Spraying advisability index using field weather observations

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Brown, R.B., Steckler, J.P., Anderson, G.W. and Khelifi, M. 1995. **Spraying advisability index using field weather observations.** Can. Agric. Eng. 37:157-162. A Spraying Advisability Index (SAI) for prediction of on-target spray deposition from a hydraulic boom sprayer is presented. It is intended for non-technical users such as farmers or custom sprayer operators. Advisability of spraying under the local weather conditions is determined from four measurements readily taken on site: wind speed, air temperature, relative humidity, and soil surface temperature. The index correctly predicted on-target spray recovery in 66 out of 82 trials conducted with water and a fluorescent tracer. When the SAI was favourable, recovery of spray from artificial targets was 80% or more of the quantity applied. Recovery was below this 80% cutoff when the SAI was unfavourable. Use of the SAI should reduce unnecessary environmental contamination due to spraying under inappropriate conditions, and will also improve application efficiency. It is particularly appropriate for post-emergence herbicide application or fungicide application.

Keywords: sprayers, herbicides, weather, drift.

Un indice de l'opportunité de pulvériser (SAI). qui permet de prédire si le produit pulvérisé à l'aide d'un pulvérisateur à rampe atteint la cible projetée, a été développé. Les usagers potentiels de cet indice sont les agriculteurs ou le travailleurs qui font la pulvérisation à forfait. L'opportunité de pulvériser selon les conditions météorologiques locales existantes peut être évaluée à partir de quatre facteurs: la vitesse du vent, la température de l'air, l'humidité relative et la température de la surface du sol. Lors d'essais de pulvérisation avec de l'eau et un traceur fluorescent, l'indice a permis de cibler correctement la pulvérisation dans 66 des 82 essais. Lorsque l'indice était favorable, les liquides récupérés des cibles artificielles représentaient 80% ou plus des quantités pulvérisées. La récupération était inférieure à 80% dans les cas où l'indice n'était pas favorable à pulvérisation. L'utilisation de l'indice développé devrait permettre de réduire la contamination environnementale qui résulte d'une pulvérisation faite dans de mauvaises conditions, et d'améliorer l'efficacité de la pulvérisation. L'indice est particulièrement utile lors de l'application d'herbicides en post-lavée ou des fongicides.

INTRODUCTION

Agricultural pesticide spraying is a sensitive issue. The chemicals used sustain the high level of productivity enjoyed by modern agricultural practice when they are properly applied. Nevertheless, if they are applied in an inappropriate manner, the effects of pesticide chemicals on the environment and the crop can be devastating. The timing, the chemicals used, and the method of application are all controlled by the sprayer operator. However, it is usually the combined effects of the uncontrolled local weather variables of wind speed, temperature, and humidity that dictate the appropriateness of field spraying. In addition to the obvious spray drift problem, biological control is reduced under certain conditions so that additional treatments, or higher rate applications, are required. A spraying advisability index, which allows the operator to account for the complex weather effects on spray deposition, would greatly reduce the occurrence of misapplication and minimize spray drift potential.

LITERATURE REVIEW

Sprayer operators need two things to help them decide whether or not to spray under a particular set of conditions. First, a basic set of instruments to monitor weather conditions in the field must be available at a reasonable cost. The second requirement is for a method of interpreting that weather data in a way that is immediately meaningful. The latter requirement was the principal objective of the work reported in this paper. Many studies on modelling spray drift and deposition have been reported, but these have been almost exclusively aimed at the scientific community. Few attempts to develop a useful tool for non-technical operators have been published.

There are several computer simulation models available for predicting drift and deposition from spray applications. These include the PKBW model for aerial application (Picot et al. 1993), the FSCBG model (Richardson et al. 1993), and the AGDISP model (Yates et al. 1988). Although very useful for research, the models are clearly unsuitable for use by non-technical persons and are not intended for ground spraying operations.

A random-walk model for quantification of spray drift from a field sprayer was developed by Thompson and Ley (1982). Several approaches for assessing spray drift from field sprayers using the mathematical model of Miller and Hadfield (1989) have been reviewed (Legg and Miller 1990). The conclusion reached was that a combination of field measurements and modelling was the most promising direction for future research. Recently, spray deposition and drift from ground spraying rigs have been modelled using the Fluent simulation package (Reichard et al. 1992). While computer simulation models have been useful to scientists and engineers for predicting weather effects on spray deposition and drift, they have not yet become prescriptive tools for routine use by sprayer operators.

A nomogram hazard rating scheme for sprayer operators, which was based upon the main factors thought to affect drift, was reported by Elliot and Wilson (1983). That index takes into

consideration time of day and cloud cover, wind speed, the type of application system, and air temperature. However, air humidity effects are not accounted for in that index and relative humidity is known to be a significant factor affecting spray loss over most of North America and especially in the arid western plains.

Elliot and Wilson (1983) also mentioned an approach for estimating the drift hazard from several in-field observations including a smoke bomb test and then assigning a score to each factor. The total score is an indication of the acceptability of spraying under the prevailing conditions. While the approach is simple to use, the scoring system is somewhat arbitrary and the factors of air temperature and relative humidity are omitted. A similar decision model for estimating spraying advisability was described by Hagenvall (1990). His model incorporated many operational parameters for the sprayer and the wind speed at boom height, but other weather effects were simply assigned "favourable" or "less favourable" designations.

A simple decision formula developed at Ciba-Geigy Canada Ltd. to aid sprayer operators in making weather-related decisions was reported by Brown et al. (1990). This formula, coined the "Atmospheric Conditions for Spraying" index (ACS), was a linear combination of the wind speed, the thermal turbulence (i.e., the difference between air and ground surface temperature) and the difference between the dry bulb and dewpoint temperature of the air (the "evaporative demand"). The ACS index was easy to calculate, but spray recovery data obtained in field trials conducted did not always match the predictions of the index. We felt that the constant weighting factors in the ACS index oversimplified the interactions occurring. The use of relative humidity rather than dewpoint temperature would also be more practical for psychrometric measurements in the field. Consequently, we sought to determine those weighting factors which should be applied to meteorological variables measured in the field to estimate the on-target deposition of spray.

OBJECTIVES

The two objectives of the study were: (1) to determine which micrometeorological variables that are easily measured in the field are also the most significant in their effects on on-target spray recovery when using a hydraulic boom sprayer, and (2) to formulate an index which combines those significant variables in a way which indicates the advisability of spraying under the prevailing weather conditions and is simple to calculate.

MATERIALS AND METHODS

Field trials

A factorial experimental design was developed with four factors (spray droplet size range, wind speed, air temperature, and relative humidity) at two levels (i.e., fine/coarse or high/low). At least three replications of each combination of factors were conducted. Experiments were conducted over a grassy sward about 200 mm tall in an open area on the University of Guelph Research Farm. The sprayer used was a conventional, 3-point hitch model with an 8 m boom and a 300 L tank (Hardi Model BL53). Only the two folding wings of the spray boom were used, not the central section below the tank.

Six XR8002VS flat-fan nozzles (Spraying Systems Ltd., Wheaton, IL) were installed at 500-mm centres on the left wing and were operated at 280 kPa to produce a fine range of spray droplets (Fig. 1). Six XR8005VS nozzles were installed on the right wing for a coarser spray. An Aerometrics phase doppler laser velocimeter (Model PDPA-100, Aerometrics Inc., SunnyVale, CA) was used at the Laboratory for Pest Control Application Technology in Wooster, Ohio to determine droplet size spectra for the sets of nozzles used in the field trials. The XR8002VS nozzle set used had an average volume median diameter (VMD) of 225 μm at 280 kPa with a standard deviation of 6.1 μm. The XR8005VS nozzles had an average VMD of 368 μm with a standard deviation of 6.4 μm.

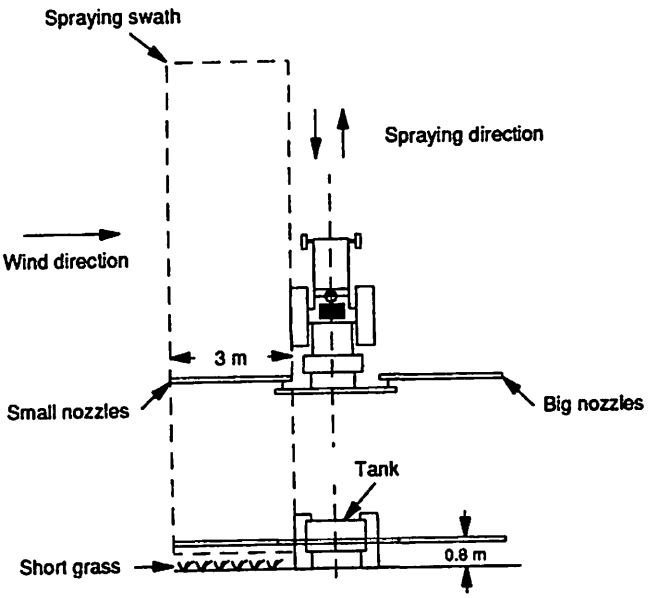

Fig. 1. General view of the sprayer in the field.

Seven targets were arranged within the spray swath to collect droplets as the boom passed over (Fig. 2). A zig-zag pattern of targets was used to account for variations in sprayer speed and terrain roughness over the plot. These targets comprised 125-mm diameter filter paper disks (Whatman Quantitative Paper No 40) attached to flat steel backing plates 90-mm square with dry mount photograph adhesive. The backing plates were held horizontally 100 mm above the grass canopy on top of 6-mm diameter spikes driven into the ground. The targets were similar to those used earlier by Ciba-Geigy Canada Ltd. in developing the ACS index (Brown et al. 1990).

The tractor carrying the sprayer was driven on a hard-packed roadway adjacent to the sward, so that ground speed was uniform and repeatable between tests. During each test, the wind direction was perpendicular to the path of the sprayer within about 20 degrees, and the tractor was always downwind of the targets. Because on-target deposition was the major element of interest in this study, each run was based on single swath spraying. The amount of spray liquid unrecov-

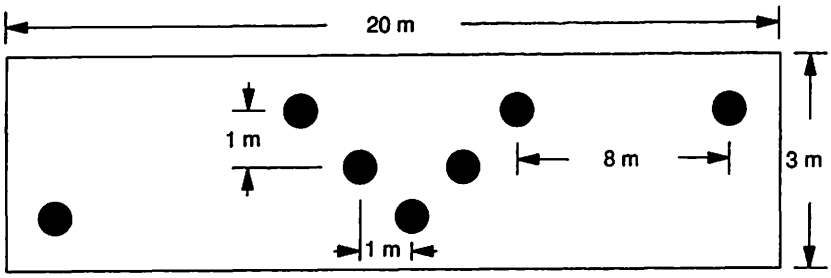

Fig. 2. Distribution of the targets in the plot.

ered was considered to be a combination of off-target deposition and drift.

The sprayer was calibrated to deliver 150 L/ha. Uvitex fluorescent tracer, formulated as Helios 010 EC (Ciba Ltd., Agricultural Division, Basle, Switzerland), was added to the spray solution at a rate of 300 mL/ha, as recommended by Ciba for artificial targets. With a flow rate of 0.75 L/min per nozzle at 280 kPa, the XR8002VS nozzles required a spraying speed of 6 km/h. The XR8005VS nozzles, with a flowrate of 1.25 L/min, required 10 km/h. The nozzle flowrates and average ground speeds were checked prior to the beginning of each trial. Boom height is known to have a major effect on spray drift and deposition, however most field crop sprayers in Ontario have the boom height set at 500 mm above the top of the plant canopy for post-emergence herbicide spraying. Boom height was set 500 mm above the targets for all tests (i.e., 800 mm above the soil surface).

The filter paper targets were stuck to the collector plates immediately before each run and weather data were collected repeatedly as each swath was sprayed. A vane airflow meter with a built-in thermistor (Model DVA6000T, Airflow Developments Ltd., High Wycombe, Bucks, England) was used to measure both wind speed and air temperature at the 800-mm height. A sling psychrometer was used for humidity readings and to double-check the dry bulb air temperature at 800 mm. The ground surface temperature was recorded from a thermometer probe inserted to a depth of 4 mm in the soil. The 4 or 5 observations of wind speed, humidity, air, and soil temperatures made over the duration of each test, about 5 minutes, were averaged and recorded as the prevailing weather conditions for each test. The ranges of weather variables observed are summarized in Table I.

When the filter paper targets were completely dry, they were carefully collected and placed individually into ziplock plastic bags and stored in a cool, dark cabinet until analysis was completed. A tank sample was taken directly from the boom at the end of each spraying trial to determine the theoretical maximum concentration of tracer chemical applied.

Table I: Ranges of weather variables observed in field tests

Variable	Low range	High range
Wind speed (m/s)	0.1 - 1.5	1.8 - 5.0
Air temperature (°C)	14.8 - 24.9	23.9 - 30.3
Relative humidity (%)	45 - 60	63 - 87

Laboratory analysis

The on-target deposition concentration was determined by washing the filter papers with HPLC grade isopropyl alcohol. The dye was extracted by placing a filter paper and 20 mL of alcohol into a 250 mL sample jar. Each jar was then shaken 200 times and 10 mL of the washing solution was removed for fluorometric analysis. Fluorescence readings for the target solutions were made with a portable fluorometer (Model PFM2, Ciba Ltd., Agricultural Division, Basle, Switzerland) and compared to those from the diluted tank sample to determine percentage recovery.

The calibration of the fluorometer was checked before each set of seven filter papers was analyzed. A zero adjustment was done for a non-treated filter paper washed with 20 mL of isopropyl alcohol to produce a baseline reading. The full-scale (i.e., 100) calibration was done with 20 mL of a standard solution of 100 µg/L of helios, which was first used to wash a new filter paper in case the paper itself produced any effects. In addition, an ultraviolet lab lamp (ULV-22, Ultra Violet Products Inc., San Gabriel, CA) was used to check target filter papers periodically for any residual fluorescence that would reveal inadequate extraction.

RESULTS AND DISCUSSION

The overall effects of the weather factors on spray recovery from the targets were determined using a General Linear Models (GLM) statistical procedure (SAS 1985) for the factorial experimental design. The results indicated that the simple factors of wind speed and droplet size range were highly significant ($p = 0.01$) in their effects on chemical deposition. Relative humidity was also significant, but at the 5% probability level. In addition, the interactive terms of air temperature with relative humidity, droplet size with wind speed, droplet size with air temperature, droplet size with relative humidity, and wind speed with relative humidity and droplet size were all highly significant ($p = 0.01$).

A separate analysis of variance for each droplet size data set was performed over the two ranges of each independent variable. The results, presented in Tables II and III, show that wind speed, temperature, and the interaction of temperature with relative humidity, all had significant, or highly significant, effects on deposition within each droplet size range. In addition, relative humidity, the interaction of wind speed with relative humidity, and the three-factor interaction of wind speed, air temperature and relative humidity, were significant for the fine spray only ($p = 0.01$).

Regression models for estimating tracer recovery from the actual values of weather variables measured during each trial were determined using a stepwise procedure and the Mallows C_p statistic for model selection (SAS 1985). Analysis of the coarse droplet data did not produce any useful model for spray recovery, although the ANOVA results (Table III) had shown significance of some factors when grouped into high and low ranges. The best combination of factors gave an r^2 value of only 0.20, which was considered to be too low for acceptable estimation accuracy. The fine droplet size data set

Table II: Analysis of variance of the fine droplet data set (XR8002VS)

Source	DF	Mean square	F Value
W[1]	1	1902.70	61.44 **
H[2]	1	769.75	24.86 **
W*H	1	421.42	13.61 **
T[3]	1	159.23	5.14 *
W*T	1	0.07	0.00 NS
T*H	1	192.21	6.21 *
W*T*H	1	251.13	8.11 **
Error	74	30.97	

1 Wind speed
2 Relative humidity
3 Air temperature
** Significant at the 0.01 level
* Significant at the 0.05 level
NS Not significant

produced a usable model ($r^2 = 0.53$) which was:

$$R = \exp(5.03 - 0.323W - 0.147T - 0.230H + 0.073T \bullet H + 0.129W \bullet H) \quad (1)$$

where:
R = percent recovery,
W = windspeed (m/s),
T = air temperature (°C), and
H = relative humidity (%).

Although this model gave a reasonable estimate of tracer recovery, and hence on-target deposition, the objective was to develop an index of advisability for spraying rather than an empirical model of spray deposition. The regression model did illustrate two important points: the weather variables affected tracer recovery in a nonlinear (i.e., exponential) manner, and the simple effect of wind speed was about twice as great as either temperature or humidity effects, which were roughly equal.

The index predicting spray recovery was prepared from the experimental observations using the main components of:

1) wind speed (W), measured at 800 mm elevation (m/s),
2) air temperature (AT), also measured at 800 mm (°C),
3) soil temperature (ST), 4 mm below the surface, and
4) relative humidity (RH), measured at the 2 m elevation (%).

Air and soil surface temperatures were combined to yield a single "thermal turbulence" indicator (TT = ST - AT) which indicates the stability of the atmosphere above the canopy.

The formulation of the Spraying Advisability Index (SAI) is outlined in Table IV. The evaluation technique consists of assigning integer weight values to different levels of each weather factor, according to its apparent effect on on-target deposition. Double weight is assigned to wind effect levels compared to the effect levels for air humidity and thermal turbulence. The range for wind speed effects was established

Table III: Analysis of variance of the coarse droplet data set (XR8005VS)

Source	DF	Mean square	F Value
W[1]	1	312.43	5.57 *
H[2]	1	22.70	0.40 NS
W*H	1	208.99	3.72 NS
T[3]	1	255.63	4.55 *
W*T	1	14.94	0.27 NS
T*H	1	318.34	5.67 *
W*T*H	1	1.54	0.03 NS
Error	74	56.14	

1 Wind speed
2 Relative humidity
3 Air temperature
* Significant at the 0.05 level
NS Not significant

Table IV: Spraying advisability index

Factors	Suggested weight
Wind speed, W, (m/s)	
W ≤ 1	0
1 < W ≤ 2	2
2 < W ≤ 3	5
3 < W ≤ 4	8
4 < W ≤ 5	11
5 < W	14
Thermal turbulence, TT, (°C)	
0 < TT ≤ 2	0
2 < TT ≤ 3	1
3 < TT ≤ 4	1
4 < TT ≤ 5	2
5 < TT ≤ 6	3
6 < TT ≤ 7	4
7 < TT	6
Relative humidity, RH, (%)	
75 < RH	0
70 < RH ≤ 75	1
65 < RH ≤ 70	1
60 < RH ≤ 65	2
55 < RH ≤ 60	3
50 < RH ≤ 55	4
RH ≤ 50	6

as 1 to 5 m/s, assuming that a light breeze gives optimal deposition and that spraying would never be advised above 5 m/s or under no-wind conditions when a stable atmosphere may develop.

Most experimental recovery measurements obtained from the coarse droplet applications were in the acceptable range

(i.e., over 80%) and were largely unaffected by the different levels of the meteorological variables. A recovery of 80% or more of the tracer dye applied from a flat artificial target indicates acceptable delivery to the plant canopy (M.A. Morse 1990 personal communication). However, under good application conditions the tracer recovery from the fine spray nozzle set was even higher. For the best set of conditions (i.e., low wind, low temperature, high humidity) recovery from the XR8002VS nozzles averaged 92.5 ± 4.6 %, while recovery from the XR8005VS set was only 81.7 ± 7.4 %. Since recovery was relatively constant for the coarse droplet spray, an index could not be developed from the data available. Therefore, results reported in Table IV apply only to the fine droplet size range.

The steps required to evaluate the SAI are:

1) Determine wind speed, air and soil temperature, and air relative humidity.
2) Calculate the thermal turbulence factor, TT, from the air and soil temperature measurements.
3) Calculate the total score, SAI, for the variables measured by adding the weights assigned to the parameters W, TT, and RH from Table IV.
4) If W < 1 m/s and TT < 0, do not spray.

The results are interpreted as follows:

- If SAI ≤ 11, the conditions are favourable for spraying.
- If 11< SAI < 13, (intermediate value) it is recommended to continue with caution and collect the data again after 5-10 minutes. If the score remains in that range for several subsequent readings, spraying is not recommended.
- If SAI ≥ 13, on-target deposition will be very low and conditions are definitely unsuitable for spraying.

The SAI predictions were checked against the field test data for actual recovery using the following scheme:

- If SAI ≤ 11, recovery should be higher than 80%,
- If 11< SAI < 13, recovery should be intermediate, between 75 and 85%, and
- If SAI ≥ 13, recovery should be less than 80%.

The index usually predicted the acceptability of spray applications correctly. Only 16 out of 82 cases presented misleading recommendations (80.5% accuracy) and among those only 8 cases, or less than 10% of the total, were cases where a low score recommending spraying actually corresponded to an unacceptable recovery (i.e. less than 80%). The remaining 8 cases yielded either intermediate or high SAI scores, for which spraying would not be recommended, when in fact tracer recovery was acceptable.

The earlier ACS index (Brown et al. 1990), with its equal weighting of factors and linear combinations for the same data, gave a prediction accuracy of 73%.

CONCLUSIONS AND RECOMMENDATIONS

The study showed that wind speed, soil surface temperature, and air temperature and relative humidity were all significant environmental factors affecting on-target spray deposition from a hydraulic boom field sprayer. These factors are easily monitored in the field with inexpensive and simple devices.

A spraying advisability index (SAI), based upon a simple scoring system for the major environmental factors, was accurate in predicting the relative on-target recovery of applied chemical tracer. The index will help spray operators decide in the field whether or not to spray under the prevailing weather conditions.

The SAI and a regression model of tracer recovery were only applicable to the fine droplet spray produced by the XR8002VS flat fan nozzle. The spray recovery from the XR8005VS nozzle operating at low pressure (i.e. 140 kPa) did not vary consistently as the weather variables changed. In fact, most of the time the coarser droplets yielded acceptable recovery regardless of the levels of the weather factors.

Further study is recommended to investigate other nozzle sizes (i.e. different droplet size distributions) as droplet size is a key factor for on-target deposition efficiency. More field data are needed to improve the index presented, as inevitably some combinations of environmental factors occur less frequently than others. In particular, low humidity conditions are difficult to observe during the summer in Ontario. A low-cost, reliable set of weather instruments should be developed for use in the field under rugged conditions. Absolute accuracy and response speed do not need to be high for this application.

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