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Comparison of Some Spraying Characteristics by Testing Different Spray Nozzle Positions on Artificial Cotton Plants when Defoliant Application

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ABSTRACT

In this study, limit application rates and different spray nozzle positions effects on coverage rate, drop diameter and amount of tracer residue values were determined of application defoliating agent before machine harvest on cotton plant. Researches were carried on two phases as indoor area trials and laboratory analysis. In these researches, artificial cotton plants were used. Indoor area trials were conducted two different application rates (20 and 40 L da^{-1}) and three different in spray nozzle positions (NP1, NP2 and NP3) by using conventional hollow cone spray nozzle. 27 pieces of sampling area were determined that they were included the two sides of the plant and plant center position of the upper-middle-lower in initiative area on plants. Six initiative areas were determined in order to record efficiency in initiative area on plants. For the purpose of deposition of trace amounts of substances were determined in sampling area; water-sensitive paper is placed on top that included both over the leaves and beneath the leaves in order to detect each filter paper, and drop diameter, rate of coverage. The amount of deposit on areas that were done analysis in laboratory conditions was determined to with spectrophotometer. Drop diameters and coverage rate detection were done analysis on image analysis. According to the results, it is determined that NP3 which is used generally in 40 L da^{-1} norm provide the best deposition and coverage rate on applications of defoliant, in addition to pesticide reach on leaf beneath in merely this spray nozzle position.

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Introduction

Cotton is an important source of fiber and oil in Turkey. *Gossypium hirsutum* L., a species belonging to the *Malvaceae* family of the *Columnifera* order, is referred to as an industrial plant (Yalçın, 1999). The increase in population in the world and the rise in living standards increase the importance of cotton day by day, as well as food items. The cotton plant, which has quite different usage areas, also constitutes the raw material of the textile industry, oil and many other industries. Today, cotton fibers are used in many industries such as various cloths, fabrics, tulle, various clothing items, yarn, twine, mattresses, quilts, smokeless gunpowder, as well as vegetable oil and pulp obtained from its seeds are used in animal feeding. In addition, the importance of cotton is better understood when considering the possibilities of using the stalks left in the field after harvest as particle board, raw pulp and fuel (Denizdurduran, 2008).

According to the data of the United States Department of Agriculture (USDA) shown in Table 1, cotton was cultivated in an area of 34,840,000 hectares in the world in the period of 2019-20, and approximately 35% of this cultivation was realized in India with a cultivation area of 13,300 thousand hectares. India was followed by the USA with 4,700 thousand hectares of cultivation area and then China with 3,450 thousand hectares. Pakistan ranks 4th with 2,450 thousand hectares, while Brazil ranks 5th with 1,670,000 hectares of cultivation area. In recent years, especially in African countries, as a result of the expansion of the volume of cotton cultivation areas, countries such as Mali, Burkina Faso and Benin have come to have a voice in world cotton production. When the world cotton cultivation areas in the 2020-21 period are examined, it is seen that the value of 34,840 thousand hectares decreased to 32,510 thousand hectares (USDA, 2021; Tokel, 2021).

The country with the highest fiber cotton yield in the world has been Australia for many years. According to USDA data, Turkey is well above the world average in terms of productivity. India, one of the world's largest cotton producers, and African countries, which have expanded their cotton cultivation areas, produce cotton with a yield below the world average (Tokel, 2021).

Due to the difficulty of cotton harvesting and the problems in the supply of workers, cotton harvesting by machine was put into practice for the first time in the 1850s and the first cotton harvesting machine was developed by Rambert and Prescott in the USA. After the 1950s, the use of harvesting machines became common as the problems in the supply of picking workers grew Denizdurduran, 2008).

In countries such as the USA, Australia and Israel around the world, the entire cotton harvest is carried out by machinery. In addition, 75% in Argentina, 5-10% in Brazil, 92% in Greece and 30-40% in Uzbekistan are harvested by machine (Chaundhry, 1997). While the number of cotton harvesters in Turkey was 1 050 in 2014, this value has increased year after year and has reached to 1 532 (TUIK, 2023).

One of the most important factors affecting cotton fiber quality is foreign materials mixed with the raw cotton, and a large part of these are leaves and leafstalk. Defoliant chemicals called defoliants should be applied before harvest in order to remove the leaves and leafstalks from the plant, since it has been determined as a result of the experiments that the plant leaves will adversely affect the harvest and fiber quality in machine harvesting. Defoliant is a chemical that encourages the opening of the boll by shedding the leaves of the cotton, which helps the harvest to collect the seed cotton more cleanly and to take the harvest early when the weather conditions are unfavorable.

Therefore, an increase in the use of defoliant applied before machine harvesting, as machine harvesting is becoming more and more widespread.

Chemical defoliants cause defoliation by promoting the formation of a separation layer where the petiole joins the branch or main stem with the effect of the pesticide absorbed from the stomata of the leaves.

Kara et al. (2018), reported in their study that stomata are densely located in the lower epidermis layer of the leaf. In line with this statement, since the application of chemical defoliants will produce successful results, it should be ensured that the spraying penetrates under the leaves.

Bainer et al. (1977) reported that the defoliation process in machine cotton harvesting has certain purposes and listed these purposes as accelerating generative development, removing leaves that cause difficulties in machine harvesting, and preventing green parts from dyeing the fiber.

Yağcıoğlu (2008) stated that during the spraying experiments, change the working pressure causes the volumetric mean diameter (VMD) value to change. Increasing the working pressure or decreasing the application rate by keeping the nozzle plate hole diameter constant reduces the VMD value. The VMD value is very important as it plays an important role in the coverage rate and drift. Another way to change the VMD value is to change the nozzle plate hole diameter.

Table 1. Cotton cultivation areas in the World distribution over the years (1000 ha) (USDA, 2021; Tokel, 2021)

Country	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
India	12.846	11.638	10.845	12.235	12.600	13.300	13.400
USA	3.783	3.291	3.848	4.492	4.130	4.700	3.640
China	4.310	3.793	3.100	3.350	3.367	3.450	3.250
Pakistan	2.958	2.670	2.496	2.665	2.325	2.450	2.200
Brazil	976	1.007	939	1.175	1.618	1.670	1.550
Uzbekistan	1.298	1.272	1.250	1.208	1.100	1.010	980
Burkina Faso	661	631	740	879	646	580	550
Mali	481	573	656	704	730	740	200
Dahomey	379	372	418	530	656	670	600
Turkmenia	545	534	545	545	534	550	600
Türkiye	460	440	420	462	520	570	350
Others	5.215	4.942	4.610	4.950	4.992	5.150	5.190
Total	33.912	31.163	29.867	33.195	33.218	34.840	32.510

Table 2. Cotton fiber yields in world cotton production (kg ha^{-1}) (USDA, 2021; Tokel, 2021)

Country	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Australia	2.228	2.196	1.598	2.088	2.071	2.268	1900
Türkiye	1.573	1.475	1.674	1.714	1.944	1.318	1.742
China	1.503	1.427	1.581	1.758	1.764	1.720	1.842
Brazil	1.507	1.506	1.629	1.707	1.640	1.759	1.686
Mexico	1.668	1.449	1.575	1.580	1.587	1.519	1.429
Greece	997	997	1.009	906	1.132	1.280	1.047
USA	939	963	972	1.014	964	922	953
World average	781	765	772	805	778	761	763

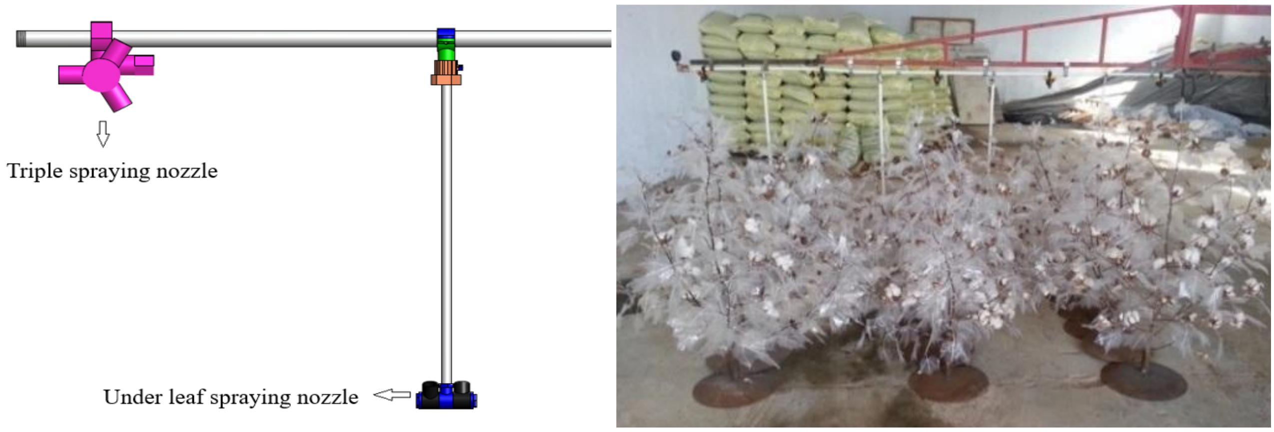

Figure 1. The image of the spray nozzle positions using the upper and under leaves

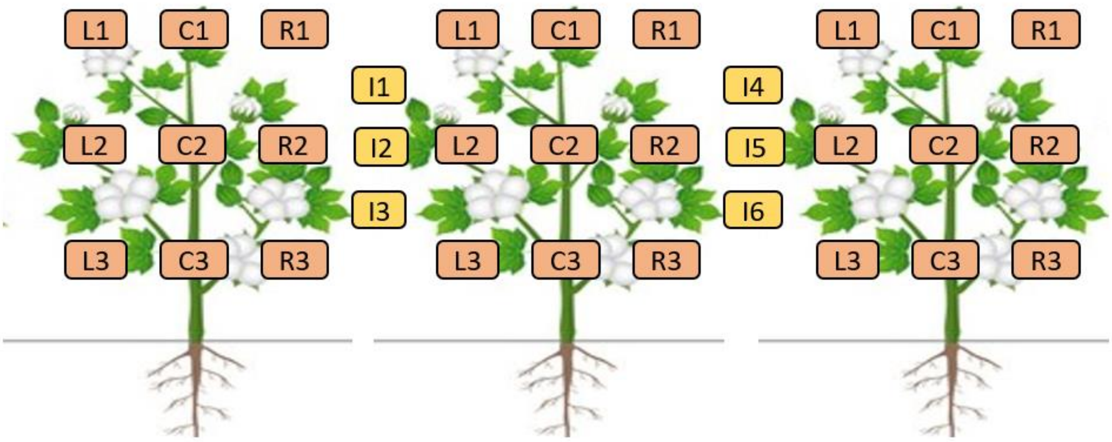

Figure 2. Schematic view of sampling regions on artificial cotton plants

There are many factors that affect the success of the spraying application. The main criteria used to express the success of the sprayer are; the amount of residue on the target plant, the surface coverage rates, the spray distribution uniformity on the target plant, the number of drops per unit area and the drop diameters. Researchers use one or more of these criteria in their studies to decide on the quality of the spraying work.

In this study, it is aimed to emphasize the importance of the under-leaf nozzles by testing the effectiveness of the under-leaf nozzles and to popularize their use in order to ensure that the defoliant application penetrates the plant stomata in the most effective way. In addition, the biological efficiency value, which was not mentioned due to the fact that the artificial plant was studied and due to the subject of the study, is also a very important criterion.

Material and Methods

Manufactured Artificial Cotton Plants

During the experiments, the use of artificial plants was required to provide controlled conditions by minimizing the effect of various weather conditions. In this direction, artificial plants were created to carry out the experiments. These artificial cotton plants manufactured under laboratory conditions, the leaf area indexes of *Gossypium hirsutum* L. plants at the time of defoliant application were calculated and patterns were created. Using these patterns, artificial leaves were cut from greenhouse nylon in exact leaf sizes. 3-row artificial cotton plant trial setup was established, with five cotton plants in each row. In order to be suitable for machine harvesting, the distances between rows were adjusted to be 75 cm and plant spacing were 15 cm on rows, respectively.

Sprayer and Spray Nozzle Components

A field sprayer located in the Application and Research Farm of Aydın Adnan Menderes University, Faculty of Agriculture was used in the experiments. A special boom assembly with a length of 380 mm was designed on this machine with a storage capacity of 800 L (Figure 1).

In order to determine the pressure difference during the trials, two manometers were connected to the machine and to the right end of the boom. On the designed boom, under-leaf nozzles were assembled with a screw system.

Establishment of Sampling Zones

Water-sensitive papers were positioned on the left side, center and right side of the plant, also, it was positioned in the upper, middle and lower positions and was cut in 5x2.6 cm dimensions and attached to the leaf with paper clips. Two pieces of water-sensitive paper were placed in each designated area, under the leaf and on the top of the leaf. In addition, 6 interference regions between 3 plants were selected and papers were placed in these interference regions (Figure 2).

Filter papers are circular in shape and have an area of 10 cm^2. Filter papers were placed in 9 different regions such as upper, middle and lower parts of the plant on the left side, center and right-side regions, as with water-sensitive papers.

In addition, filter papers were placed in 6 interference regions between 3 plants. In order to measure the drift to the ground, 2 pieces of filter paper were placed on the ground at the bottom of these interference zones and 6 pieces of filter paper were placed on the sides (ground) of the 3 plants from which the sample was taken.

Carrying out indoor Experiments

Experiments were conducted in two different application rates (20 and 40 L da^{-1}) and three different nozzle (conventional hollow cone type) positions. Nozzle positions were respectively conventional spray nozzle (NP1), close conventional spray nozzle (NP2) and conventional+under leaf spray nozzles (NP3). The NP1 consists of five units of conventional hollow cone nozzles placed at 75 cm row spacing. NP2 consists of 9 hollow cone spray nozzles at 37.5 cm row spacing, and NP3 is the nozzle position created as a combination of conventional on-row nozzles and inter-row under-leaf nozzles.

The application rates were prepared with lower and upper limit values (20 and 40 L da^{-1}) according to the limit dosage amount in the Dropp Ultra catalog (Anonymus, 2011). The experiments were conducted at 3.6 km h^{-1} ground speed using a 1 mm nozzle plate hole diameter. Pressure values were changed in different nozzle positions in order to reach these limit application rates. In order to adjust the application rates constant in this study, on different operating pressures were studied.

Laboratory Analyzes

In the researches, water-sensitive papers (Figure 3) were used to determine the volumetric mean diameter values and coverage rates, and filter papers were used to determine the amount of residue.

Tartrazine food dye was used as a trace substance in the spraying liquid to create residues on the filter papers. 1g L^{-1} trace substance was added to the sprayer tank. After the experiments, absorbance values were recorded using a spectrophotometer to determine the amount of residue in the dyed filter papers.

Laboratory devices and materials used in the experiments, respectively, are an orbital shaker (WiseShake), a spectrophotometer (UV160-A) and glass jars, disposable spectrophotometer tubes, pipettes.

Image Processing Software

In the experiments, water-sensitive papers were collected from the sampling regions and images of these papers were obtained using a scanner (Canon Pixma MP280) for using image processing. The image analysis program "Image Tool version v.3.0" was used to determine the number of drops, volumetric mean diameter and coverage rates on these obtained images (Guler, 2002).

Determining of the Coverage Rate and Drop Diameter

The Image Tool v3.0 calibration was done and then the water-sensitive paper image scanned with the File>>Open Image command was opened. In order to determine the coverage rate on the water-sensitive paper image, the image of the drops was revealed by bringing the Processing>>Color to Grayscale>>Threshold threshold value to 60. Afterward, the coverage rates were calculated by following the Analysis>> Count Black and White Pixels steps (Guler, 2002).

Drop diameter measurements were made on water-sensitive papers with a coverage rate of less than 40%. The reason for this, the sensitivity of the image analysis program is low when there are more than 40% drops on paper (Fox et al., 2003). In the drop diameter measurement, all spots found in the 'Automatic' option in the 'Find Objects' command in the 'Analysis' menu are selected.

The 'Area', 'Roudness' and 'Feret Diameter' values selected by the Image Tool v.3.0 software with the 'Analysis' command are the values we will use when calculating the volumetric mean diameter. The actual diameter was calculated by dividing the spreading factor for the spots with a sphericity of 0.75 and above.

The volumetric mean diameter (µm) specified in the equation is $D_{V0,5}$, the number of drops in the diameter n_i, the mean value (µm) of the drops in the diameter group is d_i, n represents the total number of drops (Yağcıoğlu, 2008).

$$D_{V_{0,5}} = \sqrt[3]{\frac{\sum d_i^3 \cdot n_i}{n}}$$

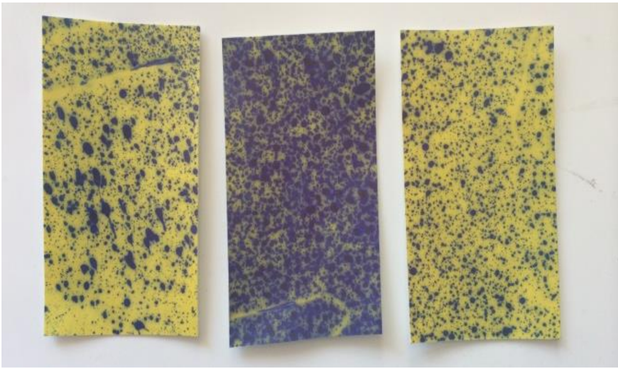

Figure 3. Water-sensitive papers obtained from indoor experiments

Results and Discussion

In Figure 4, it is observed that there is less tracer residue values in the NP1 nozzle position made using conventional nozzles compared to other applications. At the same time, at all experiments, it was determined that the amount of tracer residue on the upper and center of the plant was high compared with the lower part.

The application in which the pesticide reaches the lowest position of the plant canopy, expressed as "Lower", is seen as NP3. This situation can be explained as the use of the under-leaf nozzles increases the population of the pesticide to the lower parts of the plant.

Güler (2002) highlighted in his study, the drift off the target, the amount of residue on the target, the spray distribution uniformity on the target and the coverage rates, and determination of the machine success with the common effect of these criteria.

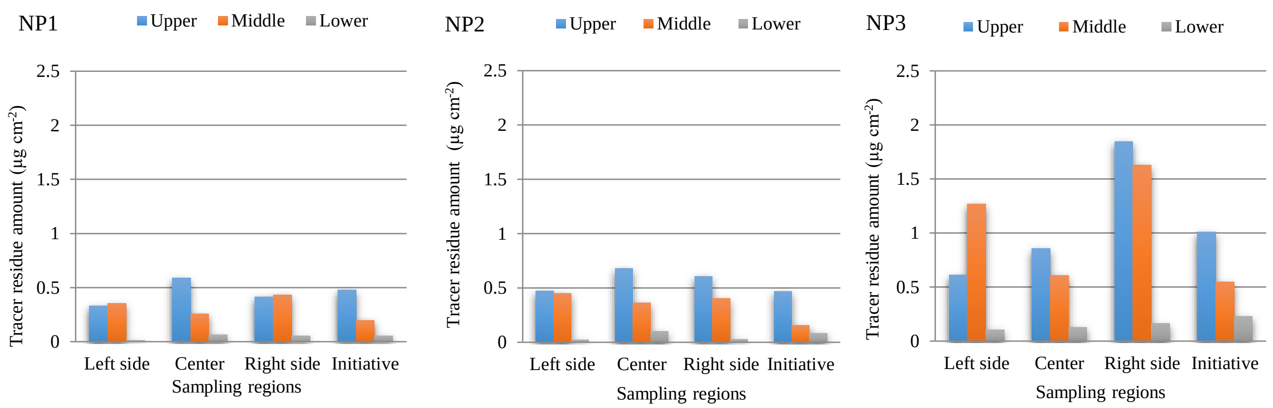

Figure 4. Mean of tracer residue amount in the 20 L da^{-1} application rate

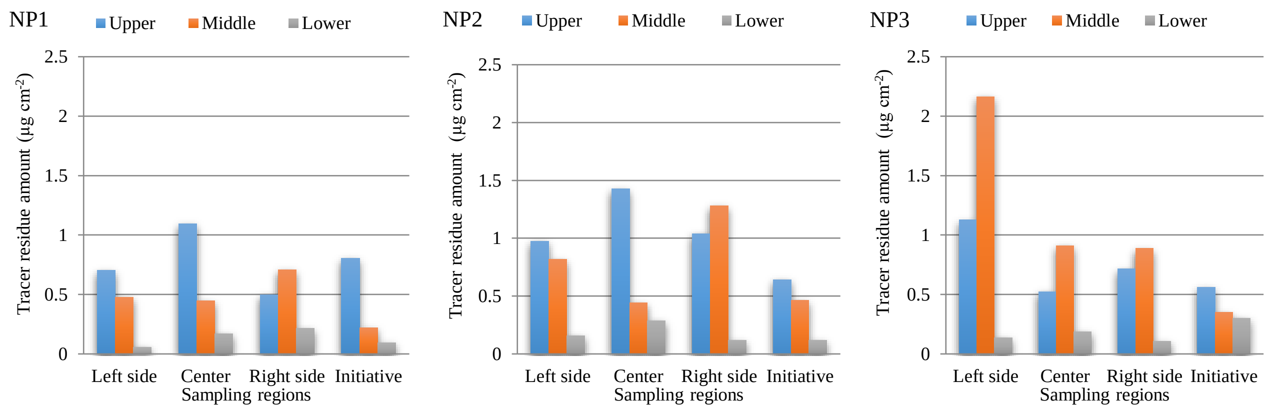

Figure 5. Mean of tracer residue amount in the 40 L da^{-1} application rate

Table 3. Coverage ratio values for all nozzle positions (%)

	NP1				NP2				NP3			
	20 L da^{-1}		40 L da^{-1}		20 L da^{-1}		40 L da^{-1}		20 L da^{-1}		40 L da^{-1}	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
L1	0.40	38.16	6.22	76.43	2.38	74.97	13.19	57.39	30.08	11.42	21.35	22.68
L2	0.77	8.83	1.62	14.16	1.84	52.14	1.68	61.56	20.11	38.87	29.22	46.64
L3	0.30	7.39	0.31	5.22	1.11	10.82	0.41	26.99	1.66	51.73	1.25	17.61
C1	0.21	64.29	0.25	27.94	0.41	75.81	7.58	64.36	1.84	34.90	6.15	36.50
C2	0	17.37	0.13	30.38	0.79	34.83	0.12	48.33	1.75	34.90	6.30	18.08
C3	1.55	11.91	0.12	18.43	2.02	7.89	0.11	49.67	0.98	13.81	11.35	28.49
R1	0.22	6.95	1.47	6.66	0.64	77.87	0.66	84.23	21.23	33.34	21.15	50.18
R2	0	40.04	0.23	62.65	0.16	83.02	2.04	50.11	41.28	79.49	41.05	54.81
R3	0	8.37	0.14	13.51	0.44	17.79	0.34	77.53	0.62	12.46	0.77	18.11
I1	1.06	20.93	0.45	62.24	1.47	29.86	9.06	56.53	20.59	29.38	7.91	45.14
I2	0	14.76	0	31.11	0.70	18.68	0.37	50.73	61.48	20.18	30.37	39.81
I3	0	3.36	0	25.62	0	7.64	0.45	10.82	0	13.09	27.35	15.07

*X: Under leaf, Y: Upper leaf

For 20 L da^{-1} application rate, it is seen that the amount of coverage in the NP1-NP2 nozzle positions is very low, but the coverage quantity in the plant increased up to 2 µg cm^{-2} in the trial at the NP3 nozzle position (Figure 4).

40 L da^{-1} application rate, the quantity of residues formed in the plant in NP2 spraying as seen in Figure 5, there is a uniformity of distribution in each region. When the results of NP3 was examined, it was seen that the distribution was not uniform. It is seen that there is a significant amount of residue on the left side of the plant. During the experiments, such a residue increase occurred on the left side due to the attachment of the under-leaf nozzles to the plant.

At 40 L da^{-1} application rate, it increases the drift values to the soil by causing washing on the plant leaves, which is increased by the amount of pesticide residue. In this case, it is known that the use of chemicals will be dragged into the soil and have a negative effect on environmental pollution.

Coverage ratio values for all nozzle positions were shown in Table 3. As the Table 3, in general, the coverage ratio values of the water-sensitive papers under the leaf were found to be low in NP1 and NP2, and it was the combination of conventional and under-leaf nozzles (NP3) where the best way to reach the medicated liquid under the leaf. Therefore, it has been determined that under-leaf nozzles make a great contribution to spraying efficiency.

Table 4. Volumetric mean diameter values (µm)

	NP1				NP2				NP3			
	20 L da^{-1}		40 L da^{-1}		20 L da^{-1}		40 L da^{-1}		20 L da^{-1}		40 L da^{-1}	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
L1	177,06	278,63	146,01	*	209,45	*	251,91	427,78	258,08	266,23	221,81	264,44
L2	159,55	223,55	177,44	329,74	191,61	*	225,16	*	211,87	266,64	177,22	294,30
L3	144,34	196,35	369,80	232,59	191,22	235,86	163,52	267,31	189,96	*	251,61	230,94
C1	127,15	*	156,311	109,92	155,11	*	120,28	143,18	321,42	266,52	240,09	260,82
C2	0	241,46	116,99	331,75	189,54	207,96	121,48	441,48	383,20	340,47	205,65	274,59
C3	180,65	222,47	130,23	312,69	223,70	254,07	109,93	363,77	338,42	340,47	178,24	231,41
R1	111,90	177,90	162,58	140,51	152,61	*	117,62	*	355,22	156,28	276,76	277,48
R2	0	229,53	185,08	534,30	151,13	*	148,11	*	*	*	396,93	*
R3	0	232,27	253,07	303,85	168,76	238,72	243,28	270,44	296,62	264,27	145,45	214,01
I1	172,08	334,19	118,44	407,49	133,65	296,69	218,89	373,19	181,88	258,55	217,49	256,70
I2	0	253,62	0	292,18	233,44	232,88	227,08	526,83	*	320,43	369,53	*
I3	0	221,22	0	247,83	0	258,74	225,22	324,47	0	248,69	275,01	241,63

*Drop diameter cannot be calculated

When the volumetric mean diameter values at the NP3 nozzle position at 20 L da^{-1} application rate and the volumetric mean diameter values at the NP3 nozzle position at 40 L da^{-1} application rate in Table 4 are compared, it is seen that the VMD values at 40 L da^{-1} application rate are higher. During the experiments, since the conventional hollow cone spray nozzle and 1 mm plate diameter were used in both norm values, the norm was adjusted by reducing the pressure, and accordingly, an increase in the drop diameters and a decrease in the drop frequency were observed. It was observed that as the drop diameter increased, the drag values to the ground increased accordingly.

Conclusion

In this research, according to the results the NP1 nozzle position, which is widely used in defoliant applications, provides less chemical spray penetration to the center and lower parts on cotton plants in terms of some spraying criteria such as tracer residue amount, coverage rate and drop diameter. There is a need for a method that provides better penetration of the chemical into the cotton plant and especially to the under leaf regions. Therefore, it was observed that the spray could penetrate more effectively under the leaf only NP3 nozzle position. This is very significant because most of the stomata are located under the leaf epidermis.

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