TOXICOLOGY AND EFFICACY OF INSECT GROWTH REGULATORS AERIALLY APPLIED AGAINST THE SPRUCE BUDWORM AT HEARST (1978), WAWA (1979) AND THE FRENCH RIVER AREA (1980).

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2. ABSTRACT

During 1978 to 1980, 5 different experimental moult inhibiting Insect Growth Regulators (EL-494, L-1215, L-7063, BAY SIR-8514, and UC-62644) were studied in the laboratory and in the greenhouse. The most active material was UC-62644 followed by BAY SIR-8514. The other 3 compounds were not very effective. UC-62644 manifested its effects within 48 h whereas the others took more than 1 week. Greenhouse trials showed similar patterns of activity.

Field trials were conducted in 1978 near Hearst, Ontario with EL-494 and BAY SIR-8514 using Dimilin (pH 60-40) and Matacil as positive controls. EL-494 showed disappointing results but BAY SIR-8514 appeared promising. Even at a high dosage (4 oz/acre or 280 g/ha) Dimilin was ineffective, confirming its poor activity against the budworm found in previous years.

Field trials were conducted in 1979 near Wawa, Ontario with several levels of BAY SIR-8514 using Matacil as a positive control. At the higher two levels (3 & 4 oz/acre or 210 & 280 g/ha) its activity in terms of population reduction was similar to that of Matacil. Because of its slow activity (> 1 week) foliage protection was less than that obtained for Matacil.

Field trials were conducted in 1980 in the French River area with BAY SIR-8514 and UC-62644 using Matacil and Dipel 88 (B.t.) as positive controls. For the first time oil formulations of the wettable powder were tested. The deposit obtained with oil formulations was far better than that with water. Even at very low dosage levels (1 & 0.5 oz/acre or 70 & 35 g/ha) UC-62644 was comparable to Matacil for both population reduction and foliage protection. (Unfortunately, supplies of this material are uncertain for the near future at least.) BAY SIR-8514 was better than most of the materials tested earlier but was not as good as UC-62644.

A spray tower system taking into account the volume/area (U.S. gal/acre or ℓ/ha) was found to provide a reasonable dosage range for field trials. Field equivalents (i.e., oz in 0.5 U.S. gal per acre or g in 4.7 ℓ/ha) were tested in the spray tower and the minimum dose required for 100% control was determined. Since the conditions in the spray tower were close to ideal unlike those in the field, this dosage was multiplied by a factor of 10 for field trials.

3. RÉSUMÉ

Au cours de la période de 1978 à 1980 5 différents régulateurs de la croissance des insectes par inhibition de la mue (EL-494, L-1215, L-7063, BAY SIR-8514 et UC-62644) ont été expérimentés au laboratoire et en serre. Le plus actif de ces composés a été l'UC-62644, suivi du BAY SIR 8514. Les 3 autres n'ont pas été très efficaces. Les effets de l'UC-62644 se sont fait sentir en l'espace de 48 h contre plus d'une semaine pour les autres. Les essais en serre ont produit des résultats similaires.

Des essais en plein champ ont été effectués en 1978 près de Hearst (Ontario) avec l'EL-494 et le BAY SIR 8514, en utilisant la Dimiline (pH 60-40) et le Matacil comme témoins positifs. L'EL-494 a donné des résultats décevants alors que le BAY SIR a semblé prometteur. Même à forte dose (280 g/ha ou 4 oz/acre) la Dimiline a été inefficace, confirmant ainsi la médiocre activité contre la tordeuse des bourgeons de l'épinette dont elle avait fait preuve précédemment.

D'autres essais en plein champ ont été aussi effectués en 1979 près de Wawa (Ontario) avec plusieurs concentrations du BAY SIR 8514 en utilisant le Matacil comme témoin positif. Aux deux plus fortes concentrations (210 & 280 g/ha ou 3 & 4 oz/acre) son activité à réduire les populations d'insectes s'est révélée pareille à celle du Matacil. A cause de sa lenteur à agir (1 semaine), la protection du feuillage obtenue avec lui a été moindre qu'avec le Matacil.

Enfin d'autres essais en plein champ ont été effectués en 1980 dans la région de la Rivière des Français avec le BAY SIR 8514 et l'UC-62644, ou le Matacil et le Dipel 88 (B.t.) tenaient lieu de témoins actifs. Pour la première fois des préparations huileuses de la poudre mouillable ont été testées. Le dépôt obtenu avec ces préparations huileuses a été de loin meilleur que celui des préparations aqueuses. Même à de très faibles concentrations (70 & 35 g/ha ou 1 & 0.5 oz/acre), l'UC-62644 a été comparable au Matacil tant pour la réduction des populations d'insectes que pour la protection du feuillage. (Malheureusement les approvisionnements en ce composé sont incertains pour l'année prochaine au moins.) Le BAY SIR 8514 a été meilleur que la plupart des composés précédemment expérimentés, mais n'a pas été aussi bon que l'UC-62644.

On a trouvé un système de pylône d'épandage, tenant compte du rapport volume/surface (l/ha ou gal U.S./acre), pour dispenser un débit raisonnable pour les essais en plein champ. Les doses équivalentes utilisées en plein champ (soit g dans 4,7 l/ha ou oz dans 0.5 gal U.S.) ont été testées dans le pylône d'épandage et la dose minimale requise pour une répression à 100% a été déterminée. Les conditions prévalant dans le pylône d'épandage étant presque idéales à l'encontre de celles qui règnent en plein champ, cette dose a été multipliée par un facteur de 10 pour les essais en plein champ.

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4. INTRODUCTION

Insect Growth Regulators (IGRs) are chemicals that adversely interfere with the normal growth and development in insects, inducing abnormal changes that are often lethal. There are 3 types of IGRs currently known and these are juvenile hormone analogs (Gilbert 1976), anti-juvenile hormones (Bowers 1979; Quistad *et al.* 1981), and moult inhibitors or disruptants (Bijloo 1975). In this report the following will be presented--

(A) A brief review of current literature on moult inhibiting IGRs and a summary of the work carried out at the Forest Pest Management Institute.

(B) Laboratory and greenhouse studies of IGRs (1978-1980).

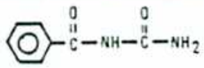
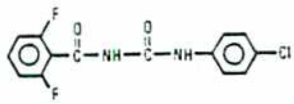
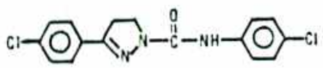
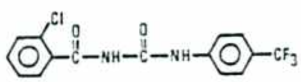
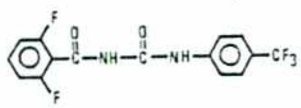
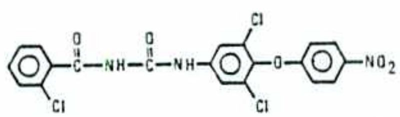
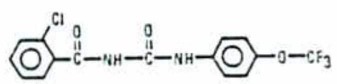
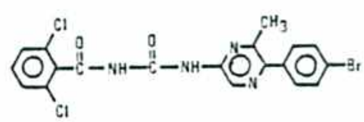
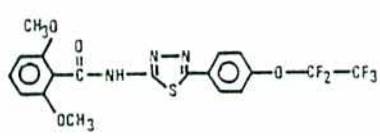
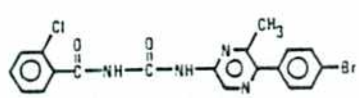
(C) Experimental aerial trials carried out in Hearst (1978), Wawa (1979) and the French River area (1980).

5. LITERATURE REVIEW

Moult inhibiting IGRs were first developed between 1970 and 1973 at the Philips-Dupher Laboratory in Holland and the compound selected for further study was Diflubenzuron (Dimilin or pH 60-40) (Post and Vincent, 1973). This IGR is a benzoyl urea with halogen substitution (Table 1). Its physio-chemical properties have been summarized by Maas *et al.* (1980). Since it is highly insoluble in water a wettable powder formulation containing Barden clay® was developed for testing on insects. Upon ingestion by larvae the compound was found to selectively inhibit chitin synthesis (Bijloo 1975; Eck 1979, Hajjar and Canida 1979).

At least 3 different physiological effects of Dimilin have been reported. The most common effect is on larvae. As mentioned earlier, the inability to synthesize chitin by the larvae results in the integument becoming so fragile that fractures occur in weakened areas at the time of moult, leading to the mortality of the insect (Bijloo 1975). Although most adult insects are not affected, a few that live for a long period as an adult and actively feed are mildly affected. Adult locusts, 3 days after ingestion, show characteristic breaks in the hind legs (Ker 1977). In the colorado potato beetle, the elytra fail to harden (Grosscourt, 1978). An ovicidal effect of diflubenzuron was reported in the boll weevil (Moore *et al.* 1978). The contamination of the egg prevents chitin synthesis in the embryo, as a result of which the embryo is unable to emerge. It is interesting to note that such an ovicidal effect has not been seen in most other insects including the spruce budworm and could very well be restricted to a few species of curculionids.

Table 1. MOULT INHIBITING INSECT GROWTH REGULATORS INVESTIGATED UP TO 1980

NUMBER	CHEMICAL STRUCTURE	COMPOUND	MANUFACTURER
1		BENZOYL UREA	-
2		PH 60-40	PHILIPS-DUPHAR
3		PH 60-41	"
4		PH 60-43	"
5		PH 60-44	"
6		BAY SIR 6874	CHEMAGRO LIMITED
7		BAY SIR 8514	"
8		EL-494	ELI LILLY & CO.
9		L-1215	"
10		L-7063	"

Dimilin is biodegradable and is easily metabolized by fungi, algae and a host of soil bacteria except *Pseudomonas* (Bull and Ivie 1978; Khan 1978; Schaeffer and Dupras 1977). The half life in water and loose soil is 1/2 to 1 week and extends to a maximum of 8 to 16 weeks in heavy clay (Verloop and Ferrel 1977).

The vertebrate toxicology of Dimilin has been well investigated and for the most part appears to be relatively safe (Maas *et al.* 1980; Quarles *et al.* 1980; Wilcox and Coffey 1978).

The effects of diflubenzuron on invertebrate species, particularly those that have a chitin synthesizing system is of concern. In general it does not appear to have any adverse effects on adult predators, parasites and pollinators (Ables *et al.* 1975; Retnakaran and Smith 1980: Wilcox and Coffey 1978). The most serious effect of this material has been observed on juvenile crustacea. In examining the effects on crustacean larvae, 2 aspects should be borne in mind. First, the solubility of diflubenzuron in water is 0.2 μg/ℓ or 0.2 ppm. Second, the half life in water is 1/2 to 1 week. Many of the crustacea have short life histories and have several generations during each season. The brine shrimp, *Artemia salina* for instance has a 2 week life history and the nauplii moult 14 times during this period, indicating rapid integument development which involves chitin synthesis. Dimilin adversely affects the nauplius at 10μg/ℓ or 10 ppb. In as much as only the juveniles are affected, as soon as the IGR is degraded in the water, the adults repopulate the area (Cunningham 1976). This temporary fluctuation in the population with subsequent repopulation has been well documented with studies on *Daphnia* species (Mulla *et al.* 1975). Some species such as *Bosmina longirostrics* and *Cyclops* show a high degree of tolerance for diflubenzuron Dimilin (Ali and Mulla 1978). The estuarine shrimp, *Mysidopsis bahia* is another species that is sensitive to Dimilin at 75 μg/ℓ or 75 ppb (Nimms *et al.* 1979). McLeese (1976) reported that while 0.6 μg/ℓ or 0.6 ppm of Diflubenzuron is toxic to lobster larvae, 0.015 μg/ℓ or 15 ppt of Fenitrothion was lethal to lobster larvae. The lethal concentration for Orthene was 0.3 μg/ℓ or 0.3 ppm and for Dinoseb it was 7.5 μg/ℓ or 7.5 ppb.

6. SUMMARY OF WORK CARRIED OUT AT FPMI

Work on Dimilin was started in 1974. The moult inhibiting syndrome was observed in the spruce budworm reared on diet treated with this IGR (Retnarkan and Smith 1975). Since then we have tested over 25 different IGRs in the laboratory and the structures of the 10 main ones are shown in Table 1 (Retnakaran 1978; 1979 a,b,c; 1980; Weatherston and Retnakaran 1975). The relative potency of the different materials were evaluated by determining the LC_{50} for the candidate compounds by incorporating the IGRs in artificial diet (Retnakaran 1980). The older larval instars of the budworm were found to be more sensitive to diflubenzuron than the earlier ones, the reverse of what one would expect with most insecticides (Granett and Retnakaran 1977; Retnakaran and Smith 1975). Since this discovery, all new compounds have been subjected to differential stadial susceptibility tests.

It was also found that some species such as the forest tent caterpillar and the white marked tussock moth were highly susceptible whereas some insects like the Eastern and Western spruce budworm were relatively insensitive to Dimilin. The reasons for the difference were, differential absorption and metabolism. The sensitive species absorbs more and metabolizes less than the refractory ones (Retnakaran *et al.* 1980; Granett *et al.* 1980).

In order to evaluate the control potential of these compounds, greenhouse tests using potted balsam fir and white spruce trees were conducted. Each tree was sprayed in a spray tower with a volume equivalent to 4.7 ℓ/ha or 0.5 U.S. gal/acre containing the active material and then colonized with budworm larvae. An equivalent of 8-10 times the greenhouse dosage approximates the effective dose required in the field (Retnakaran 1980). In the greenhouse, tests for persistence, resistance to leaching, and shortwave UV were also carried out (Retnakaran and Smith 1975; Retnakaran 1980). If a candidate compound persisted for approximately 10 days, was relatively resistant to leaching and shortwave UV, had a projected effective field dosage that was economically acceptable to the manufacturer and was reasonably safe to the environment, based on the preliminary studies on toxicology, then field testing was indicated.

Using agricultural aircraft such as Grumman Agcat or Cessna Agtruck equipped with micronair units, field trials with wettable powder formulations of IGRs in water were carried out in Ontario in 1975, '76, and '77. We found that Diflubenzuron is not effective on the spruce budworm even at high dosages that are uneconomical (Retnakaran *et al.* 1977, '78). One particular compound, EL-494 (Table 1) looked promising both in the lab and in the greenhouse but its performance in the field was extremely disappointing.

Although we had not identified any potent IGRs for the budworm by 1977, Dimilin was found to be very effective at extremely low dosages (70 g/4.7 ℓ/ha) for controlling the forest tent caterpillar (Retnakaran and Smith 1976; Retnakaran *et al.* 1979).

In collaboration with other teams in the Institute we have confirmed that Dimilin has no gross impact on mammals, birds and fish. An analog of diflubenzuron, BAY SIR-8514 (Table 2) has no effect on web-spinning in spiders (Retnakaran and Smith 1980). We also found that diflubenzuron is absent in maple sap when applied as a soil drench (Retnakaran *et al.* 1978).

7. LABORATORY, GREENHOUSE AND FIELD TRIALS (1978 to 1980)

The moult inhibiting IGRs selected for field testing were initially screened in the laboratory and in the greenhouse. Depending on (i) the quantity of material available for testing and (ii) the manpower support available for the operation, field trials of different magnitudes were carried out in 1978, '79 and '80. The results of these studies will be presented in 4 parts as: (1) laboratory and greenhouse trials; (2) 1978 trials at Hearst; (3) 1979 trials at Wawa and (4) 1980 trials near the French River area.

7.1 METHODS AND MATERIALS

7.11 Laboratory Assay:

Wettable powder formulations of IGRs were weighed and mixed in 100 ml of water containing 1 ml of green food coloring. Approximately 700 ml of molten diet were added to the test material, suspended in water and mixed thoroughly with a paint mixer using the green color as an indicator of adequate dispersion. The diet containing the IGR was weighed and the concentration of the active ingredient expressed as ppm (wt/wt). Ten ml of diet were dispensed into coffee creamer cups (capacity, 20 ml) and allowed to set. Ten larvae on the first day of each instar were placed in each cup at the start of the experiment, and the results tallied when the controls had molted into the next instar. At least 5 dosage levels were used for determining the EC_{50} of each instar, and each dosage level was tested on 100 larvae (Retnakaran 1980).

The spruce budworms used in the laboratory and greenhouse experiments were reared on a meridic diet (McMorran 1965) after the method of Grisdale (1970) at 22°C, 70% RH, and a photoperiod of 18 h light and 6 h darkness. Instars were identified by the head-capsule width and moulting larvae by a white band behind the head capsule indicating head capsule slippage (Retnakaran 1973; 1979b). Moulting larvae were placed on diet for 24 h and those that had molted were identified as day old larvae and used in the experiments.

The results were analyzed using a probit program and statistically examined for goodness of fit and scatter.

In order to test for stability, a thick slurry of the IGR was either autoclaved at 120°C for 30 min or exposed to UV under a GE-sun lamp for 24 h then freeze dried, incorporated into diet and assayed for budworm mortality (Retnakaran 1980).

Table 2. Recording sheets for pre- and post-spray counting of Spruce Budworm (Courtesy Dr. G. Howse, GLFRC).

AERIAL SPRAYING PROJECT

PRE - SPRAY

Location ____________ Tree No. ________ Crew ____________

Date collected ________ Date counted ________ Date checked ________

Name ________ Time started ________ Time finished ________

Checked by ____________

	Original		Check	
	Live	Dead	Live	Dead
Budworm II				
III				
IV				
V				
VI				
Pupae				
Emerged pupae				
Total				
Associated species				
Comments				

AERIAL SPRAYING PROJECT

POST - SPRAY

Location ____________ Tree No. ________ Crew ____________

Date collected ________ Date counted ________ Date checked ________

Name ________ Time started ________ Time finished ________

Checked by ____________

	Original				Check			
	Branch A		Branch B		Branch A		Branch B	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead
Budworm III								
IV								
V								
VI								
Pupae								
Emerged pupae								
Total								
	A + B =				A + B =			
Associated species								
Comments								

NAME

LOCATION	DATE	HOST and TREE #	ORIGINAL or CHECK	TIME STARTED	TIME FINISHED	TOTAL TIME	TOTAL LIVING BUDWORM	TOTAL NUMBER SHOOTS

7.12 Greenhouse trials:

Potted balsam fir and white spruce trees, ca. 45 cm high were placed in a spray tower, and the candidate IGR was applied. The spray tower consisted of a 157 cm high, 84 cm wide, 77 cm deep Plexiglas® cage with a turn-table at the bottom and a Micro II-19/23 nozzle mounted on top. The test material was applied at 5 cm Hg pressure to provide a droplet spectrum similar to a Micronair, AU-3000 unit. Forty-two µℓ of the IGR suspension in water was sprayed in the spray tower which covered an area of 904 cm^2, and this was equivalent to 4.7 ℓ/ha. Each potted tree received a specified amount of IGR with the volume sprayed being kept constant. Twenty, 1-day-old (< 24 h after moult) 4th instars or 5th instars were placed on each tree and the entire tree was kept in a Plexiglas cage that had a screen on top (Fig. 1). Five trees were used for each concentration of IGR tested. Mortality was recorded when all the larvae in the controls had pupated.

The methods used in determining the area covered in the spray tower and the active ingredient equivalent to be used to cover this area are shown in Figure 2. The active material in 42 µℓ in a plastic pipette tip was placed on the nozzle.

Persistence was studied by spraying the trees and maintaining them for 5, 10 and 15 days prior to colonizing the trees with larvae. Mortality was recorded as described earlier. Leaching was tested by spraying water on the treated trees with a sprinkler at the rate of 11.5 ℓ/min for 5 sec/day for 10 days prior to colonizing the trees with larvae and recording the mortality as before. UV resistance was investigated by placing a Mineralight® (254 nm) 18 cm above the treated tree and turning it on for 1 h/day for 10 days before placing the larvae on the tree (Retnakaran 1979b).

7.13 Plot Layout and Communication System:

Plots ranging from a minimum of 50 to a maximum of 200 acres (20 to 80 ha) are selected in the preceding fall based on data on egg count and infestation obtained from the Forest Insect and Disease Survey personnel. Ideally plots with an anticipated 30-40 sixth instar larvae/18" (30-40 larvae/46 cm branch tip) branch tip indicating moderate infestation are the ones best suited for our studies.

Plots are selected on the basis of (1) moderate infestation, (2) proximity to a suitable airstrip (within 40 km, (3) composition of minimum 10% white spruce and 10% balsam fir, (4) mature trees, 80 to 100 years old, (5) crown land or publicly-owned land, (6) suitable road access with a road or path at right angles to the access road preferably near the middle of the plot for locating "moving balloon" and laying out spray cards (Fig. 3). Each plot is separated from an adjacent plot by at least 1 km to allow for drift.

Sample trees, 25 each for balsam and white spruce are selected along concentric lines on either side of the moving balloon line as shown in Figure 3. The trees are not selected from close to the edge or to the moving balloon line. The trees have to be co-dominant and not covered by hardwood overstorey.

Check or control plots usually 10 in number are selected in the same general area. No boundaries are generally required and 15 each of white spruce and balsam fir trees similar to those trees selected in treatment plots are chosen as sample trees. Radio communication system from the airstrip, weather station in the plot area, mobile unit in the spray plot and aircraft are maintained during the spray operation.

7.14 Aircraft Calibration, Mixing and Loading:

A Grumman Agcat or Cessna Agtruck capable of carrying a payload of over 100 U.S. gals (3785 ℓ) is used for spraying. The aircraft is equipped with Micronair AU-3000 units with a vane setting of 35° and restrictor #11. The Agtruck flying at 55 to 65 ft (16.5 to 19.5 m) above the tree tops at speeds of 105 to 110 mph (169-177 kmh) uses pump pressure of 35 to 37 psi to deliver 0.5 U.S. gal/acre (4.7 ℓ/ha). The swath width under these conditions is 100 ft (30 m).

The micronair flow rate and droplet size are determined by the restrictors and the r.p.m. and the following equation from Ciba-Geigy handbook (1978) is utilized--

$$\text{Flow rate of micronairs } (\ell/\text{min}) = \frac{\text{spray quantity } (\ell/\text{ha}) \times \text{flying speed (m.p.h.)} \times \text{run width (m)}}{\text{constant factor } 373 \times \text{number of open nozzles or micronairs}}$$

Further details are provided by Barry and his co-workers (1978). A calculation for spraying 0.5 U.S. gal/acre using a Grumman Agcat would be as follows:

(i) 0.5 U.S. gal/acre = 4.7 ℓ/ha

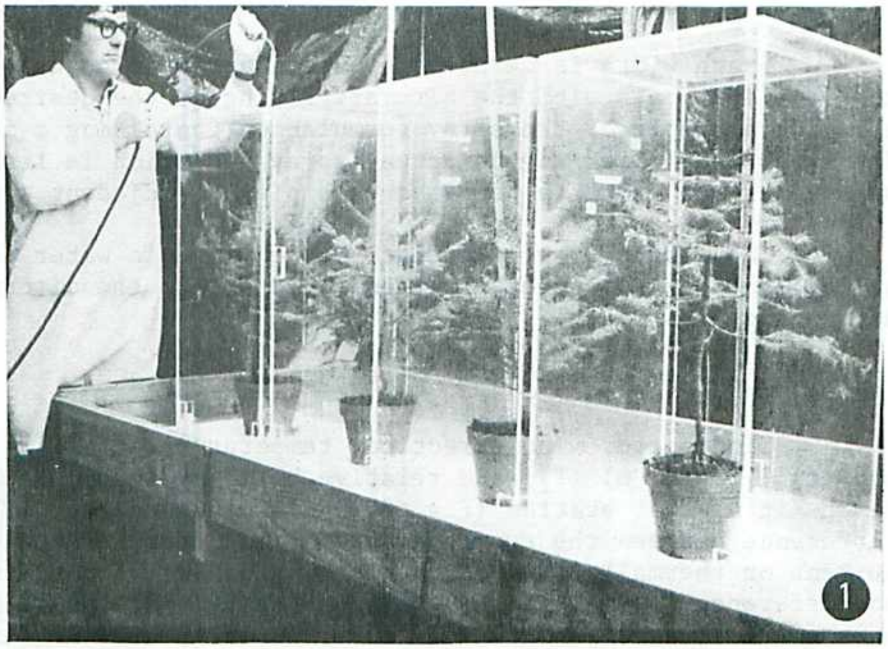
(ii) Flying speed = 90 m.p.h.

(iii) Swath = 30 m

(iv) Constant = 373

(v) No. of open micronair units = 4

$$\therefore \text{ Flow rate } = \frac{4.7 \times 90 \times 30}{373 \times 4} = 8.5\ \ell/\text{min}$$



SPRAY TOWER CALIBRATION

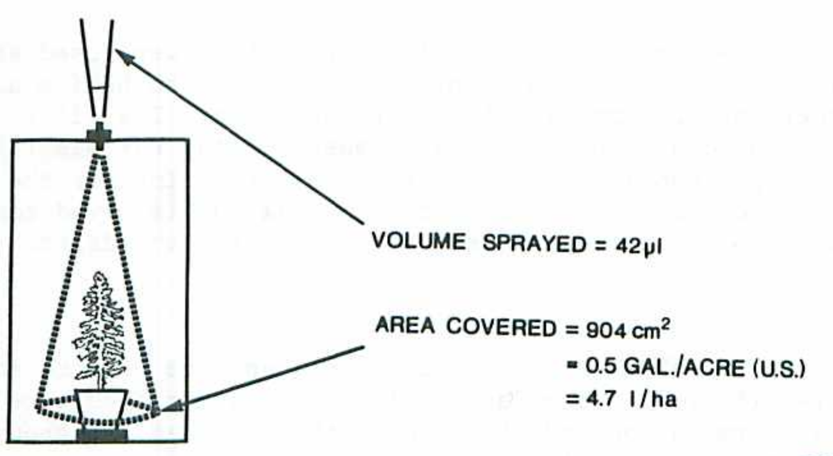


Figure 1. Plexiglas cages with treated potted trees in the greenhouse.

Figure 2. A schematic representation of the spray tower used in greenhouse studies.

Swath width is measured by using a row of cord at right angles to the flight path with the aircraft flying at the desired height and spraying a sample of the spray formulation containing a marker dye. The swath width used in the actual spray operation is less than the measured swath width to permit overlapping of adjacent swaths.

The Insect Growth Regulators are mixed in water or oil in 55 gallon drums with a power mixer and loaded into the aircraft spray tank using a pump.

7.15 Weather Station:

Wind speed, wind direction, temperatures at 30 ft (9 m) (T_1) and at 10 ft (3 m) (T_2) and relative humidity were measured using a Heath-Kit weather station (Fig. 3) and a psychrometer. The temperature difference between the two levels is an indicator of the convection current or thermally produced vertical airflow. A positive value or no difference between $T_1 - T_2$ (or) top temperature being higher or the same as the lower one indicates inversion or stable conditions. When the value of $T_1 - T_2$ is negative (or) the bottom temperature is higher, there is an upward movement of air indicating lapsed conditions for spraying.

7.16 Balloon Markers:

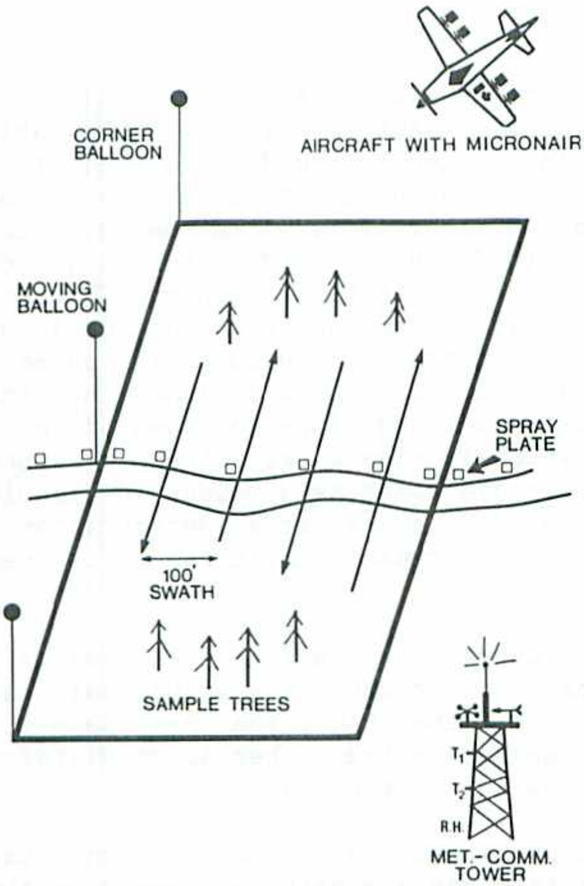
Weather balloons filled with helium were used as markers (Fig. 3). The two corner balloons are inflated with helium and tied to the corner markers immediately before spraying. The pilot, after locating the corner balloons, fixes a compass bearing for his flight path. The moving balloon is moved 100 ft (30 m) at a time for the next flight line. To compensate for drift this balloon is moved correspondingly, after the first flight pass, to correct for the drift.

7.17 Spray Plates:

Kromekote cards and glass slides were used to construct spray plates (Fig. 4) after Randall (1980). Marker dyes were mixed with the spray formulation and the deposit that reached the ground was measured using these spray plates (Barry *et al.* 1978).

The spray plates were placed at 50 ft (15 m) intervals along the moving balloon line from one end to the other end of the plot. Drift cards were placed on either end of the plot. In order to avoid confusion a precise coding system was used in numbering these plates.

In order to expose the spray plates adequately and prevent road dust from covering the plot, a 12" (28 cm) stake and platform is used as described by Randall (1980).



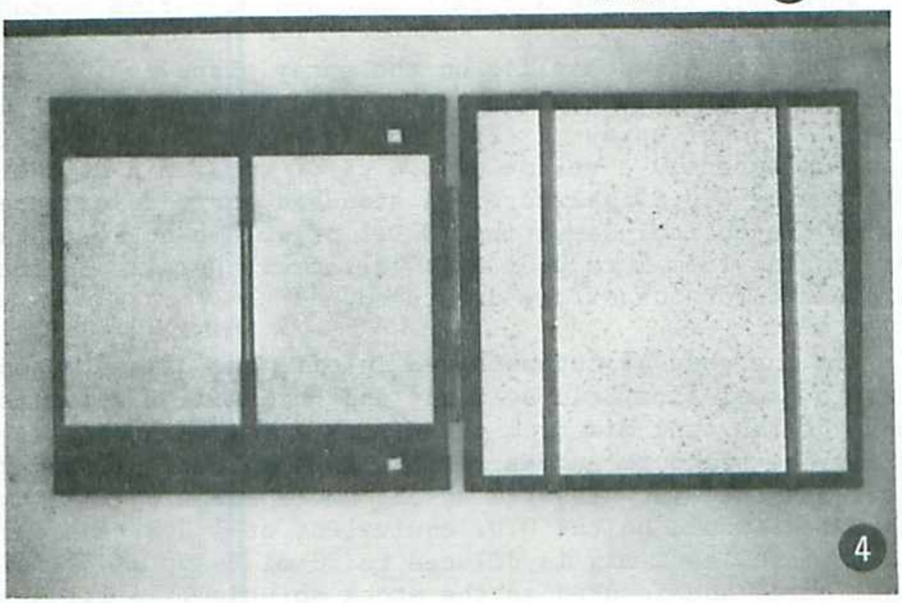


Figure 3. Typical plot layout for aerial application of IGRs.

Figure 4. Spray plate showing a Kromekote card and 2 glass slides.

In order to visualize the spray deposit a marker dye is usually added to the spray mix. Automate red "B" (available as a liquid concentrate containing 8.1 - 8.6 lb dye/U.S. gal from Morton Chemicals, (Ajax, Ontario) is oil soluble with an absorption peak of 523 nm and is used at a concentration of 1% (v/v) in the spray mix when spraying at 0.5 U.S. gal/acre (4.7 ℓ/ha). Rhodamine B is a red, water soluble dye (available as a 50% concentrate from Dupont Chemicals Ltd., Toronto, Ontario) with an absorption peak at 550 nm and is used at a concentration of 0.1% (v/v). There is some suspicion based on Ames Salmonella test conducted by Health and Welfare Canada that this might be mutogenic (Personal communication) and hence for some of the later trials, Erio acid red XB 400 which is also water soluble was substituted for water formulations. This dye comes as a powder (available from Ciga-Geigy, Etobicoke, Ontario) and is used at a concentration of 1% (v/v). For *Bacillus thurigiensis* formulations, this dye is used at a concentration of 0.025% (w/x).

The spray deposit on the 2 glass slides is used for measuring the volume of spray that reached the ground using a spectrophotometric assay system. On the other hand, the spray deposit on the Kromekote card is used for measuring the number of droplets/cm^2 and the size distribution of the spray droplets.

The spectrophotometric measurement consists of taking a sample of the spray mix from the aircraft tank and preparing a standard curve.

The area of each slide on the spray plate is (5 x 7.5 cm) 37.5 cm^2. If 0.5 U.S. gal/acre is sprayed on the plot, it is the equivalent of 1.7 μℓ of spray mix/37.5 cm^2 (or) surface area of 1 glass slide. Consequently a volume of 3.4 μℓ of spray mix on the glass slide would indicate 1 U.S. gal/acre. A standard curve is prepared by measuring the optical densities (O.D.) of volume equivalents on glass slides ranging from 1 to 0.01 U.S. gal/acre. Details of the procedure are explained for one of the dyes used.

In the case of Automate red in oil, the diluent used is absolute ethanol (for Erio acid red and Rhodamine B water is used). A sample of the tank mix from the aircraft for each plot is used for preparing the standard curves. A 3.4 μℓ sample is diluted to 5 ml in ethanol, and the O.D. measured at 523 nm (absorption maximum for Automate red) would be the O.D. equivalent of 1 U.S. gal/acre. A 34 μℓ sample of tank mix is diluted to 50 ml (same as 3.4 μℓ in 5 ml or 1 gal/acre) and is used as the stock solution. A 1:1 serial dilution of the stock solution with ethanol would yield equivalents of 0.5, 0.25, 0.125, 0.0625, 0.0313 and 0.0156 U.S. gal/acre. The O.D.s of these dilutions are plotted against gal/acre and a standard curve is constructed.

Each glass slide is washed with 5 ml of ethanol, scrubbed simultaneously with a camel hair brush and the eluent filtered through a sintered glass funnel into a test tube. The O.D. of the wash is measured in a spectrophotometer and the volume as gal/acre is determined by multiplying the value by the conversion factor. The conversion factor is the gal/acre value for 1 O.D. unit obtained from the standard curve for the particular plot.

The droplet size and number are usually measured with a dissecting microscope using a calibrated eyepiece graticule for size and counting the number per cm^2. A calibrated micro card reader and a template to measure the size made the measurements faster (Randall, personal communication). Dots from five squares (each being 1 cm^2), one from each corner and one in the middle were counted for each Kromekote card. The sizes of the spray droplets from two 1 cm^2 squares were measured for each card. The sizing was done by grouping into classes based on diameter in μm. All the cards including those for drift were measured and counted as indicated. The total number of droplets whose sizes were measured was used in calculating the percent distribution of the different sized droplets.

Spread factor data were obtained for each formulation using the rotary device described by Rayner and Haliburton (1955) for the spot size range obtained on Kromekote cards in the field (Table 3). For aqueous formulations, droplets produced by the device were collected on cards for spot size and in a silicone fluid (Dow Corning 200-30000 CS) to obtain the droplet size. The droplet diameter was measured under a microscope. Spread factor was calculated from the ratio of spot size on card/drop size in fluid. For oil-based formulations, the droplets were collected on Kromekote cards for spot size and for droplet size on Teflon discs that were calibrated against MgO coated slides for the size range of droplets for each formulation. The spot size obtained on Teflon discs were converted to droplet size and these were used in the spread factor calculation (A. Sundaram, FPMI, personal communication).

7.18 Spray Operation:

The spray operation is carried out when the bud caps on white spruce and balsam fir have fallen off and the buds are open, exposing the insect. At this time the budworm is usually at peak 4th instar.

Ideal conditions for spraying is when the temperature is a few degrees (2 or 3 at least) above freezing, the wind speed is < 3 mph (4.8 kmh), the relative humidity is $> 90\%$ and there is inversion (see under weather station). These conditions usually exist early in the morning and late in the evening. The actual spray time is limited by light and usually ranges from 5:00 to 8:00 a.m. in the morning and 9:00 to 10:00 p.m. in the evening permitting about 3 loads in the morning and 2 in the evening for 100 acre (40 ha) plots. The relative humidity is commonly lower in the evenings making morning sprays preferable, especially if the formulation is water based. Oil based formulations can be sprayed in the morning and in the evening with equally good deposit since evaporation is not a major problem. Also oil based formulations can be sprayed at freezing temperatures.

Table 3. Determination of absolute diameter of droplet from spot on spray card using spread factor (1980)*

Plot #	Material and formulation	Linear regression equation where y is the absolute diameter and x is the spot diameter (µm)
1	UC-62644 0.5 oz in 7 N oil	y = 8.29 + 0.228 x
2	UC-62644 1.0 oz in 7 N oil	y = 8.29 + 0.248 x
3	BAY SIR-8514 2.0 oz in water	y = 50 + 0.3 x
4	BAY SIR-8514 3.0 oz in 7 N oil	y = -1.88 + 0.27 x
5	BAY SIR-8514 2.0 oz in 7 N oil	y = 0.548 + 0.425 x
6	BAY SIR-8514 2.0 oz in 7 N oil + emulsifier	y = 2.83 + 0.358 x
7	BAY SIR-8514 3.0 oz in water	y = 20.2 + 0.329 x
8	Matacil 1+1 oz in 585 oil	y = 52.4 + 0.273 x
9	Matacil 1 oz in 585 oil	y = 52.4 + 0.273 x
10	Dipel 88 8 BIU in 1:1 water	Not available

*Data taken from A. Sundaram 1981, File Report No. 9, FPMI. Using the regression equation and the spot diameter on Kromekote cards, the absolute size can be calculated which can then be used for comparing with similar data of other researchers.

The first step in a spray operation is to lay down a test swath and if any drift is detected, the appropriate correction is made by shifting the moving balloon to compensate for the drift. In a 100 acre (40 ha) block of equal sides (20,871 ft or 6,361 m), the aircraft has to make about 21 passes when the swath width is 100 ft (30 m) and the permissible error is ± 1 swath.

The spray cards are collected 2 h after the spray to allow for settling of the smaller droplets.

7.19 Sampling:

The sample unit is an 18" (45 cm) branch tip collected from the mid crown region using pole clippers. Three different types of sampling are performed during the operation.

Pre-spray sampling is done within 48 h before spraying. Twenty-five balsam fir and 25 white spruce branch tips from each spray plot and 15 balsam fir and 15 white spruce branch tips from each check plot are collected. The samples from the check plots are taken 48 hours after the first spray so that the time difference from any of the spray plots will be less than 48 h. If the time difference is greater sampling of check trees is repeated.

Post-spray samples are taken when there is 50% pupation in the check plots. This second set of samples are taken from the selected trees in the same way as the pre-spray samples were taken.

Each branch tip is placed inside a paper bag that is stapled shut to prevent insects from escaping. Each bag is labelled with (i) the plot number (ii) tree species (iii) sample tree number and (iv) the date collected. The 25 balsam firs and 25 white spruce samples are packed separately in garbage bags and tied with flagging tapes on which the plot specifics are clearly written. The sample bags are temporarily stored in a cool place for later transport to the laboratory in Sault Ste. Marie where they are stored at 36°F (2°C). The samples are assessed within a week.

Periodic samples from the spray and check plots are taken at 5-day intervals from the spray date and discontinued when post-spray samples are taken. These samples are obtained from trees adjacent to the sample trees. A representative collection of a few branch tips is taken to the field laboratory and set up in ice cream cartons for rearing, using the same foliage. The IGR symptoms are monitored and any deviation is noted. Estimates of viral, fungal or parasitic effects are made.

The pre- and post-spray samples are combed for spruce budworm in Sault Ste. Marie by a counting team. Each branch sample is assessed by two different people. The first person counts and removes insects as they are found. A second person re-examines the same branch and counts and removes insects that were missed on the first count. The sum of the two counts is the total population for that sample.

The percentage counting error for the first person is calculated by dividing the second count by the total population and multiplying by 100. This error factor is used for monitoring the accuracy of the assessments. Separate tallies are kept for associated insect species (Table 2).

Post-spray counts are made in a similar fashion. All dead budworm as well as empty pupae are counted. A representative number of pupae are maintained in a petri dish for emergence. Pupal parasitism is recorded and delayed effects on pupal emergence are noted.

Natural mortality which is density dependent is taken into account in assessing the effects, by matching each treatment plot with a check plot having a similar pre-spray population density. The data is then analyzed using a modified Abbott (1925) correction (Table 4).

Table 4. Calculation of % population reduction in budworm field trials.

$$\%\text{ population} = \frac{\text{Expected post-spray density in treatment} - \text{Post-spray density in treatment}}{\text{Expected post-spray density}} \times 100$$

$$\text{Expected post-spray density in treatment} = \frac{\text{Post-spray density in control} \times \text{Pre-spray density in treatment}}{\text{Pre-spray density in control}}$$

$$\therefore\ \%\text{ population reduction} = \left[1 - \left(\frac{\text{Post-spray density in treatment}}{\text{Pre-spray density in treatment}} \times \frac{\text{Pre-spray density in control}}{\text{Post-spray density in control}}\right)\right] \times 100$$

7.2 RESULTS AND DISCUSSION

7.21 Laboratory and Greenhouse Tests:

Five different moult inhibiting IGRs, EL-494, L-1215, L-7063, BAY SIR-8514 and UC-62644 were studied in the laboratory and in the greenhouse from 1978 to 1980 (Table 1).

The EC_{50} of EL-494 for 3rd, 4th, 5th and 6th instar larvae were 0.205, 0.249, 0.287 and 0.486 ppm respectively (Retnakaran 1979). For Dimilin it was 0.36, 15, 8.3, 3.7 ppm in the same order (Granett and Retnakaran 1977). Unlike Dimilin or pH 60-40 (Table 1), the susceptibility of budworm to EL-494 decreased with age (Table 5), (Retnakaran 1979).

Table 5. Effect of EL-494 on spruce budworm larvae compared with Dimilin (pH 60-40).

	EC_{50} in ppm in diet for larval instar			
IGR	3	4	5	6
EL-494	0.205	0.249	0.287	0.486
Dimilin	36	15	8.3	3.7

EL-494 was tested in the greenhouse by pre-treating potted white spruce and balsam fir trees with a 20 μℓ/spray of a 1% wettable powder suspension. After subjecting the trees to appropriate post treatment regimens, they were colonized with 25 fifth instar larvae/tree and tested for leaching, UV-degradation and persistence. The material was active on the foliage for 15 days, survived leaching for 10 days and did not break down when exposed to 254 nm-Mineralight® (Table 6).

Table 6. Persistence and resistance to leaching and short wave UV (254 nm) degradation of EL-494.

Test for:	Pre-treatment of tree (20 ul of 1% suspension in water/tree)*	Post-treatment of tree prior to colonizing with larvae (25 L_5/tree)	Tree species (2 of each per treatment)	% larval mortality
Control	No treatment	No treatment-larvae transferred immediately	bf ws	44 26
	EL-494	No treatment-larvae transferred immediately	bf ws	100 100
Leaching	EL-494	Water sprayed at the rate of 11.5 L/min for 5 sec/day for 10 days	bf ws	96 92
Persistence	EL-494	5 days in greenhouse 10 days in greenhouse 15 days in greenhouse	bf bf bf	100 84 100
UV resistance	EL-494	1 Mineralight® (254 nm) placed 18 cm above tree and turned on 1 h/day for 10 days	bf ws	100 96

The EC_{50} of BAY SIR-8514, L-1215 (or Ly-131215) and L-7063 (or Ly 127063) (Table 1) were determined by diet incorporation studies. The EC_{50} for 3rd, 4th, 5th and 6th instar larvae were 0.08, 0.06, 0.05, and 0.06 ppm for BAY SIR-8514; 0.08, 0.07, 0.11 and 0.13 ppm for L-7063; and 0.06, 0.09, 0.10 and 0.14 for L-1215 (Table 7). BAY SIR 8514 was marginally superior to the other two.

Table 7. EC_{50} as determined by diet incorporation tests for the different instars for BAY SIR 8514, L-7063, and L-1215.

Compound tested	Instar treated (500 larvae/instar)	EC_{50} (ppm)	95% confidence limits	EC_{50} (ppm)	95% confidence limits
BAY SIR-8514	3	0.08	0.05-0.10	0.61	0.42-1.16
	4	0.06	0.03-0.08	0.50	0.34-0.99
	5	0.05	0.01-0.10	1.65	0.66-7.70
	6	0.06	0.03-0.08	0.64	0.40-1.48
L-7063	3	0.08	0.07-0.10	0.50	0.37-0.80
	4	0.07	0.06-0.08	0.37	0.29-0.52
	5	0.11	0.09-0.12	0.62	0.44-1.06
	6	0.13	0.11-0.15	0.96	0.59-2.22
L-1215	3	0.06	0.05-0.07	0.56	0.40-0.91
	4	0.09	0.08-0.10	0.62	0.46-0.94
	5	0.10	0.09-0.12	1.05	0.69-2.02
	6	0.14	0.10-0.18	1.01	0.64-2.21

Aqueous slurries of the compounds were autoclaved and exposed to 254 nm mineralight®. The treated material was tested for activity on 4th instar larvae. No loss in activity could be detected (Table 8).

Table 8. Effect of autoclaving and UV-exposure on the activity of BAY SIR-8514, L-7063 and L-1215 in diet incorporation tests.

Compound tested	Pretreatment of moult inhibitor	% mortality of 4th instar spruce budworm reared on diet containing the following dosages (ppm)[a]					
		1.0	0.5	0.3	0.2	0.1	0.0
Control	-	-	-	-	-	-	6
BAY SIR-8514	Nil	-	97	92	-	2	-
	Autoclaved	-	97	95	-	4	-
	UV-exposed	-	98	99	-	97[b]	-
L-7063	Nil	-	96	72	-	5	-
	Autoclaved	-	100	99	-	61	-
	UV-exposed	-	98	92	-	20	-
L-1215	Nil	93	68	-	64	-	-
	Autoclaved	93	60	-	40	-	-
	UV-exposed	89	67	-	73	-	-

[a] 100 larvae per dosage level.

[b] Fungal contamination.

Various field dose equivalents (i.e., equivalent to oz in 0.5 U.S. gal/acre or g in 4.7 ℓ/ha) were tested in the spray tower to determine the dose that will cause 100% larval mortality. For BAY SIR-8514 it was 7 g in 4.7 ℓ/ha (0.1 or in 0.5 U.S. gal/acre), L-7063 it was 35 g in 4.7 ℓ/ha (0.5 oz in 0.5 U.S. gal/acre), and for L-1215 it was 70 g in 4.7 ℓ/ha (1.0 oz in 0.5 U.S. gal./acre) (Table 9). All 3 compounds were relatively resistant to leaching, short wave UV and persisted for at least 15 days. In these respects they resembled EL-494.

Table 9. Field-dose-equivalent of BAY SIR-8514, L-7063, and L-1215 to cause 100% budworm mortality in greenhouse spray tower tests.

Dosage in spray tower (mg in 42 µl. to cover 904 cm^2)*	Equivalent field dosage		% mortality for the following moult inhibitors		
	g in 4.7 l per ha	Oz. in 0.5 U.S. gal/acre	BAY SIR-8514	L-7063	L-1215
control	-	-	24	17	17
0.695	70.0	1.0	100	93	88
0.347	35.0	0.5	95	98	83
0.139	14.0	0.2	-	58	75
0.069	7.0	0.1	88	78	83
0.034	3.5	0.05	60	38	78
0.007	0.7	0.01	46	-	-

*Each dosage was tested on 5 trees colonized with 20, 5th instar spruce budworm.

Union Carbide UC-62644 was by far the most promising IGR against the spruce budworm. The EC_{50} values obtained were higher than those for BAY SIR-8514 (Table 10), but the time taken for effects to appear was considerably shorter. A fourth or fifth instar larva upon injection of UC-62644 became lethargic in 24 hr and stopped feeding shortly after. By 48 hr the absence of new chitin synthesis could be observed in the dorsal abdominal region. The integument became thin and translucent, then bulged. There was also malformation of the mandibles. It was difficult to pick up these affected larvae with a camel hair brush without rupturing the abdomen.

The rapid action of UC-62644 suggested some contact activity. Preliminary experiments with topical application suggested some contact toxicity for this compound but accidental contamination of the diet ingested could not be ruled out.

Short pieces of glass tubing, with bores large enough to accommodate a larva but small enough to prevent it from turning around, were filled with synthetic diet and presented to topically treated 6th instar budworm larvae. The results indicated contact toxicity. The topical effect was further confirmed using 1st instar budworm larvae that have incomplete alimentary tracts and do not feed. Such newly emerged 1st instar larvae were topically treated with UC-62644 (25% wettable powder). The controls were treated with barden clay, the support used in making the wettable powder. The number of larvae that successfully moulted into second instars and the number that died were counted after 1 week. The mortality was over 99% in the treatments, whereas the controls showed 14% mortality. Also in the controls over 85% moulted into the 2nd instars. In the treated larvae < 1% moulted into seconds. The effects on mortality and successful moulting were significantly different between the control and treated groups (Table 11).

Table 10. The activity of UC-62644 in diet incorporation tests.

IGR	EC_{50} in ppm in diet for larval instar 3	4	5	6	Time of show effect on 4th instars (days)
UC-62644	0.23	0.10	0.11	0.19	< 2
BAY SIR-8514	0.08	0.06	0.05	0.06	> 5
Dimilin	36	15	8.3	3.7	> 5

Table 11. Contact effect of UC-62644 tested on the non-feeding, 1st instar spruce budworm.

Treatment	No. treated ($\bar{x}$ of 10 replicates)	% Mortality as 1st instar	% successful moult into 2nd instars
control (1% Barden Clay)	74.4	14.55**	85.45
1% UC-62644 - 25% WP	97.8	99.13	0.87**

**Differences in mortality and successful moult were significant at the 1% level when a T-test was performed on the Aresin transferred value.

Whether or not the larva could distinguish between treated and untreated diet was studied. Treated (1% in diet) and untreated diet were cut into small moulds using a cork borer. Four of these little cylinders (1 cm diameter x 1 cm high), 2 treated and 2 controls were placed inside petri dishes in alternate positions. Ten 5th instar larvae were placed in the middle of the dish and the feeding observed over a 24 h period. The results showed (Table 12) that the larvae could not discriminate between the treated and control diets even though the treatment diet had a massive amount of UC-62644 (1% or 10,000 ppm).

Table 12. Discrimination between treated (1% UC-62644 either incorporated or topically coated) and untreated diets by 5th instar budworm.

Treatment	No. larvae/ replicate	No. replicates	% Distribution larvae after 24 h		
			Treatment	Control	Wandering
Incorporation of UC-62644 in diet	10	10	24	34	42
Diet cylinder topically coated with a 1% slurry of UC-62644	10	10	39	33	28

No significant difference between treated and untreated diets in both instances.

Greenhouse tests were conducted to determine the field equivalent dosage to cause 100% mortality. Within 7 days after treatment most of the mortality had occurred. At the end of 10 days, the lowest dosage to cause 100% mortality was 0.05 oz (Table 13).

7.22 Field Trials Conducted near Hearst:

In 1978 the aerial field trials were conducted near Hearst, Ontario in Gill and Studholme Townships, south of Highway 11. Using the criteria for selecting spray plots described earlier, 5 treatment plots and 10 check areas were selected (Figure 5). The 5 plots were sprayed with Dimilin (pH 60-40), EL-494, Rubidium chloride, BAY SIR-8514 and Matacil respectively (Table 14).

Prior to the field season in 1978 we had completed laboratory and greenhouse investigations of EL-494 and BAY SIR-8514. Both compounds appeared to be more active and limited quantities were available for field trials. Dimilin at 280 g/ha (4 oz/acre) was used for comparison. Our earlier field trials had shown Dimilin to be ineffective at economic levels (Retnakaran *et al.* 1977; Retnakaran *et al.* 1978).

Table 13. Field-dose-equivalent of UC-62644 to cause 100% budworm mortality in greenhouse, spray tower tests*.

Spray tower dosage (mg in 42 µl to cover 904 cm^2)	Field equivalent dosage Oz. in 0.5 U.S. gals per acre	Field equivalent dosage g in 4.7 ℓ per ha	balsam fir no. used trees	5th instar larvae per tree	% Mortality
control	-	-	15	20	4
0.139	0.2	14.00	5	20	98
0.069	0.1	7.00	5	20	100
0.034	0.05	3.50	5	20	100
0.028	0.04	0.28	5	20	60
0.014	0.02	0.14	5	20	36
0.007	0.01	0.70	5	20	10

*Projected field dosage is the lowest greenhouse dosage to cause 100% mortality multiplied by a factor of 10 (to compensate for non-ideal conditions).

Table 14. The 1978 Insect Growth Regulator spray program near Hearst, Ontario.

Plot No.	Material	Amount (Active ingredient)	Area	Date	Time of application
1	Dimilin	280 g/ha (4 oz/acre)	20 ha (50 ac)	June 21	morning
2	EL-494	140 g/ha (2 oz/acre)	40 ha (100 ac)	June 21	morning
3	Rubidium chloride	70 g/ha (1 oz/acre)	40 ha (100 ac)	June 23	morning
4	BAY SIR-8514	140 g/ha (2 oz/acre)	40 ha (100 ac)	June 23	morning
5	MATACIL® (Aminocarb)	70 g/ha (1 oz/acre)	40 ha (100 ac)	June 23	morning

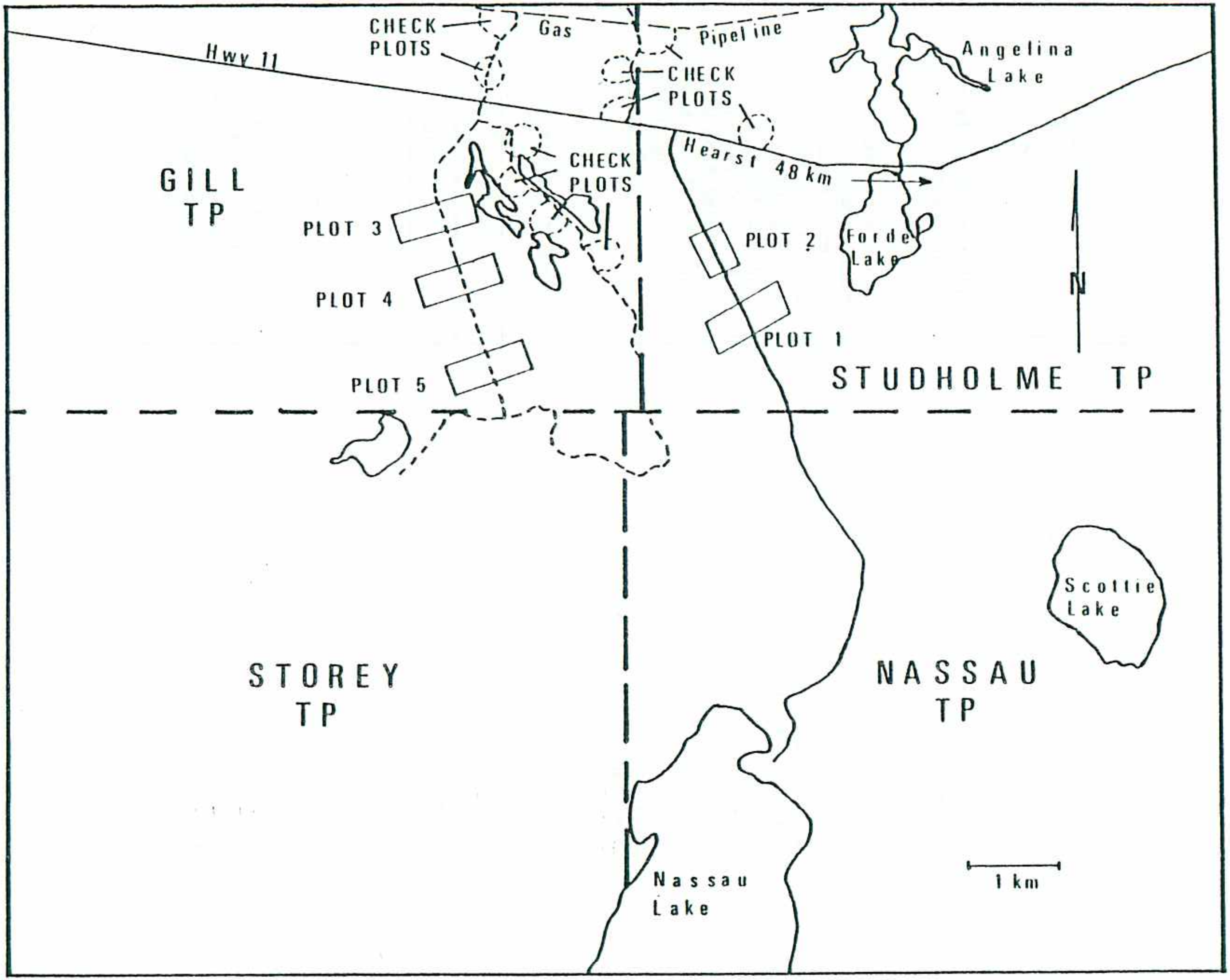


Figure 5. Plot locations near Hearst (1978).

Matacil® (aminocarb) is the carbamate insecticide currently registered as a control agent for spruce budworm. The recommended dosage is two 70 gm/ha (1 oz./acre) applications in oil (Shell "585" or its equivalent) at an interval of one week. Matacil was used as a positive control but it was sprayed only once like the other materials being tested. The rate of application was 0.5 gal (U.S.)/acre.

Rubidium chloride (0.07 oz./acre) was applied to study the value of this material as an internal marker for adult budworm (Frazer and Raworth 1974). As it turned out, the field dosage was too low for detection.

All materials, except Matacil, were sprayed in water at the rate of 0.5 U.S. gal./acre (4.7 ℓ/ha) using a Grumman Agcat aircraft equipped with 4 micronair AU 3000 units. The operation was carried out between June 21 and 23 (Table 15) when the bud caps from both white spruce and balsam fir had fallen and the budworm population was at peak 5th instar (Table 15). Spray plates were analyzed both spectrophotometrically and by counting and sizing the droplets. The average volume deposited on the plates for each plot varied from 0.08 U.S. gal/acre (0.7 ℓ/ha) for Dimilin to 0.5 U.S. gal/acre (5.3 ℓ/ha) for BAY SIR-8514 (Table 16). Considering the volume, droplet deposit and droplet size, plots 3, 4 and 5 had good deposit while 1 and 2 were poor (Tables 17 and 18).

Table 15. Development sample (Hearst 1978) taken from plots 1 and 3 on June 19.

Host	Larval stages (%)					
	L_2	L_3	L_4	L_5	L_6	Pupae
White spruce	0	0	0	53.6	46.4	0
Balsam fir	0	0	19.1	66.6	9.5	0

The weather throughout June was extremely poor for aerial spraying aqueous formulations (Table 19). Precipitation on June 22 after plots 1 and 2 were sprayed and precipitation on June 23 after plots 3, 4 and 5 were sprayed was detrimental to the operation. When this information is taken together with deposit, plots 4 and 5 (BAY SIR-8514 and Matacil) were the ones that had a reasonable chance of success.

Table 16. Spectrophotometric analysis of spray plates (Hearst, 1978).

Plot No.	Material	Emitted rate	Calculated deposit U.S. gal/ac	Calculated deposit ℓ/ha	SD	SE	No. plates analysed
1	Dimilin	4.67 ℓ/ha (0.5 U.S. gal/ac)	0.0779	0.7276	0.0155	0.00226	47
2	EL-494	"	0.3883	3.6325	0.1046	0.01386	57
3	Rubidium chloride	"	0.3943	3.6886	0.1029	0.01362	57
4	BAY SIR-8514	"	0.5720	5.3510	0.03999	0.00743	29
5	Matacil	"	0.1287	1.2039	0.0711	0.01027	48

Table 17. Mean number of droplets per cm^2 on spray cards (Hearst, 1978).

Plot No.	Application	x No. drops per cm^2	SD	SE
1 (Dimilin)	Micronair	3.793	3.547	0.648
2 (EL-494)	Micronair	10.331	6.565	1.219
3 (Rubidium chloridie)	Micronair	2.042	3.627	0.651
4 (BAY SIR-8514)	Micronair	16.423	5.911	1.079
5 (MATACIL®)	Nucribaur	57.481	28.609	5.506

Periodic samples were analyzed for symptoms of the Insect Growth Regulator as well as for effects of naturally occurring Entomophthora, viruses etc. Moult deformities were apparent in plots 2 and 4 (EL-494 and BAY SIR-8514) but no effects of micro-organisms could be detected. The possible effects of the Insect Growth Regulators on 2 hymenopteran parasites of the spruce budworm, *Apantales* sp. and *Glypta* sp. were examined. Larvae were dissected for the early emerging *Apantales*, and the pupae were held in containers to observe the emergence of *Glypta*. Very few were found and two deformed *Glypta* were observed (Table 20). No conclusions could be reached based on the small sample size.

The results of the operation based on the analyses of the pre- and post-spray samples together with the defoliation estimates based on the post-spray branch analyses are summarized in Table 21. Dimilin showed very little effect which could be due not only to the poor activity of the compound but also to the poor spray deposit and the post-spray precipitation. EL-494 showed some activity but was far

Table 18. Percentage of droplets on spray cards in different size categories (Hearst, 1978).

	Size of droplets in microns														
Plot	1-50	51-100	101-150	151-200	201-250	251-300	301-350	351-400	401-450	451-500	501-550	551-600	601-650	651-700	701-750
1	15.0	16.8	31.9	26.6	6.2	3.5	0	0	0	0	0	0	0	0	0
2	1.2	16.3	34.7	23.3	5.7	5.4	2.1	1.2	0	0	0	0	0	0	0
3	30.2	12.7	17.5	23.8	11.1	1.6	0	1.6	0	0	1.6	0	0	0	0
4	12.0	28.6	23.5	19.0	13.5	3.2	0.2	0	0	0	0	0	0	0	0
5	11.6	16.8	16.2	14.0	16.1	12.0	5.6	3.9	2.2	1.2	0.1	0.2	0	0.1	0.1

below what was expected. BAY SIR-8514 was by far the best of the 3 Insect Growth Regulators and came close to the population reduction obtained with Matacil.

Table 19. Weather data from Hearst (1978) during spray trials (OMNR, weather record).

Date	24 hr Max.	24 hr Min.	Average	24 hr Precipitation
June 1	7°C	3°C	5°C	5.4 mm
2	5	0	2.5	10.4
3	8	1	4.5	0
4	10	0	5	0.1
5	11	2	6.5	1.3
6	17	8	12.5	3.1
7	17	-2	9.5	26.2
8	4	-3	0.5	0
9	13	-1	6	10.4
10	9	0	4.5	1.4
11	21	4	12.5	5.8
12	25	2	13.5	3.9
13	10	0	5	1.1
14	14	2	8	0
15	19	3	11	0
16	22	13	17.5	0
17	21	15	18	0.4
18	28	11	19.5	1.9
20	28	13	20.5	0
21	29	12	20.5	0
22	14	13	13.5	7.6
23	9	3	6	3.0
24	26	10	18	0
25	24	14	19	0.8
26	27	14	20.5	6.1
27	20	14	17	0.6
28	22	14	18	0.2
29	26	12	19	1.2
30	22	7	14.5	0

Defoliation estimate was seriously hampered by the late season frost that destroyed a large number of buds. Moreover, the effect was not uniform but occurred in pockets in the different plots. The results did not show any foliage protection.

Table 20. Parasites from representative collections from spray plots 5 days after spraying (Hearst, 1978).

Plot	No. budworm examined	*Apantales*		*Glypta*	
		Normal	Deformed	Normal	Deformed
1 (Dimilin)	50	12	--	--	1
2 (EL-494)	50	7	--	--	--
4 (BAY SIR-8514)	50	5	--	1	1
Control	25	7	--	2	--

Table 21. Population reduction, pupal survival and foliage protection attributable to various spray treatments on balsam fir and white spruce near Hearst, Ontario, 1978.

Plot	Pre-spray larvae per tip		Surviving pupae per tip		% Population reduction due to treatment		% Successful pupal emergence*		% Frost damage		% 1978 defoliation**	
	bF	wS	bF	wS	bF	wS	bF	wS	bF	wS	bF	wS
1	6.4	25.7	2.2	3.0	4	0	47	38	77	32	100	97
Check	6.7	25.9	2.4	2.9			58	58	97	18	94	80
2	6.8	21.9	1.6	3.0	33	21	52	57	81	8	99	96
Check	6.7	20.8	2.4	3.6			58	57	97	0	94	93
4	5.1	23.3	0.8	1.8	56	50	38	51	76	66	99	98
Check	6.7	24.8	2.4	3.8			58	58	97	10	94	98
5	5.8	14.4	0.6	0.8	71	62	50	44	87	24	38	92
Check	6.7	14.7	2.4	2.1			58	44	97	4	94	97

Plot 1 - Dimilin 280 g/ha (4 oz/0.5 U.S. gal/acre)
2 - EL-494 140 g/ha (2 oz/0.5 U.S. gal/acre)
4 - BAY SIR-8514 140 g/ha (2 oz/0.5 U.S. gal/acre)
5 - MATACIL® 70 g/ha (1 oz/0.5 U.S. gal/acre)

*% Successful pupal emergence = $\frac{\text{emerged budworm}}{\text{budworm alive on sample date}} \times 100$

**Defoliation estimates based on foliage not damaged by frost.

7.23 Field Trials Conducted Near Wawa (1979):

The 1979 trials were conducted near Wawa, Ontario, in Townships 29-R24, 30-R24, 30-R26, and 30-R27. The location of the 7 treatment plots and some of the 10 check areas are shown in Figures 6, 7 and 8.

Dimilin proved to be economically unsuitable for budworm because of the high dosages necessary and since EL-494 showed disappointing results in the field, it was decided to test BAY SIR-8514 which proved to be better than any other Insect Growth Regulator available at that time. Four different levels, 4, 3, 2 and 1 oz. in 0.5 U.S. gal/acre (280, 210, 140 and 70 g in 4.7 ℓ/ha) of this material were tested using Matacil as the positive control. Matacil was sprayed in one plot as a single application similar to BAY SIR-8514 and sprayed twice in another plot as recommended for operational control. At one level (2 oz/acre or 140 g/ha) of BAY SIR-8514, Kelzan® antidrift compound was tested (0.02% w/v or 0.013 oz/0.5 U.S. gal or 0.939 g/4.7 ℓ) as an additive to improve the deposit of the water formulations. All plots were 100 acres (40 ha) in size and the spray operation was carried out between June 15 to 19 using a Cessna Agtruck equipped with 4 micronair units (Table 22). At this time the budworm larvae were at peak 5th instar on white spruce and peak 4th instar on balsam fir. Most of the bud caps had fallen off (Table 23).

The weather conditions were monitored using a mobile weather station equipped with a weather computer (Courtesy of the Meteorology section of Forest Pest Management Institute). According to the weather data, plot 6 (2nd application of Matacil) had the poorest conditions with high winds and very low R.H. but reasonable inversion. Plot 5 had borderline inversion, high winds and poor R.H. Plots 3 and 4 had poorer conditions than 1, 2, 6 and 7 (first application) (Table 24).

The spray cards were analyzed for droplets/cm^2 and droplet spectrum. As indicated by the weather conditions during the spray operation plot 5 came out the worst (1.2 droplets/cm^2) with the greatest percentage of droplets in the 150-200 μm range (Table 25 and 26). Plot 4 was also quite poor with 4.5 droplets/cm^2. However, the second application of Matacil in plot 6, which was performed under poor weather conditions, showed a much better deposit picture possibly because of the oil formulation. The addition of Kelzan (plot 3) did not appear to improve the deposit as compared with some of the other plots (plots 1 and 2). Also, addition of this material did not increase the droplet size (Table 26).

The weather conditions for the month of June are summarized in Table 27. The precipitation on the 17th after plots 4, 5, 6 and 7 were sprayed is of significance. The Matacil spray (6&7) was not affected appreciably since the material has contact toxicity and is quick acting. Conversely, BAY SIR-8514 has to be ingested and is slow acting. For this reason as well as the poor deposit due to weather conditions plots 4 and 5 showed poor results.

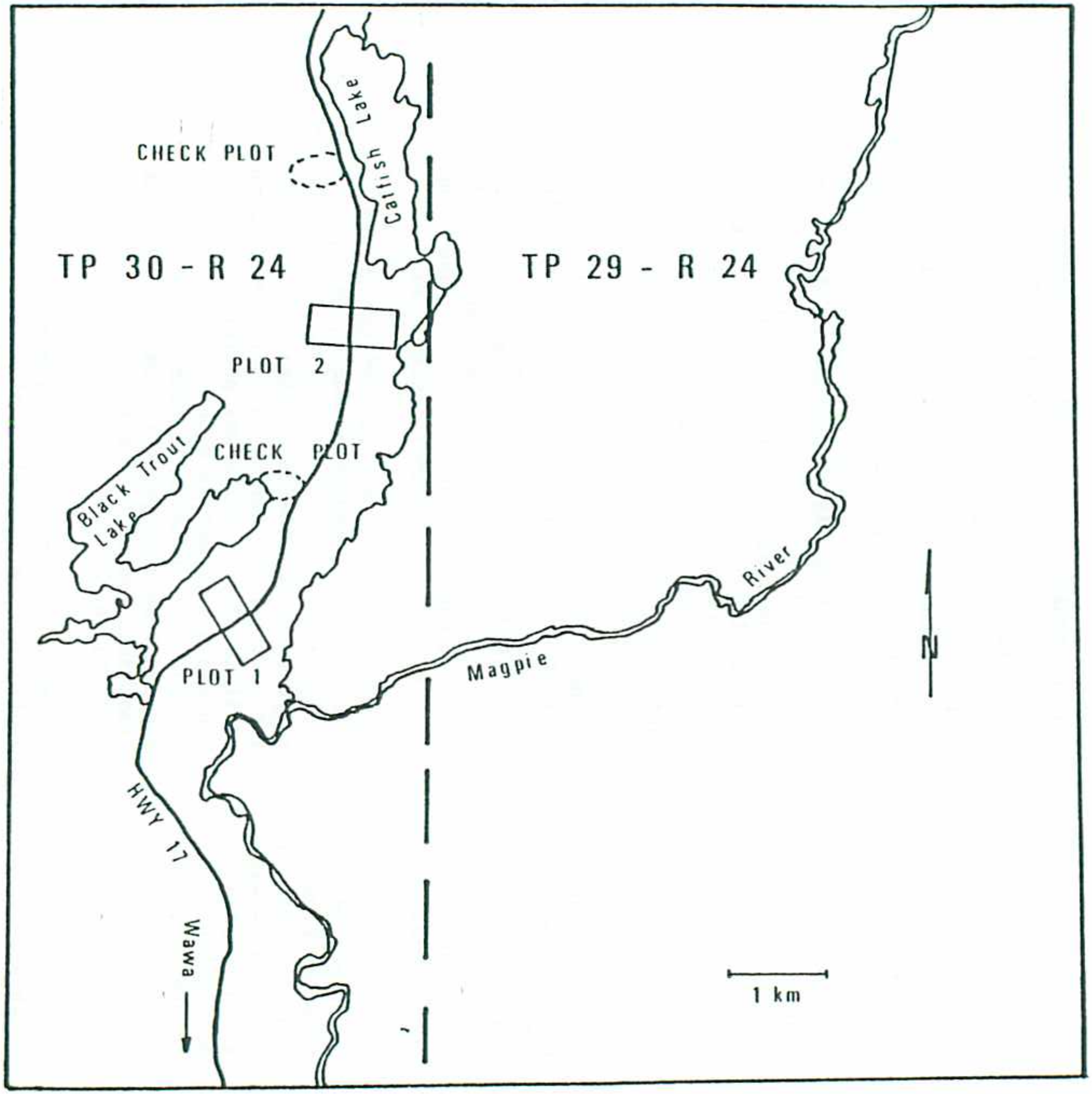


Figure 6. Location of plots 1 and 2 near Wawa (1979).

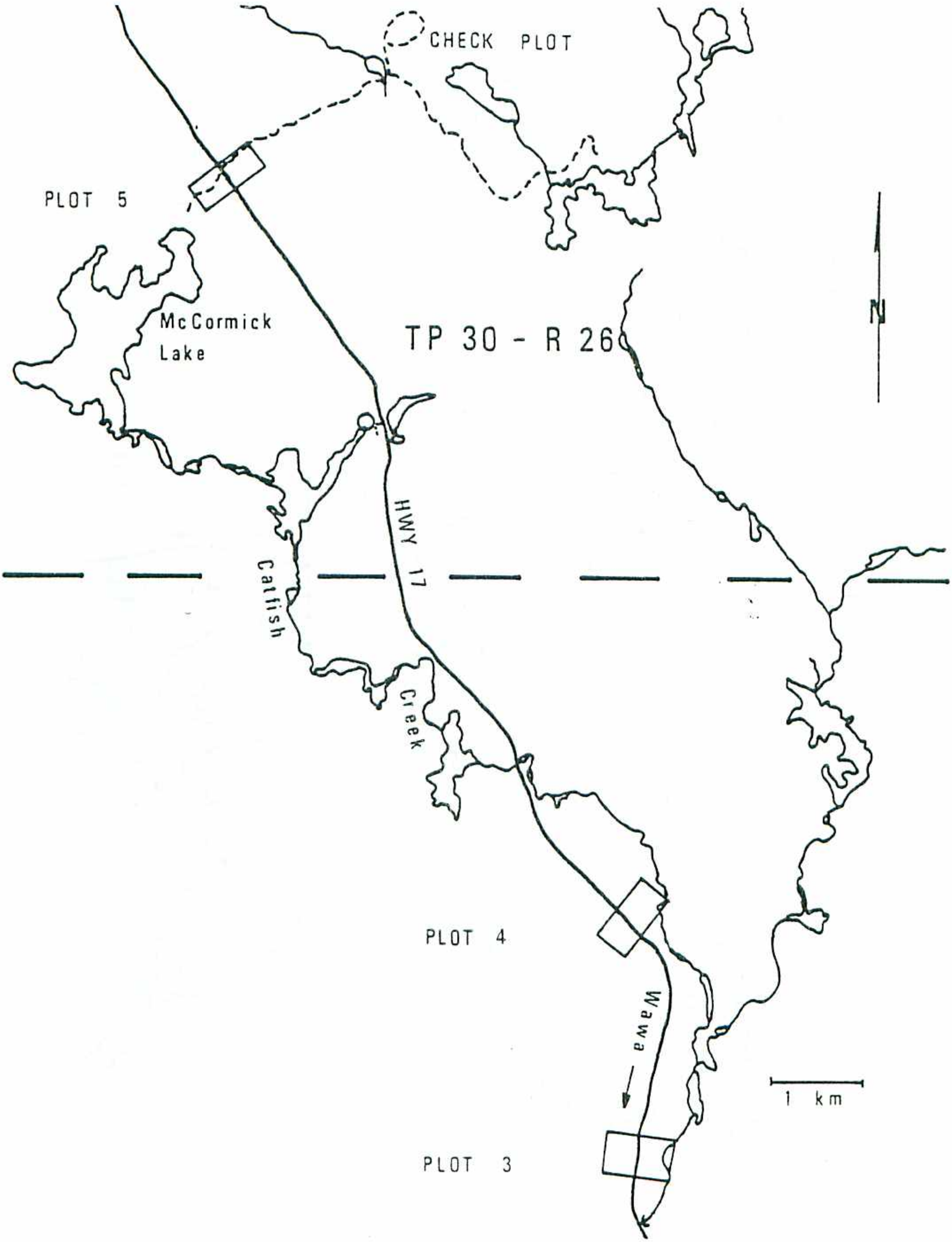


Figure 7. Location of plots 3, 4 and 5 near Wawa (1979).

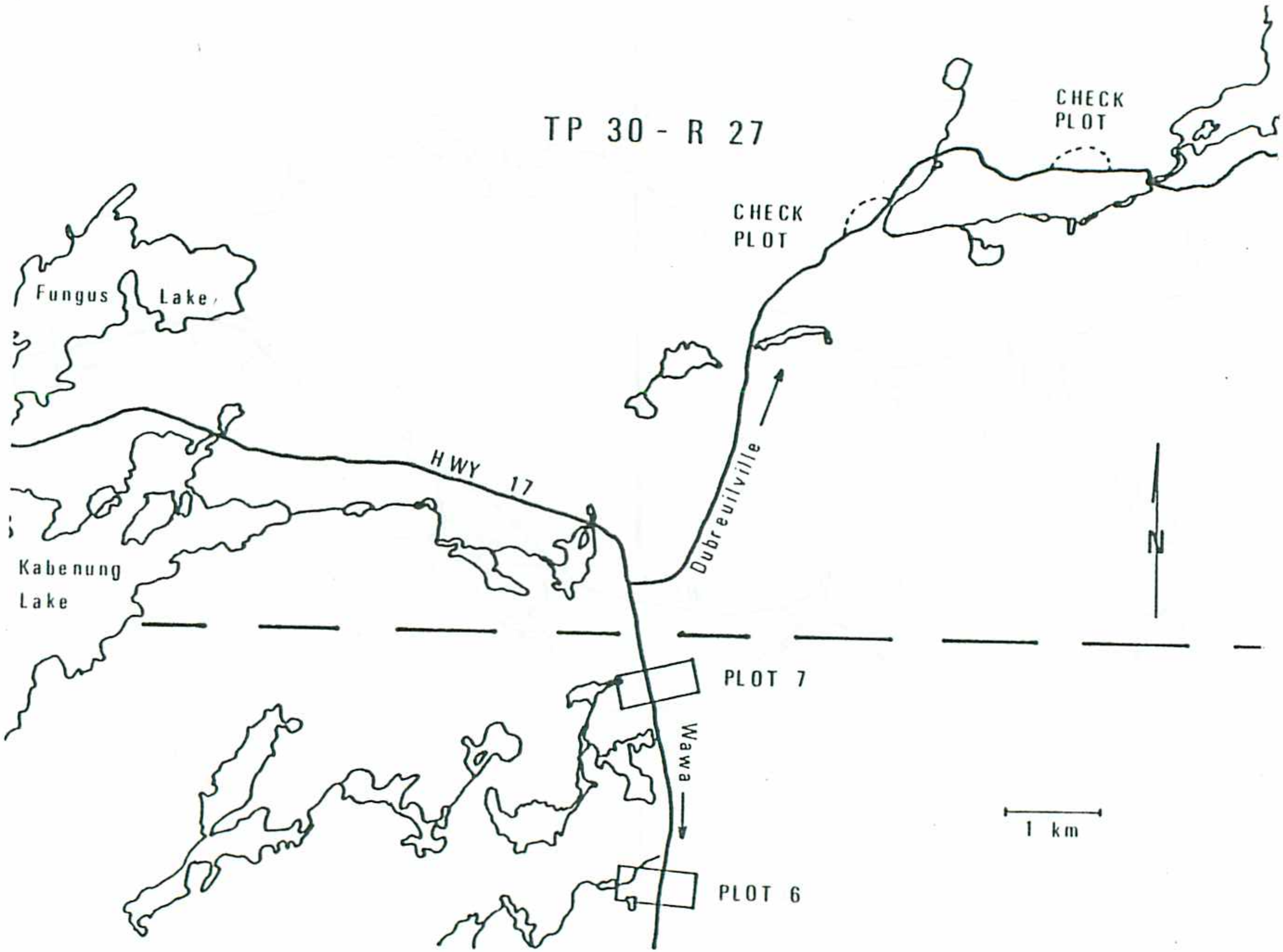


Figure 8. Location of plots 6 and 7 near Wawa (1979).

Table 22. The 1979 Insect Growth Regulator spray program at Wawa, Ontario.

Plot No.	Material	Amount	Area	Date	Time of application
1	BAY SIR-8514	210 g/4.7 ℓ/ha (3 oz/0.5 U.S. gal/acre)	40 ha (100 acre)	June 19	0650-0710 hrs
2	BAY SIR-8514	280 g/4.7 ℓ/ha (4 oz/0.5 U.S. gal/acre)	40 ha (100 acre)	June 19	0603-0620 "
3	BAY SIR-8514 with Kelzan®	140 g/4.7 ℓ/ha (2 oz/0.5 U.S. gal/acre)	40 ha (100 acre)	June 18	0811-0835 "
4	BAY SIR-8514	70 g/4.7 ℓ/ha (1 oz/0.5 U.S. gal/acre)	40 ha (100 acre)	June 17	2111-2132 "
5	BAY SIR-8514	140 g/4.7 ℓ/ha (2 oz/0.5 U.S. gal/acre)	40 ha	June 16	0814-0837 "
6	MATACIL®	70 g/4.7 ℓ/ha (1 oz/0.5 U.S. gal/acre)	40 ha (100 acre)	June 15	2112-2134 "
		"	"	June 18	2104-2121 "
7	MATACIL®	70 g/4.7 ℓ/ha (1 oz/0.5 U.S. gal/acre)	40 ha (100 acre)	June 15	2146-2202 "

Aircraft: Cessna Agtruck 188 B
Spray nozzles: Micronair - 4 units - AU3000
Airspeed: 100 m.p.h.
Flowrate: 6.0 U.S. gal/min.
Altitude: ~ 100 ft
Flight direction: east-west
Insect growth regulator: Chemagro BAY SIR-8514 - 25 WP (wettable powder - 25% a.i.) in water + 1.0% Rhodamine B (indicator dye).
Positive control: MATACIL® in "585" oil + 2.0% Automate Red (indicator dye).

Table 23. Development sample taken from plots 2 and 5, June 17 (Wawa, 1979).

	Larval stages (%)					
Host	L_2	L_3	L_4	L_5	L_6	Pupae
White spruce	3.8	23.2	31.7	26.5	4.8	1
Balsam fir	5.3	21.0	46.1	21.0	6.6	0

Table 24. On site meteorological data for actual duration of spray trials (Wawa, 1979)

			Temperature				Wind		
Plot	Date	Time	T_1	T_2	T_3	Inv. (T_1-T_2)	kmh (mph)	direction	RH
1	June 19	0615	7.5°C	7.0°C	4.7°C	0.5	1.4 (0.9)	235°(SW)	99.9%
		0630	8.2	8.1	6.7	0.1	1.8 (1.1)	248°(SW)	98.6
		0643	8.6	8.7	6.8	-0.1	1.4 (0.9)	261°(W)	93.2
		0659	9.4	9.0	8.0	0.4	1.1 (0.7)	109°(E)	97.3
		0716	10.5	9.0	9.0	1.5	1.1 (0.7)	74°(NE)	86.5
		0729	12.4	10.2	10.2	2.2	0	--	83.6
2	June 19	0531	6.2	5.3	4.2	0.9	1.4 (0.9)	251°(SW)	98.5
		0547	6.1	5.0	4.2	1.1	0	--	97.2
		0604	6.6	5.6	4.0	1.0	1.4 (0.9)	219°(SW)	98.5
		0620	7.8	7.1	5.3	0.7	0.3 (0.2)	235°(SW)	100.0
		0637	8.0	8.4	6.8	-0.4	2.6 (1.6)	242°(SW)	100.0
3	June 18	0737	12.1	10.6	10.1	1.5	2.6 (1.6)	245°(SW)	82.9
		0754	13.4	12.8	11.2	0.6	6.1 (3.8)	293°(NW)	71.4
		0816	14.5	14.0	14.4	0.5	6.1 (3.8)	293°(NW)	68.5
		0827	15.3	14.8	14.8	0.5	5.0 (3.1)	290°(NW)	68.1
		0844	16.1	16.0	16.1	0.1	6.4 (4.0)	276°(W)	62.7
		0900	17.4	17.1	18.0	0.3	5.8 (3.6)	288°(W)	58.8
4	June 17	2038	18.3	16.7	14.2	1.6	5.8 (3.6)	49°(NE)	52.7
		2055	18.1	17.3	12.3	0.8	5.8 (3.6)	25°(NE)	52.6
		2112	17.8	13.6	11.2	4.2	0.3 (0.2)	2°(N)	55.9
		2128	15.1	12.2	10.4	2.9	3.2 (2.0)	248°(SW)	73.0
		2145	13.5	11.3	9.5	2.2	2.1 (1.3)	261°(W)	78.9
		2201	11.7	10.4	8.6	1.3	0	--	84.3
5	June 16	0743	15.3	14.9	14.3	0.4	2.9 (1.8)	345°(N)	82.7
		0800	15.9	15.4	15.4	0.5	4.0 (2.5)	42°(NW)	79.2
		0817	16.1	15.9	16.7	0.2	6.1 (3.8)	51°(NE)	74.9
		0828	16.2	16.1	16.7	0.1	7.6 (4.7)	47°(NE)	73.2
		0845	16.8	16.8	17.3	0	10.5 (6.5)	55°(NE)	68.4
		0901	17.0	17.0	18.6	0	10.5 (6.5)	57°(NE)	68.7
6 (1st application)	June 15	2044	21.0°C	20.8°C	20.6°C	0.2	6.4 (4.0)	218°(SW)	78.8
		2101	20.6	20.2	20.1	0.4	7.9 (4.9)	230°(SW)	78.8
		2117	19.7	19.4	19.5	0.3	8.7 (5.4)	188°(S)	83.2
		2129	18.8	18.5	18.8	0.3	4.7 (2.9)	217°(SW)	86.3
		2145	17.5	17.2	17.5	0.3	7.6 (4.7)	207°(SW)	89.5
		2202	17.0	16.6	16.4	0.4	7.9 (4.9)	209°)SW)	95.0
6 (2nd application)	June 18	2029	22.1	21.5	19.1	0.6	8.2 (5.1)	272°(W)	42.0
		2046	21.3	21.1	18.7	0.2	9.0 (5.6)	268°(S)	41.7
		2103	20.6	19.8	16.3	0.8	9.0 (5.6)	275°(W)	41.8
		2114	20.3	19.0	14.8	1.3	7.9 (4.9)	280°(W)	42.9
		2130	19.1	17.6	13.2	1.5	5.8 (3.6)	276°(W)	46.8
		2141	19.1	17.6	12.6	1.5	6.4 *4.0)	293°(W)	45.4
		2158	16.5	14.4	11.6	2.1	1.1 (0.7)	225°(SW)	65.0
7	June 15	2117	19.7	19.4	19.5	0.3	8.7 (5.4)	188°(S)	83.2
		2129	18.8	18.5	18.8	0.3	4.7 (2.9)	217°(SW)	86.3
		2145	17.5	17.2	17.5	0.3	7.6 (4.7)	207°(SW)	89.5
		2202	17.0	16.6	16.4	0.4	7.9 (4.9)	209°(SW)	95.0
		2218	16.4	16.0	16.1	0.4	10.1 (6.3)	206°(SW)	96.0
		2224	16.2	15.9	16.1	0.3	7.6 (4.7)	220°(SW)	96.9

High Probe - 12 meters (T_1)
Med. Probe - 1 meter (T_2)
Low Probe - 1 cm (T_3)
RH - % relative humidity

Table 25. Spray card evaluation (Wawa, 1979).

Plot No.	Total no. drops $/cm^2/card$	x No. drops $/cm^2$ all cards	SD	SE	No. of cards
1	981.6	29.745	17.336	3.018	33
2	766.4	23.224	20.037	3.488	33
3	508.6	13.384	17.255	2.799	38
4	150.4	4.558	3.801	0.662	33
5	420.0	1.273	1.798	0.313	33
6 (1st appl.)	650.0	15.476	15.420	2.379	42
6 (2nd appl.)	998.2	23.767	13.317	2.055	42
7	1218.6	39.310	35.493	6.375	31

Table 26. Percentage of droplets on spray cards in different size categories (Wawa, 1979).

Plot No.	Size of droplets in micrometers (µm)								
	0-74	76-150	151-250	251-350	351-450	451-550	551-650	651-750	751-850
1	12.0	29.9	34.9	17.8	4.3	0.8	0.4	0	0
2	25.0	24.6	30.8	15.0	3.7	0.8	0.1	0	0
3	59.0	24.1	10.9	4.6	0.9	0.3	0.2	0	0
4	84.5	15.5	0	0	0	0	0	0	0
5	6.8	28.8	39.0	22.0	3.4	0	0	0	0
6 (1st appl.)	10.8	14.4	22.4	27.4	13.7	6.9	2.8	1.5	0.2
6 (2nd appl.)	13.6	24.6	31.2	19.1	6.6	3.3	1.3	0.3	0
7	10.5	22.5	31.4	19.1	9.5	5.1	1.4	0.4	0

The results of the Wawa spray operation are summarized in Table 28. The poor spray deposit coupled with the poor spray conditions clearly explains the reasons for no effects in Plot 5. Since Kelzan® had no special effects on spray deposit, plot 3 results were used comparatively against the rest of the plots. The outcome of plot 2 (2 oz/acre χ 280 gm/ha) was best followed by plots 1, 3 and 4. At the highest two levels of BAY SIR-8514 (4&3 oz/acre or 280 and 210 g/ha), the population reductions achieved were superior to that of Matacil®.

Table 27. Weather data from Wawa during the 1979 spray trials (OMNR, weather record).

Date		24 hr Max.	24 hr Min.	Average	24 hr Precipitation
June	1	17°C	8°C	12.5°C	26.0 mm
	2	11	2	6.5	2.6
	3	15	5	10	0.8
	4	15	6	10.5	0
	5	18	5	11.5	2.0
	6	17	3	10	0
	7	19	7	13	2.8
	8	24	12	18	9.2
	9	20	8	14	0
	10	28	12	20	18.8
	11	14	6	10	8.5
	12	9	4	6.5	0.5
	13	16	2	9	0
	14	20	6	13	0
	15	23	11	17	7.5
	16	20.5	9	15	2.0
	17	23	10	16.5	28.0
	18	18	10	14	0.3
	19	23	7	15	0
	20	25	11	18	0
	21	20	13	18.5	27.5
	22	20	5	12.5	7.1
	23	9	2	5.5	0.4
	24	11	3	7	0
	25	19	2	10.5	0
	26	20	7	13.5	0
	27	16	6	11	0.4
	28	15	5	10	0
	29	20	9	14.5	0
	30	20	8	14	0

Foliage protection, estimated by examining the branch tips collected for post-spray budworm count showed that Matacil out performed BAY SIR-8514. There are several possible explanations since (i) pre-spray population density will influence the amount of foliage ingested, (ii) time of pesticide application will affect amount of foliage saved (i.e., earlier the application, the more the foliage saved) and (iii) the mode of action of the pesticide (i.e., contact effect is rapid and hence there is more foliage protection than ingestion effect which is slow acting. The results show that for the first time we had an Insect Growth Regulator that was almost as good as the positive control with regard to population reduction.

Table 28. Population reduction, pupal survival and foliage protection attributable to various aerial treatments of IGRs and MATACIL® on balsam fir and white spruce in Wawa, District.

	Pre-spray larvae per 46 cm branch tip		Surviving pupae per 46 cm branch tip		% Population reduction due to treatment		% Successful pupal emergence*		% 1979 Defoliation	
Plot	bF	wS	bF	wS	bF	wS	bF	wS	bF	wS
1	4.7	11.3	.2	.8	70	55	29	49	6	8
Check	14.1	17.3	2.0	2.7			30	66	22	28
2	12.8	26.3	.3	4.4	83	60	32	65	25	41
Check	14.1	28.7	2.0	12.0			30	73	22	74
3	38.7	34.9	2.1	2.9	57	24	48	45	80	76
Check	36.7	32.9	4.6	3.6			58	48	90	68
4	33.8	56.5	7.1	4.6	48	34	75	54	98	91
Check	32.5	50.0	13.1	6.2			82	54	52	81
5	52.8	54.6	4.4	7.7	0	0	70	49	97	95
Check	46.2	50.0	3.5	6.2			36	54	96	81
6	65.0	77.6	1.7	1.6	58	83	59	43	46	54
Check	61.2	81.6	3.8	9.8			36	63	94	88
7	22.5	46.9	1.3	2.4	67	59	72	67	15	62
Check	21.2	50.0	3.7	6.2			49	54	91	81

*% Successful pupal emergence = $\frac{\text{emerged budworm}}{\text{budworm alive on sample date}} \times 100$

Plot 1 - BAY SIR-8514 210 g/ha (3 oz/0.5 U.S. gal/acre)
2 - BAY SIR-8514 280 g/ha (4 oz/0.5 U.S. gal/acre)
3 - BAY SIR-8514 140 g/ha (2 oz/0.5 U.S. gal/acre) + Kelzan®
4 - BAY SIR-8514 70 g/ha (1 oz/0.5 U.S. gal/acre)
5 - BAY SIR-8514 140 g/ha (2 oz/0.5 U.S. gal/acre)
6 - MATACIL® - 2 applications of 70 g/ha (1 oz/0.5 U.S. gal/acre)
7 - MATACIL® - 1 application 70 g/ha (1 oz/0.5 U.S. gal/acre)

7.24 *Field Trials Conducted in the French River Area (1980):*

The 1980 spray trials were conducted in and around Grundy Lake Provincial Park in the French River area. The 10 treatment plots and the 10 check areas are shown in Figure 9. The plot layouts showing the location of the sample trees, the spray card location in relation to the flight lines (numbers indicate flight line and number with subscript "A" densities mid point between flight lines) and the tree composition of balsam fir (bF) and white spruce (wS) are presented in Figures 10, 11 and 12.

The 1979 spray trials indicated that BAY SIR-8514 is relatively active against the spruce budworm. It was felt that if an oil formulation could be used, the deposit picture could be improved with a consequent increase in efficacy. The advantages of oil over water are summarized in Table 29. Since a substantial amount of BAY SIR-8514 was available, we tested both oil and water formulations. The material remained in suspension for more than an hour when mixed in oil. Also it was easier to resuspend the sediment when oil was used. Addition of vaseline petroleum jelly (4% w/v) as an emulsifier stabilized the suspension overnight (A. Sundaram, personal communication).

A new IGR, UC-62644 (Table 1), which showed excellent activity against the budworm (Tables 13, 14, and 15) became available for field trials. In addition to Matacil®, Dipel-88, a new formulation of *Bacillus thuringiensis* (*B.t.*) was used as a positive control. A summary of the 1980 field program is presented in Table 30.

Spraying was done with a Cessna Agtruck equipped with 4 micronair AU-3000 units. The vane setting of the micronairs was 35° with a #11 flow restrictor placed in line. The pump (boom) pressure was 35-37 p.s.i. The aircraft flew about 130 ft (39 m) above ground level at a speed of approximately 105 m.p.h. (168 km/h) and the swath was 100 ft (30 m). Low band Fm radio communication units were made available by the OMNR.

The entire spray operation was carried out between May 30 and June 3 (Table 30), with insect development being at peak 5th instar (Table 31). The weather conditions at spray times were near perfect (Table 32), with good inversion, low wind, and high humidity.

Visualization of the droplets on the spray cards required the use of two different marker dyes. A 2% (v/v) solution of Automate Red B was used in both oil formulations, Sunspray 7 N and Shell "585" insecticide diluent. For all the water formulations, including Dipel-88, Erio acid red was used at the concentrations of 1% w/v for BAY SIR-8514 and 0.025% w/v for Dipel-88.

The spray deposit analysis showed that the water formulations were uniformly poor compared to the oil formulations (Table 33). Plots 5 and 6 showed poor deposit even though they were sprayed with oil formulations. When the droplets/cm^2 were plotted against the spray card positions, the relative coverage became evident (Figs. 13, 14, and 15). Plots 1, 2 and 4 showed good droplet distribution. The droplet diameter when plotted as a histogram showed that plots 5 and 6 had large droplet peaks in the vicinity of 800 µm. Plots 1, 2 and 4 had a peak around 400 µm. Plots 7 and 10 had a peak near 200 µm (Figs. 16, 17, and 18). The spot size on the card is influenced by the spread factor and therefore the absolute size of the droplet will shift the spectrum either way. The volume deposited was spectrophotometrically estimated using an aliquot of the tank mix to prepare standard curves for the various plots (Figs. 19, 20 and 21). The volume deposited on each plate in each plot gave a picture of the spray coverage (Figs. 22, 23, and 24). Plot 5 showed an interesting phenomenon where the deposit

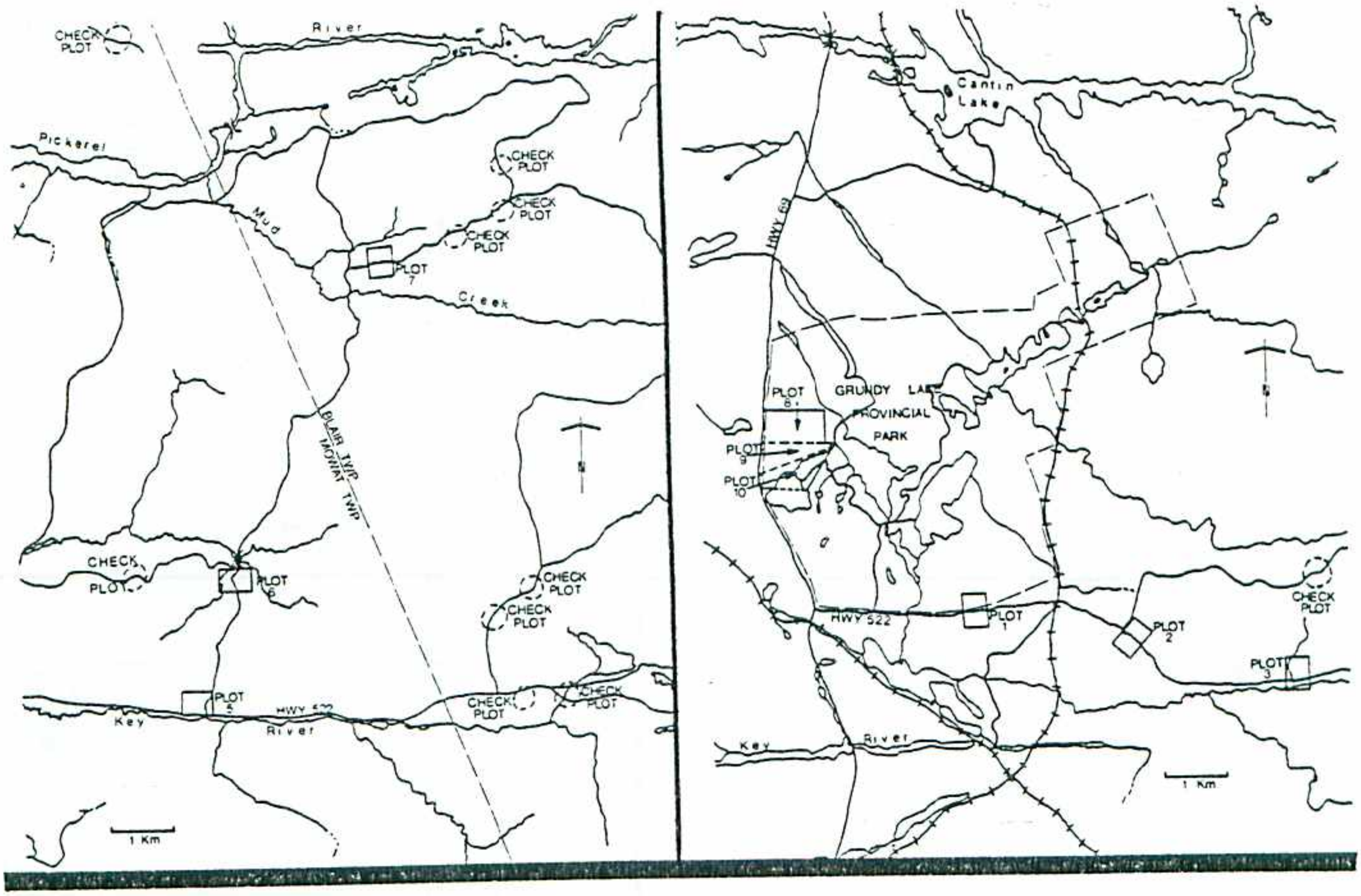


Figure 9. Plot locations in the French River area (1980).

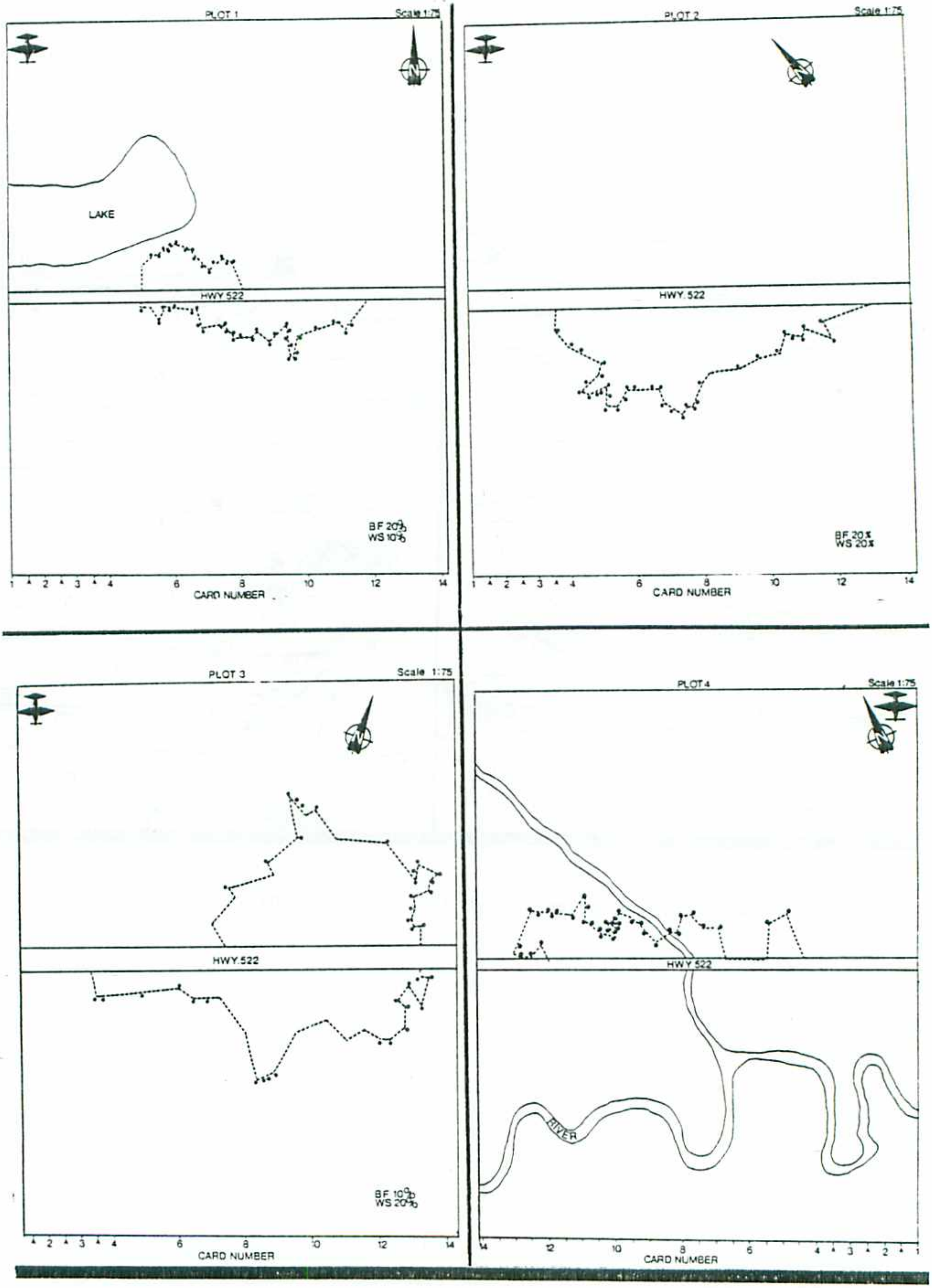


Figure 10. Detailed layout of plots 1, 2, 3 and 4 in the French River area (1980).

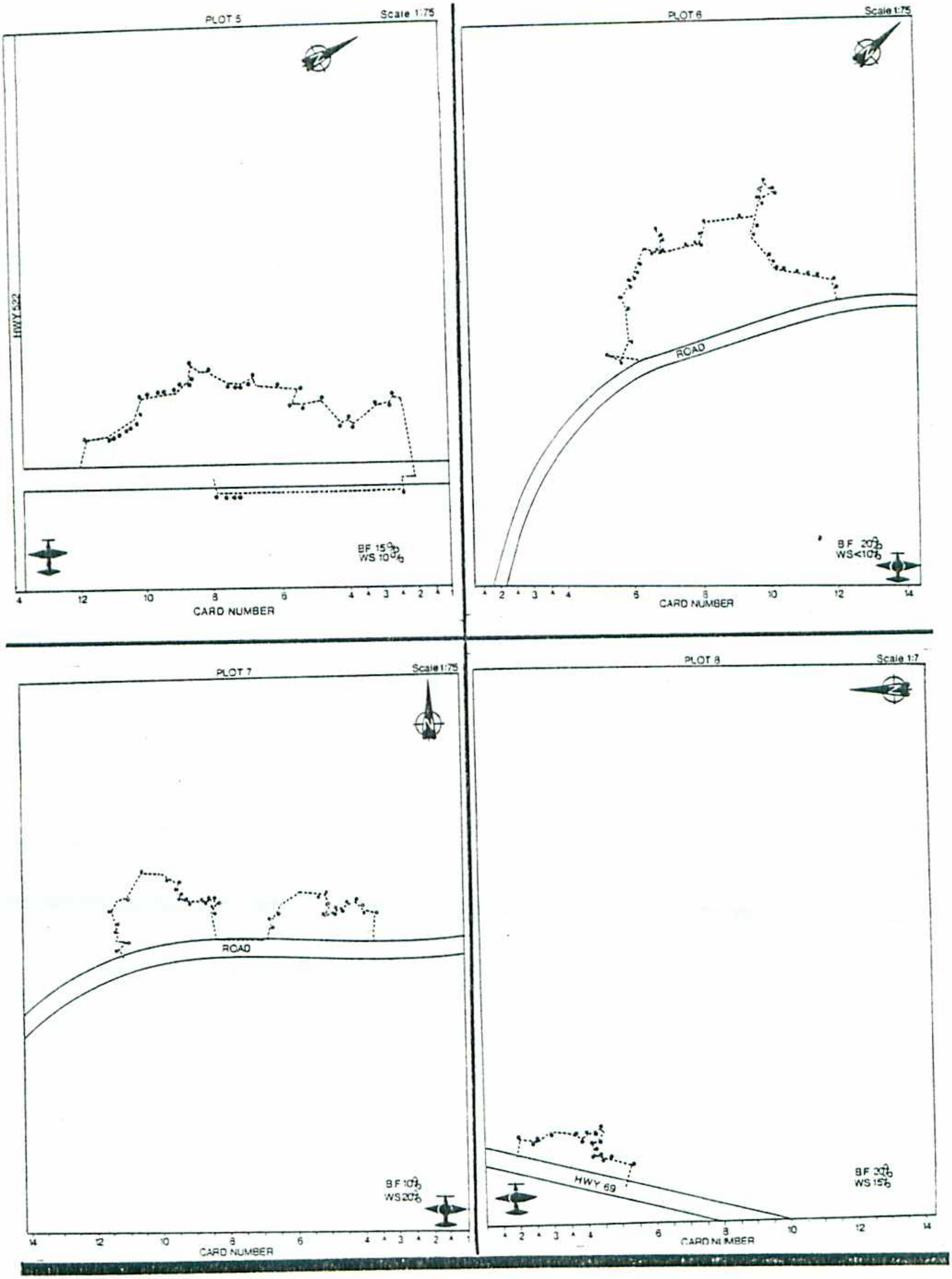


Figure 11. Detailed layout of plots 5, 6, 7 and 8 in the French River area (1980).

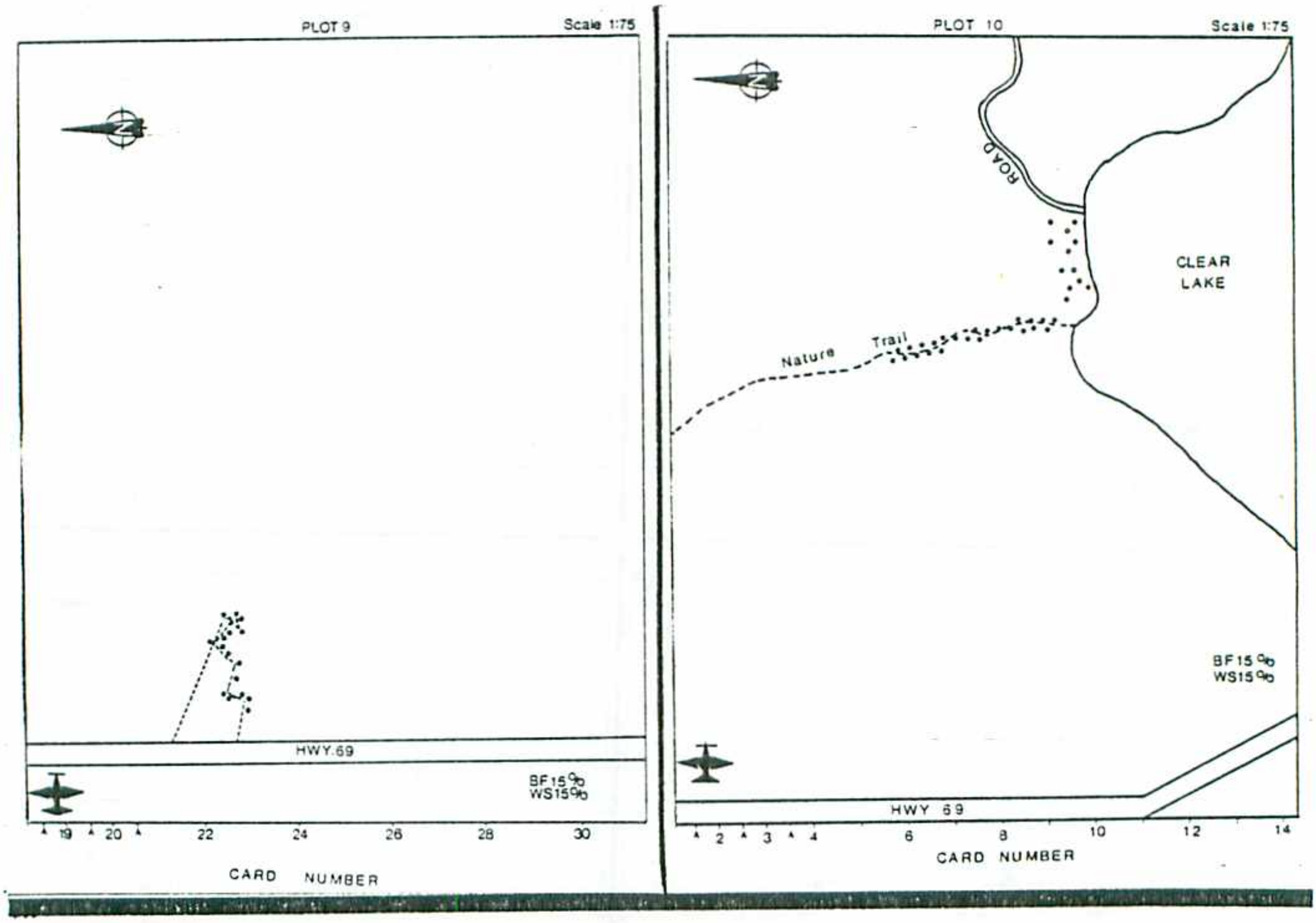


Figure 12. Detailed layout of plots 9 and 10 in the French River area (1980).

was excellent in almost every other card with the ones in between receiving very little deposit (Fig. 23). This is probably due to the perfect weather conditions during spraying. There was almost no wind, 100% R.H. and +1° inversion (Table 34). The spray cloud under such ideal conditions comes down in a narrow swath creating a "zebra" effect. This effect has been observed by others during spray operations.

Table 29. Comparison of oil and water based formulations.

Parameters influencing spray application	Water	Oil
Relative humidity	> 90% required	> 60% adequate
Temperature	> 32°F	Can be below 32°F
Deposit reaching ground	10-20% of emitted volume	40-60% of emitted volume
Optimal time for spraying	morning	morning or evening
Evaporation of emitted spray	high	low
Adhesion to foliage	requires sticker	sticker not usually required

The post-spray weather conditions were near ideal excepting for some precipitation 1 week after spraying (Table 34).

The results of the 1980 spray trials are summarized in Table 35. Double application of Matacil® (plot 8) and 1 oz of UC-62644 (plot 2) gave best results with similar population reduction. A 3 oz. application of BAY SIR-8514 in oil (plot 4) was better than 8 BIU of Dipel-88 (plot 10). As predicted, the oil formulations faired much better than the water formulations (Table 35).

Foliage protection was estimated in 2 ways; by examination of the post-spray branch sample collected for counting the number of insects, and by examination of the trees in the plot with a pair of binoculars for defoliation, as recommended by Dr. R. Blais of Laurentian Forest Research Centre, St. Fois, Quebec. As mentioned earlier, the pre-spray density of budworm, the timing of application of the control agent, and the speed of action of the material sprayed among other factors will greatly influence the defoliation picture. The Matacil® and UC-62644 plots appeared to show more foliage protection than others. It is known that UC-62644 acts within 48 h whereas BAY SIR-8514 takes over 1 week for it to show its effects.

Table 30. The 1980 spray program conducted in the French River area.

Plot No. and size in acres (ha)		Material	Oz in 0.5 U.S. gal/acre (g in 4.7 ℓ/ha	Formulation	Date	Time of spray (24 h clock)
1	50 acres (20 ha)	UC-62644	0.5 oz (35 g)	7 N oil	June 2	06:00-06:12
2	50 acres (20 ha)	UC-62644	1.0 oz (70 g)	7 N oil	June 3	06:58-07:13
3	50 acres (20 ha)	BAY SIR-8514	2.0 oz (140 g)	water	June 2	07:42-07:55
4	50 acres (20 ha)	BAY SIR-8514	3.0 oz (210 g)	7 N oil	May 28	20:10-20:30
5	50 acres (20 ha)	BAY SIR-8514	2.0 oz (140 g)	7 N oil	May 29	06:05-06:16
6	50 acres (20 ha)	BAY SIR-8514	2.0 oz (140 g)	7 N oil & emulsifier	May 29	06:53-07:07
7	50 acres (20 ha)	BAY SIR-8514	3.0 oz (210 g)*	water	May 29	07:48-08:04
8	90 (36.4 ha)	Matacil (1st) Matacil (2nd)	1.0 oz (70 g) 1.0 oz (70 g)	585 oil 585 oil	May 30 June 1	20:30-21:05 20:08-20:22
9	90 (36.4 ha)	Matacil	1.0 oz (70 g)	585 oil	May 30	20:30-21:05
10	85 (34.4 ha)	Dipel-88	8.0 BIU (20 BIU)	water (1:1 dilution)	June 2	06:45-07:04

*0.75 U.S. gal/acre (or) 7.0 ℓ/ha had to be used.

Table 31. Development sample taken from plots 1 and 10 on June 1 (French River area, 1980).

Host	Larval Stages (%)					
	L_2	L_3	L_4	L_5	L_6	Pupae
White spruce	0	0	20	55	25	0
Balsam fir	0	14.3	14.3	61.9	9.5	0

Due to an interruption in supply, UC-62644 is currently not abailable for further field trials. Hopefully this difficulty will be overcome and this very promising compound will again become available.

Table 32. Weather conditions at spray time (French River area, 1980)

Plot, material, date, and sky condition	Time (24 h clock)	Temperature in °C: High (T_1)	Low (T_2)	Inversion (T_2-T_1)	Wind speed and direction m.p.h. (km/ha	Relative humidity (%)
#1, UC-62644,	06:00	10	11	-1	1 (1.6) NE	94
(0.5 oz/acre or 35 g/ha)	06:05	11	11	0	1 (1.6) E	97
oil, June 2,	06:10	11	11	0	1 (1.6) ESE	97
heavy overcast	06:15	11	11	0	0 (0) -	97
#2, UC-62644,						
(1.0 oz/acre or 70 g/ha)	06:55	10	10	0	2 (3.2) SSW	94
oil, June 3,	07:00	10	10	0	0 (0) WSW	97
overcast	07:05	10	11	-1	0 (0) W	94
	07:10	10	11	-1	2 (3.2) SSW	95
	07:15	10	11	-1	1 (1.6) S	95
#3, BAY SIR-8514,	07:40	12	12	0	2 (3.2) E	94
(3.0 oz/acre or 210 g/ha)	07:45	12	12	0	4 (6.4) E	94
water, June 2,	07:50	12	12	0	4 (6.4) SE	91
heavy overcast	07:55	12	12	0	3 (4.8) ESE	91
#4, BAY SIR-8514	20:10	15	15	0	3 (4.8) E	43
(3.0 oz/acre or 210 g/ha)	20:15	15	15	0	2 (3.2) ENE	43
oil, May 28,	20:20	14	13	+1	2 (3.2) E	46
clear	20:25	13	13	0	1 (1.6) E	51
	20:30	13	12	+1	2 (3.2) E	53
#5, BAY SIR-8514,	06:05	1	0	+1	0 (0) -	100
(2.0 oz/acre or 140 g/ha)	06:10	1	0	+1	0 (0) -	100
oil, May 29,	06:15	1	0	+1	1 (1.6) NE	100
clear	06:20	1	0	+1	1 (1.6) NE	100
#6, BAY SIR-8514,	06:50	2	2	0	0 (0) -	100
(2.0 oz/acre or 140 g/ha)	06:55	3	2	+1	0 (0) -	100
oil + emulsifier, May 29,	07:00	3	3	0	0 (0) -	100
clear	07:05	4	3	+1	0 (0) -	100
	07:10	5	3	+2	0 (0) -	100
#7, BAY SIR-8514,	07:45	9	8	+1	1 (1.6) NNE	70
(2 oz/acre or 140 g/ha)	07:50	10	10	0	0 (0) -	69
water, May 29,	07:55	10	10	0	1 (1.6) E	62
clear	08:00	11	11	0	2 (3.2) ESE	69
	08:05	11	12	-1	4 (6.4) E	62
#8, Matacil®,	08:05	10	10	0	0 (0) -	77
(1 oz/acre or 70 g/ha)	08:10	10	10	0	0 (0) -	75
oil, 2nd application	08:15	10	10	0	0 (0) -	75
June 1, light rain	08:20	10	10	0	0 (0) -	74
sprinkle 08:35-08:50	08:25	10	10	0	0 (0) -	77
#8 & 9, Matacil®,	20:30	22	22	0	0 (0) -	81
(1 oz/acre or 70 g/ha)	20:35	22	21	+1	3 (4.8) SSW	83
oil, 1st application	20:40	21	21	0	3 (4.8) SSW	85
May 30, heavy	20:45	21	21	0	1 (1.6) S	85
rain 2 h after spraying	20:50	21	20	+1	3 (4.8) SSW	85
	20:55	21	21	0	3 (4.8) S	85
	21:00	21	21	0	2 (3.2) SSE	85
	21:05	21	21	0	3 (4.8) SSE	85
#10, Dipel-88,	06:45	11	11	0	0 (0) -	98
(8 BIU/acre or 20 BIU/ha)	06:50	11	12	-1	0 (0) -	98
1:1 dilution with water,	06:55	11	12	-1	1 (1.6) ENE	98
June 2, heavy	07:00	11	12	-1	3 (4.8) E	98
overcast	07:05	11	12	-1	3 (4.8) ESE	98

Table 33. Droplets and volume deposited on spray plates at ground level during the 1980 spray programs.*

Plot	Material	Amount of formulation	$\bar{x}$ No. droplets per cm^2 ± SE	Volume deposited U.S. gal/acre (ℓ/ha)
1	UC-62644	0.5 oz - 7 N oil	12.94 ± 1.96	0.17 (1.59)
2	UC-62644	1.0 oz - 7 N oil	35.61 ± 3.35	0.36 (3.37)
3	BAY SIR-8514	2.0 oz - water	8.68 ± 1.13	0.09 (0.84)
4	BAY SIR-8514	3.0 oz - 7 N oil	15.03 ± 2.07	0.13 (1.22)
5	BAY SIR-8514	2.0 pz - 7 N oil	2.78 ± 0.69	0.05 (0.47)
6	BAY SIR-8514	2.0 oz - 7 N oil	5.54 ± 1.07	0.08 (0.75)
7	BAY SIR-8514	3.0 oz - water	10.75 ± 1.84	0104 (0.37)
8 and 9 (1st appl.)	Matacil®	1.0 oz - 585 oil	15.10 ± 3.17	0.09 (0.84)
8 (2nd appl.)	Matacil®	1.0 oz - 585 oil	21.13 ± 1.53	0.06 (0.56)
10	Dipel-88	8 BIU - water	8.49 ± 0.49	0.09 (0.84)

*Emitted volume from aricraft was 0.5 U.S. gal/acre or 4.7 ℓ/ha

8. GENERAL CONCLUSIONS AND FUTURE OF INSECT GROWTH REGULATORS

(i) Dimilin even at 4 oz/acre (230 g/ha) is not very effective in controlling spruce budworm. This may be because of stadial susceptibility, poor absorption of Dimilin from the gut and efficient metabolism of the absorbed material.

(ii) EL-494 apparently breaks down quite readily in nature and hence the poor field results. Similar failures have been reported by others working with this compound.

(iii) BAY SIR-8514 is reasonably active against the budworm but its action is too slow to have a positive impact on foliage protection.

(iv) UC-62644 is not only fast acting but also acts at low concentrations, making it an excellent Insect Growth Regulator for budworm control.

(v) Wettable powder formulations of Insect Growth Regulators can be suspended in Sunspray 7 N oil and sprayed from a micronair system to give excellent deposit characteristics.

(vi) When spray conditions are ideal, there is a possibility of getting a "zebra" effect where every other spray card is missed. Cross winds or a weaker thermal inversion will lessen the chances of such an effect.

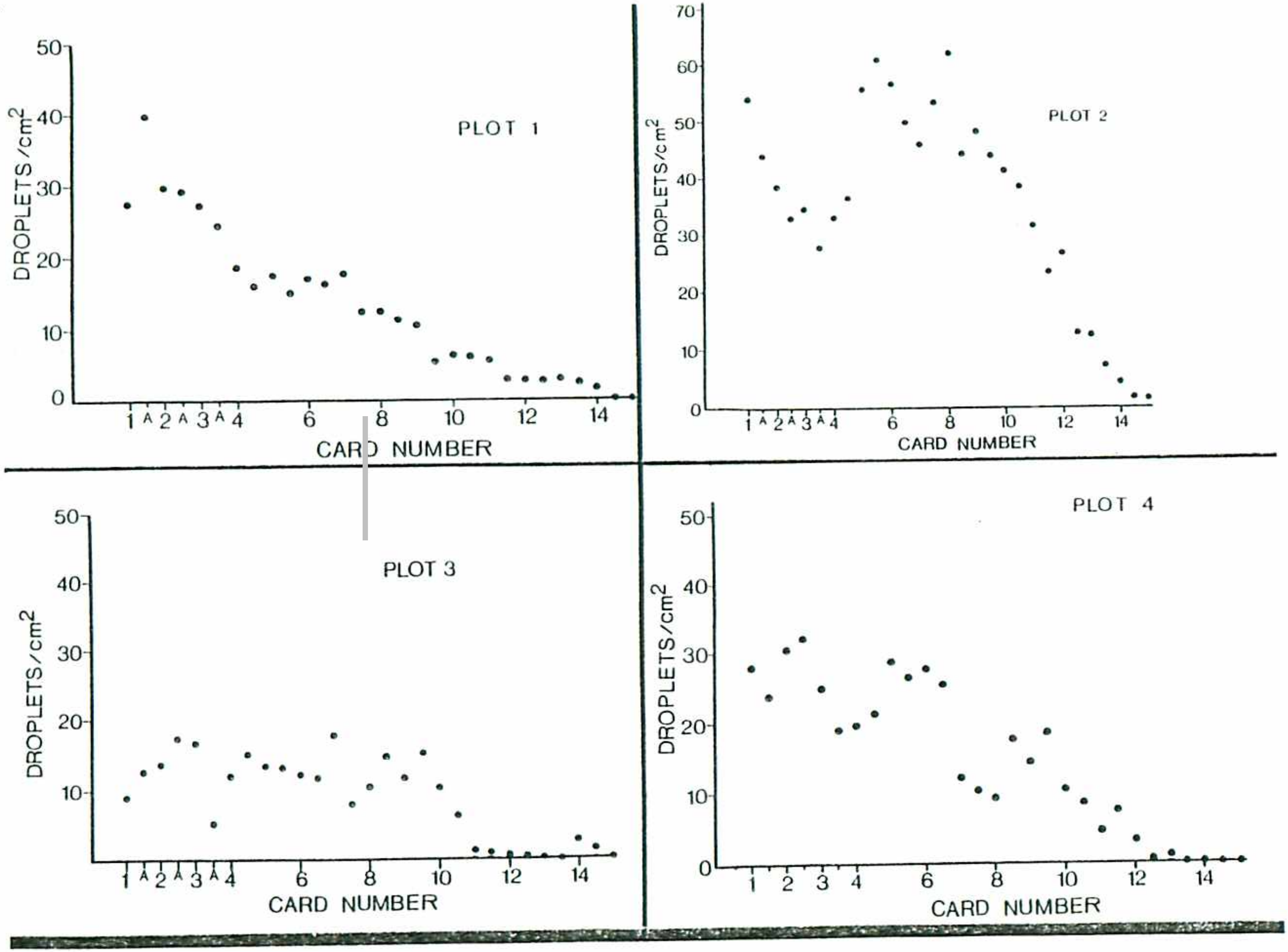


Figure 13. Distribution of spray droplets/cm^2 in plots 1, 2, 3 and 4 (1980).

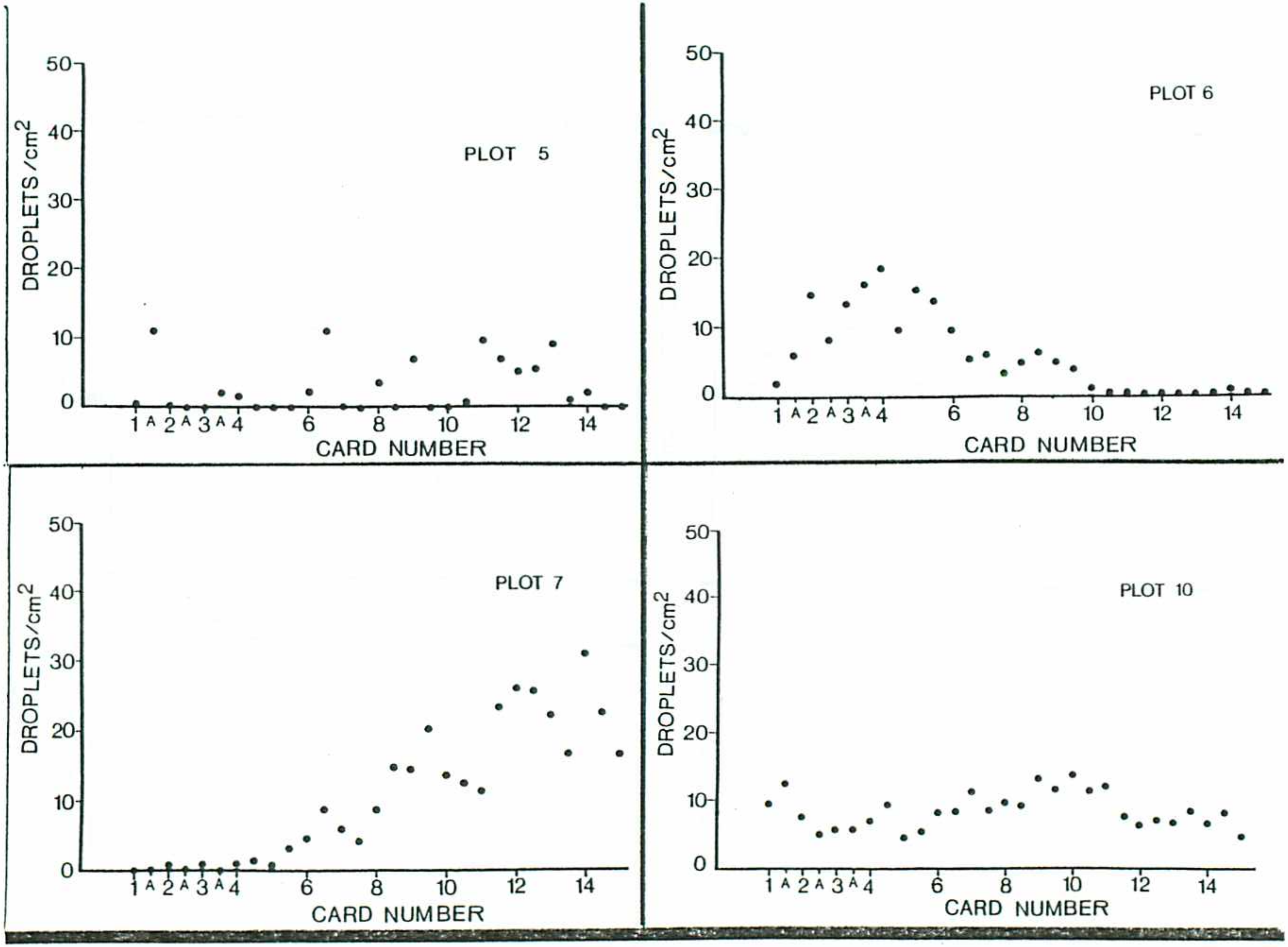


Figure 14. Distribution of spray droplets/cm^2 in plots 5, 6, 7 and 10 (1980).

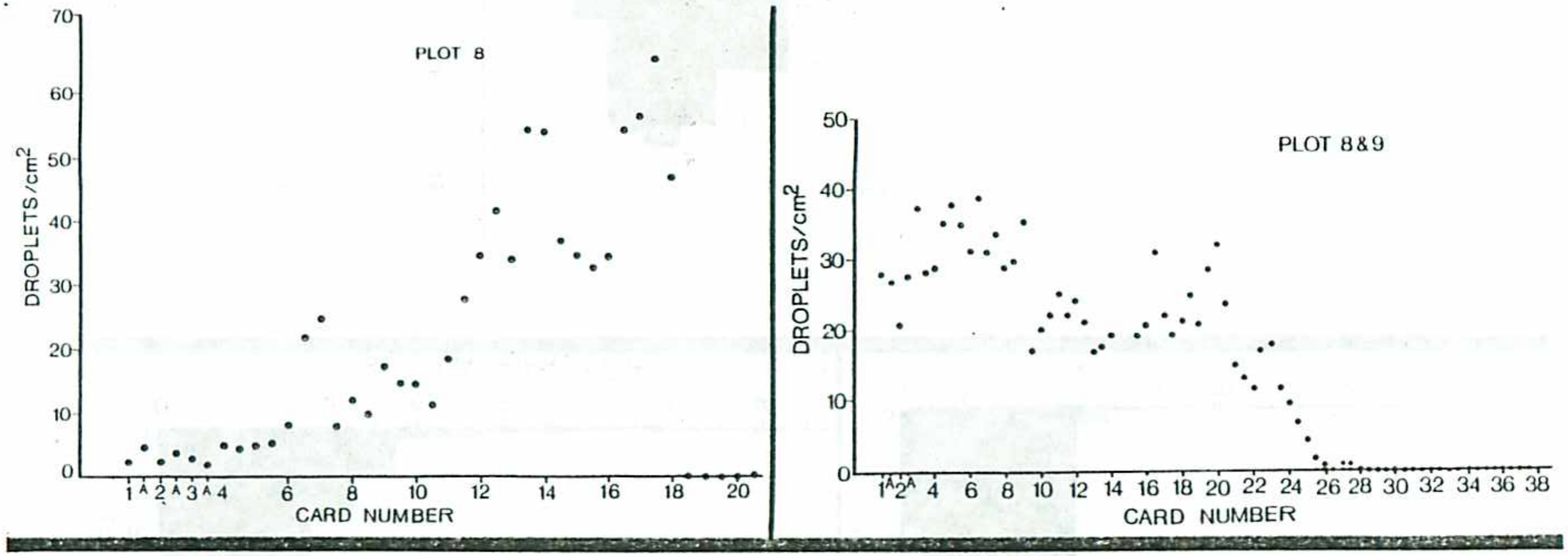


Figure 15. Distribution of spray droplets/cm^2 in plots 8 and 8 and 9 (1980).

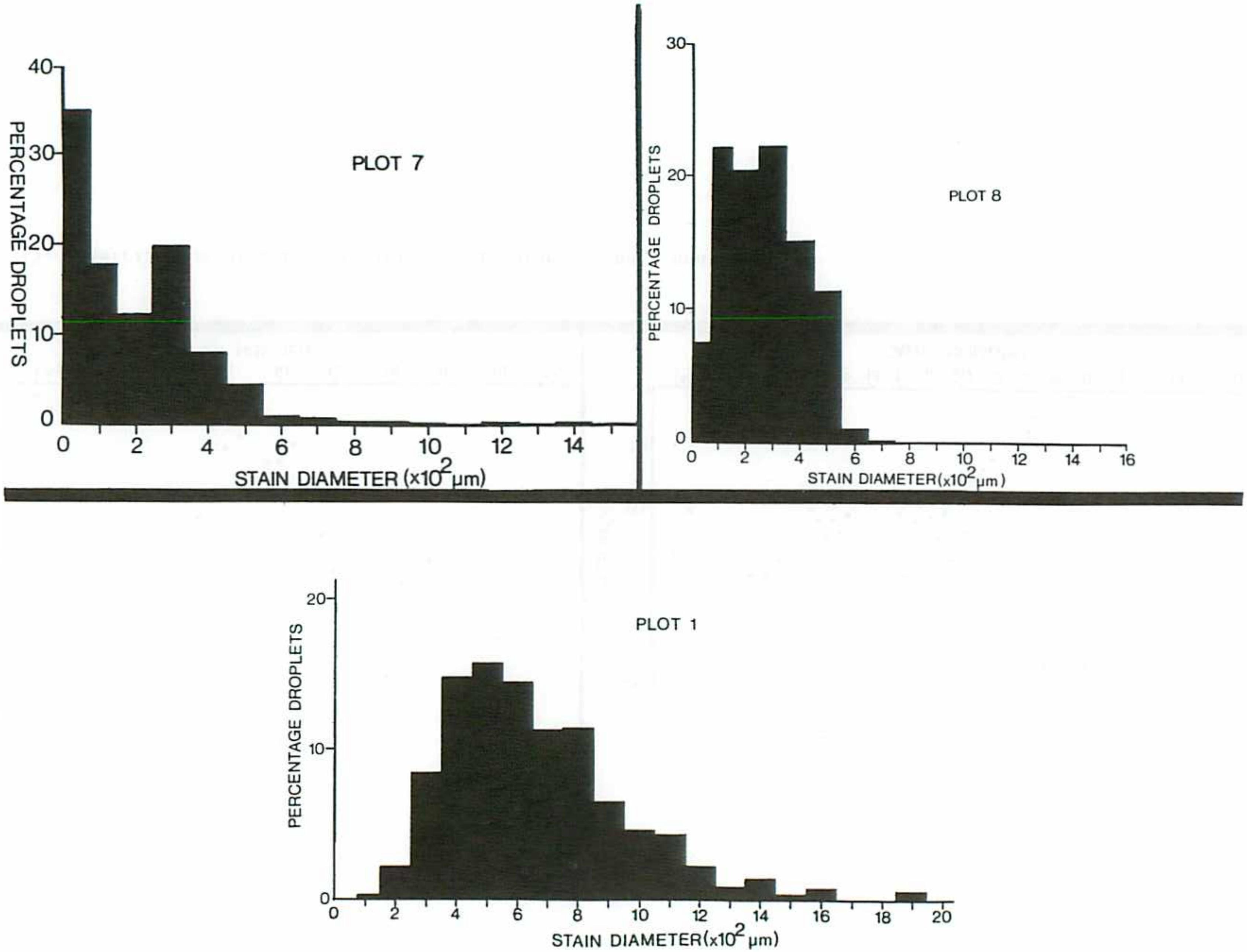


Figure 16. Histogram showing droplet spectrum in plots 1, 7 and 8 (1980).

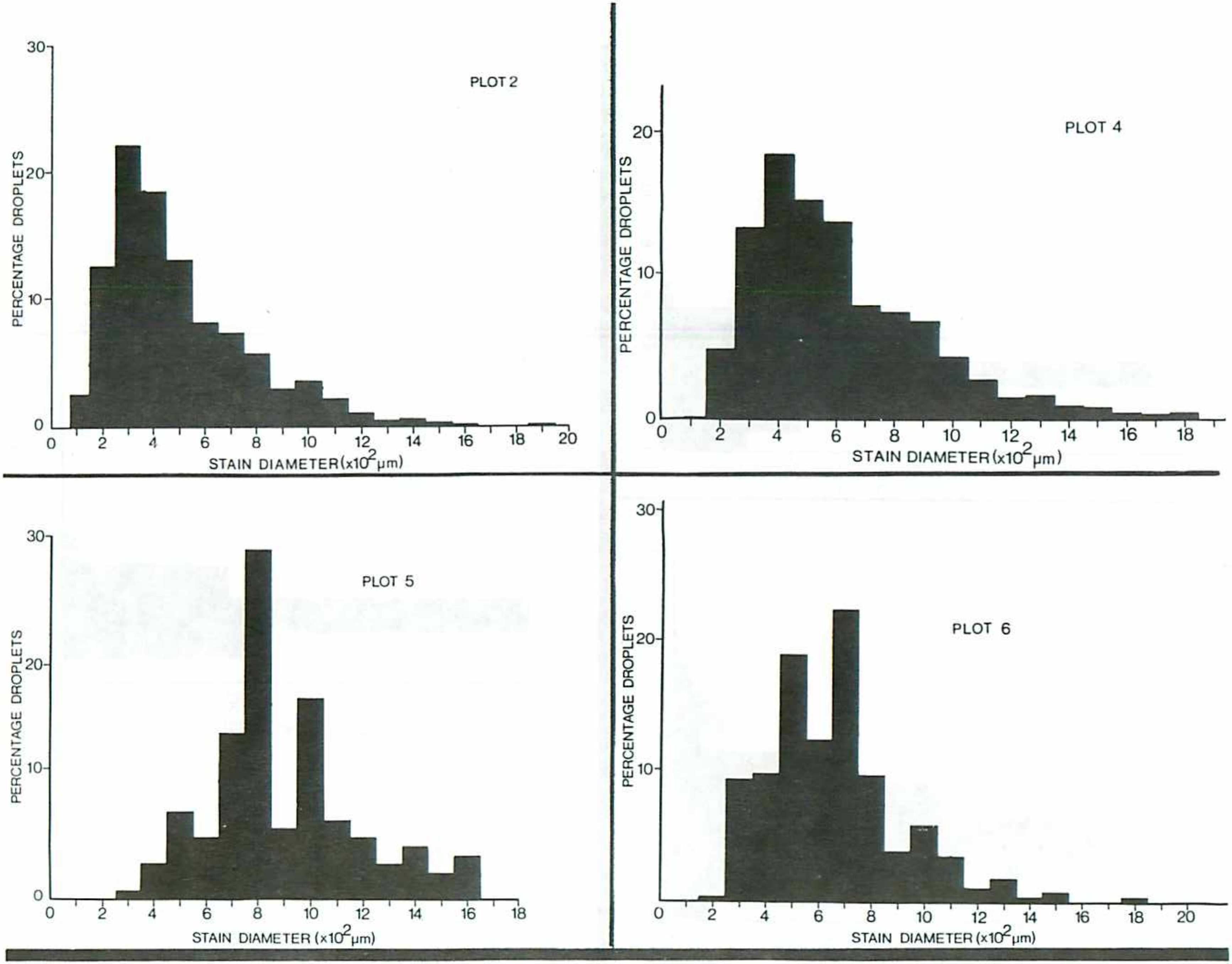


Figure 17. Histogram showing droplet spectrum in plots 2, 4, 5 and 6 (1980).

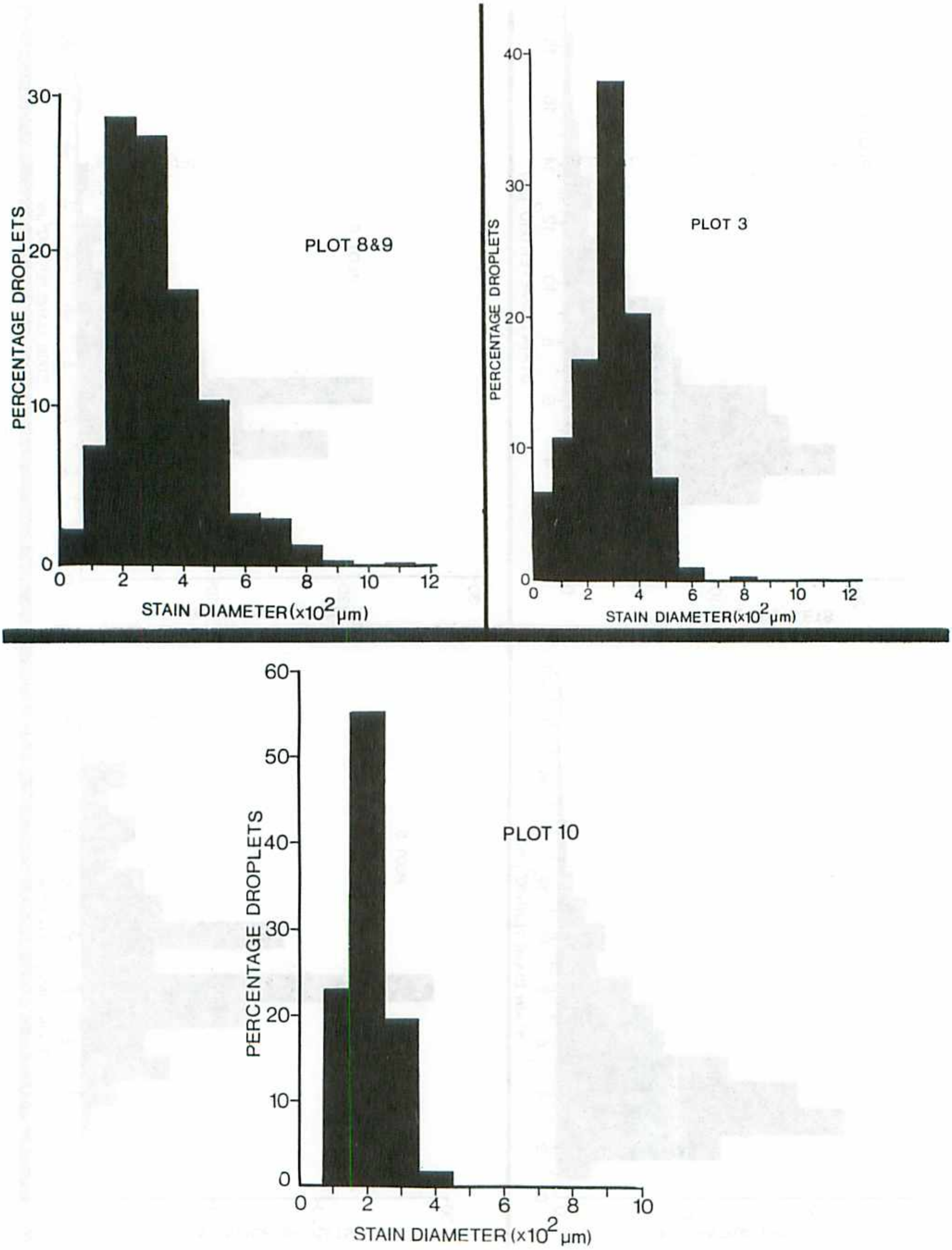


Figure 18. Histogram showing droplet spectrum in plots 3, 8 and 9 and 10 (1980).

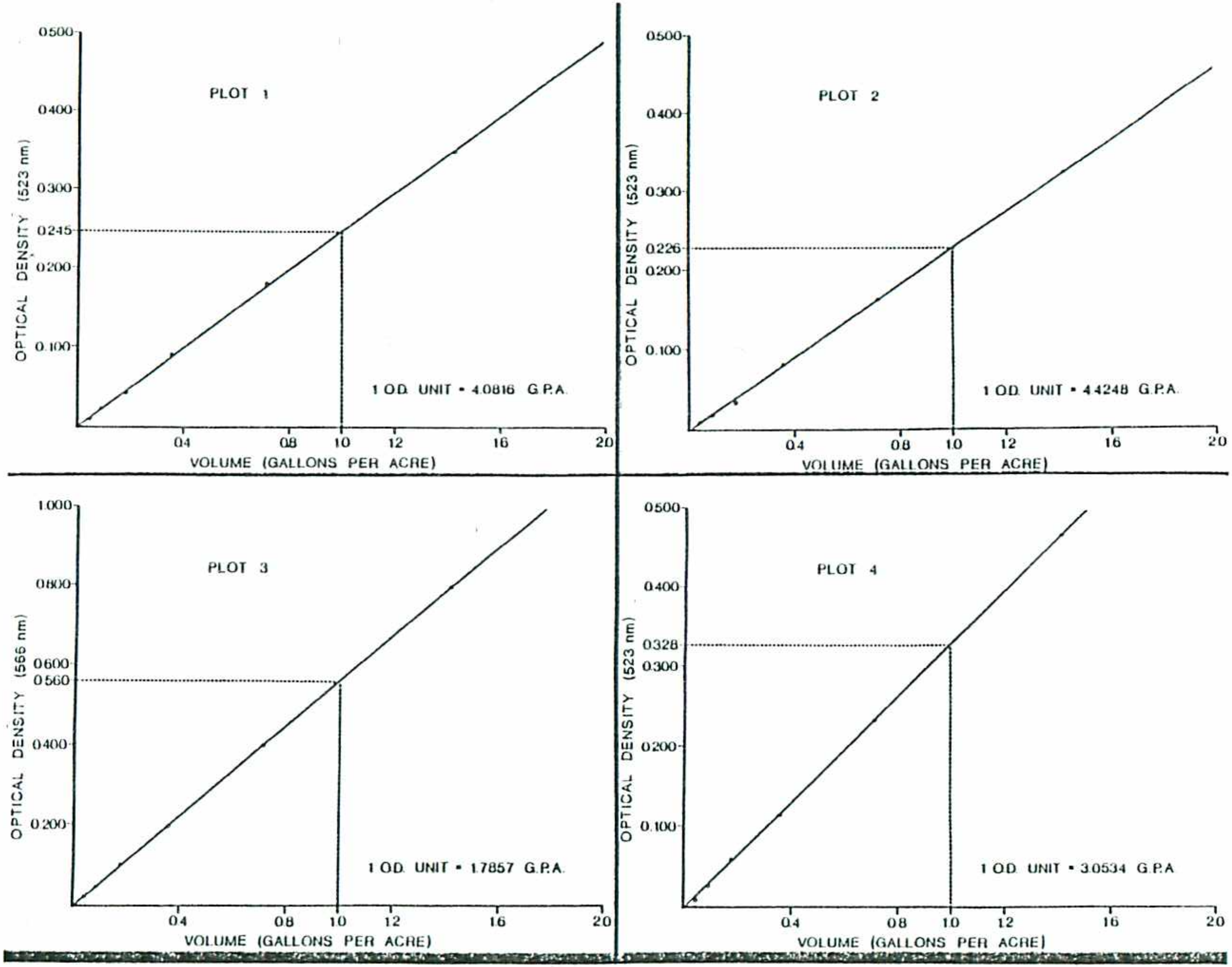


Figure 19. Standard curves for spectrophotometric analyses of volume deposited in plots 1, 2, 3 and 4 (1980).

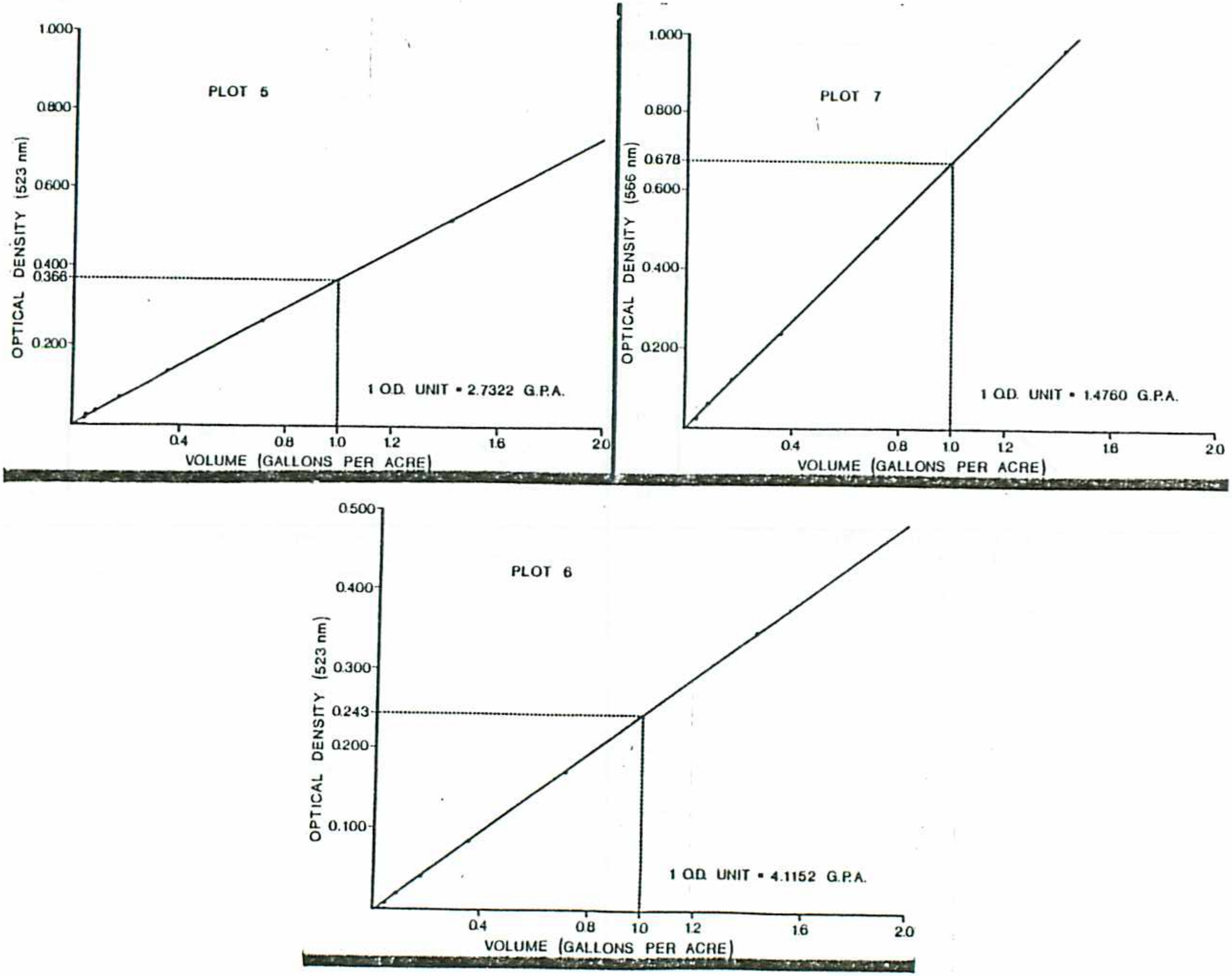


Figure 20. Standard curves for spectrophotometric analyses of volume deposited in plots 5, 6 and 7 (1980).

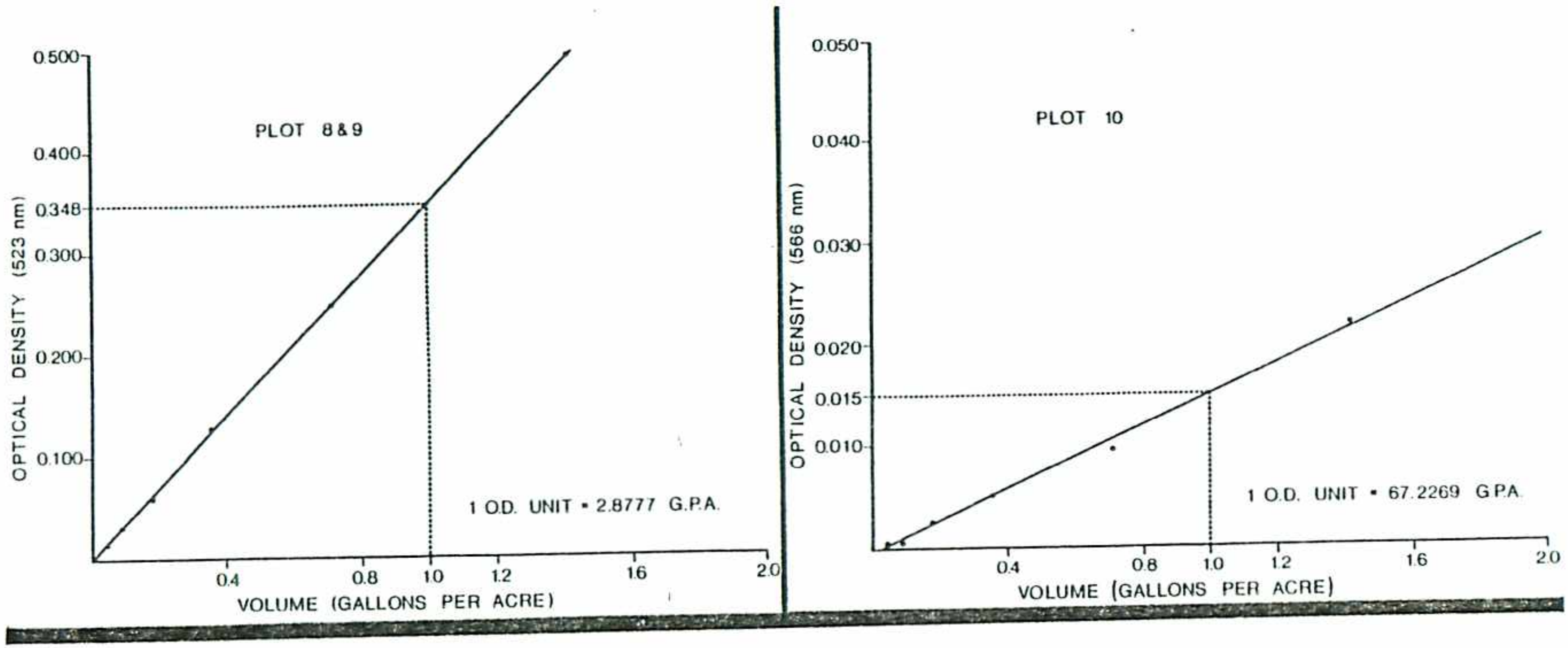


Figure 21. Standard curves for spectrophotometric analyses of volume deposited in plots 8 and 9 and 10 (1980).

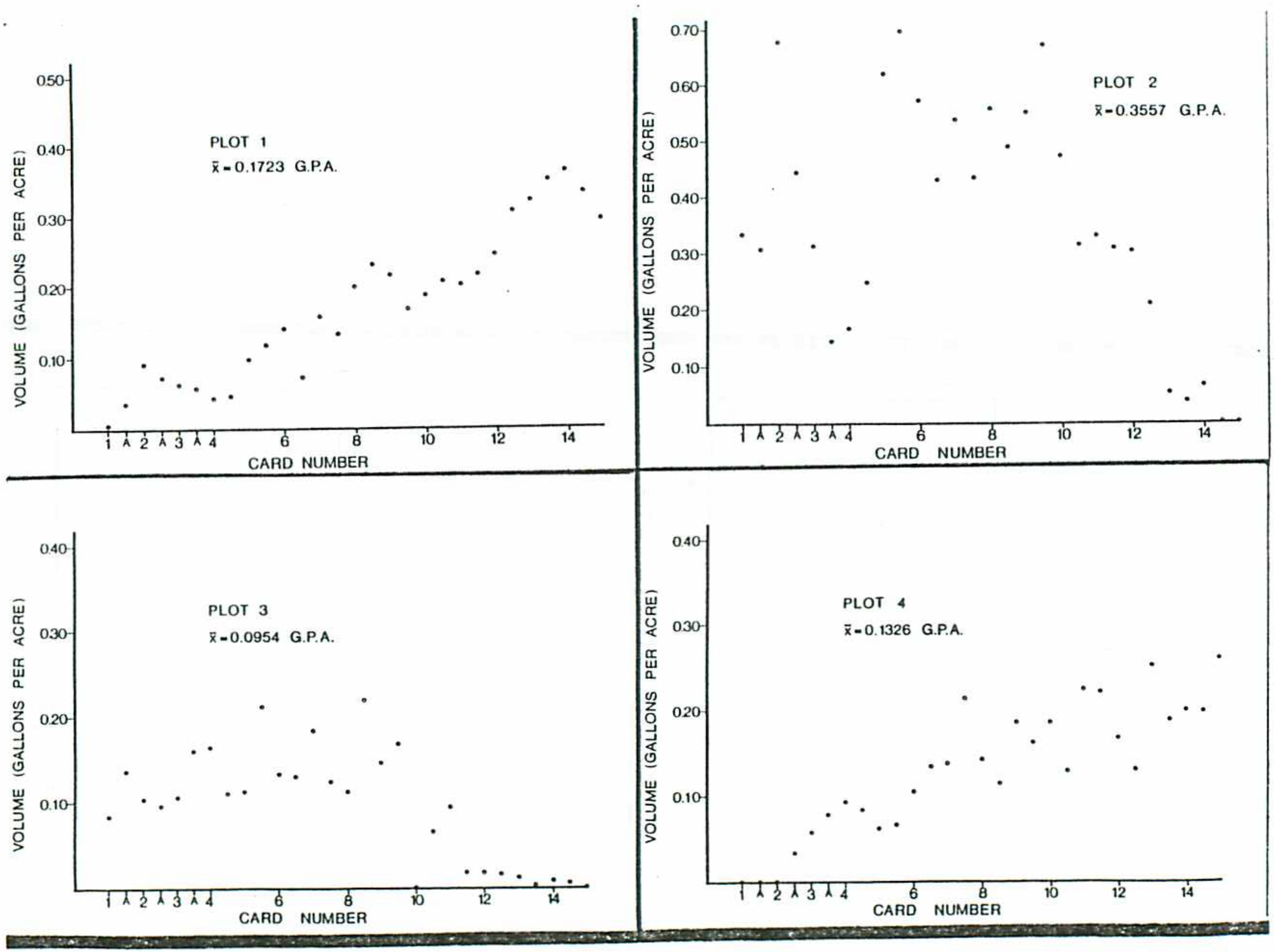


Figure 22. Spray volume distribution in plots 1, 2, 3 and 4 (1980).

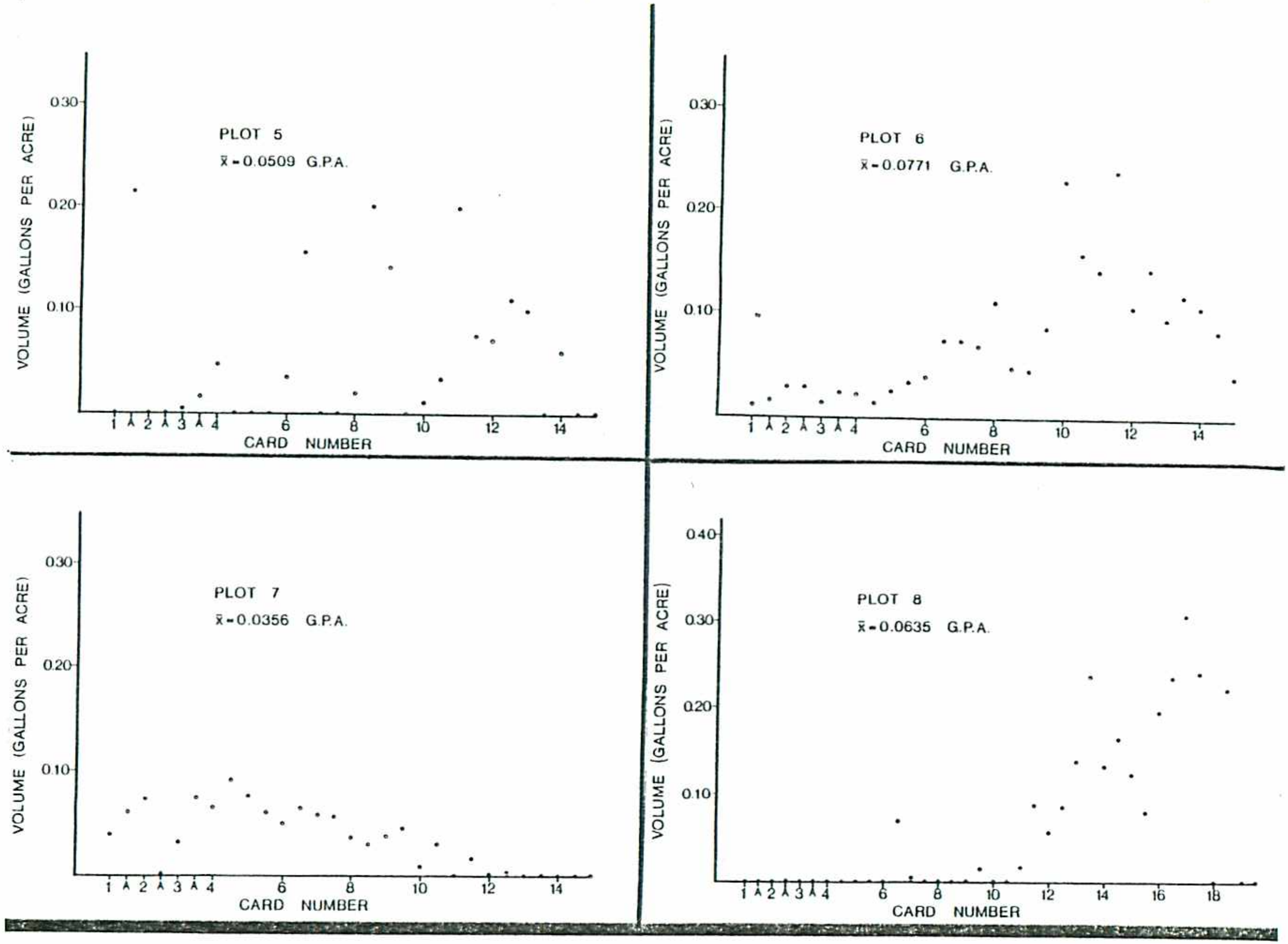


Figure 23. Spray volume distribution in plots 5, 6, 7 and 8 (1980).

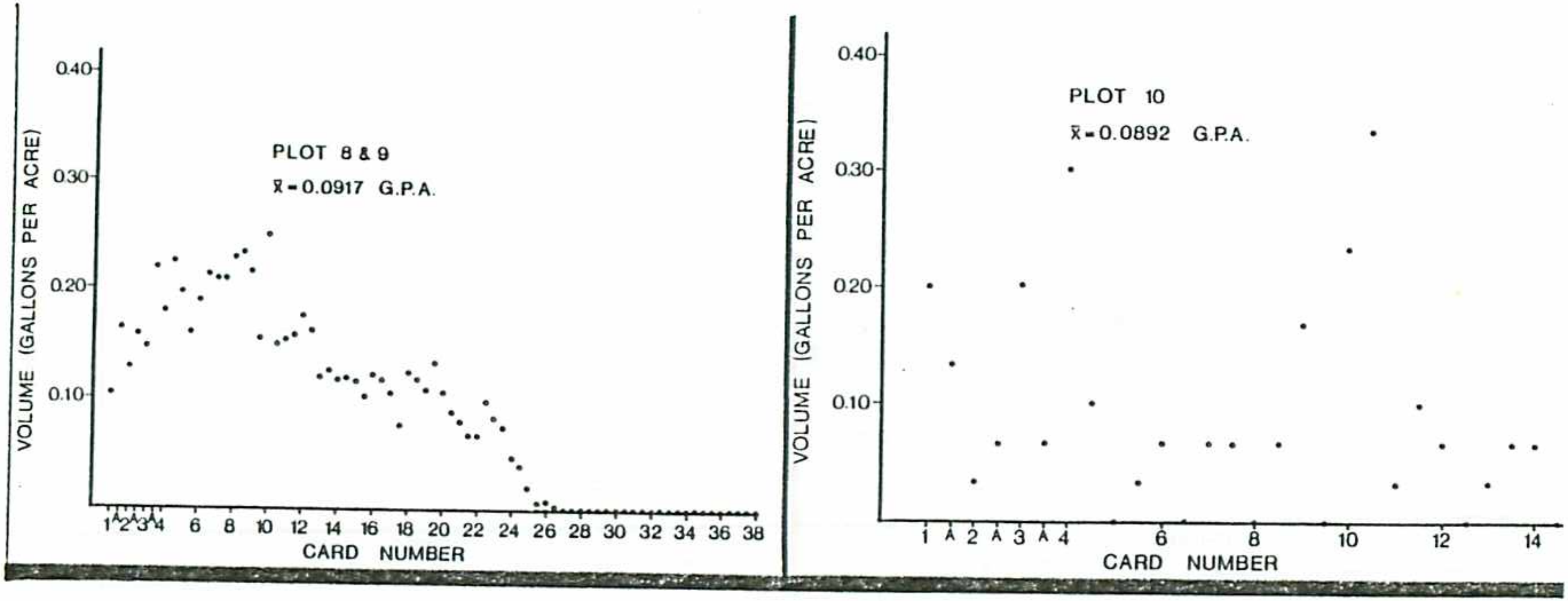


Figure 24. Spray volume distribution in plots 8 and 9 and 10 (1980).

Table 34. Weather data for parts of May and June (1980) for the French River area (OMNR, weather record).

Date		24 hr. Max. (°C)	24 hr. Min. (°C)	Average (°C)	24 hr. precipitation (mm)
May	15	12	5	8.5	0
	16	19	1	10	0
	17	21	1	10	0
	18	12	9	8.5	10.0
	19	17	5	8.5	2.2
	20	19	0	9.5	0
	21	18	1	8.5	0
	22	22	10	16	0
	23	26	11	18.5	0
	24	30	9	19.5	0
	25	19	10	14.5	0
	26	19	4	11.5	0
	27	15	6	10.5	0
	28	18	10.5	13	0
	29	23	8	15.5	0
	30	24	9	16.5	1.3
	31	17	15	16	0.2
June	1	17	5	9.5	0.2
	2	14	5	9.5	0
	3	21	9	15	0
	4	22	7	14.5	0
	5	19	6	10	0
	6	13	8	10.5	0.2
	7	11	10	10.5	12.4
	8	9	4	6.5	9.0
	9	11	4	6	3.1
	10	12	1	6.5	4.0
	11	4	4	4	0.3
	12	17	2	9.5	0
	13	20	9	14.5	0
	14	18	11	13.5	0

Table 35. Results of aerial application of Insect Growth Regulators in the French River area in 1980.

Plot and material		Pre-spray larvae per 46 cm branch tip		Surviving pupae per 46 cm branch tip		% Population reduction due to treatment		% Successful pupal emergence		% 1980 Defoliation		Ocular estimate of % defoliation	
		bF	wS	bF	wS	bF	wS	bF	wS	bF	wS	bF	wS
1	UC-62644 (0.5 oz)	44.3	41.3	1.4	4.4	86	61	64	79	68	69	23	36
Check		21.8	48.3	4.8	13.3			86	89	69	87	89	91
2	UC-62644 (1.0 oz)	34.4	70.0	.5	1.6	93	88	83	80	87	79	50	60
Check		21.8	51.9	4.8	10.1			86	99	69	92	89	94
3	BAY SIR-8514 (2.0 oz)	19.0	27.4	1.0	3.7	68	49	59	95	45	42	45	33
Check		18.5	26.9	3.0	7.1			88	96	34	83	84	99
4	BAY SIR-8514 (3.0 oz)	46.6	56.2	2.2	7.8	78	29	69	86	91	74	76	66
Check		21.8	51.9	4.8	10.1			86	99	69	92	89	97
5	BAY SIR-8514 (2.0 oz)	30.3	39.8	32.	11.8	52	0	76	95	78	82	61	75
Check		21.8	35.2	4.8	4.4			86	94	69	77	89	97
6	BAY SIR-8514	28.4	40.8	3.7	7.8	40	30	74	90	67	40	47	31
Check		21.8	48.3	4.8	13.3			86	89	69	87	89	91
7	BAY SIR-8514	19.0	52.5	3.6	9.0	0	12	75	96	59	53	28	27
Check		18.5	51.9	3.0	10.1			88	99	34	92	84	94
8	Matacil® (1+1 oz)	16.7	26.0	.1	.8	96	80	100	80	7	20	2	4
Check		16.5	26.8	2.5	3.7			71	86	42	59	100	67
9	Matacil® (1 oz)	16.7	37.7	1.2	7.3	52	0	63	92	48	59	33	37
Check		16.5	35.2	2.5	4.4			71	94	42	77	100	98
10	Dipel-88 (8 BIU)	11.0	35.1	.4	3.4	75	23	57	69	13	53	21	51
Check		11.8	35.2	1.7	4.4			68	94	29	77	40	98

Dimilin, the harbinger of all moult inhibiting Insect Growth Regulators was introduced in 1973 (Post and Vincent, 1973). Since then several companies have come up with new compounds. Eli Lilly, Gulf, Union Carbide, Monsanto, Velsicol, Stauffer, Dow Chemical, Nutrilite Products, and Upjohn are some of the companies, apart from Philips-Duphar, holding patents for Insect Growth Regulators (Mass *et al.* 1980). In less than 10 years several interesting control properties have come to light. The future looks bright for the development of moult inhibitors.

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APPENDIX

10. CONVERSION TABLE

Distance:	1 mile = 1.6 km; 1 foot = 0.3 m; 1 chain = 66 ft. 1 km = 0.6 mile; 1 m = 3.3 ft.
Area:	1 ha = 10,000 m^2 = 2.5 acre 1 acre = 43560 ft^2 = 0.4 ha 640 acre = 1 $mile^2$; 10 $chain^2$ = 1 acre; 1 $foot^2$ = 0.0929 m^2
Volume:	1 ℓ = 1000 ml = 33.814 fl. oz. = 2.113 pints = 1.056 quarts = 0.264 U.S. gal. 1 U.S. gal = 128 fl. oz. = 8 pints = 4 quarts = 3,785.33 ml = 3.785 ℓ 1 U.S. fl. oz. = 1.04842 Imp. fl. oz. 1 U.S. gal = 0.832674 Imp. gal.
Weight:	1 kg = 1000 g = 35.273 oz. = 2.204 lb. 1 g = 0.035 oz. = 0.0022 lb. 1 lb. = 16 oz. = 453.59 g 1 oz. = 283.495 g
Volume/area:	1 U.S. gal/acre = 9.353948 ℓ/ha 20 fl. oz./acre = 1.46 ℓ/ha 1 ℓ/ha = 0.10691 U.S. gal/acre.
Weight/area:	1 oz/acre = 70 g/ha 1 kg/ha = 14.275 oz/acre.