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Analysis of Spray Characteristics of Tractor-mounted Boom Sprayer for Precise Spraying

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Abstract

Purpose: This study determines the spray characteristics and effective spray width of a tractor-mounted commercial boom sprayer through experiments. **Methods:** Performance tests were conducted to investigate the spray characteristics of the nozzles on a commercial boom sprayer. The flow rate and spray width of a single nozzle were measured at three levels of spray pressure (0.5, 0.7, and 1.0 MPa) and spray height (15, 30, and 45 cm), respectively. The average value of three repetition tests was used as the representative value. A coefficient of variation (CV) was used as an index of spray uniformity, and the width that guarantees CV values of approximately 15% was determined as the effective spray width. The spray characteristics of the overall boom sprayer were derived analytically by superimposing the spray characteristics of a single nozzle. **Results:** The test results for a single nozzle showed that the spray width tended to increase as the spray height and spray pressure increased. The effective spray width for a single nozzle was the largest at a spray pressure of 1.0 MPa and spray height of 45 cm, which resulted in a coverage of 84 cm of width. The effective spray width for the entire boom sprayer was also the largest at the spray pressure of 1.0 MPa and spray height of 45 cm, with a magnitude of 424.5 cm. The chemical spraying work in an actual field was simulated by applying a spray width of 400 cm. As a result of the operation for three swaths, the CV value was less than 10% for 1,200 cm of the overall spray width, which meant that uniform application was achieved. **Conclusions:** It was reasonable to set the effective spray width of the boom sprayer used in this study to 400 cm.

Keywords: Boom sprayer, Performance analysis, Precise spraying, Tractor

Introduction

Chemical application is an indispensable agriculture work to prevent pests and diseases and to increase crop yields. This important task must be carried out several times during the cultivation period of the crop. This work must be performed safely and efficiently because such chemicals may cause pesticide poisoning of the farmer. In addition, pesticide residues in crops and the contamination of soil and ground water adversely affect the consumers' health and the environment (Shim et al., 2015).

The types of sprayers used in Korea include the knapsack-type sprayers, which use mechanical power or manpower; mist and dust blowers, which apply pesticides in an atomized state; and boom sprayers, which spray pesticides through nozzles on the boom. The knapsack-type sprayers and mist and dust blowers currently used demand a hard work from the farmer, even in the case of a powered-pump equipment, which is disadvantageous in terms of work efficiency and safety. To overcome this, it is necessary to use a tractor-mounted boom sprayer (Kim, 2000).

Because the chemical application work significantly influences the crop yield and economic efficiency of agricultural production, proper chemical application is very important. An overdose causes environmental pollution and economic loss, while an under-dose reduces the control effect on the disease and insect pest, resulting in poor productivity.

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Precise control is required to work effectively considering all the effects of the various operating conditions, such as travel speed of tractor, application amount, and application density. A proper control strategy is also necessary to adjust all the related variables simultaneously, and this should be preceded by investigation on the accurate spray characteristics of the used sprayer.

Koo and Jung (1998) developed a boom sprayer in which a travel-speed compensated total flow control mode was applied in order to maximize the chemical application effect, and evaluated its performance through a field test. Chung et al. (1995) compared and analyzed the spray pattern of different nozzle types as a prior research for the development of a boom sprayer. Cho et al. (1996) developed a system that can automatically control the amount of application depending on the travel speed for precise application. Until now, studies on the boom sprayer have just compared the spray characteristics of the prototype or single nozzle, and few studies have been conducted on the commercial product.

In this study, a performance test was carried out to investigate the spray characteristics of a tractor-mounted commercial boom sprayer. Using the derived spray characteristics, the effective spray width was determined at the actual field work. The results of this study can be utilized as basic data for site-specific precision chemical application.

Materials and Methods

Experimental sprayer

The shape of the tractor-mounted boom sprayer in this study is shown in Figure 1. The boom sprayer is mounted on the 3-point hitch of a tractor (T680, Dongyangmoolsan, Korea), and operated by the power from the tractor PTO shaft. Major components of the boom sprayer are the barrel, power sprayer pump, and boom, where 13 nozzles are installed at intervals of 30 cm. The capacity of the barrel is 200 L, and the major specifications of the power sprayer pump and nozzle are presented in Table 1 and Table 2, respectively.

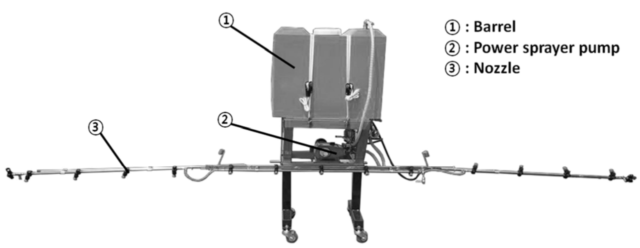


Figure 1. Structure of boom sprayer used in this study.

Experimental setup

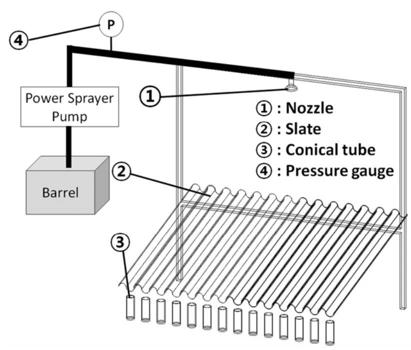
An experimental apparatus was constructed as shown in Figure 2 to investigate the spray characteristics of a

Table 1. Specifications of power sprayer pump

Item	Specifications	
	Rated	Maximum
Model/Manufacturer	BY-30A / Bumyang Co.	
Rated rotation speed (rpm)	750	
Discharge rate (L/min)	18	
Pressure (MPa)	2.3	3.5
Power (hp)	1.0	1.5

Table 2. Specifications of spray nozzle

Item		Specifications
Model/Manufacturer		N-KA-055SB/Yamaho
Maximum spray reach (m)		2
Flow Rate (L/min)	at 0.7 MPa	0.36
	at 1.0 MPa	0.43
Injection angle (°)		110
Injection hole diameter (mm)		0.55



(a) Schematic view

(b) Slanted plate

(c) Conical tubes

Figure 2. Experimental apparatus.

single nozzle. A boom with a nozzle was placed horizontally with a device to move it up and down to adjust the spray height as needed. The sprayed water was collected using a pleated-plate made of galvanized steel with 3.5 cm of furrow interval and conical tubes underneath the plate. The plate was placed slightly slanted so that the sprayed water could flow down naturally into a conical tube (50 ml of capacity). A pressure gauge (1.5 MPa, HISCO, Seoul, Korea) was installed in the pipe line of the boom to check the spray pressure.

Experimental conditions

The rotational speed of the PTO shaft was set to 750 rpm, which is the rated speed of the power sprayer pump, and the nozzle was kept open for 60 s to take a measurement of the flow rate. The lateral directional flow rate in ml/min for a single nozzle was obtained by the amount of liquid collected in each conical tube location.

As experimental factors, the spray pressure and height were selected, and the tests were replicated 3 times under each operating condition. The spray pressure was controlled by the regulator of the power sprayer pump and the spray height was determined by fixing the boom to a pre-determined position in the vertical supports. The setting levels for each experimental factor were determined considering the specifications of the spray nozzle, and their values are as follows:

① spray pressure : 0.5, 0.7, 1.0 MPa
② spray height : 15, 30, 45 cm

A coefficient of variation (CV) was chosen as an index of spray uniformity in the lateral direction from the nozzle position (ASAE S341.4, 2015). The CV is defined as the ratio of a standard deviation to a mean. In this study, it is calculated as in Equation (1) in terms of the amount of liquid collected in the conical tubes placed evenly beneath the furrows of the pleated-plate and number of tubes. A smaller CV means that spraying is done more uniformly.

$$CV = \frac{\sigma}{X} \times 100 \quad (1)$$

where σ=Standard deviation for amount of liquid collected in each conical tube, ml
X=Arithmetic mean for amount of liquid collected in each conical tube, ml

The test was conducted using a single nozzle, and the overall lateral directional spray characteristics of the boom with complete nozzles were analytically derived by superimposing the test results of a single nozzle.

Results and Discussion

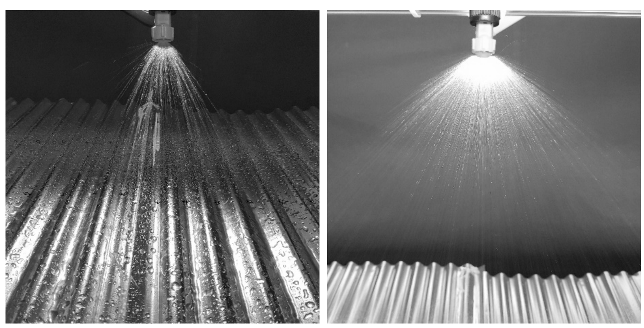
Spray characteristics of a single nozzle

Figure 3 shows spraying shapes at different spray pressures. The spray characteristics of a single nozzle according to the combination of spray pressure and height are as shown in Figure 4, where the flow rates indicated on each location were the average value of 3 replications. The lateral directional flow rate was almost the same in repeated tests under the same condition.

It was observed that the spray patterns were symmetrical in the lateral direction with respect to the nozzle position. The spray width tended to increase as the spray height and spray pressure increased. The spray width was the largest under the operating conditions of 1.0 MPa in spray pressure and 45 cm in spray height, with a magnitude of approximately 147 cm.

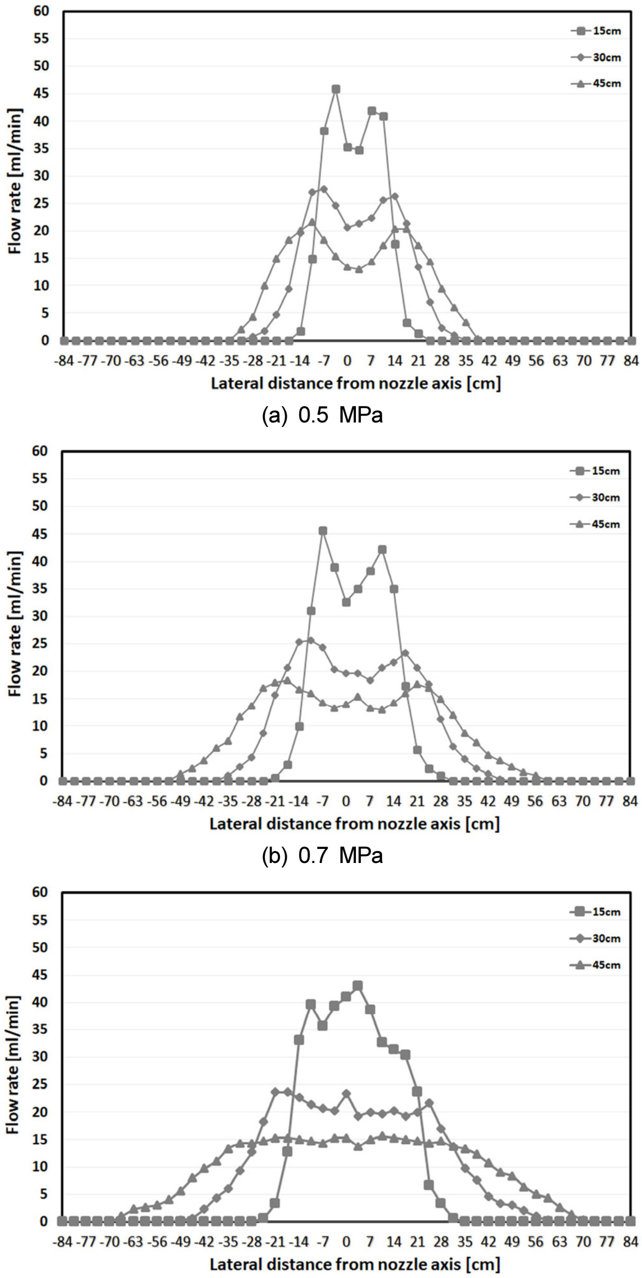
The CVs were calculated over the entire spray width for a single nozzle, and they are presented in Table 3. When moving away from the nozzle position in the lateral direction, the flow rate rapidly dropped after a certain point, so that the CV over the entire spray width was between 40.5% and 72.9%.

The flow rate was relatively uniform up to the specific spray width in the lateral direction from the nozzle position. As the spray width in consideration decreases, its CV would be reduced because the lateral directional spray becomes more uniform. By reducing the considered spray width, the CV was recalculated and the width at



(a) 0.5 MPa (b) 1.0 MPa

Figure 3. Picture of spray shape at different spray pressures.



(a) 0.5 MPa

(b) 0.7 MPa

(c) 1.0 MPa

Figure 4. Spray characteristics of a single nozzle.

which it became less than 15% was determined as the effective spray width. Because the interval between adjacent conical tubes, that is, the measurement resolution of lateral directional flow rate, is 3.5 cm, the effective spray width for a single nozzle is a multiple of 3.5 cm.

Table 4 presents the effective spray width under each operating condition. Under all spray-height conditions, the effective spray width increased to 2 times at 0.7 MPa and to 3 times at 1.0 MPa, compared to 0.5 MPa of spray pressure. Moreover, under all spray pressure conditions,

Table 3. CV for the entire spray width of a single nozzle

Item		CV (%)
Height (cm)	Pressure (MPa)	
15	0.5	67.0
	0.7	67.9
	1.0	40.5
30	0.5	72.9
	0.7	61.8
	1.0	52.0
45	0.5	61.6
	0.7	64.2
	1.0	54.9

Table 4. Spray width of a single nozzle with CV about 15%

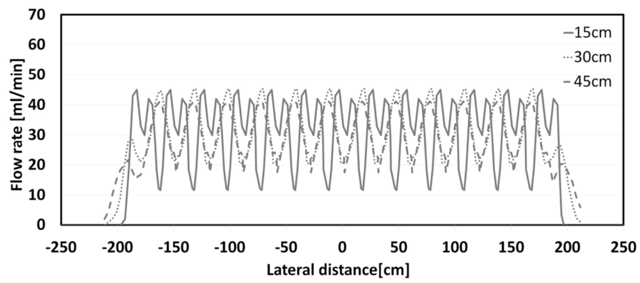
Item		CV (%)	Spray width in consideration (cm)
Height (cm)	Pressure (MPa)		
15	0.5	12.1	14
	0.7	13.9	28
	1.0	11.1	42
30	0.5	12.4	21
	0.7	13.4	42
	1.0	13.3	63
45	0.5	16.6	28
	0.7	13.4	56
	1.0	11.2	84

the effective spray width increased to 1.5 times at 30 cm and to 2 times at 45 cm, compared to 15 cm of spray height. The effective spray width was the largest at a spray pressure of 1.0 MPa and a spray height of 45 cm, and its magnitude was 84 cm.

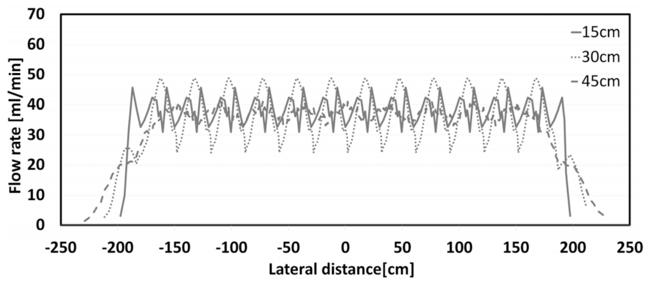
Spray characteristics of the boom sprayer

The spray characteristics of the boom sprayer equipped with 13 nozzles were derived analytically by superimposing the spray characteristics of a single nozzle. The seventh nozzle position in 13 nozzles was set to 0 cm of the lateral position.

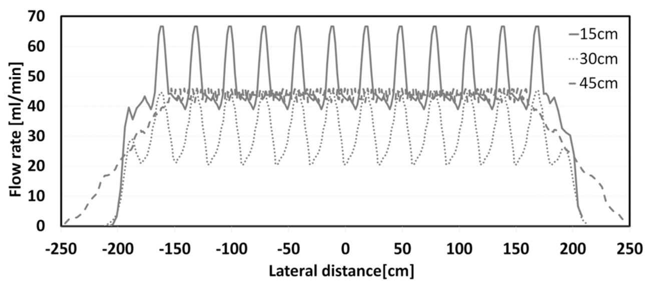
The spray characteristics of the boom sprayer under each operating condition are presented in Figure 5. In the lateral direction, the most uniform application was observed under the condition of spray pressure of 1.0 MPa and spray height of 45 cm, while the most uneven application occurred under the condition of spray pressure of 0.5 MPa and spray height of 15 cm.



(a) 0.5 MPa



(b) 0.7 MPa



(c) 1.0 MPa

Figure 5. Spray characteristics for the boom sprayer.

Table 5. CV for the entire spray width of the boom sprayer

Item		CV (%)
Height (cm)	Pressure (MPa)	
15	0.5	43.47
	0.7	32.98
	1.0	28.95
30	0.5	17.42
	0.7	26.24
	1.0	20.64
45	0.5	25.61
	0.7	20.88
	1.0	22.78

The CVs over the entire spray width of the boom under each operating condition are presented in Table 5. The CVs were in a range between 17.42% and 43.47%, which showed that the superimposition effect of the nozzles guaranteed more uniform application compared to a single nozzle.

Table 6. Spray width of the boom sprayer with CV of about 15%

Item		CV (%)	Spray width in consideration (cm)
Height (cm)	Pressure (MPa)		
15	0.7	13.6	388.0
30	1.0	14.6	416.0
45	0.7	14.3	416.0
	1.0	14.5	424.5

The spray widths having CV of about 15% under each operating condition are presented in Table 6. The spray widths with a CV lower than 15% could be obtained only in four cases of the operating conditions. These were the spray pressure of 0.7 MPa at 15 cm in height, 1.0 MPa at 30 cm, and 0.7 and 1.0 MPa at 45 cm, respectively. Under the other conditions, there was no spray width with a CV of less than 15%. Therefore, for a uniform chemical application, one of these four conditions should be applied to the chemical application work. Among these conditions, the 45 cm in spray height and 1.0 MPa in spray pressure conditions, with the largest spray width, are considered as the most suitable working conditions in terms of work efficiency. The effective spray width of the entire boom was 424.5 cm under this operating condition.

Spray characteristics of boom sprayer in actual field operation

The spray characteristics in the actual field operation were investigated based on the simulated spray characteristics of the boom sprayer. The operating condition of spray pressure of 1.0 MPa and spray height of 45 cm was assumed, and 400 cm of spray width was applied. The spray width was determined as a slightly lower value than the effective spray width derived in Table 6, considering the possible non-uniformities in the actual field. The spray characteristics for 3 swaths in the field were derived under the pre-determined conditions.

The two types of application methods mainly used in chemical application works are the race track and back and forth modes (Fig. 6). With the former, the spraying work is performed in the same direction in the successive adjacent swaths, while with the latter, it is carried out in the alternate direction every adjacent swath (ASAE S341.4, 2015).

The spray characteristics of the boom sprayer in the race track mode are shown in Figure 7. The CV was 7.13% over the entire spray width of 1200 cm. The spray width

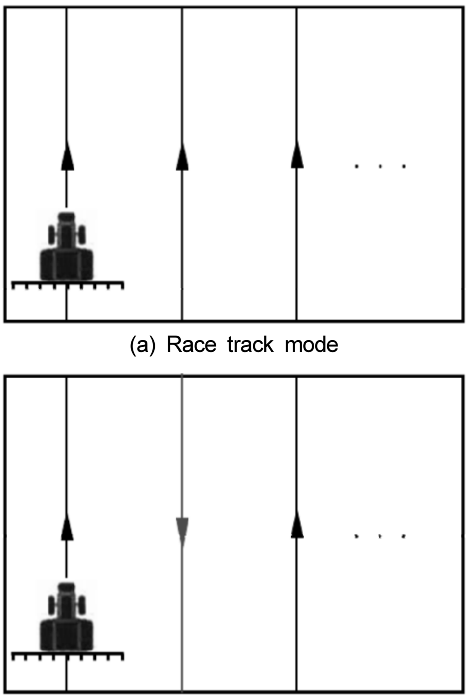

(a) Race track mode
(b) Back and forth mode

Figure 6. Operating modes for chemical application work.

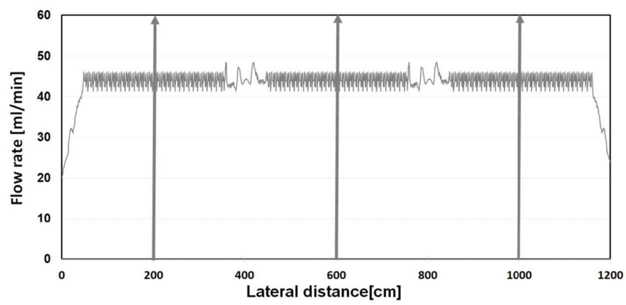


Figure 7. Spray characteristics at race track mode.

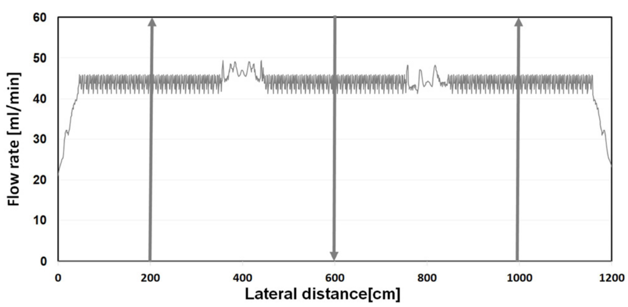


Figure 8. Spray characteristics at back and forth mode.

under which the boom sprayer applied chemicals with higher uniformity was 1117.5 cm, with a CV of 3.38%.

Figure 8 shows the spray characteristics of the boom sprayer operated in the back and forth mode. In the same manner as the race track mode, the CV over the entire spray width was 7.24%. The spray width under which the chemicals were sprayed more uniformly was 1117.5 cm, with a CV of 3.61%.

Because there was no significant difference between the two operating modes, the driver can choose any operating mode according to his own convenience.

Conclusions

In this study, the spray characteristics of a tractor-mounted commercial boom sprayer were investigated and the effective spray width was determined for the actual field operation.

Experimental equipment was constructed for investigating the spray characteristics of a single nozzle, at 3 levels of spray pressure and 3 levels of spray height. The tests were replicated 3 times under each operating condition.

The test results showed that the spray width increased as the spray height and pressure increased. The spray width necessary to have a CV of about 15% was determined as the effective spray width. The effective spray width of a single nozzle was the largest at a spray pressure of 1.0 MPa and a spray height of 45 cm, and its size was 84 cm. The overall spray characteristics of the boom sprayer were derived analytically by superimposing the spray characteristics of a single nozzle. The effective spray width was the largest at a spray pressure of 1.0 MPa and a spray height of 45 cm, and its size was 424.5 cm.

The spray characteristics in actual field operation were investigated by using the simulated spray characteristics of the boom sprayer. Between the two application methods, race track mode and back and forth mode, the CV for the transverse direction did not show significant difference, and both methods showed CVs lower than 10%.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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