



Performance Evaluation of a Boomless Oscillating Field Sprayer at Different Spraying Pressures and Oscillating Rates

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ABSTRACT: The efficiency expected from any pesticide depends largely on the type of plant protection machine used in spraying and the operating parameters of the selected machine. Today, sprayers with different spraying wing width are widely used in field spraying. Especially with field sprayers with large working widths, it is difficult to work at high spraying speeds due to the wing width and wing weight. In this study, wingless field sprayer effectiveness was evaluated. Occasionally for spraying instead of sprayers with standard type field spraying booms, the field sprayers with commercial name Electropar, which are operated with high pressure and with oscillating nozzles are used. Since the sprayer has no wings, it can spray at high tractor speeds. optimum working width of this sprayer, pestisit distribution uniformity on a horizontal surface, etc. Its parameters are unknown. In this study, the optimum working width provided by the sprayer at different operating pressures and nozzle oscillation rates, and volumetric fluid distribution throughout the working width and optimum working parameters were determined. The three different working pressures (1, 2 and 3 MPa) and the transverse volumetric fluid distribution of the three jet nozzle units moving in opposite directions relative to each other on a horizontal ground at two oscillations (44 and 60 rpm) were determined by a portable patternator. Operation of the high-pressure cone jet nozzle unit at 1 MPa pressure and 60 rpm oscillating speeds provided a more uniform transverse distribution than other operating parameters. The increase in operating pressure caused an increase in the volume of fluid accumulated in the patternator's grooves at the same working height and sampling distance. The optimum working width, depending on the operating conditions specified by the boomless sprayer, varied between 11.20 and 12.80 m depending on the spray unit oscillating speed and spray pressure.

Keywords: High pressure jet nozzles, Patternator, Transverse distribution, Spray width

Kolsuz Salımlı Tarla Pülverizatörünün Farklı Püskürtme Basınçlarında ve Salınım Hızlarında Performans Değerlendirmesi

ÖZ: Herhangi bir tarım ilacından beklenen etkinlik, büyük oranda pülverizasyonda kullanılan bitki koruma makinası çeşidine ve seçilen makinanın işletme parametrelerine bağlı olarak değişmektedir. Günümüzde tarla ilaçlamalarında yaygın olarak farklı ilaçlama kanat genişliğine sahip tarla pülverizatörleri kullanılmaktadır. Özellikle büyük iş genişliği olan geniş ve ağır kanatlara sahip tarla pülverizatörleri ile yüksek ilaçlama hızlarında çalışmak zorlaşmaktadır. Bu çalışmada kanatsız tarla pülverizatörü etkinliği değerlendirilmiştir. Zaman zaman pülverizasyon için standart tip tarla pülverizatörleri yerine, yüksek basınçlı ve salımlı memelerle çalışan Elektropar ticari adlı tarla pülverizatörleri kullanılır. Kanadı olmadığı için yüksek traktör hızlarında püskürtme yapılabilir. Bu pülverizatörün optimum çalışma genişliği, yatay bir yüzeyde yaptığı pestisit dağılımının homojenliği, vb. parametreleri bilinmemektedir. Bu çalışmada, farklı çalışma basınçlarında ve salınım hızlarında pülverizatörün sağladığı optimum çalışma genişliği ve çalışma genişliği boyunca hacimsel sıvı dağılımı ve optimum çalışma parametreleri belirlenmiştir. Yatay bir zeminde birbirine göre zıt yönlere hareket eden üç jet meme ünitesinin iki salımlı (44 ve 60 rpm) üç farklı çalışma basıncı (1, 2 ve 3 MPa) ve enine hacimsel sıvı dağılımı taşınabilir bir paternatör tarafından belirlenmiştir. Yüksek basınçlı konik jet meme ünitesinin 1 MPa basınçta ve 60 rpm salınım hızında çalışması, diğer çalışma parametrelerine göre daha düzgün bir enine dağılım sağlamıştır. Çalışma basıncındaki artış, aynı çalışma yüksekliği ve örnekleme mesafesinde paternatörün oluklarında sıvı birikimi hacminde artışa neden olmuştur. Kolsuz pülverizatör tarafından belirlenen çalışma koşullarına bağlı olarak optimum çalışma genişliği, püskürtme ünitesinin salınım hızı ve püskürtme basıncına bağlı olarak 11.20 ile 12.80 m arasında değişmiştir.

Anahtar Kelimeler: Yüksek basınçlı jet memeler, Paternatör, Enine dağılım, Püskürtme genişliği

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INTRODUCTION

In pest management, homogenous distribution of sprayed pesticide on target surface is an important aspect. The purpose is to carry out the most efficient pest management through the least spraying for a successful pest, disease and weed control. Thus, environmental risks are reduced, and cost-efficient agricultural management is performed. Homogenous distribution of chemicals on target surface is closely related with uniformity of covering branches and leaves of plants with fungicides (Göhlich, 1985).

Distribution of pesticide is determined with different methods in laboratory and field conditions. The equipment called patternator is used in laboratory environment for measuring distribution of a steady nozzle (Harrell, 2003; Debouche et al., 2000; Özkan and Ackerman, 1992). The spray distribution significantly varies depending on changes in pressure. Distribution quality of the spraying nozzles are based on several parameters such as the static and dynamic parameters of sprayer boom. In addition to this, the distribution is also affected by environmental conditions (Sinfort and Herbst, 1996). Accumulation and distribution of fungicide applied on the target surface is not only affected by flow rate of a single nozzle, but also by several factors such as nozzle spray pattern, spray direction, auxiliary airflow, drop dynamics (Foqué et al., 2012; Xie et al., 2015). For an ideal transverse distribution of field sprayers, the fluid levels collected in the receiving tubes of patternator grooves should be as much as the others. In other words, the volumes that accumulated in tubes must be in the form of a straight line parallel to the horizontal (Ergül and Dursun, 2003).

There are some methods which are used for determining the distribution quality of a spray on horizontal surface of a farm field (Anonymous, 2017). One of these methods is to make a decision based on the variability of spray water collected in grooves of a horizontal patternator. On this purpose, the CV% value which indicates the change in water collecting in the grooves along the spray width, should be calculated. Either the changes of the spray pattern of a single nozzle or the changes of

volumetric calculations along the spray booms of a field crop sprayer can be evaluated in accordance with the CV% value.

The commercial field sprayers are generally effected by soil unevenness and on the sprayer booms there are much vibrations which disturb spray pattern, increase the CV % value. Itmeç and Bayat (2019), analyzed the most used sprayer booms (10 m) in Turkey via a CAD program. As a result, fully cantilever beam profile system's natural frequency is 8.45 Hz. As the length of the boom increase, the rigidity of the sprayer booms decreases. There are too many studies about vibration damping and determining the vibration characteristics of the field sprayer boom (Lardoux et al., 2007; Ooms et al., 2002; Anthonis and Ramon, 2003). Nation (1982), explained that to resist these uncontrolled vibrations field sprayer booms must be rigid as possible. Therefore, the opinion of boomless field sprayer can be innovative design. Some companies manufacture an alternative sprayer for herbicide applications at higher spray rates ($L s^{-1}$) called as boomless oscillating field sprayer (Electro-jet, Parlayan Agriculture Company, Manisa/Turkey) which does not have spraying booms to eliminate vibrations. Instead of spray booms, these sprayers have only three high-pressurized nozzles and an oscillation system for those three nozzles.

In the study, boomless oscillating field sprayer (Electro-jet) performance was evaluated. The Electro-jet sprayer has two conical nozzles working with high pressure and a fan nozzle. The spray transverse distribution of the its sprayer is unknown. In this study, it has been tried to determine the optimum working width with the volumetric fluid distribution provided by the sprayer on a horizontal floor, at three different operating pressures and two oscillation speeds.

MATERIAL AND METHOD

In the study, the tractor mounted type boomless oscillating field sprayer with 600 L tank capacity and a high pressure piston-membrane pump (Italian AR 1064, 106 L rpm, 4 pistons, 50 bar) was used (Figure 1).

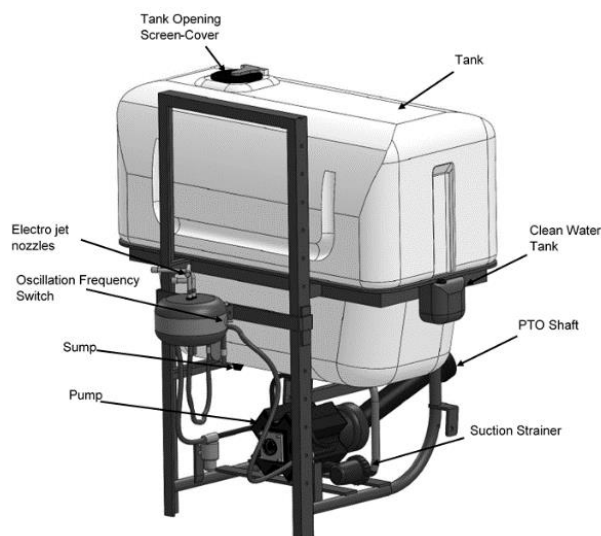


Figure 1. Electro-jet boomless sprayer (Parlayan Sprayer Company, Turkey)

The experiment was carried out at three different pressures (1, 2, 3 MPa) and the volumetric fluid distribution at the horizontal surface of the spray jets at two oscillation rates (44 and 60 rpm) was determined to find the optimum working width. The water in the tank was sprayed by a double-headed nozzle lances which were moving reverse oscillation towards right-left on mounted instead of standard spray booms of the sprayer. The lances were operated by a DC motor having four bar mechanism all in a closed box. The DC motor powered by tractor's battery which was operated in two different

revolutions and the nozzles on the spray unit were designed to oscillate reverse to each other. Both of oscillating nozzles sprayed along 180 degrees in each oscillation.

One of the oscillating lance had two nozzles in which of them was cone full nozzle (2.5 mm orifice diameter) and other a flat fan nozzle (long edge 3.6 mm, short edge 2.2 mm) however, the other oscillating lance had only one cone full nozzle (2.5 mm orifice diameter). The volume flow rate of the boomless oscillating sprayer used in the research are given in Table 1.

Table 1. Operating parameters of the Boomless oscillating field sprayer

Nozzle Pressure (MPa)	Nozzle Flowrate (L rpm)		
	Lances with two nozzles		Lance with one nozzle
	Cone nozzle	Flat Fan nozzle	Cone nozzle
1	7.60	4.02	7.75
2	10.30	5.43	10.70
3	12.40	6.93	12.70

In order to determine the transverse static spray distribution of the boomless oscillating sprayer, a 1200x800 mm portable patternator with 50 mm grooves depth and 50 mm grooves width equipped with graduated tubes was used. On the patternator, there were 23 grooves which can measure the distance of 1.15 m horizontally. The boomless oscillating sprayer was operated without a patternator, at three different pressures 1 MPa, 2 MPa and 3 MPa, and two oscillation revolution of 44 rpm and 60 rpm. Because of the plate hole diameter is larger than the nozzles used in field sprayers, nozzles on the machine can create drops at high pressures, just like a spray gun. Higher drop out speed is needed

for higher spray width. This can be achieved with high pressure. Because would be drop's speed just before impact is $V = \sqrt{2gh}$ (Halliday et al., 2017). Here h indicates pressure in terms of column of water. The electro-jet creates a spray pattern with only 3 nozzles oscillating. In order to understand the horizontal distribution pattern of the electro-jet in the field spraying, the wetting area was determined by operating the electro-jet at a speed of 44 rpm and a pressure of 1 MPa. The rails on which the patternator will move are extended to the midpoint of the wetting area formed as a semicircle with a diameter of 14.30 m, perpendicular to the direction of progress (a =

2.70 m). Measurements were continued by advancing the patterner on the rail from left to right each time as much as its own length. The same procedures were repeated for each patterner position of the spray applications of three different pressures of the 60 rpm

oscillation speed of the electro-jet. Accordingly, the widest wetting area of the boomless oscillating field sprayers' operation was determined. Finally, the rail system was mounted on the widest wetting area to collect water in all operating conditions (Figure 2).



Figure 1. The mechanism in which experiments are carried out

As shown in Figure 3, via a rail system the patternator was pulled along the wetting area left to right according to the travelling of the simulated tractor. In order to ensure that each spraying was applied for 180 seconds, the spray flow was adjusted through the control lever located on the sprayer regulator. The patternator measurements were taken

in the same position each with three replications. By the way, distribution of the application also discovered and the data was overlapped. After wetting area determination of each process condition, the experiments were started with patternator which was on a rail system with three different pressures and two oscillating rates.

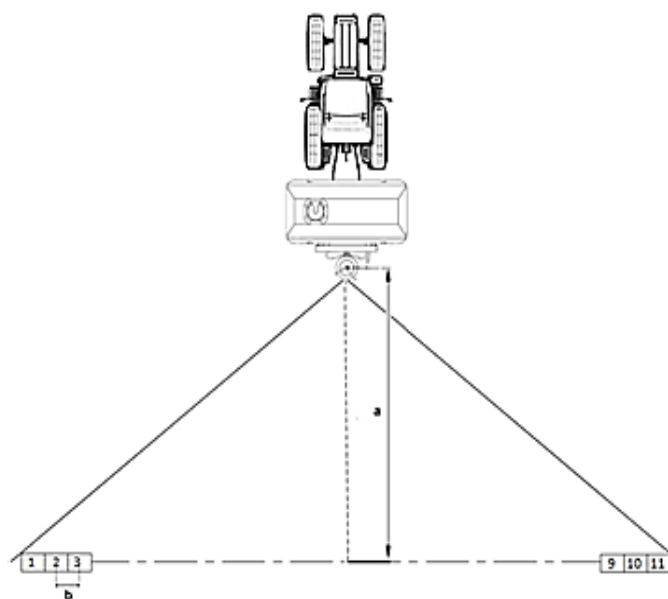


Figure 2. The method for measuring transverse spray distribution of field sprayer

During the working of the boomless oscillating sprayer, the pesticide must be overlapped a little bit on the surface of the field in each pass to distribute the pesticide better. In experiments data was obtained stationary condition, therefore for each operation data must be overlapped according to the middle axis. The CV% values was calculated for both the steady and the overlapped conditions which was determined for each experiment.

The boomless oscillating sprayer was driven at a fixed height by a speed variator to give the desired stable oscillating rate. Thus, possible changes of machine progress rate and spray height was prevented. The test runs were carried out in a closed environment for preventing the impact of lateral and frontal winds on distribution during all test runs. An AC/DC convertor was used as the power supply for the motor which was used for oscillating the spray nozzles of the sprayer. A dual-outlet Pacific brand power supply generating 0-30 Volt, 0-5 Ampere

current has been used for 12 Volt power needed for operating Boomless oscillating field sprayer device. During test runs, the temperature was measured as 22 °C and humidity as 47%.

The experiments are assessed according to the random block trial model, the triple repeat level of 2 factors the electro-jet device's two oscillating rates and three spray pressures. Anonymous (2018), package software was used in the mathematical and statistical evaluations of the obtained results. Since the data did not show normal distribution, the studies were performed in 95% confidence interval according to Friedman Multiple Variance Analysis.

RESULTS AND DISCUSSION

The volumetric distribution pattern obtained from the experiments conducted at 44 rpm and three different pressures are given in Figure 3.

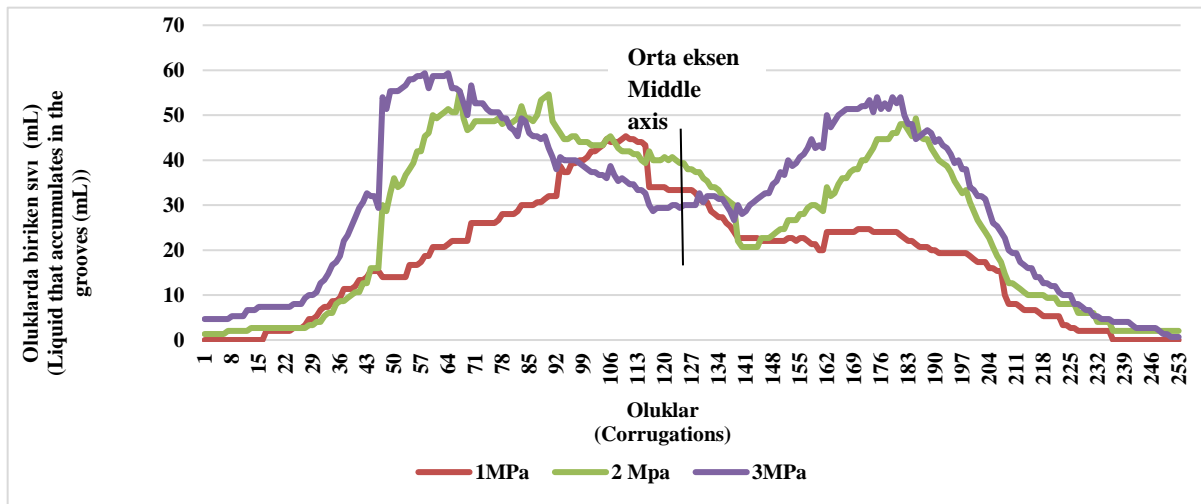


Figure 3. Static pattern at 44 rpm oscillation speed and three different pressures

Generally, it has been observed that there was more liquid accumulation at the left side of sprayer travelling direction than the right side. There are two nozzles on the left application lever of the device.

Designed for application towards the center of the target surface, the second nozzle appears to cause more fluid to accumulate (Table 2) on the left surface rather than its center (Figure 4).

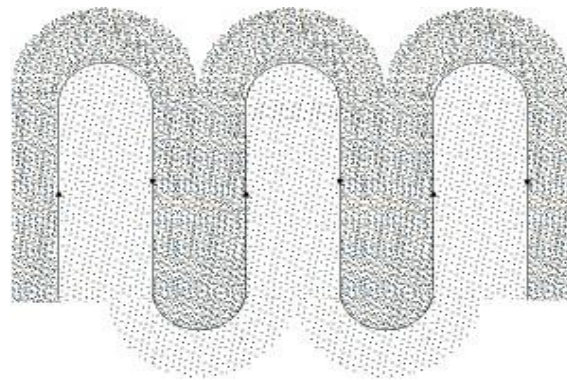


Figure 4. Field application representation pattern of the sprayer

Table 2. The amount of liquid sprayed by the electro-jet device to the left and right side of the middle axis (mL)

Oscillation speed (rpm)	Direction	Pressure (MPa)	Liquid amount (mL)	%
44 rpm	Left	1	2669	58
		2	3833	57
		3	4187	54
	Right	1	1938	42
		2	2933	43
		3	3589	46
60 rpm	Left	1	3757	54
		2	3833	57
		3	5293	56
	Right	1	3223	46
		2	2933	43
		3	4167	44

Especially, it was observed that there is an excessive liquid accumulation 300 to 540 cm from the left side of the axis of the sprayer travelling direction. This is close to the results reported by Tücer (2008). In addition, the difference between the travel speeds in terms of drop numbers reaching 2.5m, 5m and 10 meters was found statistically insignificant with 99% probability. This causes the distribution to be irregular. Three different pressure applications of 44 rpm speed are designed as field applications considering ISO 5682-2 (2017) standard. By analyzing the distribution pattern of the device at 1 MPa, we can say that a bad distribution is obtained with the high 57.33% coefficient of variance shown in Table 3. According to the variation coefficient and the standard deviation stated in Table 3 of this application and the direction of movement specified in Figure 4 according to, effective spray width is

obtained as 11.20 m when the indentation dimensions in Figure 5 are applied (Table 3).

Spray distribution of the device at 44 rpm oscillation speed and 2 MPa pressure has caused accumulation on the right side and especially on the left sides. On the left side of the direction of travelling, more and relatively more favorable distribution has occurred than on the right side. As coming closer to the middle axis, the amount of application liquid has reduced. This reduction is at a level, which will distort the desired covering order. The effective spray width of the patternator was determined as 11.80 m according to the variation coefficient and standard deviation related to Table 3 which was created taking into account the data obtained from the position of the patternator on the rail.

Table 3. Standard deviation, standard error, %CV, and spray length values obtained from patternator corrugations

Oscillation rate (rpm)	Pressure (MPa)	Pattern type	Standard deviation	Standard error	CV %	Spray length (m)
44	1	Static	12	0.79	57.33	14.30
	2		17	1.12	59.97	16.40
	3		17	1.14	52.86	17.60
	Overlapped	1	7	0.49	29.19	11.20
		2	9	0.62	22.64	11.80
		3	10	0.66	24.45	12.00
60	1	Static	17	1.10	59.26	14.30
	2		18	1.12	65.17	16.40
	3		20	1.23	52.25	17.60
	Overlapped	1	7	0.47	17.28	11.55
		2	9	0.61	23.49	11.55
		3	11	0.73	23.28	12.80

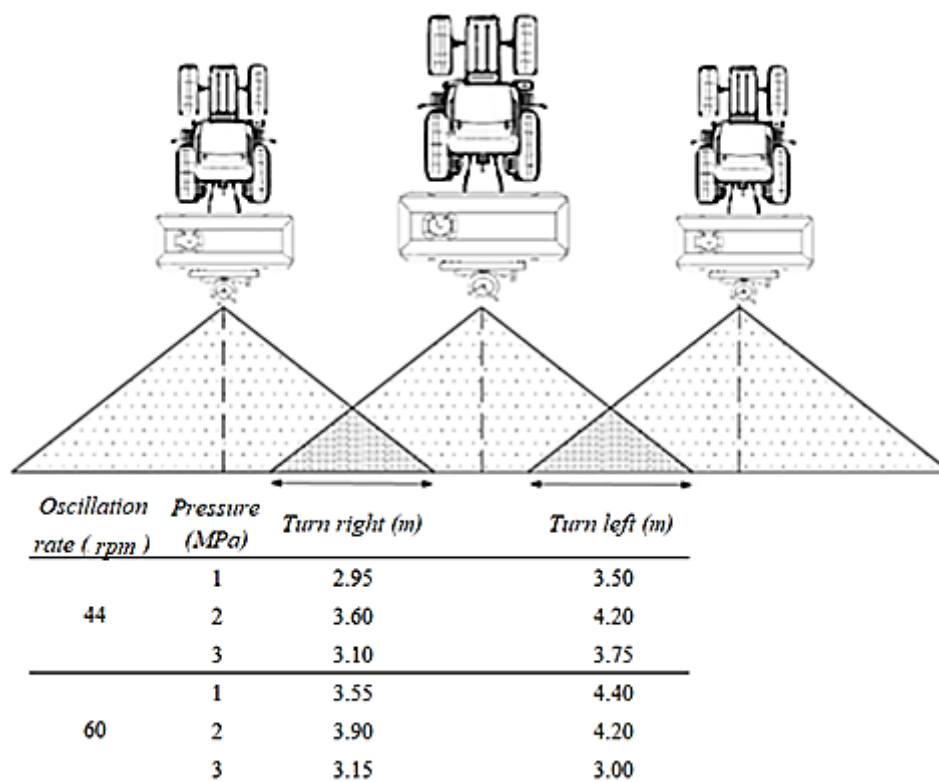


Figure 5. Indentations to be considered in turns for a proper distribution in field application

Considering the variation factors of effective spray width and standard deviation consisting a stable distribution of this application where, for a good practice, the activities should be carried out in accordance with the effective spray width by considering the covering rate. If, the graphic indicating the distribution pattern at 44 rpm oscillation speed and 3 MPa pressure is analyzed, the most significant characteristic of distribution is that the device distorts the order by accumulating

distribution from the center point to right and left side. It has been observed that there was more accumulation at the left side while there was also a hill formed distribution on both sides. Considering that the positions of the patternator on the track with 17.60 m maximum covering width (wetting width) measured directly at the application area, it has been determined based on the standard deviation and coefficient of variation the effective spray width was 12.00 m (Table 3). In 3 MPa pressure setting at the

same oscillation speed, the coefficient of variation factor has given the highest result with 24.45% value. 3 MPa pressure application 44 rpm oscillation speed gives and the worst distribution pattern results which should be avoided

When the spray values obtained at the same speed at different pressures are compared, all three distributions cannot achieve the desired level of distribution according to the coefficient of variation. According to the standard error in Table 3, it can be said that there is an increase in deterioration with increasing pressure. Wolf et al. (2014), reported that at low pressures, they formed a uniform volumetric

distribution throughout the transverse distribution of the nozzles, and at high pressures, pattern distortions occurred. The most important disadvantage of working at low pressures is application with a small amount of liquid.

Figure 6 is formed by overlapping the covering rates obtained by the indentation sizes indicated in Figure 5 of the right and left booms of the nozzles. Accordingly, the best spray pattern at an oscillation rate of 44 rpm is obtained by applying 2 MPa pressure with a variation coefficient of 22.64%, and 1 MPa pressure with a variation coefficient of 29.19%.

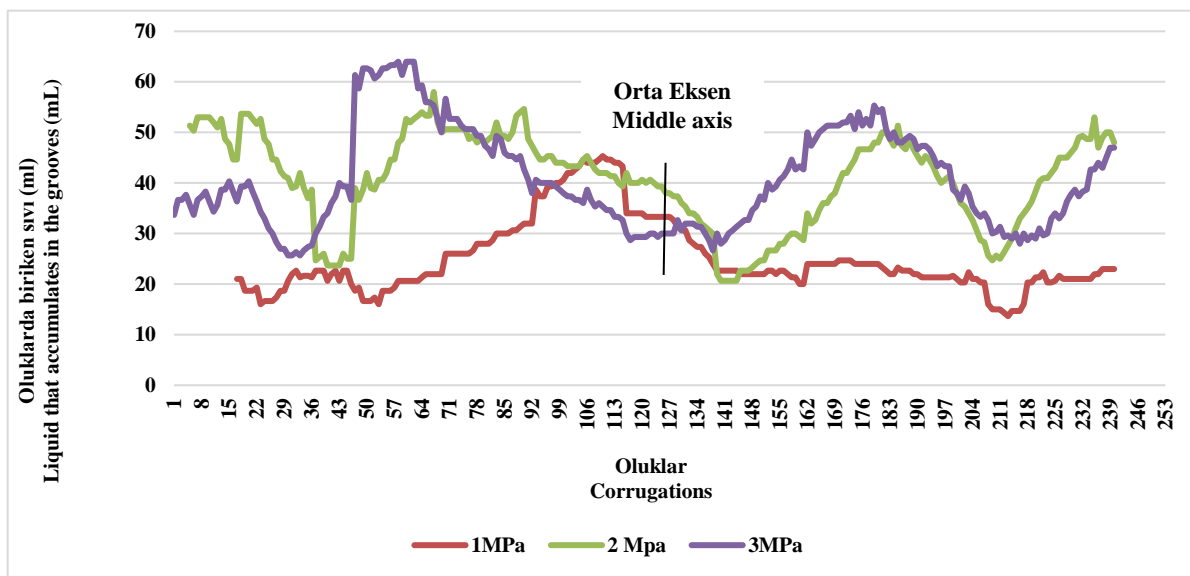


Figure 6. Static pattern with overlapping pulverization application at 44 rpm oscillation speed and covering rate addition at three different pressures

The distribution data obtained from the second speed level of boomless oscillating field sprayer device which is 60 rpm oscillation speed and 1 MPa pressure are given in Figure 7. While, the maximum spray width directly determined during application has been found as 14.30 m, it has been detected that the effective spray width is 11.55 m considering the standard deviation and coefficient of variation (Table 3).

In addition, the spray pattern obtained from the same pressure and different oscillation speeds gave different results when compared to standard errors. According to the pattern data which was obtained at 60 rpm oscillation speed and 2 MPa pressure, there

has been approximately more accumulation from 180 to 420 cm at the left side of axis of travelling direction. For both oscillating speed, this pressure has accumulated the liquid amount applied on the axis of travelling direction at edges and caused important distortions by leaving the center significantly empty. Consequently, it is not recommended to work at this pressure for obtaining a proper distribution pattern. During the application, it has been determined that the effective spray width is 11.55 m (Table 3) according to the standard deviation and coefficient of variation in this distribution where the maximum covering spray width was measured as 16.40 m.

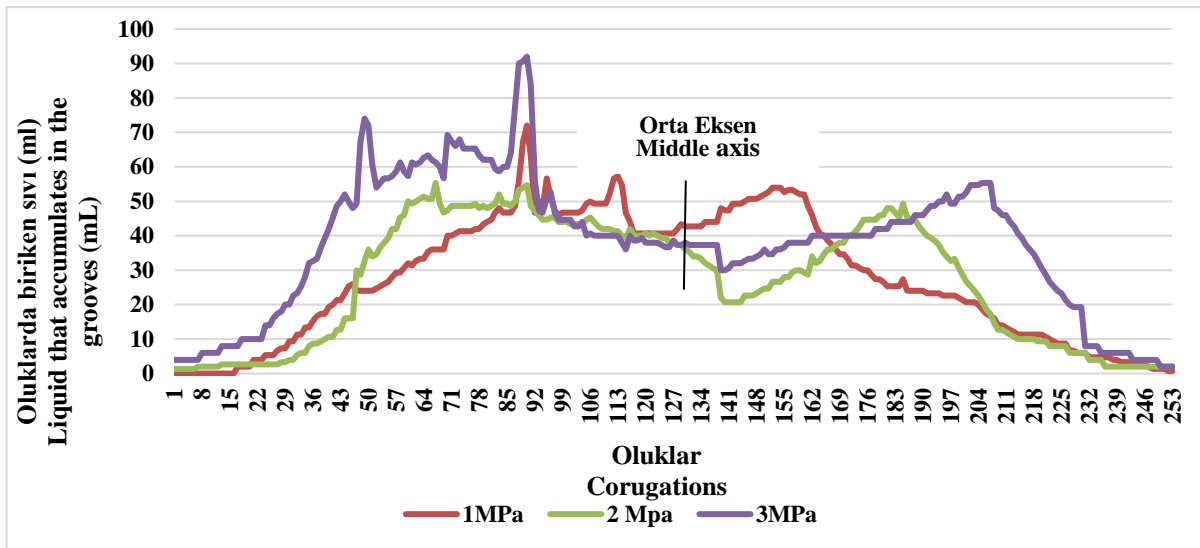


Figure 7. The static pattern at 60 rpm oscillation speed and three different pressures

Three different pressure applications of 60 rpm speed are designed as field applications considering ISO 5682-2 (2017) standard. The covering ratios formed by the spray nozzles were determined by overlapping the data obtained from the corrugations with each other during simulated turns. The 17.28% coefficient of variation, standard deviation and Figure 8 which has been obtained from 60 rpm oscillation speed and 1 MPa pressure application is the most efficient pulverization application done by Boomless oscillating field sprayer device. The acceptable CV% differs based on the research sector. Basically, CV <10 is very good, 10-20 is good, 20-30

is acceptable and CV > 30 is unacceptable (Gomes, 2009).

According to this, spraying should be done at 60 rpm oscillation speed and 1 MPa pressure setting in an operation to be conducted by this device with an efficient spray width, amount of liquid and proper distribution pattern. The variation factor for the distribution pattern obtained at the same speed and 3 MPa pressure setting has been determined as an intermediate level as 23.28%. During this spraying application, the maximum covering width has been determined as 17.60 while its effective spray width has been determined as 12.80 m.

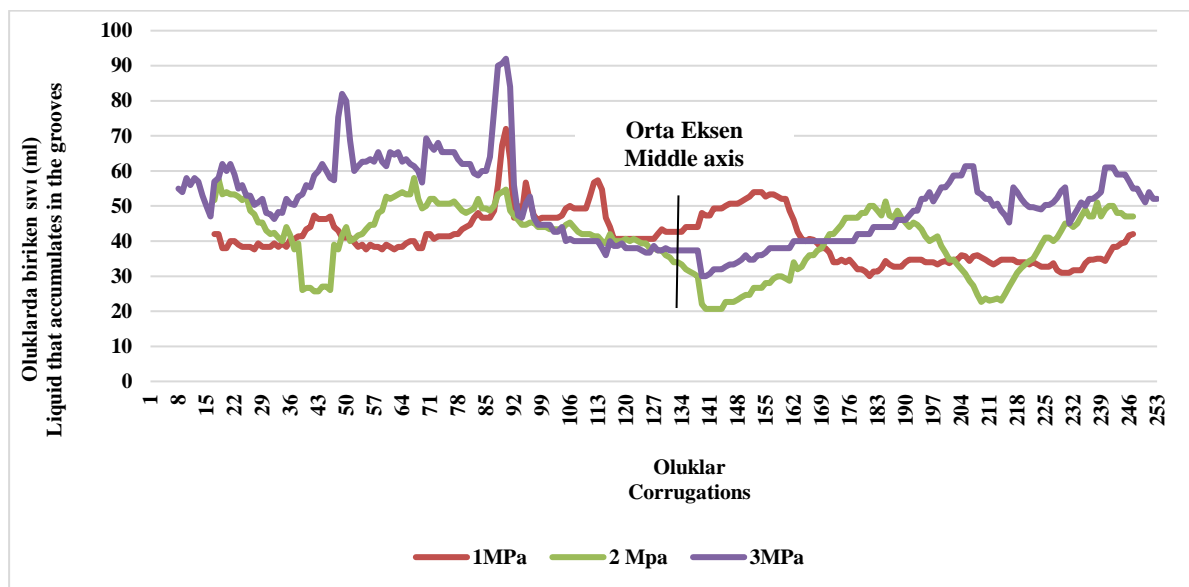


Figure 8. Static pattern with overlapping pulverization application at 60 rpm oscillation speed and covering rate addition at three different pressures

When the oscillation rates in Table 3 are compared according to standard errors, it was observed that the spray data obtained from 44 rpm oscillation speed 1 MPa pressure and 60 rpm oscillation speed 1 MPa pressure give close results.

Effective work widths achieved are greater than the maximum work width specified by Anonymous (2020) and Tücer (2008).

Table 4. Statistical analysis

<i>Test Statistics^a</i>	
<i>N</i>	6831
<i>Chi-Square</i>	9095,075
<i>df</i>	2
<i>Asymp. Sig.</i>	,000

a. Friedman Test

<i>Test Statistics^a</i>			
	<i>Pressure - Speed</i>	<i>Data - Speed</i>	<i>Data - Pressure</i>
<i>Z</i>	-28,104 ^b	-70,322 ^b	-70,070 ^b
<i>Asymp. Sig. (2-tailed)</i>	,000	,000	,000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

CONCLUSIONS

The change of spray swath of boomless oscillating field sprayer caused by the increasing pressure gives similar results for classical type sprayers with similar capacities. However, the distribution smoothness of a classical type sprayer decreases after the outer spray jet of the last nozzle, this decrease can be obtained from boomless oscillating field sprayer in a longer distance. Consequently, while shorter marker recesses are left for covering parts of classical type sprayers in turns for ensuring proper distribution on the field surface, the obtained results that this recess should be more for boomless oscillating field sprayer.

Considering the field applications, it is estimated that there will be excessive liquid accumulation at the left side of travelling direction of the tractor. And a less accumulation will be applied at the right side during an application to be carried out by boomless oscillating field sprayer. On the other hand, as the left side of the travelling direction will be subjected to excessive fungicide/herbicide accumulation as the left and right boom applications always correspond to the same direction in turns and there will be less accumulation at the right side, there will be an irregular distribution pattern on the field.

The second fan nozzle placed on the lever carrying out spraying at left side of the travelling direction of Boomless oscillating field sprayer device loads along the left lance it is connected to instead of spraying the liquid to the target zone which is the center. Instead of this, if this nozzle is reconfigured

In the statistical comparison of the average corrugations data obtained from the sprays in two different oscillation speeds and three different pressure applications the differences between the groups were found to be significant at $P < 0.05$ confidence level (Table 4).

in order to provide 90° of spraying on axis of travelling direction as running as an independent lance, it is inevitable to obtain a spraying pattern with proper distribution. Additional constructions lances up to the working width can be attached to the sprayer. Spray width can be increased three times with two new electro-jets placed on the right and left sides.

Statement of Conflict of Interest

The authors declare that they have no conflict of interest.

Authors' Contribution

MCT, AB and MI designed and analyzed the research, organized the study, conducted the preparation of pictures and tables. All authors contributed to the writing, took part in the process of publication, read and approved of the manuscript.

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