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ABSTRACT

A field survey of 140 private and commercial pesticide applicators was conducted during the spring of 1986 in 12 counties of central and eastern Nebraska. The results showed that one out of every three cooperators was applying pesticides within ±5% of their intended application rate. Results indicated that applicators have reduced application errors from that of a similar survey conducted in 1979. However, most errors still can be traced to incorrect calibration. Ninety-four percent of the cooperators used some type of calibration method. Two-thirds used the "Known Area" method. Those using a calibration method more than once a year had the fewest application errors. The commercial applicators had approximately 50% fewer errors in applying chemicals than private applicators. They also accounted for about twice the land area chemically treated of those sampled. Nozzle discharge uniformity was not a major problem suggesting that chemical applicators are changing nozzle tips more frequently than 8 years ago or more durable materials are being used.

INTRODUCTION

With the increased use of agricultural pesticides, the proper application of pesticides has never been more important than today. The margin of application error has narrowed, especially with low-rate, more selective pesticides, causing the accuracy of application to be more critical. The emphasis for proper efficient use of pesticides comes from both economic and environmental concerns.

The cost of most active ingredients has risen from 30 to 60% over the last 5 years. Overapplication of pesticides causes increases in production costs, potential crop damage, pollution and excessive residue carryover. For example, a 10% overapplication of chemicals costing $37.5/ha ($15/acre) would add $450 to the cost of spraying 120 ha (300 acres). This figure represents only the overcharge for additional chemical without accounting for other possible damages. Underapplication can be just as costly because the chemical does not control the pest. This may require an additional application which means additional field traffic, added fuel and labor, plus the chemical application may be at an ineffective time in the pest's growth cycle.

Proper pesticide application results from the proper selection of equipment, mixing and calibration. Accurate testing and calibration of application equipment is largely dependent on the competence and reliability of the person applying the pesticide. In most states, certified pesticide applicators receive training concerning safe handling of pesticides, equipment calibration and proper application conditions. However, there are no assurances that the guidelines are used extensively by those handling restricted and non-restricted use pesticides. According to the Guide for Commercial Applicators (USEPA and USDA, 1975) the application error should be within plus or minus ±5% of the recommended or intended rate; however, some specialists use a ±10% criteria. In either case, accurate knowledge of calibration will enable an operator to establish a ratio at which pesticides and carrier must be added to the spray tank. In this manner, the intended chemical rate of application specified by the pesticide container label can be achieved for the "target" pest and crop-soil conditions.

LITERATURE REVIEW

In 1976 the National Agricultural Development and Advisory Service (ADAS) studied 91 sprayers in England and Wales (ADAS, 1976). An advisor visited the farm site and performed a routine inspection and a calibration check of the sprayer. Forty percent of the sprayers checked had not been previously calibrated by their owners and 54% of the units checked were properly calibrated. A 10% variation in nozzle output from the average was considered satisfactory. Only 24% of the nozzles checked were within this satisfactory criteria. In some cases, different nozzle sizes were being operated on the same units.

A similar study was conducted in Nebraska in 1979 (Rider and Dickey, 1982). A total of 152 private and commercial pesticide applicators were surveyed to check both calibration and mixing accuracy. Of those applying liquid pesticides, (95 cooperators) 47% had a calibration error and 7% had a mixing error of greater than 5% of

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the operator's intended rate. An additional 31% had both of these errors. Thus, 85% of the applicators had a calibration and/or mixing error in excess of 5%. Almost 40% of the applicators were satisfactory when the tolerance was expanded to within 10% of intended application rates.

Further separation of the type of applicators revealed that commercial applicators did a much better job of application. Almost two-thirds of the commercial applicators were within ±10% of their intended application rate.

Rider and Dickey (1982) also observed the uniformity of nozzle discharge from 18 liquid applicators. The results showed that more than 60% of the liquid applicators had a coefficient of variation (CV) greater than 10%.

The most common method of calibration used by the Nebraska farmers was the "Known Area" method. No statistical differences between the type of calibration method and application error were detected.

From a questionnaire returned by 184 crop producers of northeast Missouri, Hoehne and Brumett (1982) reported that over 70% of the respondents were satisfied with the effectiveness of the chemicals applied. Only 14% of the producers reported incorrect application rates as a contributing factor to poor results. Fifty percent of the respondents reported using the "Catch Container/Time and Ground Speed" or the "Known Area" methods of calibration. Almost one-fourth of the producers relied on the previous years setting as the calibration method. About one-third of the respondents admitted that the calculation of the mixing ratio of chemical to carrier had caused an error.

Hofman and Hauck (1983) observed 60 North Dakota farm sprayers inspected, only 11 (18%) were found to be in excellent shape and were applying chemicals as the owner predicted. Sixty percent of the sprayers checked had calibration errors greater than ±10% of the owner's prediction. Forty-three percent had one nozzle greater than ±10% variation of the average nozzle discharge. Thirty-two percent had inaccurate travel speeds.

English and Friesen (1985) evaluated 49 crop sprayers at farms throughout Manitoba. Their findings showed that over 50% were equipped with TeeJet* 8002 stainless-steel fan nozzle tips. Ninety-five percent of the nozzles checked using these tips were within ±5% of the average discharge. Almost half of the nozzle tips constructed from brass had more than a 15% increase of output as compared to new nozzles. Of the sprayers checked, 75% of the applicators were within ±10% of their desired rate and no applicator had errors in calibration greater than ±20%. Only 32% of the cooperators had chemical rate errors greater than ±10% of desired rate.

Nelson (1986) and his county staff conducted 61 sprayer clinics in 39 Montana counties during 1983 to 1985. They evaluated 804 private and commercial sprayers. The results showed that almost 40% of the applicators were within ±10% expected application rate. The average applicator error of these cooperators was 23% of expected rate.

Ozkan (1987) also evaluated 32 sprayers in Iowa and Ohio at "drive-in calibration clinics". Of the sprayers calibrated, only seven sprayers were applying a tank mix within ±5% of what the operators predicted. The magnitude of the errors ranged from 75% underapplication to nearly 50% overapplication. Almost 65% of the sprayers had a coefficient of variation among nozzle discharge volumes of less than or equal to 10%, with a maximum CV of 21%.

OBJECTIVE

The primary purpose was to assess the accuracy of pesticide applicators in calibrating and checking pesticide application equipment while applying chemicals under Nebraska field conditions. Other objectives were to determine what application equipment and calibration methods were being used.

PROCEDURES

Technicians made observations on the farm site during calibration and/or field application. Many of the randomly selected cooperators had no prior notice of the technician's arrival. All the cooperators applied liquid solutions with a majority applying herbicides. On-site observations consisted of a short interview followed by the measurement of sprayer performance.

During the interview period, the technicians would gather information concerning: the applicator, sprayer set-up, system pressure, nozzle type, the chemical(s) used, intended chemical rates, amount of chemicals added to the tank, intended application rate, estimated travel speed, the type of calibration used and frequency of use. The items measured were nozzle delivery rates, nozzle spacing, nozzle heights, and travel speed. The nozzle delivery rates were measured in a stationary position over a given time period (either 15 or 30 s) using the field operating pressure. In some cases, the solution contained herbicide, in which case, all discharge was caught with buckets and then returned to the tank after measurement. This prevented loss of expensive chemicals and excessive accumulation of chemical residues at the calibration site. The travel speed was timed over 26.8 m (88 ft) for units traveling less than 13 km/h (8 mph) and for those faster a distance of 91.5 m (300 ft) was utilized.

From these measurements, the measured application rate (V) was calculated as:

$$V = \frac{K\,Q}{S\,W} \qquad \text{[1]}$$

where

V = measured application rate, 1/ha (gpa)
K = constant, 60,000 (5940)
Q = average measured nozzle flow rate, 1/min (gpm)
W = nozzle spacing or width, cm (in.)
S = travel speed, km/h (mph)

If travel speed was measured, it was used to calculate the application rate but if not measured, then the estimated speed given by the applicator was used. With the

*Mention of trade and company names included are for the benefit of the reader and do not infer endorsement or preferential treatment of the product names by the University of Nebraska, Lincoln.

knowledge of the application rate, the measured chemical rates (Vc) was determined as:

$$Vc = \frac{V\,A}{T} \qquad [2]$$

where

Vc = measured chemical rate, L/ha (pt/acre or qt/acre)

A = amount of chemical added to tank, L (pt or qt)

T = volume used in spray tank, L (gal)

To determine uniformity of nozzle discharge across the boom, output from individual nozzles was measured (at least 75% of total nozzles) and compared to the average nozzle discharge. As a measure of discharge uniformity, coefficient of variation (CV) was calculated as:

$$CV = \frac{SD * 100}{\bar{Q}} \qquad [3]$$

where

CV = coefficient of variation of nozzle discharges, %

SD = standard deviation of nozzle discharge across the unit

$\bar{Q}$ = the average nozzle discharge across the unit, 1/min (gpm)

These measured values were then compared with those that the cooperator's expected. The percent error was calculated as:

$$\%\ Error = \frac{\text{Measured Rate} - \text{Estimated Rate}}{\text{Estimated Rate}} * 100 \qquad [4]$$

RESULTS AND DISCUSSION

A total of 140 liquid pesticide applicators cooperated in the survey, of which 24 units (17%) were designated as commercial and the remaining 116 units (83%) were private applicators.

Types of Spray Units

The field sprayers studied were classified into 4 groups: (a) banding chemicals while planting, (b) broadcasting chemicals while planting, (c) broadcasting chemicals only and (d) broadcasting chemicals and incorporating it with a tillage device. The results of these groups compared to the application error measured are shown in Table 1. Units had about the same application error except "Broadcast-Only" which had less errors. This group contains all of the commercial units since most private applicators were spraying during other operations such as planting or tillage.

TABLE 1. TYPES OF SPRAYER UNITS CORRELATED WITH APPLICATION ERRORS WITHIN ±10% OF INTENDED APPLICATION RATE

Type of sprayer	% applicators within ±10% error	% of sample
Planters/Banding	58.7	33.3
Planters/Broadcast	58.3	8.7
Broadcast only	67.3	35.5
Tillage/Broadcast	56.7	22.5
		100%

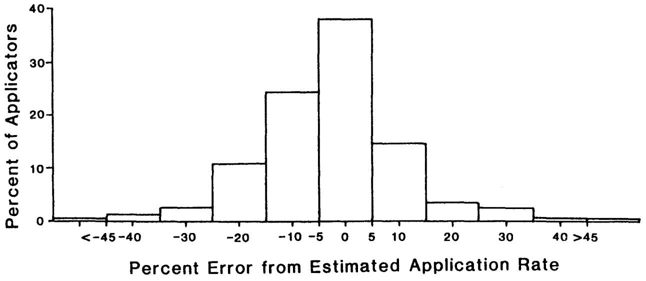

Fig. 1—Percentage distribution of application errors for actual liquid chemicals. These errors are the result of improper mixing, calibration or a combination of both.

Liquid Applicator Errors

Liquid pesticide applicator errors can result from incorrect calibration, incorrect mixing ratio of the pesticide with carrier (generally water), or some combination of both. Over 60% of the cooperators observed had a calibration and/or mixing error in excess of 5% (Fig. 1). Commercial applicators had almost 50% fewer errors than private applicators (Table 2). In either case, calibration errors accounted for a large portion of the errors. Using ±5% error as a satisfactory guideline, over 10% of both commercial and private applicators had errors of both calibration and mixing. Forty percent of the commercial units (Fig. 2) had calibration errors only, while almost two-thirds of the private applicators experienced calibration errors. Expanding the tolerance limits to ±10% of intended application rate, showed 75% of the commercial and 60% of the private applicators were satisfactory. This indicated that a majority of the applicators could make a simple adjustment, such as a speed change or pressure change, to correct their inaccuracy.

The magnitude of calibration errors ranged from over 40% underapplication to more than 60% overapplication. If an error occurred, there was a tendency to under apply.

Although incorrect calibration was primarily responsible for tank mix errors, both calibration and the

TABLE 2. LIQUID APPLICATION RATE ERRORS CORRELATED WITH COOPERATORS MAKING ERRORS GREATER THAN ±5% OF INTENDED RATE

Error	% making errors (Number in sample)	
	Type of applicator	
	Commercial	Private
Both calibration & mixing errors	12.5 (3)	10.7 (11)
Calibration errors	33.3 (8)	53.4 (55)
Mixing errors	12.5 (3)	8.7 (9)
No errors	41.7 (10)	27.2 (28)

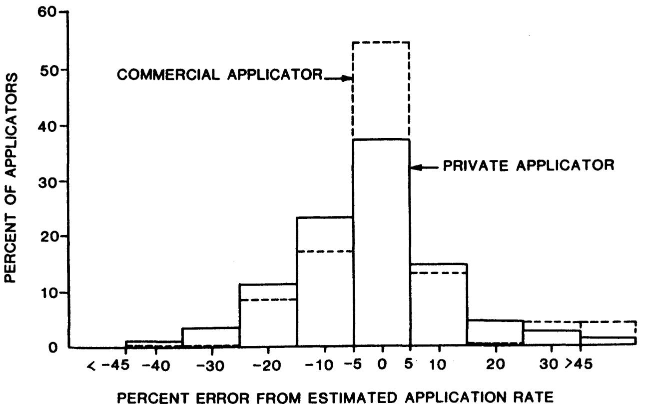

Fig. 2—Percentage distribution of application errors from commercial (24 units) and private (116 units) applicators. These errors are the result of improper mixing, calibration or a combination of both.

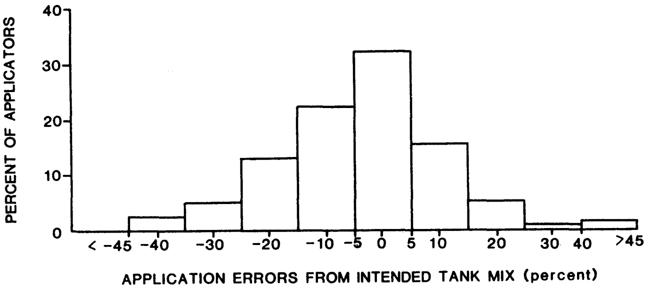

Fig. 3—Percentage distribution of application errors of tank mixes. These errors are mainly the result of improper calibration.

amount added to the tank influence the actual chemical application rate. Fig. 3 shows the percentage distribution of chemical application errors which ranged from approximately 40% under application to over 60% overapplication. Since incorrect calibration has a dominant influence, Figs. 1 and 3 were very similar. Over two-thirds were applying two or more chemicals that required handling of multiple containers. In several cases, one chemical was properly mixed and the second was not, these cases were reported as mixing errors.

By comparing the results from the survey (Rider and Dickey, 1982) conducted 8 years ago, many of the extreme application errors (>25%) have been reduced (Fig. 4). The applicators are doing a much better job of applying chemicals and have reduced their mixing errors considerably.

The land area covered by 22 commercial units was

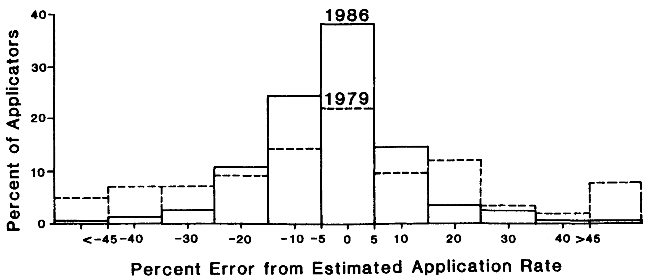

Fig. 4—Percentage distribution of application erors from two surveys: current results (1986) and from 1979 survey by Rider and Dickey (1982). These errors are the results of improper mixing, calibration or a combination of both.

TABLE 3. THE ANNUAL AREA COVERED PER UNIT CORRELATED WITH APPLICATION ERRORS WITHIN ±10% OF INTENDED APPLICATION RATE

ha (acres)	% of applicators within ±10% error	Number of units	% of sample
>4040 (>10,000)	83.4	6	5.3
2030-4040 (5,000-10,000)	87.5	8	7.0
970-2030 (2,400-5,000)	57.1	7	6.2
730-970 (1,800-2,400)	66.6	6	5.3
490-730 (1,200-1,800)	41.5	13	11.3
240-490 (600-1,200)	64.5	31	26.8
120-240 (300-600)	44.1	34	29.3
<120 (<300)	50.0	1	9.5

66,900 ha (165,200 acre) while 29,300 ha (72,300 acre) was chemically treated by 95 private applicators. On the average, this survey showed that commercial applicators covered 10 times more area than typically expected from a private applicator.

Table 3 shows the influence of annual area covered per unit to applicators within 10% of intended application rate. Seventeen of the 24 commercial units had the largest land coverage (>5000 acre) and their application errors were relatively small (Table 3). The group that had the most errors of calibration appeared to be those applying chemicals to less than 243 ha (600 acre) annually. These applicators accounted for almost 40% of those surveyed.

According to equation [1], if any factor is poorly estimated then the application rate would be in error accordingly. The average speed of 88 applicators was 10.5 km/h (6.5 mph), with a range from 4.8 km/h (3.0 mph) to 37.0 km/h (23 mph). Table 4 shows the speed deviation of applicators from their estimated rate. About 50% were within ±5% of their estimated speed and three-fourths were within ±10% of their estimated speed. This may indicate that applicators were relying on their speedometers but these meters do not consider the influence of wheel slip or other errors possible with

TABLE 4. THE SPEED DEVIATION CORRELATED TO THE PERCENTAGE OF APPLICATION MEASURED

% error	% of applicators within range	# of applicators
+5 to -5	51.1	45
+10 to -10	77.3	68
+15 to -15	89.8	79
+25 to -25	97.8	86
+50 to -50	100.0	88

TABLE 5. PERCENTAGE DISTRIBUTION OF THE COEFFICIENT OF VARIATION (CV) FOR UNIFORMITY OF NOZZLE DISCHARGE VOLUME

CV	% of pesticide applicators	
%	1986*	1979†
0-5	75.5	11.1
5-10	14.3	27.8
>10	10.2	61.1

* Measured from 49 applicators
† From 18 liquid applicators of Rider and Dickey (1982)

TABLE 6. TYPES OF NOZZLES TIPS CORRELATED WITH APPLICATION ERRORS WITHIN ±10% OF INTENDED RATE

Nozzle tips	% used by applicators	% of applicators within ±10% of intended application rate
Fan	51.9	65.5
Flooding	38.2	72.0
Raindrop	8.4	45.5
Hollow-Cone	1.5	50.0

mechanical meters. The speed deviation could account for inaccuracy seen in some of the applicators.

Uniformity of Nozzle Discharge

Uniformity of nozzle discharge was measured on 49 applicators. The CV among nozzles averaged 4.5% which is a sharp reduction from the 22% reported in the 1979 survey (Rider and Dickey, 1982). The maximum CV was 21.3%. For this dramatic drop to occur, applicators must be keeping newer nozzles on their units, using nozzle cleaning and installation methods that do not damage the tips or using nozzle tip materials that are more durable. Table 5 compares the coefficient of variation along with data observed by Rider and Dickey (1982).

The type of nozzles used is important to the effectiveness of the spray solution. Table 6 shows that of the applicators surveyed, Fan and Flooding-Nozzles predominated during pesticide application. Flooding-Nozzles had the fewest errors and a large portion of the commercial applicators use this nozzle tip. Most of the Fan Nozzles (Table 7) were used for applications under 76 L/min (20 gpm) while most Flooding-Nozzle tips were used over 38 L/min (10 gpm). Most of the sprayers used with a tillage device applied about 76 L/min (20 gpm) and were either Flooding-Nozzles or Raindrop tips. These tips are "self-cleaning" and can effectively operate under dusty conditions. Most of the banding units used during planting used an even-spray Fan nozzle tip and operated under 38 L/min (10 gpm).

Calibration Methods

Calibration methods most often listed by liquid pesticide application were:

1. Known Area
2. Manual Recommendation
3. Timed Bottle
4. Timed Bottle and Distance
5. Monitor/Controllers
6. Equipment setting same as previous year

The "Known Area" method observes the amount of tank mix that is applied to a measured area. The application rate can be determined by dividing the volume by the area covered. The "Manual Recommendations" method required that the applicator set the equipment according to manufacturer's (either the sprayer or nozzle) suggest guidelines and specifications. Then they followed the procedure recommended in these manuals for field adjustments. The "Timed Bottle" method caught the nozzle discharge during a stationary test and by using the estimated travel speed, the application rate was calculated using equation [1]. The "Timed Bottle and Distance" method is very similar to "Timed Bottle" except that the travel speed was measured over a given distance instead of using an estimated speed or speedometer reading. Controllers combine electronic metering and sensing devices that control the amount of chemicals applied (depending on speed, etc.) while monitors are electronic sensing devices that give a current display of application rate but have no controlling influence.

The survey showed that 94% of the applicators used some type of calibration method to check their units and 92% used that method at least once a year. Thus, only 8% used no method or used the equipment setting of the previous season. Almost 20% of the applicators used two methods of calibration to check the application rate. Table 8 shows the calibration methods listed in order of priority of use and the applicators that were within 10% of intended application rate.

The "Known Area" method of calibration was the most common technique and was used by 64% of the cooperators (Table 7). The measured area of coverage for the "Known Area" method ranged from 0.04 ha (0.1 acre) to 16.2 ha (40 acre). The only method that greatly

TABLE 7. TYPES OF NOZZLES TIPS CORRELATED WITH THE MEASURED APPLICATION RATE

Nozzle	% of applicators			
	Measured application rate (L/min)			
	<40 (<10 gpm)	40-<80 (10-<20 gpm)	80-<110 (20-<30 gpm)	≥110 (≥30 gpm)
Fan	48.5	50.0	1.5	--
Flooding	8.0	60.0	20.0	2.0
Raindrop	9.1	72.7	18.2	--
Hollow-Cone	50.0	50.0	--	--

TABLE 8. TYPE OF CALIBRATION METHOD CORRELATED WITH APPLICATION ERRORS WITHIN ±10% OF INTENDED APPLICATION RATE

Type	Frequency used*	% of applicators within ±10% error
Known area	64.4	61
Timed bottle	21.2	57
Manuals	17.4	61
Monitors/Controllers	8.3	91
Time bottle and distance	4.6	50

* Some applicators (≈20%) used more than one method.

TABLE 9. THE FREQUENCY OF CALIBRATION USE CORRELATED TO THE APPLICATION ERRORS WITHIN ±10% OF INTENDED APPLICATION RATE

Time period	% of applicator within ±10% error	% of sample
All the time	71	21.8
2 to 3 times per year	75	3.7
Once a year	59	72.7
Less than once a year	100	1.8
		100.0%

reduced application errors were those that relied on "Monitors/Controllers." Of those that relied on these "Monitors/Controllers," none had recalibrated these units since installation. These units may give a false-security to applicators especially if these units are not checked for wear from extended use. However, those applicators that pay for the extra expense and time for these electronic units greatly enhance their ability to apply chemicals properly.

Table 9 shows the frequency with which applicators used their calibration methods. Over 70% used a calibration method only once a year. This same group also had the lowest percentage of applicators within 10% of intended application rate range. Over 20% remarked that they calibrated "All-the-time". However, in reality they were checking the amount of volume going onto a known field size. This is a good check but it does mean that a total field could be treated before an error is detected.

CONCLUSIONS

Only one out of three liquid pesticide applicators applied chemicals within ±5% of their intended application rate. The major source of application errors was incorrect calibration (55%). Tank mix errors were detected in 19% of the applicators. These results indicated that applicators have reduced application errors from that of a similar survey conducted in 1979. The commercial applicators had approximately 50% fewer errors of applying chemicals than private applicators and they also accounted for twice the land area chemically treated of those sampled.

Uniformity of nozzle discharge on a spray unit was not a major concern. Over 75% of the applicators had CV's less than 5% compared to only 11% of the applicators observed 7 years earlier. This suggested that applicators were replacing nozzle tips more frequently and were not damaging tips during cleaning and installation. Most often used nozzles tips were Fan and Flooding-Nozzles.

Ninety-four percent of the applicators used a calibration method and almost 20% used more than one method. Most applicators used the "Known Area" method of calibration. Those that used "Monitors/Controllers" had the fewest application errors of the calibration methods listed. Over 70% of the applicators only calibrated once a year and improvement of application accuracy could be shown by more frequent use of a calibration method.

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