Journal of ASTM International, Vol. 7, No. 6
Paper ID JAI102771
Available online at www.astm.org

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Analysis of Impact of Various Factors on Downwind Deposition Using a Simulation Method

ABSTRACT: The drift of aerially applied crop protection and production materials is studied using a novel simulation-based design of experiments approach. Many factors that can potentially contribute to downwind deposition from aerial spray application are considered. This new approach can provide valuable information about the significant level of the impact from all factors and interactions among them that affect drift using simulation software such as AGDISP. The application efficiency, the total downwind drift, the cumulative downwind deposition between 30.48 m (100 ft) and 45.72 m (150 ft), and the deposition at 30.48 m (100 ft), 76.2 m (250 ft), and 152.4 m (500 ft) are established as the performance metrics. The most significant factors will be identified using statistical analysis based on simulation results, and suggestions for improvement will be made. Through preliminary study, the new simulation-based method has shown the potential for statistic analysis without conducting time-consuming field experiments. The new method can be used to search for the optimal spray conditions, which could be used to generate guidelines for applicators to achieve an optimal spray result. The effective use of simulation tool through the identification of significant factors can greatly simplify the field study.

KEYWORDS: spray drift, aerial application, simulation, design of experiments

Introduction

Off target movement of aerially applied agricultural production materials is a well studied phenomenon with a long history of research spanning 4 decades [1–10]. Minimization of the drift associated with aerially applied sprays is critical as many of the materials applied can cause damage to other crops and may be harmful to the environment. A commensurate increase in application efficiency can also be achieved and cost reduced when the drift is minimized. Much of the research effort has been made in the area of prediction of drift [11–13] in aerial spray and optimal selection of spray parameters. Several standards were established in this area [14–16]. Guidelines were established for spray drift testing [17].

The movement of aerially applied sprays is influenced by many factors including atmospheric conditions [3,18–22], canopy structure [23], droplet size [24], tank mix [25], plant structure [26], and other factors [27]. Applicators are responsible for taking all these factors into consideration to minimize drift. In general, these factors tend to be either controllable variables that can be adjusted by the applicator or uncontrollable variables that applicators must account for. Examples for the controllable variables include aircraft type, distribution of nozzles, nozzle type and orientation, spray pressure, and release height. Uncontrollable variables include temperature, relative humidity, atmospheric stability, wind speed, and direction. It is desirable to know how to select the values for the controllable variables to compensate for the impact of the uncontrollable variables on the outcome.

The research work in this field mainly falls into two categories: Field data analysis and simulation. The first approach is mostly dependent on the statistical analysis of actual test data [2,3,7,9,19,23,28]. The other focuses on modeling and simulation [11,12,29–35]. Each of these approaches has its advantages and disadvantages. The field test data often are collected without the ability to control the uncontrollable variables. This typically skews the test data and can be insufficient for statistical analysis. The field data approach usually is time consuming and costly. The simulation approach allows one to vary the uncon-

Manuscript received October 6, 2009; accepted for publication May 25, 2010; published online June 2010.
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trollable variables to cover a complete set of use case scenarios. However, the results depend very much on the accuracy of the model.

Most of the results in the literature focused on one of several factors such as temperature, humidity, etc. In order to find the impact of each factor, all other factors have to be fixed. This can be difficult to achieve when the study is conducted in the field since many factors cannot be controlled. A significant effort was made by the Spray Drift Task Force to exam many factors [28]. However, there is no systematic approach to find the impacts of all the factors and their interactions. As pointed out in Ref 28, "Due to the complexity of evaluating all possible interactions of the numerous application variables, a computer model is the most practical way to conduct spray drift risk assessments." This research uses a simulation approach to identify the main factors and interactions among factors that have significant influence on drift of aerially applied sprays using the design of experiments (DOE) technique. The DOE technique was first introduced by Tauguchi [36] and has been used mainly in the manufacturing field to solve engineering problems [37–39]. Agricultural dispersion (AGDISP) [13] was selected as the simulation model. AGDISP is a Lagrangian based aerial spray dispersion model that models spray material movement accounting for effects of aircraft wake effects and turbulence from both aircraft and ambient sources with over 30 years of development and validation testing. The functionalities and accuracy of AGDISP have been extensively studied in the literature [11,30,31]. The AGDISP simulation results are used to conduct statistical analysis using software Minitab [40,41]. A recommendation for reducing downwind drift is made based on the DOE analysis. The DOE analysis is the first step toward a solution to minimize the downwind drift from aerially applied agricultural production materials.

The remainder of the paper is organized as follows. Section II discusses the experimental setup using the DOE technique. Section III analyzes the results from DOE simulation tests. Conclusion and discussion are included in Sec. IV.

Design of Experiments

In industry, especially in manufacturing applications, there are many factors that influence the product quality. Often times, there are interactions among multiple factors. DOE is a tool that can be used to systematically study the influence of many factors and their interactions on the outcome. An interaction occurs when the effect of one input variable is influenced by the level of another input variable. The main idea for DOE is to design the experiments such that the impact of each factor and the interactions between factors can be discovered without conducting all possible combinations of factors taking different values [36–38]. Well-designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. In addition, a well-designed experiment will ensure that one can evaluate the important effects. For example, if one believes that there is an interaction between two factors, be sure to include both variables in your design rather than doing a "one factor at a time" experiment. In DOE, several factors are changed from one experiment to the next. The DOE can be easily generated using software such as Minitab [37,40,41].

Typically, a successful DOE analysis can narrow the factors down to a few important ones. Further detailed study can then be carried out by focusing on these factors [37–39]. For this reason, the DOE technique is often used to screen for important factors so that one has less factors to study. This can significantly simplify the original problem. One has to be careful about drawing conclusions from DOE analysis. An insignificant factor simply means that its impact is much less compared to some other "significant" factors; it does not mean that it has no impact on the result. As a matter of fact, usually some effort will be made after the significant factors are identified to minimize the impacts of these factors. After that, another round of DOE tests can be done to re-evaluate the impacts. The originally insignificant factors may very well become significant then.

In DOE, extreme levels for each factor are chosen, and the factors are varied simultaneously rather than one at a time. This improves the efficiency in terms of time and cost; more importantly the interactions among factors can be studied. Minitab is a commonly used software package that allows the user to easily setup a test matrix and conduct statistical analysis based on the experimental results to find out which factors have significant impact on the outcome. Results of DOE analysis in Minitab include the main effects graph that identifies factors that have significant influence on the outcome with a given level of confidence. Interactions among factors can also be plotted. The DOE plots can also provide information

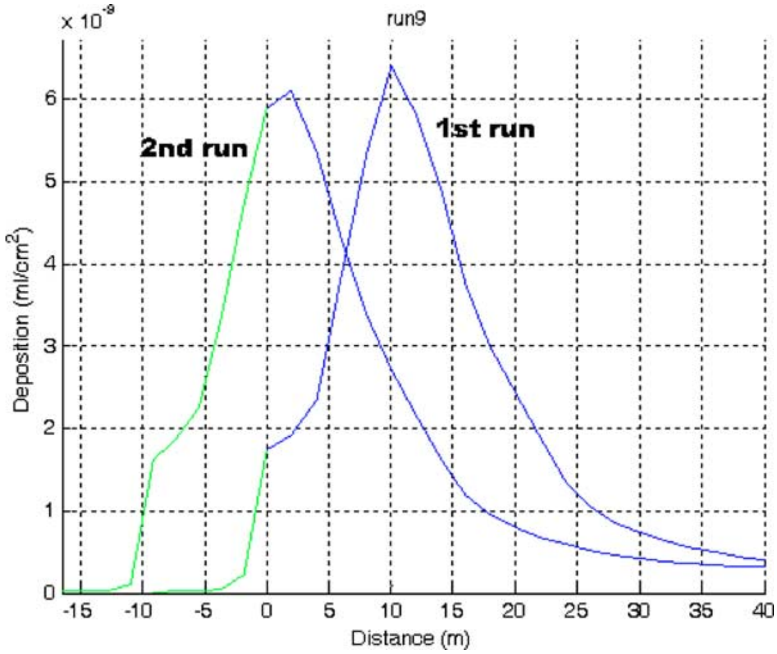

FIG. 1—*Effect of swath displacement.*

on how to select the values for the controllable variables to achieve better results. There are drawbacks for the DOE technique. For example, if the impact of certain factor is highly nonlinear or nonmonotonic, then the selection of the extreme values must be done very carefully. If not done properly, wrong conclusions may be drawn. In a sense, the success of DOE deployment depends very much on the expert knowledge of the user. Readers are referred to Ref 38 for more details on DOE.

In order to apply the DOE technique to the problem of drift from aerially applied agricultural production materials, specific metrics with numerical values must be established first. The influence of the factors and their interactions will be evaluated using these metrics as a measure of the outcome. There are many metrics that one can use to measure the outcome of spray drift, such as drift residue, drift field deposition, and drift residue on crop downwind [9,17,42]. In this paper, the application efficiency, the total downwind drift, the cumulative downwind deposition between 30.48 m (100 ft) and 45.72 m (150 ft), and the deposition at 30.48 m (100 ft), 76.2 m (250 ft), and 152.4 m (500 ft) are selected as the metrics for outcome. The same analysis can be applied if other types of metrics are used to measure the outcome.

The following six factors (variables) were studied: Release height, nozzle extent (i.e., effective boom width), droplet size, wind speed, temperature, and relative humidity. Detailed definitions for these variables can be found in Refs 3, 13–15, 19, and 30. The selection of these variables was based on past field experience and related prior research in the field of downwind drift analysis [1–13,17–23,25–35,42]. Swath displacement is the offset of the flight trajectory in the direction perpendicular to the swath lines. It is usually used to compensate for wind speed. Intuitively, the impact from the swath displacement is a shift of the downwind deposition in the direction perpendicular to the swath lines. This can be easily verified by AGDISP simulation. Two simulation runs were conducted with identical simulation parameters except for the swath displacement. The first run had no swath displacement; the second run has 9 m swath displacement. The downwind depositions as a function of the downwind distance for the two runs were plotted together in Fig. 1. If the deposition curve from the second run is shifted to the right by 9 m, it will almost be identical to that of the first run. The small difference is caused by the difference in sampling times.

Since the goal of DOE is to identify which variables have significant impact on the outcome and we know the exact impact from swath displacement, we chose not to include it as a variable in the DOE analysis. Each variable takes two extreme levels, each representative of the typical extremes that might be seen under field conditions for aerial applications. These values are defined as follows:

- Release height: 1.893 m (6.21 ft) and 6.1 m (20 ft)
- Nozzle extent: 50 % and 85 % of spray boom width
- Droplet size: ASABE very fine and ASABE very coarse [14]
- Wind speed: 0.45 m/s (1 mph) and 6.71 m/s (15 mph)

- Temperature: 7.2°C (45°F) and 35°C (95°F)
- Relative humidity: 35 % and 100 %

These extreme values were based on practical considerations along with limitations of AGDISP. For example, the lowest release height allowed by AGDISP is 1.893 m (6.21 ft). Initial simulation runs were conducted to check that the impacts are not highly nonlinear or nonmonotonic between the two extreme values. Since only a limited number of runs were simulated, there is always a possibility that such complex impact might have been missed. However, the results will be validated in a follow up paper and potentially field tests. Any missed complex impact will be discovered and the DOE will be revised and re-ran.

Other AGDISP simulation parameters are specified as follows:

- Stability: Day/moderate
- Spray volume rate: 46.76 L/ha (5 gal/ac)
- Canopy height: 0
- Spray line: 1
- Swath width: 18.29 m (60 ft)
- Wind direction: −90°
- Swath displacement: 0 m (0 ft)
- Aircraft type: Air Tractor AT-402B
- Nozzle number: 44
- Swath offset: 0
- Evaporation calculation option in the model turned on

The influence of these specified variables on the outcome will not be studied in this paper. It is worth noting that the spray volume rate has no impact on the final result since changing its value simply changes the results proportionally. "Extreme values" for some factors may not be the absolute minimum or maximum. For example, wind speed may be higher than 6.71 m/s (15 mph); release height may be larger than 6.1 m (20 ft); temperature may be lower than 7.2°C or higher than 95°C; and relative humidity may be lower than 35%. However, these should not stop one from seeing the effectiveness of the DOE technique. As the result of DOE shows, for example, temperature has very small impact. Increasing the high temperature from 35 to 40°C will not change any conclusion from the DOE analysis.

A two level full factorial DOE with six factors would have 64 runs (=2^6). Sometimes, it is desirable to reduce the total number of runs in order to reduce cost and time. When the number of runs is reduced from the full factorial design, the resolution is reduced. A resolution is an indication on how effects can be confounded due to the reduced number of runs. A resolution III design has no main effect confounded with any other main factors, but main factors may be confounded with two-factor interactions. A resolution IV design has no main effects confounded with any other main factors or two-factor interactions, but some two-factor interactions may be confounded with other two-factor interactions and the main effects may be confounded with three-factor interactions. A resolution V design has no main effects or two-factor interactions confounded with any other main effect or two-factor interactions, but two-factor interactions may be confounded with three-factor interactions and the main effects may be confounded with four-factor interactions. A resolution VI design has no main effect or two-factor interactions confounded with any other main effect, two-factor interactions, or two-factor interactions, but a main effect may be confounded with five-factor interactions. Two-factor interactions may have confounded with four-factor interactions. Three-factor interactions may have confounded with other three-factor interactions. Interested readers are referred to Refs 37 and 40 for more details on the resolution of DOE.

Depending on the number of runs conducted and the number of variables, fractional DOE test matrices can be designed with different levels of resolutions [37,40]. For example, a two level half fractional design with six factors requires 32 (=$2^6/2$) runs. This design is a resolution VI DOE. For the application discussed in this paper, higher order interactions are assumed to be unlikely. To illustrate the concept of fractional DOE, a one half fractional DOE was selected. As a result, there were 32 (=$2^6/2$) simulation runs. The reduction of experiments using fractional DOE may not save much time in simulation, but the time and cost saving could be significant if the experiments were conducted in the field. Similar to experimental data, simulation data have errors due to modeling error and small numerical errors due to rounding. But, unlike experimental data, the simulation data give consistent results when repeated. Therefore, there is no need or benefit in repeating the same simulation run, which is a common practice in

TABLE 1—*DOE test matrix.*

Run	Release Height (m)	Nozzle Extent (%)	Droplet Size	Wind Speed (m/s)	Temperature (°C)	Relative Humidity (%)
1	1.89	50	Very fine	0.45	7.2	35
2	6.1	50	Very fine	0.45	7.2	100
3	1.89	85	Very fine	0.45	7.2	100
4	6.1	85	Very fine	0.45	7.2	35
5	1.89	50	Very coarse	0.45	7.2	100
6	6.1	50	Very coarse	0.45	7.2	35
7	1.89	85	Very coarse	0.45	7.2	35
8	6.1	85	Very coarse	0.45	7.2	100
9	1.89	50	Very fine	6.71	7.2	100
10	6.1	50	Very fine	6.71	7.2	35
11	1.89	85	Very fine	6.71	7.2	35
12	6.1	85	Very fine	6.71	7.2	100
13	1.89	50	Very coarse	6.71	7.2	35
14	6.1	50	Very coarse	6.71	7.2	100
15	1.89	85	Very coarse	6.71	7.2	100
16	6.1	85	Very coarse	6.71	7.2	35
17	1.89	50	Very fine	0.45	35	100
18	6.1	50	Very fine	0.45	35	35
19	1.89	85	Very fine	0.45	35	35
20	6.1	85	Very fine	0.45	35	100
21	1.89	50	Very coarse	0.45	35	35
22	6.1	50	Very coarse	0.45	35	100
23	1.89	85	Very coarse	0.45	35	100
24	6.1	85	Very coarse	0.45	35	35
25	1.89	50	Very fine	6.71	35	35
26	6.1	50	Very fine	6.71	35	100
27	1.89	85	Very fine	6.71	35	100
28	6.1	85	Very fine	6.71	35	35
29	1.89	50	Very coarse	6.71	35	100
30	6.1	50	Very coarse	6.71	35	35
31	1.89	85	Very coarse	6.71	35	35
32	6.1	85	Very coarse	6.71	35	100

collecting experimental data. The order of runs also has no impact on the results; therefore there is no need to randomize the simulation runs. The DOE test matrix is shown in Table 1.

The following measurements were taken from simulation results:

- Application efficiency (%)
- Total downwind drift as a percentage of the total application (%)
- Cumulative downwind deposition between 30.48 m (100 ft) and 45.72 m (150 ft) in mL/cm^2
- Deposition at 30.48 m (100 ft) in mL/cm^2
- Deposition at 76.2 m (250 ft) in mL/cm^2
- Deposition at 152.4 m (500 ft) in mL/cm^2

Downwind deposition results can be plotted relative to downwind distance from to point of application (Fig. 2). Notice that in order to zoom in the detail of the downwind deposition near 0 distance, its values for distance beyond 40 m (131.23 ft) are not displayed. The values beyond 40 m (131.23 ft) are small but not necessarily zero. They were still included in all of the calculations.

The simulation results for all 32 tests are recorded in Table 2. The application efficiency and total downwind deposition were recorded directly from AGDISP as percentages of the total application. The other outcomes can be calculated using Excel, MATLAB (version R2008b) [43], or similar tools based on the downwind deposition as a function of the downwind distance. These include cumulative deposition between 30.48 m (100 ft) and 45.72 m (150 ft) downwind, which is the integration of the curve in Fig. 1 between the two distances, deposition at 30.48 m (100 ft) downwind, deposition at 76.2 m (250 ft) downwind, and deposition at 152.4 m (500 ft) downwind.

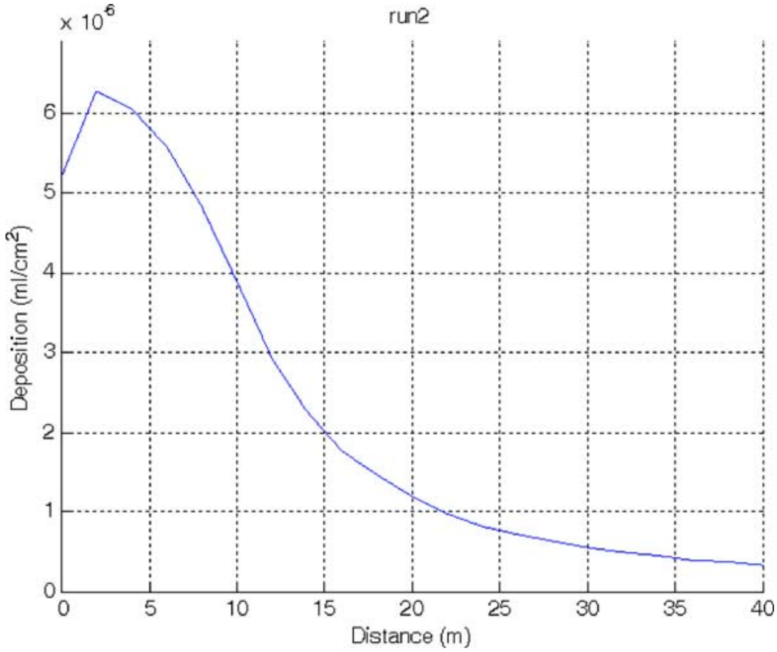

FIG. 2—*Downwind deposition as a function of distance.*

Analysis of Simulation Data

Based on the simulation results in Table 2, DOE analysis was conducted using the Minitab software. The reader is referred to Ref 40 for detailed operation of Minitab. The Pareto Chart for total downwind deposition, which indicates the influences from each variable and their interactions, is plotted in Fig. 3.

With confidence level of 95 %, factors that have significant impact on the total downwind deposition are wind speed and the interaction between the wind speed and droplet size. This conclusion is based on the observation that these factors (D or wind speed and CD or the interaction between the wind speed and the droplet size) are above the threshold line of 2.228. The calculation of the threshold is done by the Minitab software. Interested reader is referred to the research work by Lenth [44]. All other factors have statistically insignificant impact on the total downwind deposition.

The main effect plot, as shown in Fig. 4, is a simple representation of the DOE analysis result. It does not include the possible interactions between different variables. One can see that the wind speed is the most significant factor. This is illustrated by the line with steep slope. A flat line indicates no impact. The −1 and 1 levels for each factor correspond to the two levels defined earlier. For example, −1 and 1 for release height correspond to 1.893 m (6.21 ft) and 6.1 m (20 ft), respectively; −1 and 1 for nozzle extent correspond to means 50 % and 85 %, respectively.

In addition, the main effects plot (Fig. 4) provides information such as the direction of the influence. A positive slope means that a larger variable results in a larger total downwind deposition. A negative slope means exactly the opposite. For instance, higher relative humidity results in higher total downwind deposition; wider nozzle extent results in lower total downwind deposition; and higher wind speed results in higher total downwind deposition. When the slope is small, one should avoid drawing such conclusions since the sign of the slope may be changed by small errors in the simulation data.

Similar graphs as Fig. 3 can be plotted for other performance metrics. From these graphs, Table 3 is created, where A is the release height, B is the nozzle extent, C is the droplet size, D is the wind speed, E is the temperature, F is the relative humidity, and all two letters represent the interaction between the two factors. A "+" in a cell means the larger the factor, the larger the outcome. A "−" in a cell means the larger the factor, the smaller the outcome. Interactions cannot be simply characterized as a + or a − since these involve more than one factor, and the outcome depends on both factors. An "x" in a cell means that the interaction between factors has a significant impact on the corresponding outcome. For example, there are two significant factors/interactions, wind speed and the interaction between wind speed and droplet size, for the total downwind deposition. Note that interactions among three or more factors are not considered here.

TABLE 2—*DOE test results.*

Run	Appl. Efficiency (%)	Total Deposition (%)	Depo100_150[a]	Depo_100[b]	Depo_250[c]	Depo_500[d]
1	34.05	65.95	1.60×10^{-6}	4.01×10^{-8}	1.07×10^{-8}	3.52×10^{-9}
2	23.40	76.60	4.43×10^{-6}	1.29×10^{-7}	1.80×10^{-8}	2.62×10^{-9}
3	38.23	61.77	2.45×10^{-6}	9.41×10^{-8}	6.80×10^{-9}	1.18×10^{-9}
4	35.55	64.45	4.61×10^{-6}	1.16×10^{-7}	5.11×10^{-8}	2.28×10^{-8}
5	46.66	53.34	1.23×10^{-7}	8.23×10^{-10}	0.00	0.00
6	44.59	55.41	2.12×10^{-7}	6.23×10^{-9}	8.03×10^{-10}	2.57×10^{-10}
7	50.62	49.38	1.19×10^{-7}	3.17×10^{-9}	4.60×10^{-10}	1.27×10^{-10}
8	46.84	53.17	2.18×10^{-7}	7.09×10^{-9}	1.10×10^{-10}	8.66×10^{-13}
9	1.39	96.31	5.55×10^{-6}	1.73×10^{-7}	4.24×10^{-8}	1.48×10^{-8}
10	0	57.95	1.28×10^{-5}	3.20×10^{-7}	6.69×10^{-8}	1.37×10^{-8}
11	0.14	81.54	6.46×10^{-6}	1.72×10^{-7}	4.88×10^{-8}	1.43×10^{-8}
12	0	87.25	1.17×10^{-5}	2.65×10^{-7}	1.12×10^{-7}	4.67×10^{-8}
13	5.51	94.44	2.18×10^{-7}	6.46×10^{-9}	5.87×10^{-10}	1.75×10^{-10}
14	0	100	5.70×10^{-6}	2.69×10^{-7}	8.55×10^{-9}	1.24×10^{-9}
15	16.28	83.72	2.66×10^{-6}	1.14×10^{-7}	3.72×10^{-9}	3.85×10^{-10}
16	0	99.48	1.34×10^{-5}	4.09×10^{-7}	2.82×10^{-8}	3.02×10^{-9}
17	36.10	63.90	4.21×10^{-7}	1.30×10^{-8}	1.02×10^{-9}	4.99×10^{-11}
18	26.59	73.41	6.79×10^{-6}	1.66×10^{-7}	5.62×10^{-8}	2.02×10^{-8}
19	36.04	63.96	3.48×10^{-6}	7.95×10^{-8}	3.35×10^{-8}	1.04×10^{-8}
20	21.41	78.59	7.06×10^{-6}	2.15×10^{-7}	3.35×10^{-8}	6.92×10^{-9}
21	46.55	53.45	4.21×10^{-8}	1.46×10^{-9}	1.84×10^{-10}	7.42×10^{-11}
22	44.87	55.13	9.43×10^{-8}	3.67×10^{-9}	1.87×10^{-11}	0.00
23	50.62	49.38	3.59×10^{-8}	2.52×10^{-9}	1.74×10^{-9}	0.00
24	45.46	54.54	6.99×10^{-7}	1.80×10^{-8}	3.34×10^{-9}	9.55×10^{-10}
25	0.06	85.74	4.08×10^{-6}	1.08×10^{-7}	3.47×10^{-8}	2.02×10^{-8}
26	0	90.54	1.71×10^{-5}	4.24×10^{-7}	9.61×10^{-8}	3.37×10^{-8}
27	1.92	96.41	8.83×10^{-6}	2.30×10^{-7}	7.04×10^{-8}	2.00×10^{-8}
28	0	47.61	7.64×10^{-6}	1.80×10^{-7}	5.77×10^{-8}	1.70×10^{-8}
29	5.52	94.48	2.34×10^{-7}	6.78×10^{-9}	5.46×10^{-10}	1.45×10^{-10}
30	0	99.60	5.77×10^{-6}	2.66×10^{-7}	8.23×10^{-9}	1.09×10^{-9}
31	16.19	83.71	2.68×10^{-6}	1.11×10^{-7}	3.77×10^{-9}	6.32×10^{-10}
32	0	100.29	1.35×10^{-5}	4.14×10^{-7}	2.91×10^{-8}	$3.78\mathrm{E}\times10^{-9}$

[a]Column Depo100_150 is cumulative deposition between 30.48 m (100 ft) and 45.72 m (150 ft) downwind.
[b]Column Depo_100 is the deposition at 30.48 m (100 ft) downwind.
[c]Column Depo_250 is the deposition at 76.2 m (250 ft) downwind
[d]Column Depo_500 is the deposition at 152.4 m (500 ft) downwind.

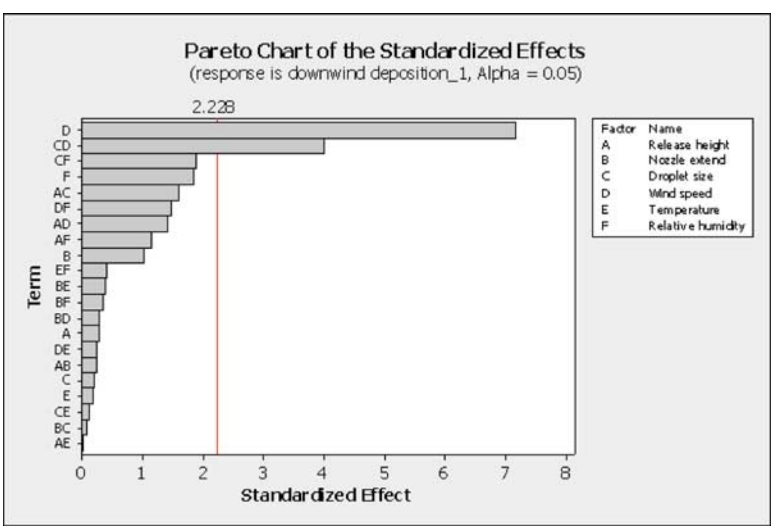

FIG. 3—*The Pareto chart.*

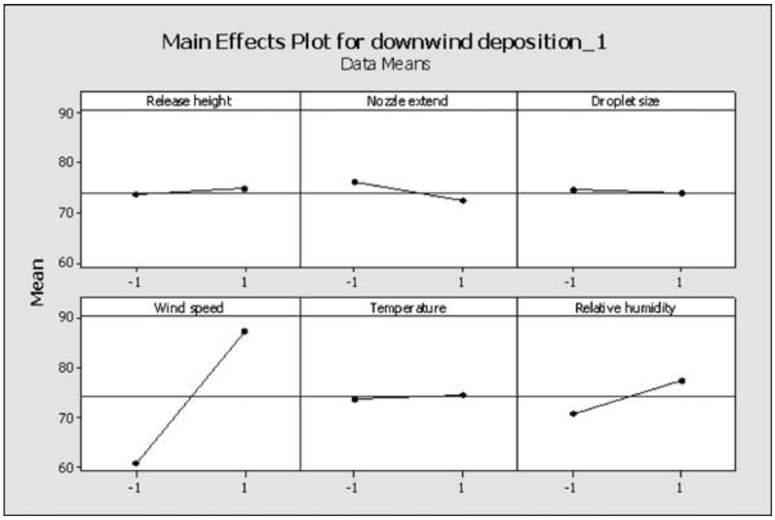

FIG. 4—*Main effects plot for total downwind deposition.*

From Table 3, one can make some interesting observations.

- Wind speed has significant impact on every outcome. Higher wind speed results in worse outcomes.
- Reducing droplet size improves most of the outcomes.
- Reducing the release height improves most of the outcomes.
- Nozzle extent, temperature, and their interactions with other factors have no significant impact on any of the outcomes.
- All significant interactions involve wind speed.
- The relative humidity only has significant contribution to downwind deposition far away through the interaction with wind speed.

As discussed earlier, factors having no significant impact does not mean they have no impact on the outcome. It means that compared to the significant factors, their impact is much less. As pointed out in Ref 28 and other papers in the literature, many of these factors such as nozzle extent, temperature, and relative humidity do have impact on the downwind drift.

The observations based on the DOE analysis allow us to focus on a few factors that have significant impact on the outcomes. In future analyses, we can simply assume constant values for temperature and nozzle extent. This will reduce the number of individual factor by two. Simulation runs will be simplified, for example, the one half factorial DOE matrix would require only eight runs compared to the original 32. This simplification can greatly reduce the time and cost when implemented in field experiments.

The analysis method used in this paper does not provide a solution, but it can lead the investigators in the right direction. It also can simplify the problem so that finding a solution becomes more feasible.

Conclusion and Discussion

DOE analysis is applied to the off target movement in aerial spray of agricultural production materials using the simulation software AGDISP. The factors and the interactions among factors that have more significant impacts than others are identified. Initial results from this study are very promising. Based on the DOE analysis, it was found that wind speed had significant impact on every outcome; nozzle extent,

TABLE 3—*Significant impact factors on outcomes.*

Outcomes/Factors	A	B	C	D	E	F	AB	AC	AD	AE	AF	BC	BD	BE	BF	CD	CE	CF	DE	DF	EF
Total downwind deposition				+												x					
Application efficiency	−		+	−												x					
Deposition between 30.48 and 45.72 m	+		−	+					x												
Deposition at 30.48 m	+		−	+					x												
Deposition at 76.2 m	+		−	+												x				x	
Deposition at 152.4 m			−	+												x				x	

temperature, and their interactions with other factors had no significant impact on any of the outcomes; all significant interactions involved wind speed; and the relative humidity had only a significant contribution to deposition a long distance downwind through the interaction with wind speed.

Being able to quantify the effect of each factor and their interactions using simulation methods is an important achievement. The unique approach of DOE analysis based on AGDISP simulation adopted in this paper has the advantage of being able to find the interactions among factors. This is not easy to achieve with field test data since many factors cannot be controlled to the desired extreme values. The DOE technique also allows one to improve the analysis efficiency since one does not have to run all possible combinations of the values for the factors.

This paper only presents initial results with simplifying assumptions to illustrate of the process. For example, only six factors are considered. But it is apparent that with more factors the approach can still be applied. There is much more research in the area of statistical analysis that can be done using simulation tools such as AGDISP. The effective use of simulation tool through the identification of significant factors can greatly simplify the field study. Ongoing research includes characterizing more detailed information than Table 3 on the relationship among the application efficiency, the total downwind drift, the cumulative downwind deposition between 30.48 m (100 ft) and 45.72 m (150 ft), the depositions at 30.48 m (100 ft), 76.2 m (250 ft), and 152.4 m (500 ft), and main factors such as wind speed, droplet size, and release height. It is expected that a numerical relationship among the main factors will be characterized. This characterization allows one to come up with optimal selection of the droplet size and release height based on the wind speed, thereby providing useful information for the applicators to achieve a better spray result. During the optimization process, the results will be validated using simulation or field experiments. Specifically for simulation validation, the values for all the factors considered here will be randomized with large sample size and simulated in AGDISP. Any inconsistence with the analysis in this paper will then be reviewed, and the DOE analysis will be modified and re-ran.

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