International Journal of u- and e- Service, Science and Technology
Vol.8, No. 11 (2015), pp.221-230
http://dx.doi.org/10.14257/ijunesst.2015.8.11.22

Effect Factor Analysis of Spraying Quality for Agricultural Chemicals

Wenfeng Sun, Qichao Li, Yongcun Fan, Yanhua Wan, Teng Wang and Baozhong Cong

Engineering Institute, Northeast Agriculture University, Harbin, 150030, China

Abstract

As one of the most important parts of the agricultural work, agricultural chemicals spray is to protect the plants from weeds, pest and bacteria. With development of high efficient agricultural chemicals, the consumption of agricultural chemicals should be controlled within a couple of liter per hectare in theory. But it's very hard to realize effective use of agricultural chemicals in fact. In this paper, the most effect factors of spray quality such as droplets size, environment temperature, droplets density, nozzle type and spray method were analyzed in agricultural chemicals spray operation. Droplet size effects drift and uniformity of droplet distribution directly. Environment temperature effects drift and uniformity of droplet distribution greatly. Character of nozzle affects spraying quality directly. All research of the paper can offer valuable reference to appropriate application of agricultural chemicals.

Keywords*: Agricultural Chemical; Spraying Quality; Droplet; Nozzle*

1. Introduction

There are many factors which can affect the spaying performance of the agricultural chemicals droplet of plant protection equipment, such as plant equipment, geometrical shape of plants, weather, extent of damage of disease and insect pests, professional level of spraying operation [1]. The right agricultural chemicals and right spraying time are key point for the perfect performance of agricultural chemicals spaying operation with minimum quantity of chemicals and spraying operations. The most optimal performance can be gotten hardly in fact spraying operation. Even though the more accurate and timelier information could be provided by advanced monitoring method with the development of high technology such as GPS and GIS. The cost of advanced plants and weeds recognition system is too high for the general user [2-4].

The agricultural chemicals spraying can be disassembled into a series of interrelated dynamic processes where chemicals loss occur [5]. The chemicals loss could be caused by improper use of equipment, drift and evaporation of droplet, dilution, high temperature, washout, volatilization, hydrolyzation, photochemical degradation, absorption and drainage of soil, bacterial degradation, dissolution, *etc*. And furthermore, the effectiveness of agricultural chemicals could be reduced as the trait of plant leaves. Now, increase effectiveness of agricultural chemicals and decrease of contamination of food and environment become the focus of public attention.

2. Indexes of Spraying Quality

Uniformity of droplet distribution, drift and coverage rate are the most important spraying quality index that can be known by studying the droplets of spraying operation. The uniformity of droplet distribution, represented by the variation coefficient of spray distribution in quantity, is uniformity coefficient of droplet distribution on target. Distance, height and droplet pattern of nozzles are main effective factors of uniformity

ISSN: 2005-4246 IJUNESST
Copyright ⓒ 2015 SERSC

of droplet distribution. The drift, represented by the ratio of deviated droplets to total spraying droplets, means the deviation trend of droplets from targets. The most immediately reason of drift is crosswind [6-10]. Droplets sprayed from some special nozzle (low drift nozzle) provide low drift for their larger initial speeds and more uniform and bigger size than from general nozzles. Some anti-drift technology can be used in spray operation to avoid drift such as assisted air. The coverage rate of droplets means coverage degree to targets with droplets represented by the number of droplets per unit area. It's obvious that the coverage rate of smaller droplets is higher than that of bigger droplets [11-12].

Three spraying quality indexes are mutually associated and constrained. More intensive spraying patterns provide low drift and bad uniformity of droplet distribution. Although uniformity of droplet distribution will be good spraying with small size droplets, more drift will come on. Uniformity of droplet distribution could be improved by increasing vertical distance between nozzle and target, but more drift would come on inevitable. So it is very hard to get the most optimal parameters for all spraying quality indexes at the same time [13-15].

3. Influence Factor of Spraying Quality

3.1. Effect of Droplet Size

The quantity of droplets deposition on the plants wields significant influence on the agricultural chemicals effect. Therefore, it's necessary to know about the effect of droplets size to droplets flow and deposition on the target. Considering coverage rate only, the smaller droplets are, the better coverage rate is. But smaller droplets will cause much more drift especially in herbicide spay.

Droplets size classification usually used is offered by Matthews, British scientist, in 1975 that is showed as Table 1.

Table 1. Size Classification of Droplet

Volume Median Diameter of Droplets(um)	Classification
<50	aerosol droplet
50—100	mist droplet
101—200	fine droplet
201—400	medium droplet
>400	coarse droplet

The better biological effect will be get by small droplet, but more drift will come on. Droplet drift can be improved greatly by adjusting the factors of spray that can reduce environment pollution.

Spray drift and coverage rate is directly related with droplets size. To control diseases and insect pests with minimum consumption of agricultural chemicals, proper size of droplets should be chosen, which could reduce environmental pollution because the consumption of agricultural chemicals is proportional to three power of droplet diameter. The optimal droplets size is changed with different target and condition. In general, the droplets will be absorbed more easily by insect pests and leaves when droplets size is smaller than 100 um. For spraying of water-based agricultural chemicals in high environment temperature, diameter of droplet quickly reduces with evaporation

 Copyright ⓒ 2015 SERSC

which cause more drift distance for high density fine droplets. So drift of droplets is a serious issue. For lush plant, the bigger uniform droplets could reach to the middle zone of canopy with less drift.

3.2. Effect of Environment Factor

Accuracy of reaching target droplets is affected by environment factors including temperature, relative humility, wind speed and direction.

3.2.1. Effect of Environment Temperature and Wind Speed on Spray

Test condition: environment relative humility 50%, wind speed range 0.5-10 m/s, environment temperature 10℃, 20℃, 30℃

Data processing: the effect of environment temperature on diameter of terminal and medial drift distance of water-based droplets is showed as Table 2.

Table 2. Effect of Environment Temperature and Wind Speed Diameter of Terminal and Drift Distance for Different Initial Diameter Droplet

Initial diameter of droplets (um)	wind speed (m/s)	Diameter of Terminal(Dt), Drift distance(Dd)					
		Environment temperature(℃)					
		10		20		30	
		Dt	Dd	Dt	Dd	Dt	Dd
50	0.5	0.0	3.53*	0.0	3.00*	0.0	2.97*
50	2.5	0.0	16.20*	0.0	10.00*	0.0	7.17*
50	5.0	0.0	32.30*	0.0	18.70*	0.0	12.60*
50	10.0	0.0	63.60*	0.0	35.90*	0.0	23.10*
70	0.5	59.4	1.58	43.6	1.92	0.0	3.81*
70	2.5	59.2	7.97	42.7	9.80	0.0	11.80*
70	5.0	59.0	16.00	41.9	19.70	0.0	21.40*
70	10.0	58.8	32.30	40.4	40.30	0.0	40.40*
100	0.5	96.7	0.65	93.7	0.65	88.7	0.72
100	2.5	96.7	3.21	93.7	3.27	88.7	3.55
100	5.0	96.7	5.94	93.7	6.55	88.7	7.13
100	10.0	96.6	13.10	93.5	13.30	88.7	14.50
150	0.5	149	0.18	148	0.18	147	0.18
150	2.5	149	0.83	148	0.87	147	0.91
150	5.0	149	1.70	148	1.75	147	1.84
150	10.0	149	3.65	148	3.74	147	3.91
200	0.5	200	0.04	199	0.04	199	0.04
200	2.5	200	0.17	199	0.17	199	0.17
200	5.0	200	0.36	199	0.36	199	0.36
200	10.0	200	0.82	199	0.82	199	0.82
300	0.5	300	0.01	300	0.01	299	0.01
300	5.0	300	0.10	300	0.10	299	0.10
300	10.0	300	0.21	300	0.21	299	0.21

Note:* droplets evaporate thoroughly before reaching the ground.

For small droplets, impact of environment temperature on the diameter of terminal droplets is much bigger than that of big droplets, which is showed as Table 2. Using droplets 70 um in diameter as an example, their maximum diameter of terminal decline from 59.44 um in 10℃ to 0 um in 30℃. For droplets of diameter greater than 200 um, the environment temperature has little effect on diameter of terminal. In same environment temperature and 5 m/s wind speed, volume change of 100 um and 200 um droplets is 20.9% and 1.5% which show the relative evaporation of small droplets is greater than big droplets. When wind speed is less than 10 m/s wind speed impact of

Copyright ⓒ 2015 SERSC

small droplets on diameter of terminal is less than that of big droplets. For water-based droplets of 70 um diameter, diameter of terminal decline with rising of wind speed, which cause volume of droplet reduce 75.5% to 80.0% of original volume.

Environment temperature carries more effect on drift distance to smaller droplet. Under the same condition, drift distance of droplet smaller than 70 um is impacted greatly by environment temperature. When droplet size is larger than 200 um there is no obvious effect of environment temperature on drift distance.

3.2.2. Wind Speed and Relative Humidity Effect on Droplet Drift Distance

Test condition: environment temperature 20 ℃, height of nozzle 0.5 m, initial downward speed of droplets 20 m/s. Test data processing is showed as Table.3.

Table 3. Effect of Wind Speed and Relative Humidity on Droplet Drift Distance

Droplet diameter (um)	wind speed (m/s)	drift distance(m)			
		relative humility(%)			
		20	40	60	80
50	0.5	2.2l*	2.54*	3.86*	7.41*
50	2.5	7.92*	8.89*	12.00*	20.60*
50	5.0	15.00*	16.70*	22.10*	36.50*
50	10.0	29.10*	32.20*	42.10*	69.20*
70	0.5	2.54	2.1l	1.77	1.56
70	2.5	13.80*	10.90	8.94	7.83
70	5.0	26.4*	22.30	18.00	15.70
70	10.0	51.1*	46.80	36.50	31.70
100	0.5	0.67	0.615	0.65	0.64
100	2.5	3.32	3.29	3.24	3.18
100	5.0	6.64	6.59	6.48	6.36
100	10.0	13.50	13.40	13.20	13.00
200	0.5	0.04	0.04	0.04	0.04
200	2.5	0.17	0.17	0.17	0.17
200	5.0	0.37	0.36	0.36	0.36
200	10.0	0.82	0.82	0.82	0.82
300	0.5	0.01	0.01	0.01	0.01
300	5.0	0.10	0.10	0.10	0.10
300	10.0	0.2l	0.21	0.21	0.21
500	0.5	0.00	0.00	0.00	0.00
500	2.5	0.02	0.02	0.02	0.02
500	5.0	0.04	0.04	0.04	0.04

Note: * droplet is completely evaporated before reaching ground.

Diameter of droplets of most spraying application are larger than 70 um. When environment humility is above 40% and wind speed is below 10 m/s all droplets whose diameter is greater than 70 um could reach any point within 0.5 m from the nozzle. That means the droplet has reached the target before completely evaporating. Drift distance of 70 um droplets quickly decline with increase of environment temperature in steady wind. For 100 um droplets, drift distance decline slowly in same wind speed condition. Effect of environment temperature on drift distance of droplet larger than 200 um is very small. The drift distance of 200 um droplet increase with wind speed. Wind speed, relative humility and droplet size have great impact on droplet evaporation that determine the drift distance of droplet.

 Copyright ⓒ 2015 SERSC

3.3. Effect of Droplet Density

The droplet density is an important factor of coverage rate. The droplet density is related with inspect pest density and mobility, active ingredient of agricultural chemicals and redistribution of active ingredient on target. For same droplet size, different droplet density means different consumption of agricultural chemicals. In order to get minimal consumption of agricultural chemicals and effective coverage rate, ample fine droplets are used in spray. When 1 L agricultural chemicals is sprayed on 1 hectare area and droplets is uniformly distributed on smooth surface the droplet density in theory is showed as Table 4.

Table 4. Droplet Density in Theory

Diameter of droplet（um）	Droplet density(number/cm^2)
10	19099
20	2387
50	153
100	19
200	2.4
400	0.298
1000	0.019

Droplet density (droplet number per smooth unit area) is:

$$n = \frac{60}{\pi}\left(\frac{100}{d}\right)Q$$

The formula, where d is diameter of droplet and Q is volume of spray, presents the relation between diameter of droplet and droplet density.

Without considering other aspect of drift, the coverage rate depends on droplet size mostly.

3.4. Effect of Spray Nozzle

As the most important component of spray equipment, spray nozzle is related with droplet size, droplet density, and distribution directly. Pressure type and centrifugal nozzle are widely used in spray equipment now. Application history of pressure type nozzle is longer than centrifugal nozzle especially in large volume spray operation. For larger initial speed and size spectrum of droplet form pressure type nozzle, the performance of pressure type nozzle is better than centrifugal nozzle in preventing drift and worse in precise spray. There are many types pressure type spray nozzle including flat fan, hollow cone spray nozzle and twin fluid spray nozzle, *etc*. Droplet spectrum of centrifugal spray nozzle is smaller than pressure type spray nozzle, so it’s easy to get different size droplet from same spray nozzle. Spray flow is related with spray pressure and size of spray nozzle. Generally, different spray performance can be gotten by adjusting spray nozzle size, spray pressure, movement of spray equipment and height of spray nozzle to the ground. Proper spray nozzle is one of an essential factor of good spray performance because of different characters of droplet from different spray nozzle and the difference of spray nozzles in principle, application condition.

Interval and height of spray nozzle are the same important parameter as the type of spray nozzle in droplet distribution. Interval of spray nozzle depends on spray cone angle and height of spray nozzle is related with interval of spray nozzle. Overlap and miss could be induced by mismatch of the two factors in whole area spray operation which need droplets distribution is uniform in whole area. In band spray, interval of spray nozzle depends on the row space of row spacing and height of spray nozzle

Copyright ⓒ 2015 SERSC

depends on height and width of plant. It's advisable to cover the plant completely for band width of spray.

Pressure type spray nozzle is used in the test and the result of test is showed as Table 5 and Table 6.

Table 5. Coefficients of Variation of Droplet Distribution Uniformity for Different Type and Size Nozzle

Nozzle type	Spray pressure (kPa)	Height of spray nozzle(cm)					
		30		50		65	
		Vertical nozzle	45°inclined nozzle	Vertical nozzle	45°inclined nozzle	Vertical nozzle	45°inclined nozzle
TJ8002VB	200	12.0	11.5	7.7	10.0	6.1	11.0
	280	8.0	8.2	7.5	12.5	7.2	9.6
TJ8004VB	200	17.1	13.5	7.4	8.5	11.0	10.6
	280	9.3	8.0	9.8	10.9	8.9	12.0
XR8002VB	200	20.0	11.8	9.7	9.4	8.0	10.3
	280	17.6	14.6	11.3	12.4	8.0	7.6
XR8004VB	200	22.0	7.1	5.1	6.5	6.7	6.7
	280	11.6	6.2	5.2	6.3	5.4	7.1
TF8002VB	200	5.3	3.4	2.1	3.3	5.6	4.2
	280	4.2	3.2	3.2	2.1	2.3	2.1
TF8004VB	200	5.8	4.3	2.9	2.9	2.2	3.3
	280	3.2	3.1	3.6	1.9	1.9	2.3

Known as Table 5, more uniform droplet distribution was induced by higher spray pressure. There is no clear connection between coefficients of variation and flow of spray nozzle. Uniformity of droplet distribution was improved in spray with 45° inclined spray nozzle. The greatest improvement came on when the height of nozzle was 30 cm. with increasing of height of nozzle, the effect of inclined spray nozzle on uniformity of droplet distribution declined gradually.

Coefficients of variation of distribution tended toward convergence for same type spray nozzle when height range of nozzle was reduced.

Type and height of spray nozzle are two important factors of effect on coefficient of variation of distribution. Different spray nozzles were used in the tests. The distribution performance of spray nozzle with 110°spray cone angle showed as Table 6 is better than that of spray nozzle with 80°spray cone angle showed as Table 5. Coefficients of variation in Table 6 are less than that of Table 5 and height of nozzle with best uniform distribution is different in two test. It shows that here are interaction between type of spray nozzle and height of spray nozzle.

 Copyright ⓒ 2015 SERSC

Table 6. Coefficients of Variation of Distribution under Different Spray Pressure and Height of Nozzle Condition

Pressure (kPa)	Height of nozzle(cm)		
	30.0	40.0	50.0
140	12.9	9.6	11.3
280	11.2	7.7	12.0
400	14.2	7.7	11.8

3.5. Choice of Spraying Method

Spraying technology is very important in agricultural chemicals application since more than 100 years ago when mixture chemicals applied 50-2 000L. Most agricultural chemicals is sprayed as liquid droplet with nozzle of sprayer. The range of spraying volume is very large between 50L per hectare and 2000L per hectare because of different requirement of dilution. More than 40% of chemicals will fall down to the ground in spraying application to plant leaves. It will be greater when the spraying volume is large. If rain comes soon after spraying environment will be contaminated greater. Moreover, some droplets missing the target or floating in air will harm the environment and other creatures. So it is very important that new technology for improving spraying quality.

3.5.1. Electrostatic Spraying

The first electrostatic spraying application was applied for cotton field in Africa. The application of electrostatic spraying proved quite effective, which can reduce the spraying volume to 1L per hectare. This method is invented for severe drought area. A little chemicals can be used in electrostatic spraying because the ingredient of farm chemicals is required strictly by the method.

3.5.2. Assistant Air Technology

It's hard to penetrate the canopy of plant for droplets in spraying application with regular pressure nozzle. Spraying application was suggested to be applied without wind before to reduce drift. At present, new research show the distribution of droplets can be improved by proper wind speed which upper limit of wind speed is 1.5 m/s (3 m/s for herbicide). Initial assistant air system of sprayer with tube–axial fan was designed to apply in spraying application for trees. The best effect of assistant air is from natural wind comparing various kinds of assistance air system design.

3.5.3. Other Development

Now, some electrical and computer system are applied to monitor and control sprayer that is not wildly used because of the cost and requirement of working condition in the field. Spraying application is improved by GPS which can record the geographic information instead of mark on ground. Prescription map can be presented by the new technology to instruct spraying application.

Copyright ⓒ 2015 SERSC

3.6. Effect of Spraying Effectiveness in Agricultural Chemicals

The efficiency of agricultural chemicals in real spraying application is very low for various reasons. Tests revealed that efficiency of pesticide for aphid in pulse crop protection is 0.02%. At present, the best efficiency of spraying application is 6%. The efficacy of agricultural chemicals is decided by spraying quality when agricultural chemicals is sprayed to leaves and stems of plant by sprayer. Effect of crop protection is affected if any index of spraying quality is not proper. Chemicals droplet will miss the target in the spraying application with high drift and nonuniform distribution of droplet which can caused phytotoxicity. It cannot control the insect pest, weeds, and germ. Spraying quality is significance for agricultural chemicals application.

Resistant to drugs grows up gradually because the same or similar chemicals is used in the same field by farmer. To solve the resistant to drugs, most farmers increase the dosage and times of spraying operation. The right method is applying the other chemicals with different active ingredient, decreasing time and times of spraying application, and confining the use of the chemicals inducing the resistance in certain time period and place. The resistant to drugs can be reduced by optimal spraying method which can optimize the coverage rate of droplet and chemicals dose per unit area. Chemicals dose per unit area is related to the lethal dose.

4. Conclusions

Uniformity of droplet distribution, drift and coverage rate to target are the main indexes of evaluation of spray quality. Wind speed is direct reason of droplet drift; environment temperature and relative humility are indirect reason of droplet drift. Droplet size, uniformity and drift are related each other closely. Droplet size is related directly to type of spray nozzle, height of spray nozzle and spray pressure.

Liquid chemicals spray will be still the main method of agricultural chemicals operation inside quite long henceforth period of time. It is very important to improve the performance of existing equipment and reduce environment pollution. Comprehensive analysis of all factors, which could effect on quality of spray operation, provides technical parameter and support in theory for the future research.

Acknowledgment

This study was funded by the Special Fund for Agro-scientific Research in the Public Interest (No.201303011-3-5) and Applied Technology Research and Development Programs of Science and Technology Department (No. GC13B307).

References

[1] Y. Guo, "Protection of Environmental and plant", Plant Protection Technology and Extension, vol. 19, no. 4, **(1999)**.

[2] Z. Fu and L. Qi, "Optimization of Agricultural Chemicals Spraying Technology", China Agriculture Science and technology Press, **(2003)**, p. 12.

[3] Y. Ye, Z. Wu and S. Huang, "Problems and Prospect of Developing Pesticides", Journal of South China University of Tropical Agriculture, vol. 9, no. 2, **(2003)**, pp. 26-31.

[4] X. He, "Improving Severe Draggling Actuality of Plant Protection Machinery and Its Application Techniques", Transactions of The Chinese Society of Agricultural Engineering, vol. 20, no. 1, **(2004)**, pp. 13－15.

[5] X. Liu, H. Zhou and J. Zheng, "Research Advances of the Technologies for Spray Drift Control of Pesticide Application", Transactions of The Chinese Society of Agricultural Engineering, vol. 21, no. 1, **(2005)**, pp. 186-190.

 Copyright ⓒ 2015 SERSC

[6] E. Y. Zhai and J. Q. Zheng, "Erosion Wear Analysis of Fan-shaped Spraying Nozzle Affected by Particles", Transactions of The Chinese Society of Agricultural Engineering, vol. 28, no. 12, **(2012)**, pp. 18－22.
[7] L. Shi, X. Zhang and H. Wu, "Experimental Research on Spray Distribution Uniformity of Fan Nozzle", Journal of Yunnan Agricultural University, vol. 26, no. 3, **(2011)**, pp. 389－394.
[8] J. Zhang, S. Gong and J. Song, "Performance of Two-phase Gas-liquid Electrostatic Induction Nozzle", Transactions of the Chinese Society for Agricultural Machinery, vol. 42, no. 12, **(2011)**, pp. 107－110.
[9] C. Xie, X. He and J. Song, "Herbst. Comparative Research of Two kinds of Flat Fan Nozzle Atomization Process", Transactions of The Chinese Society of Agricultural Engineering, vol. 29, no. 5, **(2013)**, pp. 25－30.
[10] X. Yang, J. Zhou and X. He, "Influences of Nozzle Types on Pesticide Deposition and Insecticidal Effect to Wheat Aphids", Transactions of The Chinese Society of Agricultural Engineering, vol. 28, no. 7, **(2012)**, pp. 46－50.
[11] C. Shen, S. Jia and Z. Tang, "Research Actuality and Application Prospects of Pesticide Electrostatic Spraying", Journal of Agricultural Mechanization Research, vol. 32, no. 4, **(2010)**, pp. 10-13.
[12] R. Yu, J. Zheng and H. Zhou, "Design and Experiment of Double-nozzle of Aerial Electrostatic Sprayer", Transactions of the Chinese Society for Agricultural Machinery, vol. 38, no. 12, **(2007)**, pp. 58－61.
[13] D. Wei, D. Weimin and X. He, "Technologies and Evaluation Methodology of Variable Spray", Journal of China Agricultural University, vol. 14, no. 3, **(2009)**, pp. 94-102.
[14] E. S. R. Negeed, S. Hidaka and M. Kohno, "Experimental and Analytical Investigation of Liquid Sheet Break Up Characteristics", International Journal of Heat 30 and Fluid Flow, vol. 32, no. 32, **(2011)**, pp. 95-106.
[15] L. Yang, B. Xu and Q. Fu, "Linearinstability Analysis of Planar Non-Newtonian Liquid Sheets in Two Gas Streams of Unequal Velocities", Journal of Non-Newtonian Fluid Mechanics, vol. 167, no. 168, **(2012)**, pp. 50-58.

Author

Wenfeng Sun was born on December 24, 1973, in Nenjiang, China. Professor. Master degree of Engineering. Work unite: Engineer Interpret Northeast Agriculture University. Research interest: Agricultural Engineering.
E-mail: 13304508203@163.com

 Copyright ⓒ 2015 SERSC