INFLUENCE OF AN ADJUVANT ON DROPLET SPECTRA AND HERBICIDAL ACTIVITY OF GLYPHOSATE SPRAY MIXTURES ON SOME FOREST WEEDS

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A. Sundaram and R. Prasad

Environment Canada
Forestry Service
Forest Pest Management Institute
1219, Queen Street East, Box 490
Sault Ste. Marie, Ontario
P6A 5M7

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ABSTRACT

Triton® X-114 was added to Roundup® spray mixtures at 0.0, 0.5, 1.0 and 5.0% (v/v), and sprayed at the rate of 1.8 kg a.i./50 L/ha, onto white birch, speckled alder and trembling aspen seedlings in a spray chamber, using a twin fluid nozzle. Droplet size spectra were assessed using Kromekote® cards for droplet collection. No dramatic changes were evident in the droplet spectra because of the addition of Triton® X-114. Weekly evaluation of phytotoxicity over a 3-week period indicated that only white birch showed an increased toxicity due to the adjuvant

at 0.5 and 1.0% levels. The 5% level was too high and failed to provide greater phytotoxicity than 1% level. The speckled alder showed an inhibitory effect at all concentrations. The trembling aspen showed a similar response to all spray mixtures with or without the adjuvant. The study indicated that any addition of adjuvants to the Roundup® spray mixtures should be based on detailed research with specific weed species and that any indiscriminate addition should be avoided.

INTRODUCTION

Adjuvants are used in herbicidal formulations to modify spray droplet spectra or to enhance herbicidal activity.[1] Off-target drift can be a potential problem for herbicide applicators unless precautionary measures are introduced to minimize the fine droplets produced during atomization.[2] However, any process that accomplishes this should not interfere with herbicide effectiveness.[3] This implies that the concentration of the adjuvants should be optimized with respect to droplet spectra, effectiveness and weed species. The influence of droplet size on herbicidal activity has been studied previously.[4,5] The role of surface active agents and other additives in enhancing herbicidal activity has also been reported.[6,7] However, studies that can simultaneously provide comparative droplet spectra and herbicidal activity at different concentrations of adjuvants, and under controlled experimental conditions, are sparse in the literature.

Roundup® [Glyphosate, N-(phosphonomethyl) glycine] is a broad spectrum herbicide of Monsanto Agricultural Products Company, USA. The commercial formulation contains the mono-isopropylamine salt of glyphosate, a surfactant and other adjuvants. However, the type and concentrations of the surfactant used may not necessarily be optimum for the specific weed species prevalent in Canadian forests. Research studies to optimize adjuvant types and concentrations, and spray droplet sizes are valuable for reducing the dosage rates and application costs, together with increased weed control. In addition, they are absolutely essential for minimizing the amounts of herbicide chemicals released into the environment.

Triton® X-114, a nonionic surfactant of Rohm and Haas Canada Ltd. (West Hill, Ontario) has been shown to alter the physical characteristics of some insecticide formulations and to reduce the proportion of fine droplets (unpublished data of the senior author), indicating the potential for drift control in pesticide applications. It has also been shown to play a role in increasing the foliar stability of certain pesticides.[8] The present paper describes a laboratory study undertaken to investigate the optimum concentration of the surfactant, Triton® X-114, which would provide the least proportion of fine droplets of a glyphosate spray mixture without lowering the herbicidal effectiveness on three weed species distributed in Canadian forests. The objective is to understand the influence of the adjuvant on the herbicidal activity, as related to plant species, adjuvant concentrations, physical properties of formulations and spray droplet spectra.

MATERIALS AND METHODS

Roundup® Spray Mixtures and Physical Properties

Roundup® spray mixtures were prepared without and with Triton®X-114 at three concentrations (Table 1) to provide a dosage rate of 1.8 kg a.i in 50L/ha. Physicochemical properties studied were:
i) viscosity, ii) density, iii) surface tension and iv) evaporation characteristics (Table 1 and Fig. 1), following the experimental details

described by Sundaram.[9] To increase the visibility of liquid films in capillary tubings and viscometers, a dye tracer, Erio Acid Red (Ciba-Geigy, Dorval, Quebec) was added to each formulation at 0.1% (w/v) (Table 1).

Spray Application and Herbicidal Activity

Potted seedlings of white birch (*Betula papyrifera* Marsh.), speckled alder (*Alnus rugosa* [Du Roi] Spreng.) and trembling aspen (*Populus tremuloids* Michx.), grown in the greenhouse for 6 months under constant conditions of temperature (21° ± 1°C), photoperiod (16 h light, 8 h dark) and 70 ± 7% relative humidity (RH), were used for the assessment of herbicidal activity.

Spray application was made in a chamber of 4.3 m x 0.9 m x 3.05 m (Fig. 2), using a twin fluid nozzle (Desaga Spraygun, Desaga, Heidelberg) at 2 m above the canopy of the potted (pot height 13 cm) seedlings of height 25 to 30 cm, containing no branches and 15-25 leaves, in almost still air at 20° ± 1°C and 50 ± 2% RH. Spray droplets were allowed to fall freely and impact on the plant and on two Kromekote® cards placed one at either side of the seedling close to the midcrown (Fig. 2). Fifteen minutes after, the seedlings and the cards were removed for analysis. The seedlings were returned to the greenhouse for assessing herbicidal activity based on visual rating of the degree of foliar brownout, a technique adopted by Palfrey and Silver.[10] Droplet stains on the Kromekote® cards were counted and sized under a dissecting microscope at 40X, 100X and 200X and grouped into different size ranges. The

Table 1. Formulation Composition and Physical Properties at 20°C

Composition, physical properties and droplet data		F1	F2	F3	F4
Composition of ingredients (v/v%)	Glyphosate	10	10	10	10
	Triton® X-114	-	0.5	1.0	5.0
	Water	89.9	89.4	88.9	84.9
	Erio Acid Red	0.1*	0.1	0.1	0.1
		100.0	100.0	100.0	100.0
Viscosity (cp)		1.30	1.32	1.35	2.13
Density (g/ml)		1.015	1.015	1.014	1.014
Surface Tension (dyne/cm)		23.8	24.7	26.0	30.4
Droplet density (No./cm^2)		304	307	224	178
NMD (μm)		13	14	17	21
VMD (μm)		75	67	77	73
Dmax (μm)		117	117	129	145

* The Erio Acid Red dye is a solid and hence 0.1 g/100 ml

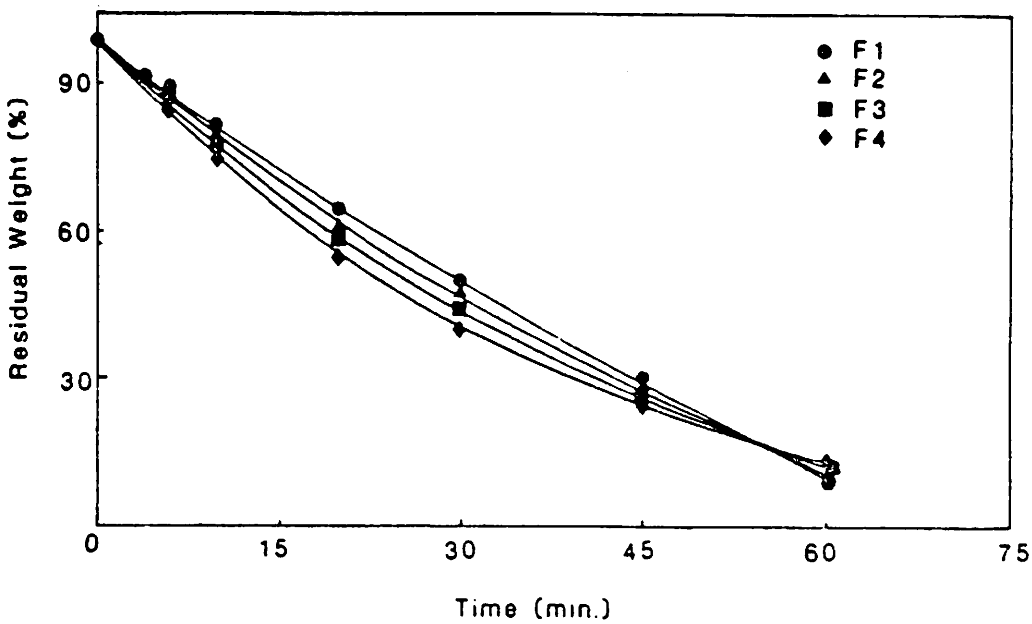
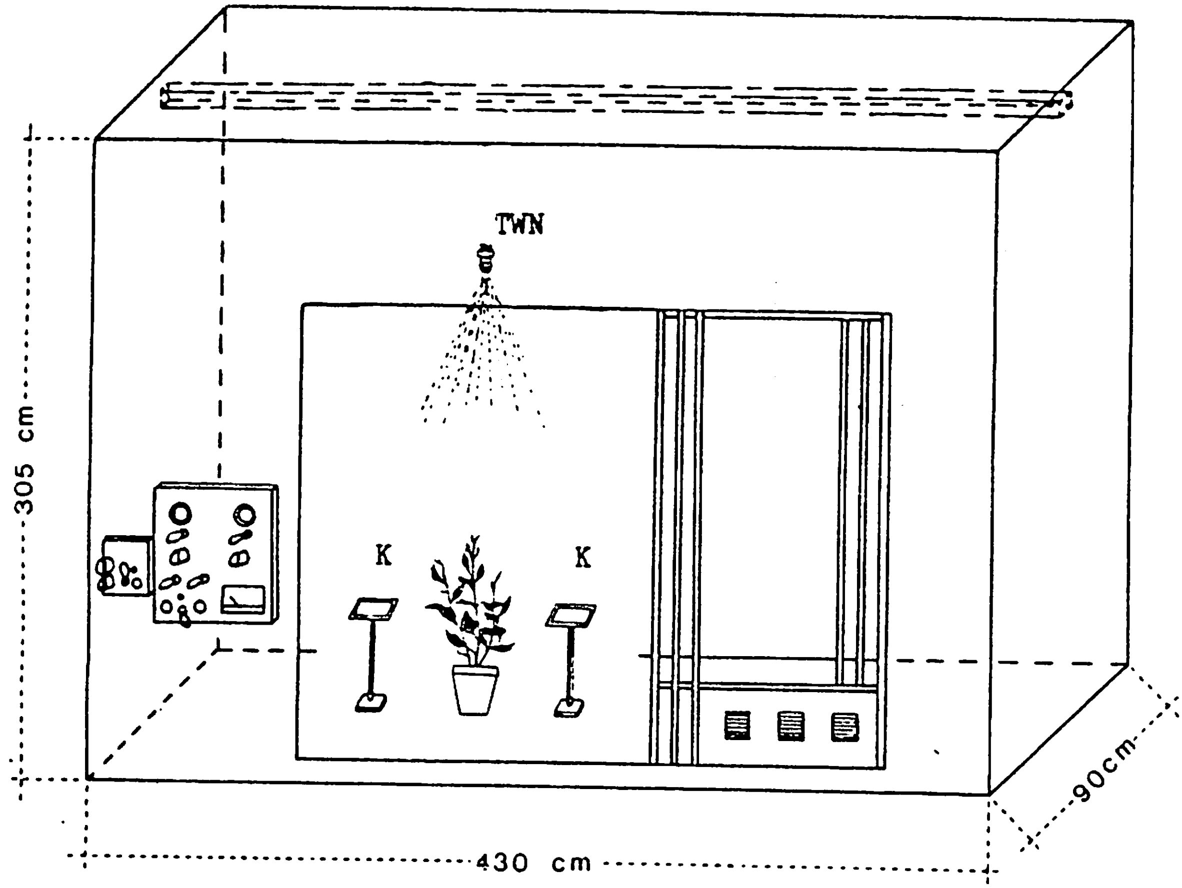


Fig.1: Evaporation characteristics of Roundup® spray mixtures.

study was carried out in triplicate at the rate of one seedling and two cards per treatment to provide a total of 3 seedlings and 6 cards per formulation and per species. The mean herbicidal activity, expressed as the mean percentage of the brownout area of the total number of leaves in the 3 seedlings, is presented in Fig. 3 for each weed species and for formulations F1 to F4. For droplet analysis, a 2 cm^2 area was used in each card to provide the data for 12 cm^2 per 6 cards for each formulation and weed species and from this, the droplet density (no./cm^2) was calculated (Table 1).

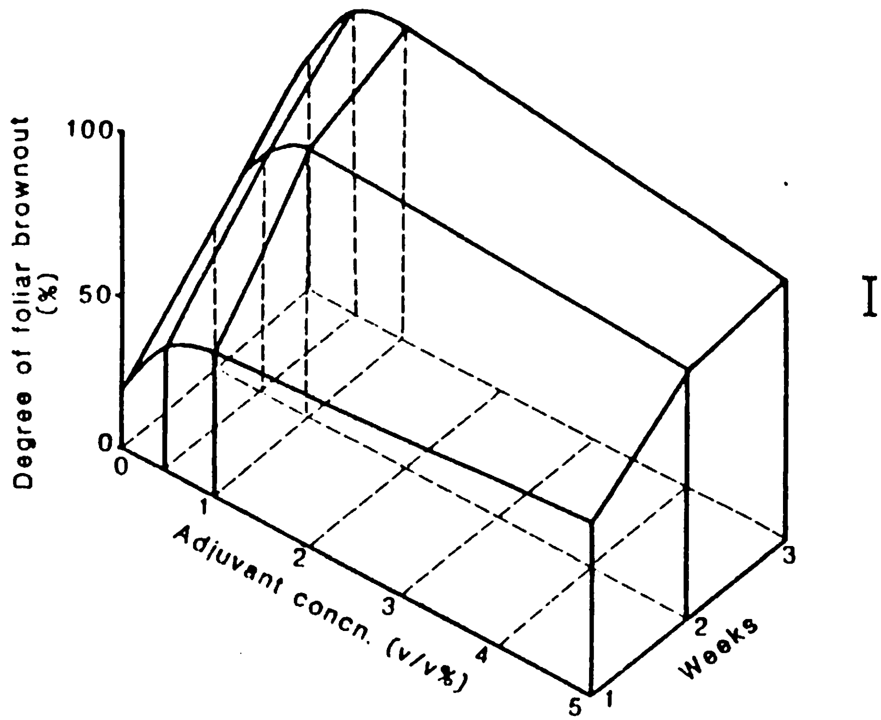
Spread factor, SF, was determined by producing uniform droplets using the rotary device designed by Rayner and Haliburton[11] and capturing them on a glass fibre of 5.6 ± 0.8 μm diameter and on the Kromekote® cards. The droplet diameter 'd' was measured on the fibre for the droplet stain of diameter 'D' on the card SF was obtained from SF = D/d. This was used to convert the droplet stains, obtained on the Kromekote® cards used in the spray chamber, into the corresponding aerodynamic droplet sizes for evaluating the number and volume median diameters (NMD and VMD) and maximum diameter (Dmax) (Table 1). The droplet number and volume distribution in different size categories was evaluated in percentages and is presented in Fig. 4.

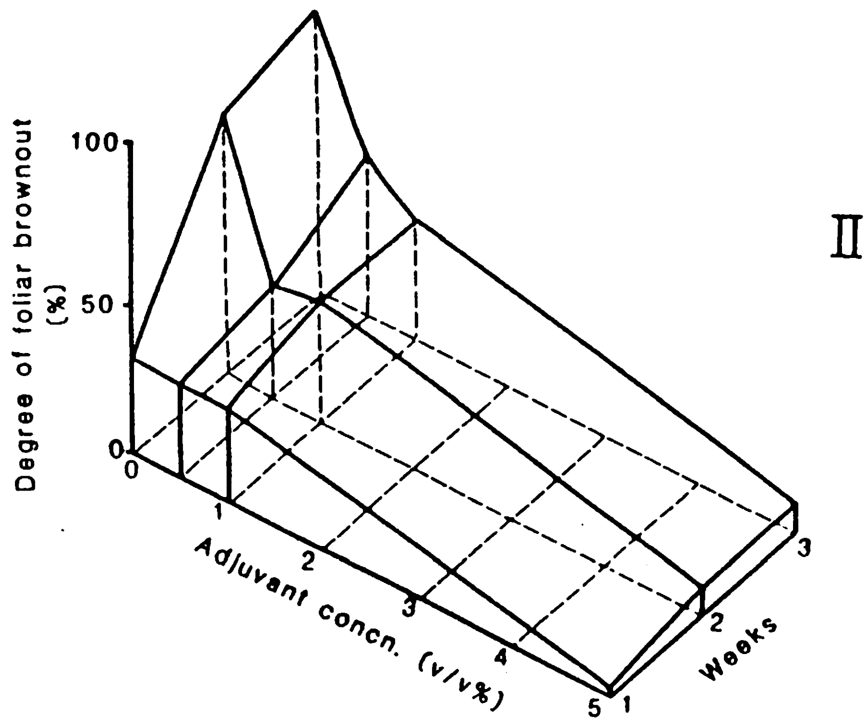
Fig.- 2. Spray chamber



TWN: Twin fluid nozzle. K: Kromekote card.

The spray application part of the study was carried out twice with white birch, one on June 15, 83 and the other on June 23, 83 (Fig. 3). The first trial was intended as a test case for observing the response at the applied dosage rate and for optimizing the interval of scoring the degree of foliar brownout. Since a three week period was found to be optimum for obtaining the maximum % damage with majority of plants, this period was used for the entire study, and only one trial was made with alder and aspen seedlings (Fig. 3). For the white birch however, the data from both trials were pooled before evaluating the % damage.





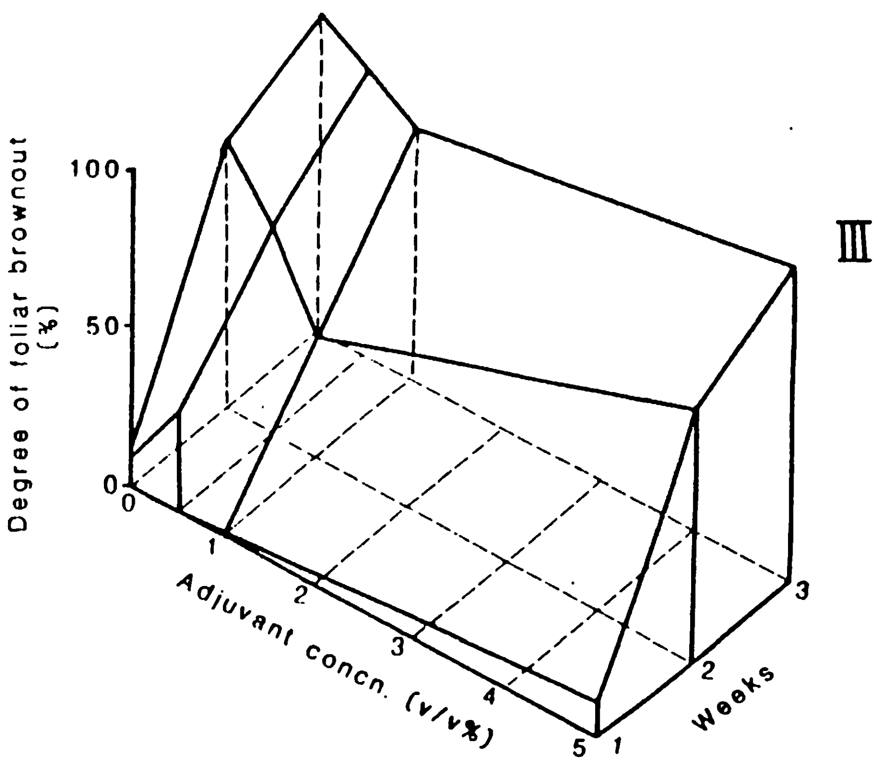


Fig.3. Relationship between adjuvant concentration and herbicidal activity over a 3-week post-spray period.

I. White birch: 6 seedlings for each concentration of the adjuvant.

II. Speckled alder: 3 seedlings for each concentration of the adjuvant.

III. Trembling aspen: 3 seedlings for each concentration of the adjuvant.

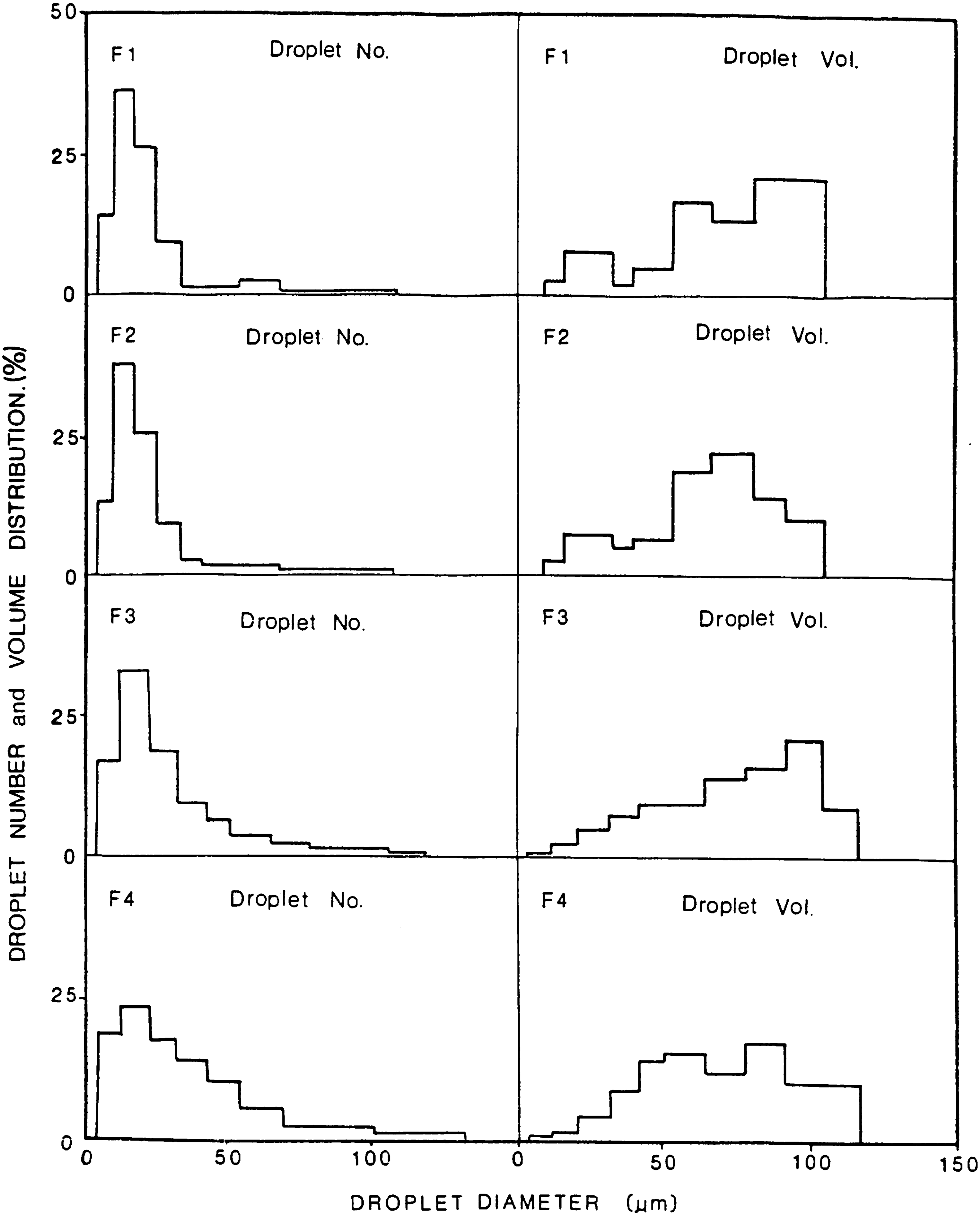


Fig. 4. Droplet number and volume distribution according to size category for Roundup® spray mixtures.

RESULTS AND DISCUSSION

Physical Properties and Droplet Size Spectra of Roundup Spray Mixtures

The physical properties of formulations F1 to F4 did not exhibit great variations when the concentration of Triton® X-114 was increased from 0.0 to 5.0% (Table 1). The viscosities showed a slight increase only at the 5% level, whereas the surface tension values increased progressively with increasing surfactant concentrations. The evaporation characteristics of the four formulations, on the other hand, were very similar (Fig. 1). Spray droplet sizes increased slightly from F1 to F4, as indicated by the larger NMD and Dmax values. However, these increases were not of great importance since the VMD were approximately the same for all formulations. Droplet densities showed a slight decrease from F1 to F3, but the large decrease for F4 appears to be important. This was obviously due to the large droplet sizes which caused reduced number of droplets per unit area for the same application rate. Reduction in droplet density, sometimes can result in poor coverage of the target area and lessen the effectiveness of herbicide treatment. However, in the present study, the droplet densities are very high for all formulations and a reduction from 304 to 178 from F1 to F4 (Table 1) is highly unlikely to diminish target coverage and herbicide toxicity. The droplet size spectra (Fig. 4) for F1 and F2 were finer, but they were slightly coarser for F3 and F4. However, no marked variations were observed in the droplet spectra when the concentration of the surfactant was increased from 0.0 to 5.0% in the spray mixtures. These data suggest that Triton® X-114, unlike with some insecticides, does not alter the physical characteristics or spray droplet spectra of Roundup® spray mixtures.

Herbicidal Activity

Herbicidal activity of the four formulations were estimated at the end of every week for 3 consecutive weeks. The data are presented graphically in a 3-dimensional plot for each weed species (Fig. 3). Generally, all species indicated a damage of only about 50% or less during the first week. This however, gradually increased during the 2nd week and reached a level of 80 to 100% at the end of the 3rd week (Fig. 3).

However, some species-related differences were noted in the plant response to different concentrations of the adjuvant (Fig. 3). The white birch showed a progressive increase in toxic effects with increasing concentration of the adjuvant from 0.0 to 1.0%, but the effect tapered off at the 5% level. This trend persisted throughout the 3-week observation period (Fig. 3.I). The data thus indicate that the 5% level is too high for increasing phytotoxicity on the white birch. The speckled alder, on the other hand, showed a progressive decrease in response to increasing adjuvant concentration, indicating an inhibitory effect at all levels of Triton® X-114, which persisted throughout the observation period (Fig. 3.II). The trembling aspen showed a slight decrease in toxicity as the concentration of the adjuvant rose up to

1.0%, but this decrease was compensated at the 5% level, and the herbicidal response was back to the original level started with F1 with no adjuvant (Fig. 3.III). The data thus indicate no beneficial effect of Triton® X-114 for enhancing phytotoxicity of glyphosate on the trembling aspen. The reason for the observed differential response among woody species is probably due to the variable proportions of cutin, waxes and plaslemma (ectodesmata) on their leaf surfaces[12-14], resulting in diversified interactions at droplet/target interface.

Several researchers have studied[15-19] the influence of different surfactants on herbicidal activity on many weed species. Many theories were proposed to correlate the structure-activity relationships with the mode of action. However, these authors found their results quite variable and difficult to interpret in terms of physical characteristics of the spray mixtures alone[20-22]. The conclusion was that interactions among the surfactant, herbicide and plant species are highly complex and that, therefore, any addition of a surfactant to glyphosate spray mixtures which already contain a surfactant, warrants additional research studies for specific weed species. In contrast, the recent work of Ivany[23] points out that the addition of two adjuvants (Agral 90 and frigate), in combination with ammonium sulfate, markedly improved the efficacy of the commercial formulation of glyphosate on quack grass. These effects were evident only at low rates (0.25 to 0.5 kg a.i/ha) of glyphosate application; at high rates, i.e. ≤ 1.0 kg/ha, the positive effects of the adjuvants were nullified.

In the present study, although some differences were observed in the initial plant response to different concentrations of the adjuvant, all plants except the speckled alder showed a similar maximum response after 3 weeks. This is probably due to the high dosage rate (1.8 kg a.i/ha) applied. Further studies with lower dosage rates are likely to bring out the importance of the adjuvant in enhancing the herbicidal effectiveness of glyphosate. However, the 5% level is not beneficial to any plant species studied, and therefore should not be used for the control of these weed species. Moreover the addition of Triton® X-114 should be totally avoided for the control of speckled alder since it can only bring disadvantages (Fig. 3.II). The present results support the conclusion of the earlier workers that any addition of a second surfactant to Roundup® which already contains a surfactant should be based on extensive research with specific species types and that any indiscriminate addition should be avoided. Moreover, in the present study, Triton® X-114 failed to provide significant changes in the spray droplet spectra observed on the Kromekote® cards, thereby indicating that it probably cannot even modify the atomization characteristics of the Roundup spray mixtures. In parenthesis, it is emphasized that studies on adjuvant/herbicide interactions are highly complex. There is a whole array of factors, such as volume rates of application, a.i. dosage rates, droplet sizes, stage of plant growth, weather conditions, species-related variations etc., that ought to be considered. Further research is needed to investigate these aspects in future.

CONCLUSIONS

In summary, the present study indicates the following:

1. Addition of Triton® X-114 adjuvant did not alter the physical characteristics of spray mixtures markedly. Viscosities, surface tension and evaporation rates were approximately the same for all spray mixtures investigated.

2. The spray droplet spectra were not influenced markedly by lower concentrations of the adjuvant. However, at 5% (v/v) level, the spectrum was slightly coarser with larger NMD, VMD, and Dmax values. The droplet density was consequently lower. At any rate, no dramatic changes in droplet size spectrum was noticeable even at 5% level.

3. Among the three species tested, the white birch is the only species which showed beneficial effects of the adjuvant, Triton® X-114, at concentrations of 0.5 to 1.0% (v/v).

4. The speckled alder showed inhibitory effects of adding Triton® X-114 at all concentrations, indicating that the adjuvant should not be used for weed control of speckled alder.

5. The trembling aspen, however, exhibited similar response with or without the adjuvant regardless of the concentration used, thus indicating no real advantage of Triton® X-114 at any concentration studied.

6. The data from the present study indicate that any addition of an adjuvant to the Roundup spray mixtures which already contain a surfactant should be based on detailed research with specific

weed species, and that any indiscriminate addition should be avoided.

7. It is also evident from the present study that, the observed variations in plant response to the four spray mixtures were solely due to the adjuvant and not because of changes in the droplet size spectrum.

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APPENDIX

PHYSICAL PROPERTIES, DROPLET NUMBER AND VOLUME DISTRIBUTION PERCENTAGES FOR GLYPHOSATE FORMULATIONS

Physical Properties of Glyphosate Formulations at Different Temperatures

Formulation No.	Viscosity (cp) at temperatures of 5°	10°	15°	20°	25°
F1	1.94	1.61	1.39	1.30	1.14
F2	2.02	1.65	1.40	1.32	1.15
F3	2.08	1.77	1.47	1.35	1.17
F4	2.85	2.43	2.14	2.13	1.93
	Density (g/ml)				
F1	1.018	1.017	1.016	1.015	1.014
F2	1.018	1.017	1.016	1.015	1.014
F3	1.017	1.016	1.015	1.014	1.013
F4	1.017	1.016	1.015	1.014	1.013
	Surface tension (dyne/cm)				
F1	25.6	25.0	24.5	23.8	22.9
F2	26.7	26.2	25.5	24.7	23.8
F3	27.9	27.4	26.8	26.0	25.3
F4	30.50	30.45	30.40	30.35	30.3

Evaporation Characteristics of Glyphosate Formulations at 20° ± 1°C and at Relative Humidity (RH) of 50 ± 2%

Formulation No.	Percentage of mass remaining at time 't' (min)							
	0	4	6	10	20	30	45	60
F1	100	91.6	89.9	82.0	63.8	50.4	31.0	9.62
F2	100	91.8	89.2	79.2	62.0	47.4	30.0	9.82
F3	100	92.0	86.5	78.5	59.2	45.2	27.0	10.2
F4	100	92.1	85.1	77.1	54.9	39.6	26.1	11.5

Herbicidal Activity of Glyphosate Formulations With and Without Adjuvants on Different Weed Species

Species and date of treatment	Formulation No.	Percentage of effectiveness[a]		
		1st week	2nd week	3rd week
White birch (June 15, 1983)	F1	5	50	98
	F2	40	75	100
	F3	45	85	100
	F4	45	75	80
White birch (June 23, 1983)	F1	25	35	45
	F2	40	75	95
	F3	45	88	100
	F4	65	80	85
Speckled alder (June 24, 1983)	F1	30	85	90
	F2	30	35	50
	F3	30	40	40
	F4	2	10	10
Trembling aspen (June 27, 1983)	F1	10	85	100
	F2	30	65	90
	F3	0	40	80
	F4	10	80	100

[a] Values from triplicate measurements were pooled and presented as the mean percentage of the brownout area of the total number of leaves in three seedlings per formulation.

Kromekote Card Data Using Twin Fluid Nozzle
Droplet Number Distribution According to Size Category
Formulation F1. RH = 50 ± 2%, Temp. 20° ± 1°C

Stain diameter range (μm)	Spread factor	Droplet diameter range (μm)	Average droplet diameter (μm)	Total droplets per 48 cm^2	Droplets per cm^2	Frequency (%)	Cumulative frequency (%)
8 - 20	2.10	3.8- 9.5	6.65	2208	46	15.2	15.2
21 - 40	2.20	9.6- 18.2	13.9	5664	118	38.6	53.8
41 - 60	2.25	18.3- 26.7	22.5	4080	85	28.2	82.0
61 - 80	2.25	26.8- 35.6	31.2	1488	31	10.2	92.2
81 - 100	2.30	35.7- 43.5	39.6	192	4	1.39	93.6
101 - 135	2.30	43.6- 58.7	51.2	240	5	1.72	95.3
136 - 170	2.30	58.8- 73.9	66.4	336	7	2.46	97.8
171 - 205	2.30	74.0- 89.1	81.6	144	3	0.90	98.7
206 - 240	2.35	89.2-102.1	95.7	144	3	0.82	99.5
241 - 275	2.35	102.2-117.0	109.6	96	2	0.57	100.0
			TOTAL		304		

Kromekote Card Data Using Twin Fluid Nozzle
Droplet Volume Distribution According to Size Category
Formulation F1. RH = 50 ± 2%, Temp. 20° ± 1°C

Droplet diameter range (μm)	Average droplet diameter (μm)	Volume of one droplet (10^{-8} cc)	Droplets per cm^2	Volume of deposit (mL/ha)	Droplet volume distribution (%)	Cumulative droplet volume distribution (%)
3.8 - 9.5	6.7	0.02	46	0.7	0.11	0.11
9.6 -18.2	13.9	0.14	118	16.6	2.62	2.73
18.3 -26.7	22.5	0.60	85	50.7	8.00	10.7
26.8 -35.6	31.2	1.60	31	49.3	7.80	18.5
35.7 -43.5	39.6	3.30	4	13.0	2.10	20.6
43.6 -58.7	51.2	7.00	5	35.1	5.50	26.1
58.8 -73.9	66.4	15.3	7	107.3	16.9	43.0
74.0 -89.1	81.6	28.4	3	85.3	13.5	56.5
89.2-102.1	95.7	45.9	3	137.7	21.7	78.2
102.2-117.0	109.6	68.9	2	137.9	21.8	100.0
Total				633.6		

Kromekote Card Data Using Twin Fluid Nozzle
Droplet Number Distribution According to Size Category
Formulation F2. RH = 50 ± 2%, Temp. 20° ± 1°C

Stain diameter range (μm)	Spread factor	Droplet diameter range (μm)	Average droplet diameter (μm)	Total droplets per 48 cm^2	Droplets per cm^2	Frequency (%)	Cumulative frequency (%)
8 - 20	2.10	3.8- 9.5	6.7	2016	42	13.7	13.7
21 - 40	2.20	9.6- 18.2	13.9	5856	122	39.7	53.4
41 - 60	2.25	18.3- 26.7	22.5	3984	83	27.0	80.4
61 - 80	2.25	26.8- 35.6	31.2	1344	28	9.12	89.5
81 - 100	2.30	35.7- 43.5	39.6	480	10	3.27	92.8
101 - 135	2.30	43.6- 58.7	51.2	288	6	1.95	94.7
136 - 170	2.30	58.8- 73.9	66.4	384	8	2.60	97.3
171 - 205	2.30	74.0- 89.1	81.6	240	5	1.63	98.9
206 - 240	2.35	89.2-102.1	95.7	96	2	0.65	99.6
241 - 275	2.35	102.2-117.0	109.6	48	1	0.33	100.0
			TOTAL		307		

(A)

Kromekote Card Data Using Twin Fluid Nozzle
Droplet Volume Distribution According to Size Category
Formulation F2. RH = 50 ± 2%, Temp. 20° ± 1°C

Droplet diameter range (μm)	Average droplet diameter (μm)	Volume of one droplet (10^{-8} cc)	Droplets per cm^2	Volume of deposit (mL/ha)	Droplet volume distribution (%)	Cumulative droplet volume distribution (%)
3.8 - 9.5	6.7	0.02	42	0.84	0.14	0.14
9.6 -18.2	13.9	0.14	122	17.1	2.79	2.93
18.3 -26.7	22.5	0.60	83	49.8	8.13	11.1
26.8 -35.6	31.2	1.60	28	44.8	7.31	18.4
35.7 -43.5	39.6	3.30	10	33.0	5.39	23.8
43.6 -58.7	51.2	7.00	6	42.0	6.86	30.6
58.8 -73.9	66.4	15.3	8	122.4	20.0	50.6
74.0 -89.1	81.6	28.4	5	142.0	23.2	73.8
89.2-102.1	95.7	45.9	2	91.8	15.0	88.8
102.2-117.0	109.6	68.9	1	68.9	11.2	100.0
Total				612.6		

Kromekote Card Data Using Twin Fluid Nozzle
Droplet Number Distribution According to Size Category
Formulation F3. RH = 50 ± 2%, Temp. 20° ± 1°C

Stain diameter range (μm)	Spread factor	Droplet diameter range (μm)	Average droplet diameter (μm)	Total droplets per 48 cm^2	Droplets per cm^2	Frequency (%)	Cumulative frequency (%)
8 - 25	1.95	4.0- 12.8	8.4	1968	41	18.3	18.3
26 - 45	1.98	12.9- 22.7	17.8	3744	78	34.8	53.1
46 - 70	2.03	22.8- 34.5	28.7	2160	45	20.1	73.2
71 - 95	2.08	34.6- 45.7	40.2	1104	23	10.3	83.5
96 - 115	2.10	45.8- 54.8	50.3	720	15	6.70	90.2
116 - 150	2.10	54.9- 71.4	63.2	384	8	3.57	93.8
151 - 185	2.15	71.5- 86.0	78.8	288	6	2.68	96.5
186 - 220	2.18	86.1-100.9	93.5	192	4	1.79	98.2
221 - 255	2.20	110.0-115.9	113.0	144	3	1.34	99.6
256 - 290	2.25	116.0-128.9	122.5	48	1	0.45	100.0
			TOTAL		224		

Kromekote Card Data Using Twin Fluid Nozzle
Droplet Volume Distribution According to Size Category
Formulation F3. RH = 50 ± 2%, Temp. 20° ± 1°C

Droplet diameter range (μm)	Average droplet diameter (μm)	Volume of one droplet (10^{-8} cc)	Droplets per cm^2	Volume of deposit (mL/ha)	Droplet volume distribution (%)	Cumulative droplet volume distribution (%)
4.0 -12.8	8.4	0.03	41	1.23	0.12	0.12
12.9 -22.7	17.8	0.30	78	23.4	2.31	2.43
22.8 -34.5	28.7	1.24	45	55.8	5.51	7.94
34.6 -45.7	40.2	3.40	23	78.2	7.73	15.7
45.8 -54.8	50.3	6.66	15	99.9	9.87	25.5
54.9 -71.4	63.2	13.2	8	105.6	10.4	35.9
71.5 -86.0	78.8	25.6	6	153.6	15.2	51.1
86.1-100.9	93.5	42.8	4	171.2	16.9	68.0
110.0-115.9	113.0	75.6	3	226.8	22.4	90.4
116.0-128.9	122.5	96.3	1	96.3	9.52	99.96
Total				1012.0		

Kromekote Card Data Using Twin Fluid Nozzle
Droplet Number Distribution According to Size Category
Formulation F4. RH = 50 ± 2%, Temp. 20° ± 1°C

Stain diameter range (μm)	Spread factor	Droplet diameter range (μm)	Average droplet diameter (μm)	Total droplets per 48 cm^2	Droplets per cm^2	Frequency (%)	Cumulative frequency (%)
8 - 25	1.90	4.2- 13.2	8.7	1776	37	21.0	21.0
26 - 45	2.00	13.3- 22.5	17.9	2016	42	23.6	44.6
46 - 70	2.05	22.6- 34.1	28.4	1632	34	18.9	63.8
71 - 95	2.05	34.2- 46.3	40.3	1248	26	14.8	78.6
96 - 115	2.05	46.4- 57.5	52.0	912	19	10.70	89.3
116 - 150	2.10	57.6- 75.0	66.3	480	10	5.84	95.1
151 - 185	2.10	75.1- 92.5	83.8	192	4.0	2.25	97.4
186 - 220	2.10	92.6-110.0	101.3	154	3.2	1.80	99.2
221 - 255	2.10	110.1-127.5	118.8	58	1.2	0.67	99.9
256 - 290	2.10	127.6-145.0	136.3	38	0.8	0.45	100.0
			TOTAL		178		

Kromekote Card Data Using Twin Fluid Nozzle
Droplet Volume Distribution According to Size Category
Formulation F4. RH = 50 ± 2%, Temp. 20° ± 1°C

Droplet diameter range (μm)	Average droplet diameter (μm)	Volume of one droplet (10^{-8} cc)	Droplets per cm^2	Volume of deposit (mL/ha)	Droplet volume distribution (%)	Cumulative droplet volume distribution (%)
4.2 -13.2	8.7	0.03	37	1.10	0.12	0.10
13.3 -22.5	17.9	0.30	42	12.6	1.30	1.40
22.6 -34.1	28.4	1.20	34	40.8	4.30	5.70
34.2 -46.3	40.3	3.40	26	88.4	9.40	15.1
46.4 -57.5	52.0	7.40	19	140.6	14.9	30.0
57.6 -75.0	66.3	15.3	10	153.0	16.2	46.2
75.1 -92.5	83.8	30.8	4.0	123.2	13.0	59.2
92.6-110.0	101.3	54.4	3.2	174.0	18.4	77.6
110.1-127.5	118.8	87.8	1.2	105.4	11.2	88.8
127.6-145.0	136.3	132.6	0.8	106.1	11.2	100.0
Total				945.2		