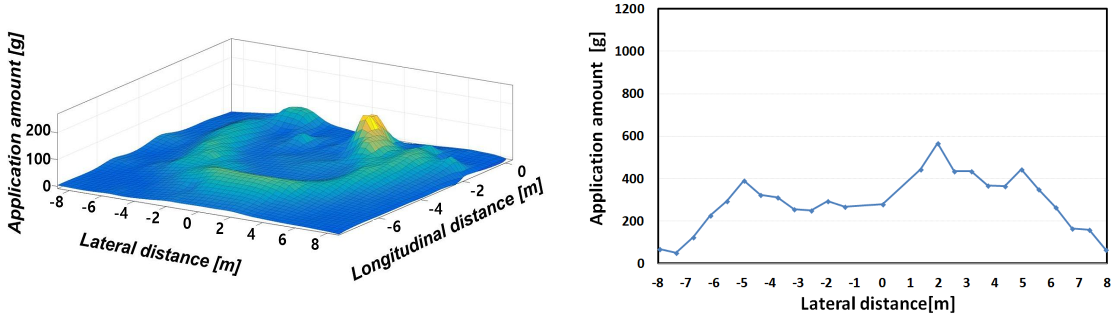


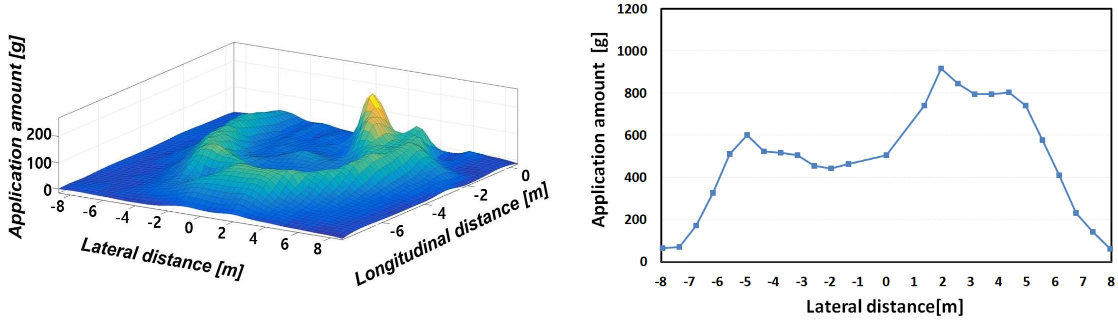
Fig. 9 R/L ratio according to shutter opening ratio in static condition



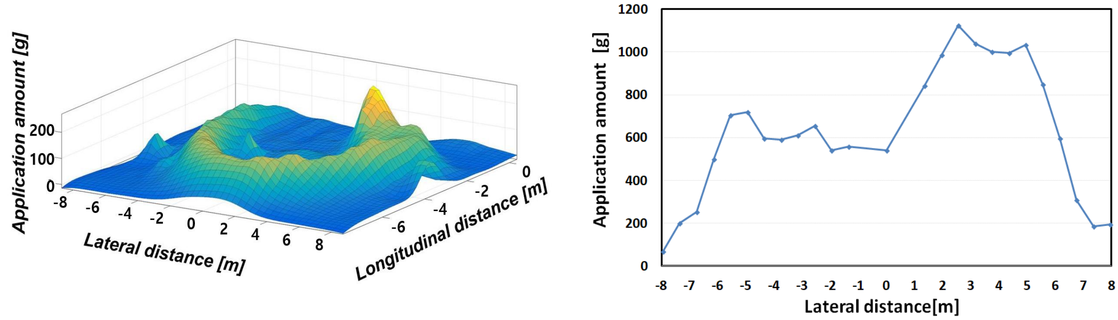
(a) 25%



(b) 50%

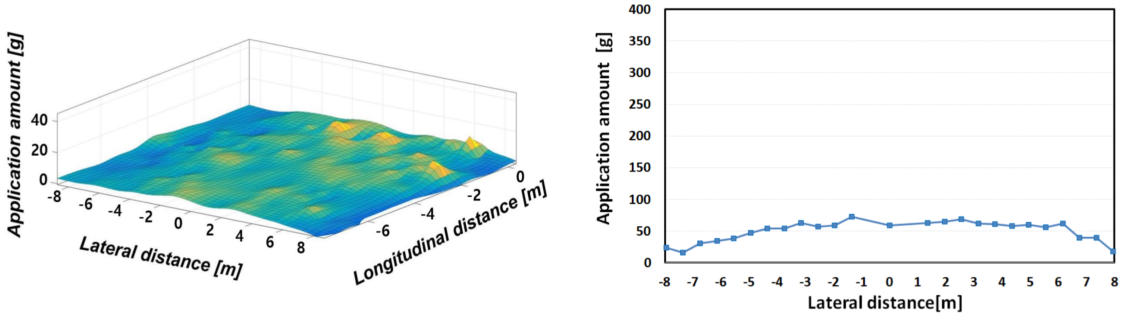


(c) 75%

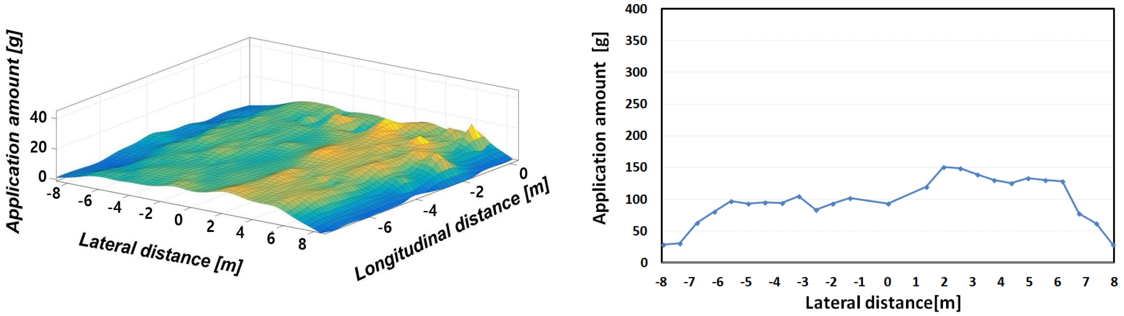


(d) 100%

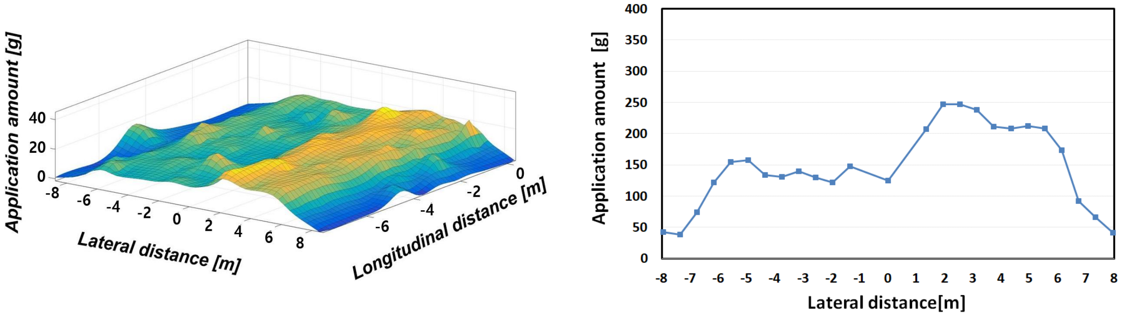
Fig. 7 The amount of sprayed fertilizer according to shutter opening ratio in static condition



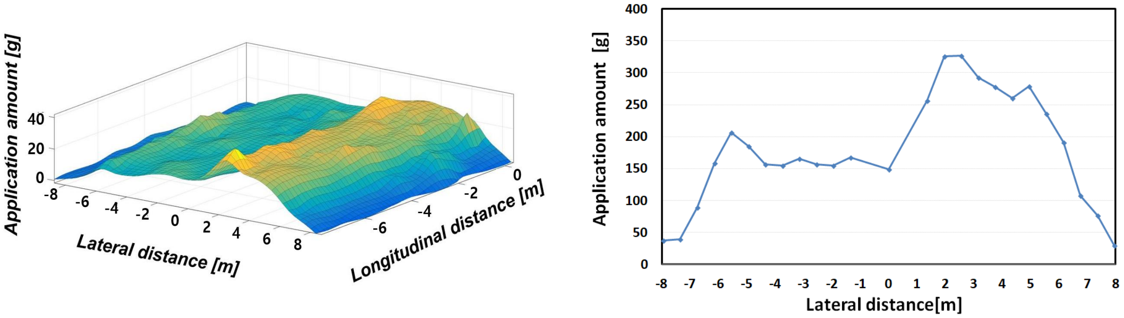
(a) 25%



(b) 50%



(c) 75%



(d) 100%

Fig. 10 The amount of sprayed fertilizer according to shutter opening ratio in dynamic condition

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3.2 Dynamic spray pattern test

Fig. 10 and 11 show the amount of sprayed fertilizer at each longitudinal or lateral distance from the tractor center, under dynamic condition. The application amount by location was derived in the same way as the static test. The measured total spraying width was 1,590 cm. The trends in application amount according to lateral distance were similar as in the static test. In other words, the amount of sprayed fertilizer on the right side was higher than left side.

The R/L ratio in dynamic condition is shown in Fig. 12. The ratio were 1.18, 1.42, 1.54, and 1.59 at 25%, 50%, 75%, and 100% of shutter opening ratio, respectively. It tended to increase as the shutter opening ratio.

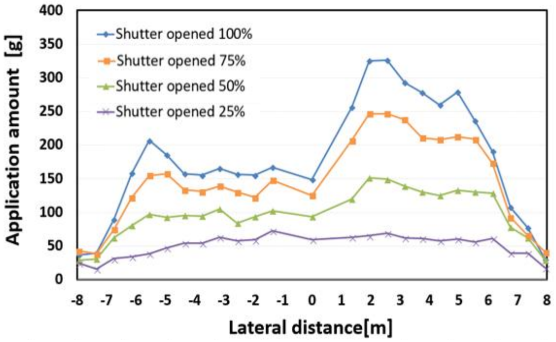


Fig. 11 The amount of sprayed fertilizer in lateral direction according to shutter opening ratio in dynamic condition

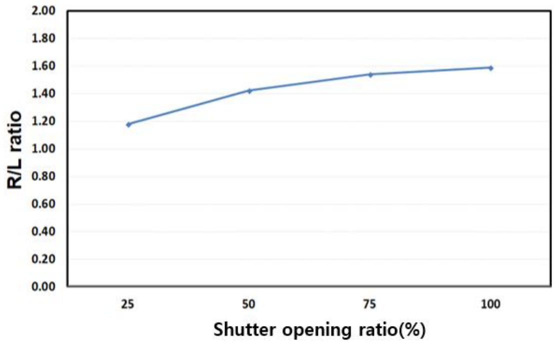


Fig. 12 R/L ratio according to shutter opening ratio in dynamic condition

3.3 Spray uniformity analysis

To investigate the spray uniformity in lateral direction, coefficient of variation (CV) was derived using the result of dynamic spray pattern test. As shown in Equation (1), coefficient of variation for lateral direction can be obtained as a percentage of the standard deviation divided by the average, based on the application amount in each column. The smaller CV means more uniform application in lateral direction[9].

$$CV = \frac{N \times \left[\frac{\Sigma(X_i - X)^2}{N-1}\right]^{\frac{1}{2}}}{\Sigma X_i} \times 100 \qquad (1)$$

Where,

CV = Coefficient of variation for lateral direction (%)

X = Average amount of sprayed fertilizer in each column (g)

X_i = Sum of the collected fertilizer in each column (g)

N = Number of columns

The CV for the total spraying width (1,590 cm) during single path of tractor travel is shown in Table 4. CV values were 33.22%, 36.08%, 42.6%, and 47.11% at 25%, 50%, 75%, and 100% of shutter opening ratio, respectively. It was found that the spray uniformity was the best when the shutter opening ratio is 25%.

Table 4 Coefficient of variation for total spraying width

Shutter opening ratio (%)	Coefficient of variation (%)
25	33.22
50	36.08
75	42.60
100	47.11

Coefficient of variation was analyzed for the tractor travel method of race track mode. The race track mode is the method of tractor traveling that the tractor enters the agricultural field in the same direction with the near line (Fig. 13).

The lateral application amount measured from the dynamic spray pattern test was overlapped to derive total lateral application amount for several times of travel. In this case, the driving width of tractor is critical factor to determine the spray uniformity. Therefore, the effective driving width that has the CV closest to 15% was derived using the overlapped total lateral application amount. The total application amount according to driving width is shown in Fig. 14.

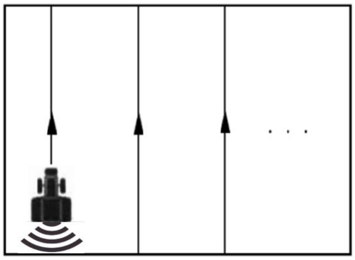
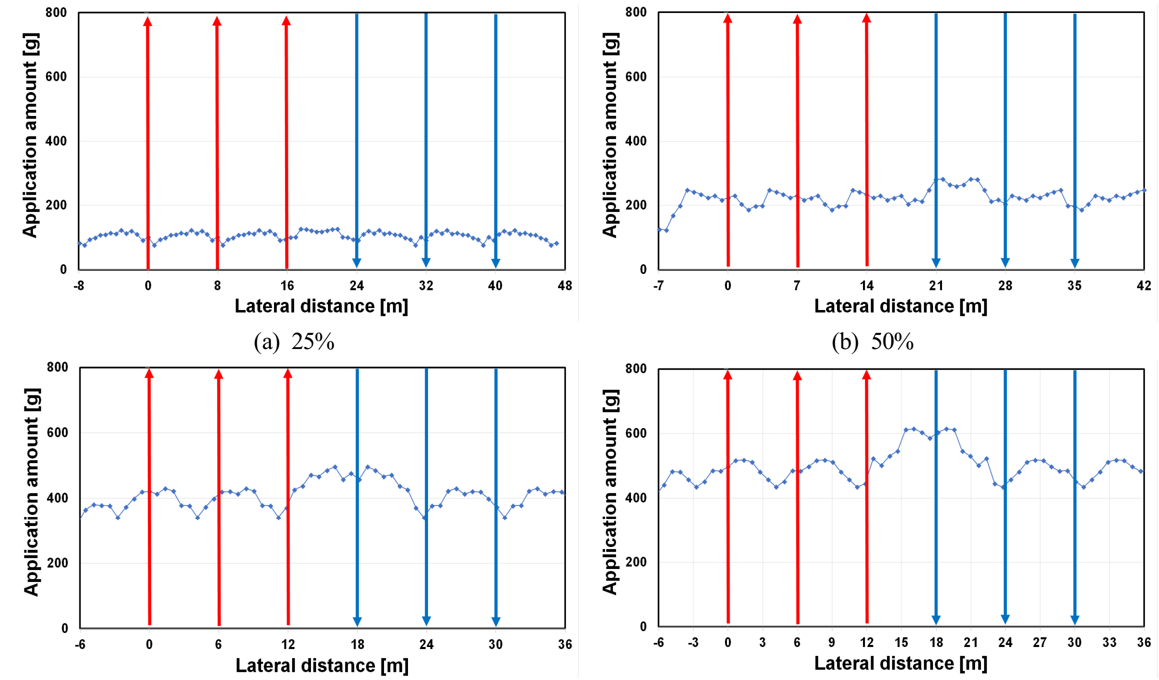


Fig. 13 Operating mode of the race track travel

Coefficient of variation was analyzed for the tractor travel method of back and forth mode. The back and forth mode is the method of tractor traveling that the tractor enters the agricultural field in the opposite direction with the near line (Fig. 15). The lateral application amount measured from the dynamic spray pattern test was overlapped to derive total lateral application amount for several times of travel. The effective driving width that has the CV closest to 15% was derived using the overlapped total lateral application amount. The total application amount according to driving width is shown in Fig. 16.



(a) 25% (b) 50%

(c) 75% (d) 100%

Fig. 14 The amount of the sprayed fertilizer according to driving width in race track mode

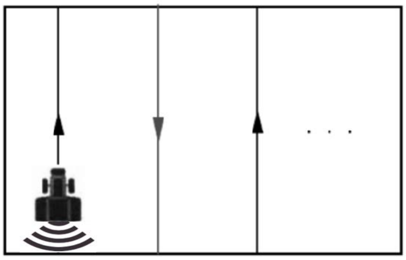


Fig. 15 Operating mode of the back and forth travel

Coefficient of variation closest to 15% according to shutter opening ratio and tractor driving mode is shown in Table 5. The race track mode showed the lower coefficient of variation than the back and forth mode for the same driving width. Also, as the shutter opening ratio was smaller, coefficient of variation was lower.

In the race track mode, the conditions that satisfied CV closest to 15% were tractor driving width of 8 m

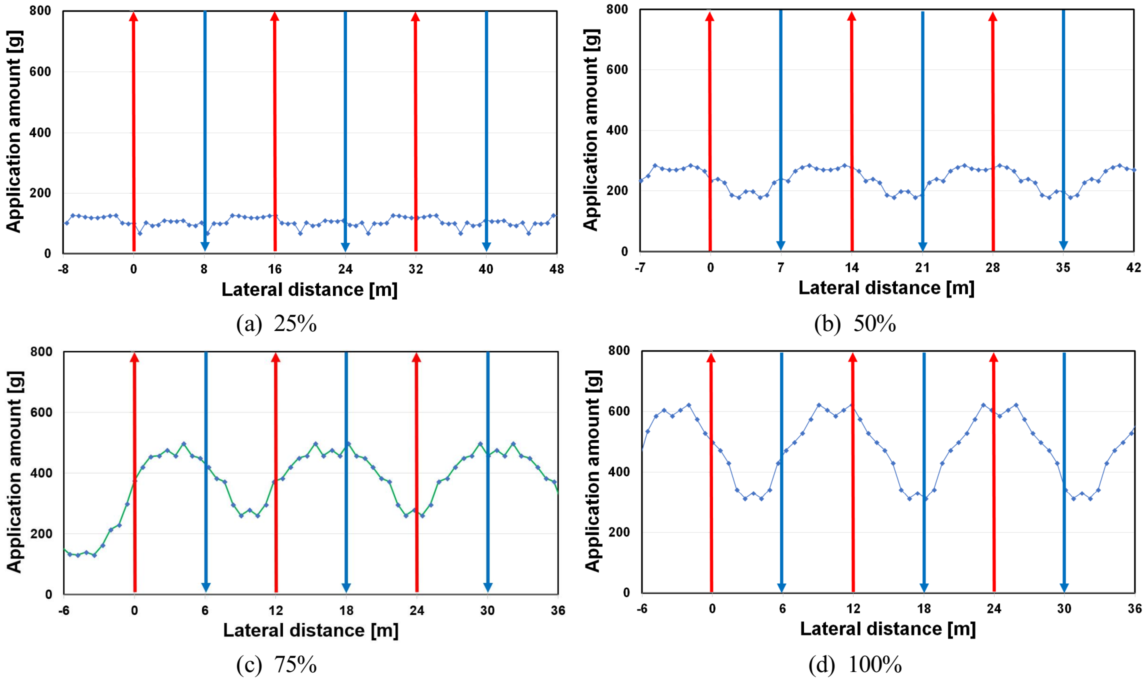


Fig. 16 The amount of the sprayed fertilizer according to driving width in back and forth mode

Table 5 Coefficient of variation closest to 15% according to shutter opening ratio and tractor driving method

Shutter opening ratio (%)	Race track mode		Back and forth mode	
	Tractor driving width (m)	coefficient of variation (%)	Tractor driving width (m)	coefficient of variation (%)
25	8	12.27	8	14.62
50	7	14.24	7	17.60
75	6	19.50	6	24.82
100	6	19.83	6	26.45

at shutter opening ratio of 25% and tractor driving width of 7 m at shutter opening ratio of 50%. For the conditions, CV values were 12.27% and 14.24%, respectively. Also, in the back and forth mode, only one condition satisfied CV closest to 15%. The condition was tractor driving width of 8 m at shutter opening ratio of 25%, and the CV value was 14.62%.

In conditions of shutter opening ratio of 75% and 100%, CV were exceeded 15% for all the driving width and driving methods. In those shutter opening ratios, CV was the lowest when the tractor driving width is 6 m, and it increased when the driving width is shorter or longer than 6 m. It appear that the spraying uniformity does not increase even if the tractor driving width is less than 6 m because R/L ratio is higher in larger shutter opening ratio.

4. Conclusions

This study analyzed the spray pattern of the two shutter-type centrifugal distributor, and effective driving width was derived to satisfy proper spraying uniformity. Through static and dynamic spray pattern tests, the amount of sprayed fertilizer scattered in space was measured through three repeated test by setting shutter opening ratio (25%, 50%, 75%, 100%) as the experimental factors. The scattered fertilizer was collected using the evenly spaced 275 collectors, and the PTO shaft speed and the height of the fertilizer distributor were set at 540 RPM and 80 cm, respectively. The spray pattern was analyzed by the amount of the sprayed fertilizer. Using the analyzed spray pattern, the effective driving width according to the tractor driving pattern (race track mode, back and forth mode) was derived, based on the CV closest to 15%. The main results of this study are as follows:

1. When the shutter opening ratio is 25%, 50%, 75%, 100%, the application rate of fertilizer is 533 g/s, 980 g/s, 2,134 g/s, 3,275 g/s, respectively. The application rate tended to be proportional to the shutter opening ratio.
2. In static spray pattern test, the R/L ratio were 1.57, 1.42, 1.54, and 1.56 at 25%, 50%, 75%, and 100% of shutter opening ratio, respectively. Also, in dynamic spray pattern test, R/L ratios were 1.18, 1.42, 1.54, 1.59 at 25%, 50%, 75%, and 100% of shutter opening ratio, respectively. The amount of sprayed fertilizer on the right side was higher than left side.
3. In single path of tractor travel, coefficient of variation for total spraying width (1,590 cm) were 33.22%, 36.08%, 42.6%, 47.11% at 25%, 50%, 75%, and 100% of shutter opening ratio, respectively. The spray uniformity was the best when the shutter opening ratio is 25%. The coefficient of variation tended to increase as the shutter opening ratio.
4. In the race track mode, conditions that satisfied CV closest to 15% were tractor driving width of 8 m at shutter opening ratio of 25% and tractor driving width of 7 m at shutter opening ratio of 50%. CV values were 12.27% and 14.24% for each condition. Also, in the back and forth mode, only one condition satisfied the CV criteria. It was tractor driving width of 8 m at shutter opening ratio of 25%, and the CV value was 14.62%.

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