

# PERSISTENCE AND DISSIPATION OF GLYPHOSATE IN FOLIAGE AND SOILS OF A CANADIAN COASTAL FOREST WATERSHED

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## ABSTRACT

The environmental persistence and behavior of glyphosate and its major metabolite - aminomethylphosphonic acid (AMPA), were investigated in terrestrial components of a Canadian coastal forest watershed, following aerial application of ROUNDUP herbicide. The uniformity of herbicide deposition resulting from rotary-wing application with a MICROFOIL BOOM was assessed through analyses of deposit collectors and initial soil residues at three sampling sites located in the upper, middle and lower sections of the watershed. Samples of soil from three depth-layers were analyzed to determine the persistence and leaching of glyphosate and AMPA in both seasonally flooded and well-drained soils. In addition, foliage and leaf litter of two brush species, salmonberry (*Rubus spectabilis*) and red alder (*Alnus rubra* Bong) were monitored to determine initial foliage residue, residues associated with leaf litter and to estimate the degree of residue input via leaf fall.

Both the deposit collector and soil residue methods provided average estimates of initial deposit rates (2.52 and 1.85 kg/ha, respectively), which were reasonably close to the nominal application rate of 2.0 kg/ha. Both data sets also indicated that deposition rates varied greatly between different sites, ranging from a low of 0.60 kg/ha to a high of 3.42 kg/ha. Time of application, meteorological conditions and individual site characteristics may all have contributed to variable chemical deposit.

Analyses of initial foliage samples also indicated highly variable chemical deposition. Residue levels in both salmonberry and leaf litter collected 15 days post-application were significantly lower ( $P > 0.05$ ) than initial foliage residues. Subsequently, leaf litter residues of glyphosate and AMPA in both species declined over time and less than 1% remained 29 days post-application. The significant difference between initial foliage residues and the first leaf litter residues was attributed to wash-off resulting from a rainfall event which occurred 1 day post-application. The results indicate that while leaf-litter residues would be an unimportant transient source of chemical contamination, wash-off of unabsorbed foliage residues may provide an important non-point source input, if rainfall occurs shortly after application.

Soil residue determinations showed that both glyphosate and AMPA were retained primarily in the upper, organic-rich soil layer, 0-15 cm. Of 63 determinations of mean glyphosate distribution, only 10 data points indicated greater than 10% of total soil core residue in the 15-30 cm layer. No quantifiable residues were detected in samples taken from the 30-35 cm layer. Residues of glyphosate declined with time at all locations so that only 6-18% of initial levels remained after 360 days. Declining glyphosate residues coupled with transient increases in AMPA residues were indicative of microbial degradation. Insufficient replication, high variability in

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soil residues and site location effects on chemical behavior prohibited accurate derivation of persistence endpoints by regression analysis. However, pooling of the data provided an approximate time to 50% dissipation of glyphosate from watershed soils of 45-60 days. The results of this one-year monitoring study indicate that glyphosate and its major metabolite AMPA are non-persistent in terrestrial components (soil and leaf-litter) of a Canadian coastal rainforest watershed. In addition, the data clearly showed that neither glyphosate nor AMPA are susceptible to leaching under the conditions studied. The data provide no evidence of potential for long-term groundwater or surface water contamination as a result of inputs from terrestrial substrates.

## INTRODUCTION

The herbicide ROUNDUP<sup>1</sup> (active ingredient - glyphosate), received federal registration for silvicultural use in 1984. Since that time, use of this chemical in Canada has been steadily increasing. The environmental fate and persistence of glyphosate in soils has been extensively investigated by a number of researchers (Rueppel *et al.* 1977; Edwards *et al.* 1980; Hance 1976; Sprankle *et al.* 1975; Muller *et al.* 1981; Moshier and Penner 1976). However, the majority of this research has been conducted in the United States and pertains primarily to persistence and adsorption in agricultural soils. The environmental behavior of glyphosate in other terrestrial ecosystems has been less thoroughly studied. Newton *et al.* (1984) and Torstensson and Stark (1981), have both reported on the fate and behavior of glyphosate in forest soils: both studies indicating that glyphosate is relatively non-persistent. Torstensson (1985) indicated that the persistence of glyphosate in soils is affected by a multiplicity of factors that mediate microbial activity, the primary mechanism by which this herbicide is degraded.

In the coastal area of British Columbia, typical climatic conditions include frequent autumn and winter rainstorms with annual rainfall often exceeding 2000 mm annually. The results of such a precipitation pattern are: areas of high water table, seasonally saturated soils and frequent surface runoff events following major storms. Typically, soil profiles in the floodplain of coastal forest watersheds are highly stratified into organic-rich (30% or greater organic matter content) upper horizons, underlain by coarse-textured mineral soils, low in organic matter. Thus, from a purely physical standpoint, terrestrial forest ecosystems are vastly different than the more homogeneous agricultural soil systems that are traditionally studied. The potential for vertical leaching, loss through surface runoff and persistence of glyphosate under such soil and climatic conditions is unknown.

A relatively large amount of information is available with respect to the fate and behavior of glyphosate in plants. However, most of these studies have been conducted on agricultural crops or specific weed species, which may have little relevance to typical crop and weed species in forest environments. Newton *et al.* (1984) monitored the persistence of glyphosate in red alder (*Alnus rubra* Bong.) and other forest hardwood species. Lund-Hoie (1976) reported on the uptake, distribution and metabolism of this herbicide in spruce (*Picea abies*) and later in two brush species - ash (*Fraxinus excelsior*) and birch (*Betula verrucosa*) (Lund-Hoie 1979). Putnam (1976) studied the translocation and persistence of glyphosate in various deciduous fruit tree species following basal bark applications. During aerial application of herbicides, chemical is intercepted primarily by the broadleaf-target species. The herbicide may persist in or on the leaf tissue until senescence and leaf fall during autumn. In this way, chemical may be transported to the forest floor in the form of leaf-litter residue. The degree to which foliar interception and deposition (via subsequent leaf fall) occurs has not been adequately quantified.

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<sup>1</sup>Registered trademark of Monsanto Agricultural Products Co., St. Louis, Missouri.

Although an extensive data base exists with respect to the environmental fate and behavior of glyphosate in terrestrial ecosystems, little is pertinent to the conditions typical of the western coastal forest region where glyphosate receives widespread use for conifer release and site preparation. Federal and provincial regulatory agencies require further information on the fate and persistence of glyphosate relevant to its operational use under local geological and climatic conditions.

The research described in the following manuscript was undertaken to provide data relevant to the concerns of federal and regional regulatory agencies in Canada and to address questions that are inadequately dealt with in the current literature.

The specific objectives of the study were:

- a) To assess the uniformity of deposition of glyphosate following a rotary-wing, aerial application with a MICROFOIL BOOM<sup>2</sup>, under near-operational conditions in a coastal British Columbia watershed.
- b) To monitor the persistence of glyphosate and its major degradation product, AMPA, in both well-drained and seasonally flooded soils over a one year period following aerial application.
- c) To determine the leaching potential of glyphosate and AMPA in soil systems typical of a coastal British Columbia watershed.
- d) To determine the initial residue levels associated with the major target species and to monitor the degree to which residues are transported to the forest floor as leaf-litter residue.

## MATERIALS AND METHODS

### Site Description

The experimental study site is located in the Carnation Creek watershed on the west coast of Vancouver Island, British Columbia (48°50'N, 125°2'W), about 200 km west of Victoria (Fig. 1). The 10-km watershed is within a coastal hemlock and cedar ecozone (Krajina 1969). Annual precipitation ranges from 2500 to 3800 mm and occurs primarily from October through March (Hetherington 1982). The study site was clear-cut in 1975 and site-prepared and planted in 1976 (Dryburg 1982). At the time of chemical application (September 1984), thick vegetation dominated by salmonberry (*Rubus spectabilis* Pursh) and red alder (*Alnus rubra* Bong.) covered the area, ranging in height from 1.5-2.5 m and 7-10 m respectively. Characteristics of soils within the watershed (Table 1) were determined from samples taken immediately prior to herbicide application.

### Site Preparation

Three soil sampling sites were chosen within the watershed as indicated in Figure 1 and Table 2. Soil sites were selected in both the upper (stations 1-3) and lower (stations 7-9) sections of the watershed to monitor persistence and leaching in well-drained soils. The mid-watershed soil site (stations 4-6) was established in a low-lying area known to be seasonally flooded. At each site, three 5 x 5 m areas were cleared by removing above-ground vegetation.

<sup>2</sup>Registered trademark of Union Carbide Inc., Ambler, Pennsylvania.

Table 1. Soil characteristics of the Carnation Creek Watershed study site

Soil Depth (cm)	OM (%)	CEC	N (%)	P (ppm)	K (%)	pH	Sand (%)	Silt (%)	Clay (%)
<u>Stations 1-3</u>									
0-5	30.39	45.85	0.60	17.05	0.03	4.94	55.85	23.70	20.46
5-15	19.47	51.33	0.50	15.18	0.02	4.55	55.79	23.73	20.48
15-35	9.28	26.37	0.21	1.47	0.01	5.28	62.01	17.50	20.49
<u>Stations 7-9</u>									
0-5	30.90	50.47	0.12	54.04	0.03	4.49	62.02	24.99	12.99
5-15	14.88	48.13	0.84	10.55	0.02	4.20	54.68	24.90	20.42
15-35	10.21	27.44	0.07	1.03	0.01	4.65	65.80	16.23	17.97

C E C = Cation exchange capacity                      OM = Organic matter  
N = Nitrogen    P = Phosphorous                      K = Potassium

Table 2. Herbicide application data for the Carnation Creek Watershed study site\*\*

Sampling stations	Application specifics			Treatment area <sup>+</sup>
	Date	Time	Nominal rate kg/ha	
Soil (1,2,3) Leaf-litter (A-1*)	06-09-84	1935-2005	2.0	I
Soil (4,5,6) Leaf-litter (S-1*)	14-09-84	1430-1539	2.1	III
Leaf-litter (A-2,S-2*)	14-09-84	1730-1814	2.1	III
Soil (7,8,9)	06-09-84	1900-1925	2.0	I

\* A-1/A-2 = Alder - stations 1 and 2, respectively.

S-1/S-2 = Salmonberry - stations 1 and 2, respectively

\*\* Reynolds *et al.* 1989

<sup>+</sup> Treatment areas as shown in Figure 1.

large debris and slash, with minimal disturbance to the forest floor. Three replicate sampling stations were created. At each site, a total of eight deposit plates, each with a surface area of 400 cm<sup>2</sup>, were placed around the periphery of the sampling stations. The deposit collectors were used to provide an estimate of the initial residue deposited on the soil surface and to allow assessment of the uniformity of chemical application using the MICROFOIL BOOM.

Duplicate leaf-litter sampling stations were established in each of two separate areas dominated by salmonberry and red alder respectively (Fig. 1 and Table 2). Sampling plots for

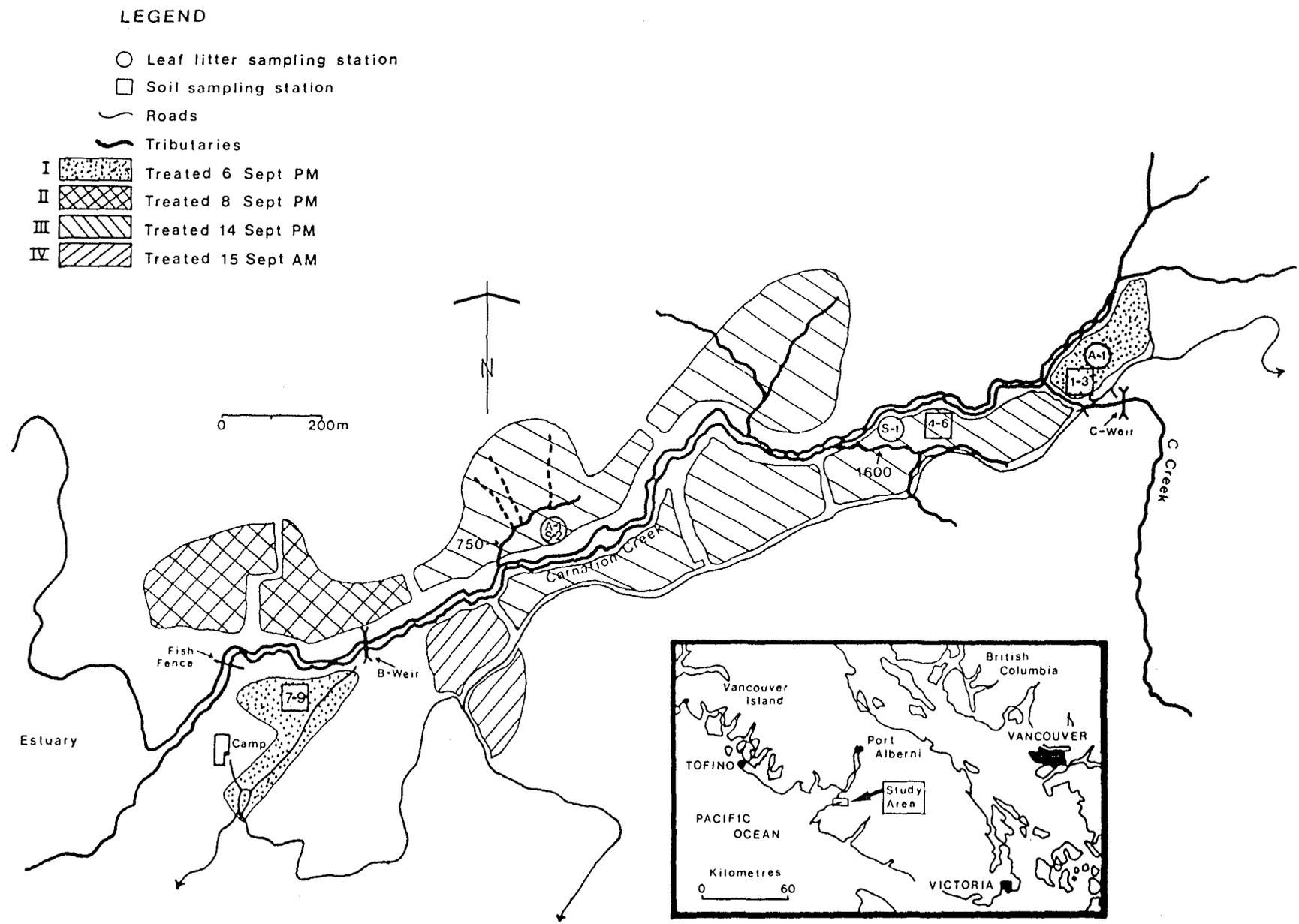


Figure 1. Location of the Carnation Creek Study Area and Terrestrial Sampling Stations.

interception estimates were at sites removed from those used to determine leaf-litter residues. A total of 20 m<sup>2</sup> surface area of nylon mesh was placed under appropriate species to trap leaf-litter, thus providing a sample substrate for leaf-litter residue determinations.

### Herbicide Application

ROUNDUP (isopropylamine salt of glyphosate) was applied at a nominal rate of 2 kg/ha active ingredient with a Bell-47 helicopter and a MICROFOIL BOOM equipped with 1.5 mm hayrack nozzles (Reynolds *et al.* 1989). The volume application rate was calibrated to be 258.25 L/ha. Due to inclement weather conditions, chemical applications were made over a 9-day period on 11 spray blocks (Fig. 1 and Table 2). During application to the pertinent areas, meteorological conditions monitored by the weather station established near the mouth of Carnation Creek were as follows: relative humidity - 61%, air temperature - 24°C, windspeed - 11 km/h.

### Sampling Methodology

Soil samples were obtained from each sampling station with a Campbell soil coring device, as described elsewhere (Feng and Klassen 1986). Soil cores were taken to a depth of 30 cm and each core was sliced into three sections corresponding to soil depths of 0-5 cm, 5-15 cm and 15-30 cm layers respectively. Volume, fresh weight and air dry weight were determined for each layer. These determinations allowed computation of moisture content, bulk density and residue concentration on both an area and dry weight basis. Soil samples were collected before and immediately after chemical application and thereafter on an increased temporal spacing (i.e. 3 day intervals for the first month, weekly during the second month, biweekly for the third month and monthly between the fourth and twelfth months). The exact times of soil sampling are presented in Appendix 1.

Aluminum foil sheets (400 cm<sup>2</sup>) on corrugated cardboard plates were used to provide initial deposit samples. Deposit sampling sheets were collected immediately following chemical application, packaged, stored and shipped according to procedures as described by Feng and Klassen (1986).

Fresh leaves were collected immediately following treatment by felling a representative tree (red alder) or clipping brush (salmonberry). Individual leaves were then harvested to provide a composite sample for each species at each sampling site. Leaf senescence began in mid-September 1984, and leaf-litter samples were collected from nylon mesh traps between 01 October and 30 November. Samples of leaf-litter were collected biweekly generally and on a weekly schedule during the peak leaf fall period. Details of sampling methodologies for all substrates are reported by Feng and Klassen (1986).

### Residue Analysis

#### Formulation analysis

Samples of ROUNDUP formulation (356 g a.i./L) were collected before mixing for application and kept at ambient temperature. Quadruplicate 1 mL aliquots were serially diluted (10<sup>5</sup> X) with KH<sub>2</sub>PO<sub>4</sub> buffer solution as described in Table 3. The diluents were filtered with Millipore filter units (Millex HV, 0.45 µm) and subjected to high performance liquid chromatographic (HPLC) analysis for glyphosate and its major degradation product - aminomethylphosphonic acid (AMPA).

Table 3. Specifications of HPLC instrumentation

Component	Specification
HPLC System:	Varian Model 5560 Ternary HPLC, Model 8085 Autosampler
Detector:	UV-200 variable wavelength detector set at 570 nm
Derivatization System:	Ninhydrin post column reactor (100°C) System V Model 5000 (Varian Inc.)
Analytical Column:	Bio-Rad Aminex A-9 10 cm X 4.6 mm i.d.
Guard Column:	Bio-Rad Aminex A-9 (K <sup>+</sup> form cartridge)
Mobile Phase:	0.005 M KH <sub>2</sub> PO <sub>4</sub> buffer in 4% methanol pH = 1.9
Flow Rate:	0.5 nL/min <sup>2</sup> (iso-cratic)
Column Temperature:	50°C

#### Tank mix analysis

Tank-mix samples (400 mL) collected immediately prior to application to Treatment Area III, were stored frozen until analyzed. Duplicate 1 mL aliquots were diluted ( $10^3$  X) in buffer solution, filtered and analyzed for both glyphosate and AMPA, as described above.

#### Deposit collector sample analysis

Residues of glyphosate and AMPA were extracted from the deposit collecting sheet by a multiple rinsing/shaking and sonicating procedure using 0.1 N HCl as the extraction solvent (Feng and Klassen 1986). The extracts were then subjected to cation and anion exchange column cleanup prior to quantification by HPLC analysis. Herbicide quantities (glyphosate plus AMPA as glyphosate equivalent) on the deposit plates, were converted to kg/ha rates using the equation:  $\text{kg/ha} = 2.5 \times 10^{-4} \times R$  where R = total residue ( $\mu\text{g}$ ) per deposit collector ( $400 \text{ cm}^2$ ).

#### Leaf-litter and foliage sample analysis

Whole samples of foliage and leaf-litter were air-dried and macerated by passage through a Hobart chopper. Finely chopped particles were mixed in large, inflated, plastic bags, to provide a homogeneous sample. From the homogenized samples, two subsamples (5 g) were taken and used for determination of oven-dry weight and for residue content, respectively. The analytical procedures used for leaf litter and foliage sample analyses are detailed in Thompson *et al.* (1989). Briefly, the method involves triplicate extraction with 0.5 M NH<sub>4</sub>OH, pre-concentration on an anion exchange column, cleanup via cation exchange, evaporation, solvation in mobile phase solution and HPLC analysis (Table 3). Results were corrected for recovery efficiency of the analytical method (Table 4) and reported as  $\mu\text{g}$  per g of oven-dried leaf tissue.

Table 4. Validation data for analytical methods

Substrate level	Fortif.	N	Analyte	% Recovery	LOD*	LOQ**
	Mean $\pm$ s.d. (cv%)					
Deposit Collector					+	+
Humus Soils	0.1-6.0	132	GLYH	77.7 $\pm$ 8.9 (11.56)	0.05	0.10
	.025-1.5	132	AMPA	67.7 $\pm$ 10.9 (16.09)	0.01	0.03
Mineral Soils	0.1-6.0	30	GLYH	73.5 $\pm$ 7.7 (10.53)	0.02	0.05
	.025-1.5	30	AMPA	58.2 $\pm$ 10.9 (12.77)	0.02	0.05
Leaf Litter (s)	0.5-5.0	4	GLYH	84.4 $\pm$ 5.3 (6.25)	0.10	0.30
	0.1-1.0	4	AMPA	54.7 $\pm$ 1.7 (3.21)	0.03	0.08
Leaf Litter (a)	0.5-5.0	4	GLYH	81.3 $\pm$ 7.7 (9.47)	0.10	0.30
	0.1-1.0	4	AMPA	60.9 $\pm$ 12.2 (20.03)	0.03	0.08

All values presented in terms of ppm =  $\mu\text{g/g}$  dry mass (for solids).

\* LOD = limits of detection = detector response equivalent to 2X S:N ratio.

\*\*LOQ = limits of quantification = detector response 6X S:N ratio.

+LOD and LOQ values for deposit collectors equate to  $2.5 \times 10^{-5}$  and  $1.25 \times 10^{-4}$  kg/ha respectively.

#### Soil sample analysis

Soil samples obtained from the Carnation Creek study site were immediately frozen, shipped and stored under cold ( $-10^{\circ}\text{C}$ ), dark conditions until analysis. Owing to the large number of samples of various substrates taken during the course of the study and the requirement for priority on aquatic substrates, soil samples were not analyzed until 2 years after the study was initiated.

Subsamples (5 g) of air-dried and homogenized soils were extracted three times with 0.5 M  $\text{NH}_4\text{OH}$ . Extracts were diluted to 1800 mL, concentrated on an anion exchange column and processed as described above for leaf-litter and foliage samples. Aliquots (100  $\mu\text{L}$ ) of the final solutions were analyzed by HPLC (Table 3). Results were corrected for recovery efficiency of the analytical method (Table 4) and reported as  $\mu\text{g}$  of glyphosate per g of air-dried soil. For samples taken at 0-time, soil residues (glyphosate + AMPA as glyphosate equivalent) were converted from total micrograms found to initial deposit in terms of kg/ha, using the following equation:

$$R/A/10 = \text{kg/ha}$$

where R = initial residue (total  $\mu\text{g}$  of glyphosate and AMPA)

A = cross-sectional surface area of soil auger (78.54)

## High Performance Liquid Chromatography (HPLC)

Determination of glyphosate residues in environmental substrates continues to be one of the more difficult aspects of herbicide analytical chemistry. A variety of methods are described in the literature, with some validation data also available (Lundgren 1986; Monsanto 1986; Seiber *et al.* 1984; Glass 1983; Edwards *et al.* 1980; Moye and St. John 1980; Monsanto 1977). The analytical methods used for determination of AMPA and glyphosate in soil and leaf litter samples were modifications of the Monsanto (1986, personal communication) method, supplied courtesy of Dr. J. Cowell, Monsanto Co. Inc., St. Louis, Missouri. A detailed description of the method is given in Thompson *et al.* (1989). Briefly, the method employs cation exchange - HPLC, coupled with a post-column ninhydrin derivatization to separate glyphosate and AMPA analytes from co-extractive interferences and provide derivatization products capable of absorbing in the visible portion of the spectrum. Characteristics of the HPLC system are described in Table 3.

Preliminary validation tests of the analytical method indicated that the determination of glyphosate and AMPA in fortified substrates derived from the Carnation Creek study site were relatively accurate and precise, with no co-extractive interferences at the retention times of the two analytes. Throughout the course of analytical determinations a quality control (QC) program was conducted. Results of the QC samples, which were processed and analyzed daily in conjunction with field samples, confirmed that the accuracy and precision of the method (Table 4). While not ideal, these data were similar to reported values in the available literature. The QC data were subsequently used to correct the field sample data for recovery efficiency of the analytical method.

## RESULTS AND DISCUSSION

### Formulation Analysis

Analysis of the ROUNDUP formulation utilized for the herbicide application in this study indicated that the amount of active ingredient (glyphosate) was 363 g/L  $\pm$  2% cv, approximately 2% in excess of the label concentration (356 g/L). No AMPA was detected in the formulation, which had been stored at ambient temperature for 3 months.

### Tank Mix Analysis

Results of the analyses conducted on the tank mix showed concentrations of 7889 and 58  $\mu$ /L of glyphosate and AMPA respectively. There was a 6% v/v contamination of the tank-mix from a six-day old mixture used to spray adjacent areas of the watershed. The amount of AMPA detected (0.7% of glyphosate concentration in the tank mix) indicated a 13% degradation of glyphosate in the previous mixture after six days of storage at ambient temperature. The initial concentration of the tank mix was corrected by converting the AMPA concentration to a glyphosate equivalence. The corrected value was 103% of the concentration required to yield an application rate of 2 kg a.i./ha.

### Deposit Collector Analysis

Analysis of deposit collectors placed around the periphery of the sampling stations allowed empirical estimation of the initial deposit rate and subsequent comparison with similar estimates based on soil residues. Thus variability of initial chemical deposition both within and among site locations could be determined. The results indicate that the deposit collectors con-

sistently estimated higher deposition rates with greater precision than estimates from soil residues. Differences in rate estimates derived from deposit collectors and soil residues were significant ( $P > 0.05$ ) for the upper and middle sampling locations. This discrepancy may be due in part to differences in replication ( $n = 3$  for soil samples per location;  $n = 8$  for deposit collector samples per location) and to interception of chemical by ground vegetation. Analysis of variance (ANOVA) and multiple comparison procedures (LSD and Bonferroni), indicated that mean rate estimates as determined by deposit collectors, were significantly different for each of the three locations ( $P > 0.05$ ). Mean rate estimates at the three different sites as derived from soil residues were not significantly different due to greater variation in these samples.

The average empirical rate estimates of 2.52 and 1.85 kg/ha, as determined by deposit collector analysis and by soil residue analysis respectively, were reasonably close to the nominal value of 2.0 kg/ha (Table 5). However, significant differences between deposition rates at various sites, as previously noted, indicate extreme variability in chemical deposition to different areas of the watershed (section on Herbicide Application and Table 5). Both methods of empirical estimation indicated that application rates for the lower portion of the watershed were higher than for the upper watershed. The mid-watershed site (Treatment Area III) received the least chemical deposition, probably owing to the gusty wind conditions prevailing during the mid-afternoon application (Table 2). The high mean value in soil residues recorded for the lower sampling location, resulted from one station (station 8) with a reported initial deposit equivalent to 5.67 kg/ha. No explanation could be found for this anomalous result. Initial levels of AMPA were less than 2% of corresponding glyphosate residues for all deposit collector samples, but varied between 4 and 13% for initial deposit as determined from soil sample residues. The higher levels of AMPA in O-time soil samples, when compared with deposit collector samples, may be indicative of minor degradation of glyphosate during the 2-year storage period for soil samples.

Table 5. Comparison of nominal and empirical estimates of initial glyphosate deposition at Carnation Creek Watershed study sites

Sampling location	Treat. area	*	Initial deposition rate estimates (kg/ha)	
			Deposit collector**	Soil residue**
Stations 1-3 (Upper Watershed)	I	2.0	2.54 ± 0.32 (13% cv)A	1.72 ± 0.31 (18% cv)
Stations 4-6 (Mid Watershed)	III	2.1	1.62 ± 0.24 (15% cv)B	0.60 ± 0.09 (16% cv)
Stations 7-9 (Lower Watershed)	I	2.0	3.42 ± 0.46 (14% cv)C	3.23 ± 2.30 (71% cv)
Overall Average		2.0	2.52 ± 0.90 (36% cv)	1.85 ± 1.32 (71% cv)

\* Nominal rates as reported by Reynolds *et al.* (1989).

\*\* Values based on total residue (glyphosate plus AMPA) with  $n = 8$  for deposit collectors and  $n = 3$  for soil residues.

Deposit collector values followed by different letters are significantly different ( $P > 0.05$ ) as determined by LSD and Bonferroni multiple comparison procedures.

Within each sampling location (i.e. amongst replicates), the variability (as denoted by the coefficient of variation) was similar for deposit collectors and soil residue estimates, with the exception of the lower location. The higher variation at this location is also the result of one anomalous data point as described previously.

Results of the quality control program, comprising over 160 samples analyzed in conjunction with field samples throughout the 8-month analysis period, indicated that analytical variability (coefficient of variation) for soil residue determinations was less than 12% for glyphosate and less than 16% for AMPA. These results indicate that significant differences exist in deposition between various locations, however, the average deposition for the entire watershed is reasonably close to the nominal rate. The differences observed may be attributed to variable meteorological and application parameters for different spray blocks. The data also indicate that greater replication in soil residue sampling would be required to achieve precision equivalent to the deposit collector method for estimating initial deposit.

### Leaf-Litter and Foliage Sample Analysis

Results of the leaf litter and foliage sample analyses are presented in Table 6. In general, the data show that residues decline over time in both salmonberry and alder leaf litter. Statistical analysis (ANOVA) of the results indicated that the decline in glyphosate residues is significant for both alder and salmonberry ( $P > 0.0589$  and  $P > 0.0001$  respectively). This rapid dissipation from foliage may be attributed to wash-off caused by the rainfall event (39 mm) that occurred 23 h post-application. Residues continued to decline throughout the observation period to the extent that less than 0.1% of initial levels remained 75 days post-application.

Table 6. Residues of glyphosate and AMPA associated with leaf litter of two target species from the Carnation Creek\*

Days (post-spray)	Alder		Salmonberry	
	Glyphosate	AMPA	Glyphosate	AMPA
0	261.0 ± 153.0	2.9 ± 2.5	447.6 ± 117.7	6.2 ± 0.1
15	12.5 ± 9.8	0.3 ± 0.1	19.2 ± 10.6	1.2 ± 0.0
29	1.2 ± 1.2	0.1 ± 0.1	1.9 ± 0.9	0.1 ± 0.0
45	0.5 ± 0.3	0.1 ± 0.0	0.9 ± 0.4	0.1 ± 0.0
58	0.2 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.1 ± 0.0
75	0.2 ±	0.1	0.3 ± 0.1	0.1 ± 0.0

\*Residue values are means of two replications in  $\mu\text{g}$  per gram dry tissue.

Residues of AMPA found on either type of foliage immediately after application were less than 2% of glyphosate residues, a result that is in good agreement with both the tank mix analysis and deposit collector results. No transient increase in AMPA residue was observed for either foliage type after leaf fall.

The results of leaf tissue analyses indicate that both target species intercepted a relatively large amount of chemical and that leaf-litter contained much less residue, which dissipated slowly with time. In general, these results support those of Lund-Hoie (1979), who found that only 20% of the glyphosate initially applied was absorbed in ash and birch foliage and that 35% of the absorbed amount was decomposed within 2 months, little being recovered as AMPA.

The data derived from this experiment suggest that glyphosate residue levels in leaf-litter of major brush species would present an insignificant, transient source of chemical input onto forest floor or into streams. One may hypothesize that foliage residues present a major source for ecosystem contamination only through wash-off of unabsorbed chemical, with contamination via leaf-fall being relatively minor. Further research is required on the aspect of binding and subsequent wash-off of glyphosate from treated leaf surfaces.

### Soil Sample Analysis

#### Leaching potential

Residue analyses were conducted on each of three individual layers - 0-5 cm (organic), 5-15 cm (organic), 15-30 cm (organic and mineral) - from each soil core. In addition, at sampling dates beyond 150 days post-application, a fourth layer [30-35 cm (mineral)] was obtained and analyzed. Results of these analyses are presented in terms of means for replicate samples taken throughout the observation period at each of the soil sampling locations (upper, middle and lower watershed). The histograms and tabular data indicate the percent of total residue distributed throughout the various layers (Fig. 3 & Appendices). Quantifiable residues of glyphosate were found in only one of the 30-35 cm layer samples, the residue (0.46 ppm) being equivalent to 11.5% of the total found in the core. This anomalous result was attributed to mislabeling during the air-drying process, however, positive proof of this could not be obtained from available laboratory records. In general terms, virtually all (>90%) of the residue was associated with the 0-5 cm organic layer. Two anomalous values were observed at day 60 for glyphosate in the lower watershed site (30.28% of total glyphosate in layer C) and at day 360 for AMPA in the lower watershed (27.28% of total AMPA in layer C). Although of little practical importance, higher mean residue levels in layer C from stations 7-9 relative to other sites indicated a slightly greater tendency towards leaching in these soils. No differences in leaching potential between the seasonally flooded and well-drained soil sites was apparent.

Results of the vertical distribution determinations indicate that neither glyphosate nor AMPA are susceptible to leaching. The findings are consistent with the general literature (Helling 1971; Sprankle *et al.* 1975; Rueppel *et al.* 1977; Damanakis 1976; and Edwards *et al.* 1980) and support the conclusion of Torstensson (1985), who stated that glyphosate is practically immobile in soil.

The majority of research conducted on the adsorption of glyphosate to soils or soil fractions (i.e. mineral components), suggests that glyphosate is bound to soils through the phosphonic acid moiety and that sorption is positively correlated with clay content, cation exchange capacity and unoccupied phosphate sorption capacity (Sprankle *et al.* 1975; Hance 1976; Glass 1987). Since Carnation Creek soils are characterized by a relatively high cation-exchange capacity and organic matter content, especially in the upper 15 cm layers (Table 1), we suggest that the lack of vertical mobility exhibited by glyphosate in these soils is due to strong adsorption to cation saturated clays and/or organic matter in the upper soil horizons. An essentially identical leaching pattern was exhibited by AMPA in this study.

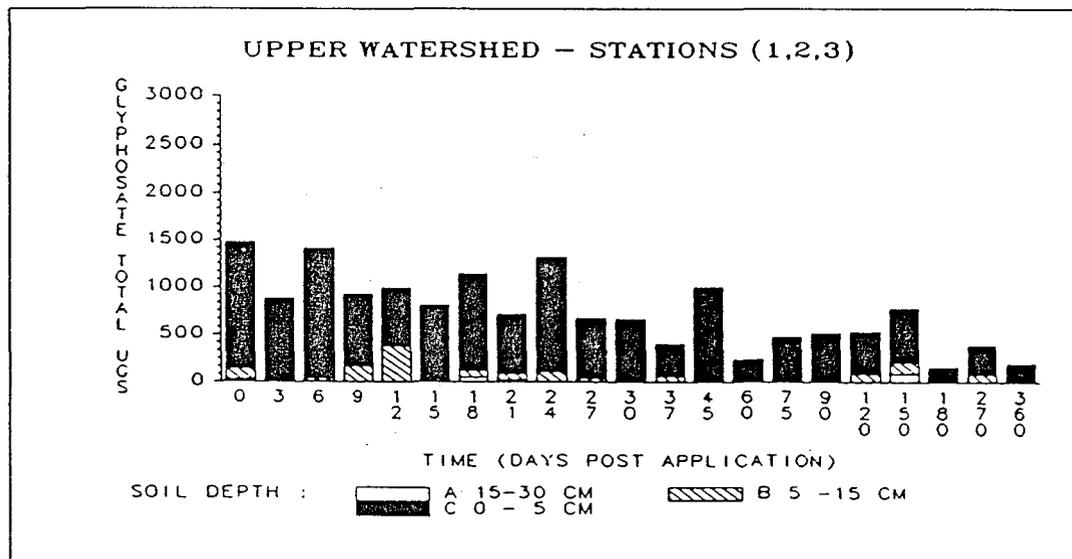
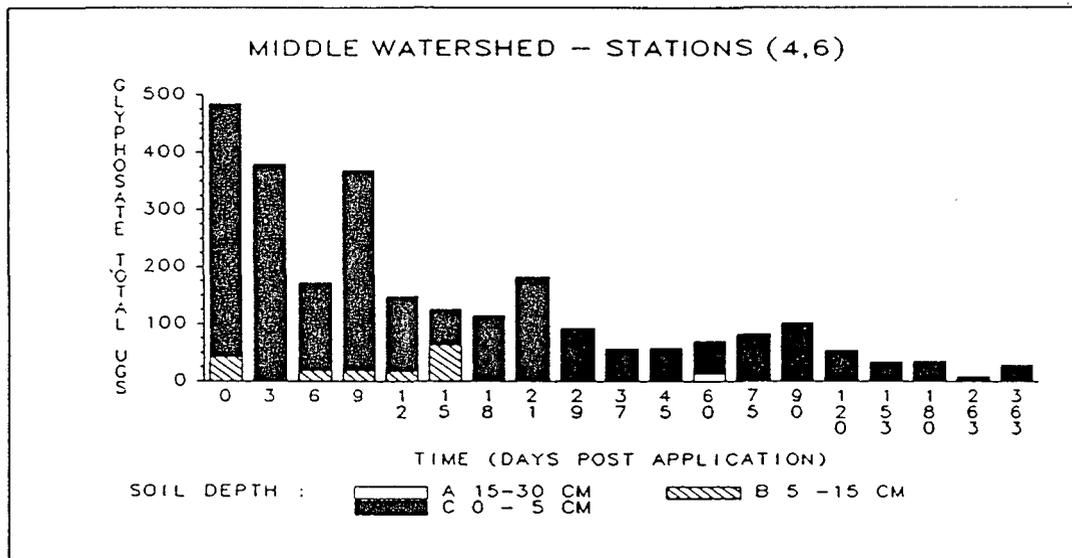
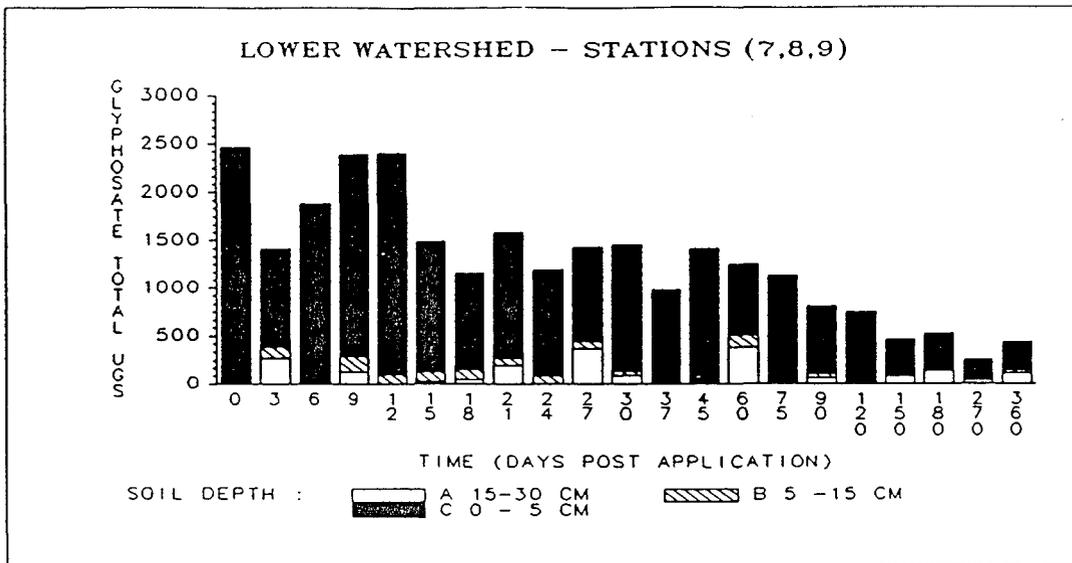


Figure 2. Persistence and distribution of glyphosate and AMPA in Carnation Creek Watershed Study soils.

## Persistence

Computation of mean soil residues of glyphosate and AMPA in the 0-30 cm soil layer was done at each sampling time to allow determination of persistence in each sampling location - upper, middle and lower watershed. (Figure 2 and Appendices).

Although the data clearly show that residues decline over time (Fig. 2), variability within replicates resulted in poor regression coefficients for both linear and log transformed data ( $.17 < r > .46$ ), which prohibited the use of regression equations for estimation of time to 50% and 90% dissipation ( $DT_{50}$  and  $DT_{90}$ , respectively). In addition, no statistically valid comparisons could be made with respect to persistence of glyphosate or AMPA in seasonally flooded soils or in well-drained soils. Quantifiable residues of both glyphosate and AMPA did remain after 360 days. In terms of percent of initial residues, these values ranged from 6-18% and 16-27% for glyphosate and AMPA, respectively. AMPA residues, which were initially very low (4-13% of glyphosate residues), followed a pattern of transient increase and subsequent decline at all sampling locations (Appendices 2.1-2.3). Peak residue means were less than 40% of mean initial glyphosate residues for the respective sites.

The general decline in glyphosate residues over time at all three sampling locations, coupled with transient increase in AMPA residues is indicative of microbial degradation of glyphosate in the soils studied. Although accurate estimates of  $DT_{50}$  and  $DT_{90}$  could not be made from regression analysis, averaging glyphosate residues for all sample locations indicated that glyphosate residues were consistently less than 50% of initial residues after 45-60 days post-application. At the end of the observation period, both glyphosate and AMPA residues were lowest in the middle watershed site. Due to the nature of this site (low-lying and seasonally flooded), it is probable that reduced residue levels could be attributed to movement of chemical away from the sampling with surface water present at time of application.

Laboratory experiments conducted by Torstensson and Stark (1981), showed that the time to 50% degradation of glyphosate in a number of different forest soils was quite variable, ranging from 6 days in an iron podsol to 200 days in a podsol with ashes. Torstensson (1985) noted that the variable rate of degradation of glyphosate cannot be correlated to a single soil factor, but reflects the general microbial activity of the soils being investigated, which in turn is affected by a multiplicity of environmental factors. Since the influencing factors may vary from soil to soil and/or from year to year, prediction or comparison of glyphosate persistence, based on either laboratory studies or field studies, should be avoided unless most of the important influencing variables are quantified or controlled. Newton *et al.* (1984) estimated time to 50% dissipation of glyphosate as 40.2 days based on the results of a study conducted in a semi-arid Oregon forest watershed. However, owing to the differences between the two studies, especially with respect to the method by which the persistence estimates were derived, no valid conclusion can be drawn regarding glyphosate persistence estimates (similarity or lack thereof). In general terms, however, the results of Oregon study and the Carnation Creek study are in agreement. In short, the Carnation Creek study provides no evidence of extraordinary soil persistence of either glyphosate or AMPA.

## ACKNOWLEDGEMENTS

This research, supported under the British Columbia Forest Resource and Development Agreement (FRDA), was conducted by members of the Forest Pest Management Institute (FPMI), of the Canadian Forestry Service. Cooperation of the British Columbia Ministry of Forests, the Pacific Forestry Centre (PFC), Fisheries and Oceans Canada, MacMillan Bloedel Ltd., and Monsanto Canada

Inc. were integral to the success of this project. Herbicide application was contracted to Rotor Vegetation Control (R. Rowe) and Alpine Helicopters (D. Gubbels and D. Cholka) both of Calgary Alberta, was coordinated by Dr. P. Reynolds (FPMI). The authors sincerely appreciate and acknowledge the excellent technical assistance in residue analysis of B. Staznik, T. Buscarini, V. Manniste-Squire, and L. MacDonald (FPMI), and of H. Klassen and D. DeKoven (V.A. Poulin and Assoc. Ltd.) who performed the field sampling.

## REFERENCES

- Cowell, J.E., J.L. Kunstman, P.J. Nord, J.R. Steinmetz and G.R. Wilson. 1986. Validation of an analytical residue method for analysis of glyphosate and metabolite: An interlaboratory study. *J. Agric. Food Chem.* 34:955-960.
- Damanakis, M.E. 1976. Behaviour of glyphosate in the soil (adsorption, leaching, degradation). *Annales del l'Institut Phytopathologique Benaki.* 11:153-167. (As cited by Torstensson, L. 1985. Behaviour of glyphosate in soils. pp. 137-150 *In*: *The Herbicide Glyphosate.* E. Grossbard and D. Atkinson (eds.). Butterworths, London.
- Dryburg, J.G. 1982. Carnation Creek logging and silvicultural treatment program. pp. 36-43 *In* G.F. Hartman (ed.) *Proceedings of the Carnation Creek workshop, a 10-year review.* February 24-26, 1982. Malaspina College, Nanaimo, B.C.
- Edwards, W.M., G.B. Triplett and R.M. Kramer. 1980. A watershed study of glyphosate transport in runoff. *J. Environ. Qual.* 9(4): 661-665.
- Feng, J.C. and H.D. Klassen. 1986. Forestry field and laboratory manual for herbicide residue sampling, sample processing and reporting. *Can. For. Serv., For. Pest Manage. Inst., Sault Ste. Marie, Ont. Inf. Rep. FPM-X-72.* 38 p.
- Glass, R.L. 1983. Liquid chromatographic determination of glyphosate in fortified soil and water samples. *Journal Agric. Food Chem.* 31:280-282.
- Glass, R.L. 1987. Adsorption of glyphosate by soils and clay minerals. Abstracts of The American Chemical Society National Meeting, September 7-10, 1986, Anaheim, California.
- Hance, R.J. 1976. Adsorption of glyphosate by soils. *Pesticide Science.* 7:363-366.
- Helling, C.S. 1971. Pesticide mobility in soils. 1. Parameters of soil thin-layer chromatography. *Proceedings of the Soil Science Society of America.* 35: 732-737.
- Hetherington, E.D. 1982. A first look at logging effects on the hydrologic regime of Carnation Creek experimental watershed. pp. 11-15 *In* G.F. Hartman (ed.) *Proceedings of the Carnation Creek workshop, a 10-year review.* February 24-26, 1982. Malaspina College, Nanaimo, B.C.
- Krajina, V.J. 1969. Ecology of forest trees in British Columbia. pp. 1-146 *In* V. Krajina and R. Brooks (eds.) *Ecology of western North America.* Vol. 2, Nos. 1 and 2. Dep. Botany, Univ. B.C., Vancouver, B.C.
- Lundgren, L.N. 1986. A new method for the determination of glyphosate and (aminomethyl) phosphonic acid residues in soils. *J. Agric. Food Chem.* 34:535-538.

- Lund-Hoie, K. 1976. The correlation between the tolerance of Norway spruce (*Picea abies*) to glyphosate (N-phosphonomethylglycine) and the uptake, distribution and metabolism of the herbicide in spruce plants. As cited in: D. Coupland. 1985. Metabolism of glyphosate in plants. Chapter 3 p. 25-34. In E. Grossbard and D. Atkinson (eds). The Herbicide Glyphosate Butterworths, London.
- Lund-Hoie, K. 1979. The physiological fate of glyphosate-<sup>14</sup>C in *Betula verrucosa* and *Fraxinus excelsior*. The effect of ammonium sulphate and the environment on the herbicide. As cited in: D. Coupland. 1985. Metabolism of glyphosate in plants. Chapter 3 p. 25-34. In E. Grossbard and D. Atkinson (eds) The Herbicide Glyphosate. Butterworths, London.
- Monsanto. 1977. Methods for individual pesticide residues "Glyphosate" In: Pesticide Analytical Manual 1977. Vol. 2. Food and Drug Administration. Washington, D.C. Pest. Reg. Sec. 180:364.
- Moshier, L.J. and D. Penner. 1976. Factors influencing microbial degradation of <sup>14</sup>C-Glyphosate to <sup>14</sup>C-CO<sub>2</sub> in soil. Weed Science 26:686-691.
- Moye, H.A. and P.A. St. John. 1980. A critical comparison of pre-column and post-column fluorogenic labeling for the HPLC analysis of Pesticide Residues. In Harvey J. Zweig Jr. (ed.) Pesticide Analytical Methodology. ACS Symposium Series 136:89-102. American Chemical Society. Washington, D.C.
- Muller, P.M., C. Rosenberg, H. Siltanen and T. Wartiovaara. 1981. Fate of glyphosate and its influence on nitrogen-cycling in two Finnish agricultural soils. Bulletin of Environmental Contamination and Toxicology. 27:724-730.
- Newton, M., K.M. Howard, B.R. Kelsas, R. Danhaus, P.M. Lottman and S. Dubelman. 1984. Fate of glyphosate in an Oregon forest ecosystem. J. Agric. Food Chem. 32: 1144-1151.
- Putnam, A. 1976. Fate of glyphosate in deciduous fruit trees. Weed Science. 24:425-430.
- Reynolds, P.E., J.C. Scrivener, L.B. Holtby and P.D. Kingsbury. 1989. An overview of Carnation Creek herbicide study: historical perspective, experimental protocols, and spray operations. This proceedings.
- Rueppel, M.L., B.B. Brightwell, J. Schaefer and J.T. Marvel. 1977. Metabolism and degradation of glyphosate in soil and water. J. Agric. Food Chem. 25:517-528.
- Seiber, J.N., M.M. McLesney, R. Kon and R.A. Leavitt. 1984. Analysis of glyphosate residues in kiwi fruit and asparagus using high performance liquid chromatography of derivatized glyphosate as a cleanup step. J. Agric. Food Chem. 32:678-681.
- Sprankel, P., W.F. Meggitt and D. Penner. 1975. Adsorption, mobility and microbial degradation of glyphosate in the soil. Weed Science. 23:229-234.
- Thompson, D.G., B. J.E. Cowell, R.J. Daniels, B. Staznik and L. MacDonald. 1989. An alternative method for quantification of glyphosate and AMPA Residues in organic and mineral soils, streams sediments and hard wood foliage. J. Assoc. Off. Anal. Chem. (in press).
- Torstensson, L. 1985. Behaviour of glyphosate in soils. pp. 137-150 In E. Grossbard and D. Atkinson (eds.) The Herbicide Glyphosate. Butterworths, London.

Torstensson, L. and J. Stark. 1981. Decomposition of  $^{14}\text{C}$ -labeled glyphosate in Swedish forest soils. pp. 72-79 In Proceedings of the EWRS Symposium on Theory and Practice of the Use of Soil Applied Herbicides.

APPENDIX 1.1 CARNATION CREEK SOIL RESIDUE DATA - GLYPHOSATE  
 SAMPLING LOCATION - LOWER WATERSHED (STATIONS 7,8,9)

Time (days)	Total residue ( $\mu\text{g/s}$ )				Distribution of residues (%)		
	(0-30 cm core)				0-5 cm	5-15 cm	15-30 cm
0	2469.11	+	1763.37	(71.4)	98.33	1.67	0.00
3	1413.61	+	749.08	(52.9)	72.30	8.46	19.23
6	1889.74	+	1061.57	(56.1)	99.63	0.37	0.00
9	2391.87	+	760.40	(31.7)	86.64	7.85	5.51
12	2408.22	+	1488.79	(61.8)	95.82	4.18	0.00
15	1491.85	+	838.63	(56.2)	90.62	6.92	2.46
18	1156.54	+	575.29	(49.7)	85.69	9.78	4.53
21	1586.90	+	196.94	(12.4)	81.68	5.87	12.45
24	1197.29	+	840.91	(70.2)	92.21	7.79	0.00
27	1430.13	+	552.84	(38.6)	68.26	6.23	25.51
30	1456.88	+	574.10	(39.4)	89.28	3.98	6.73
37	989.57	+	376.70	(38.0)	99.33	0.67	0.00
45	1414.60	+	2096.59	(148.2)	100.00	0.00	0.00
60	1248.91	+	1478.50	(118.3)	59.14	10.58	30.28
75	1129.65	+	687.63	(60.8)	98.9	1.03	0.00
90	814.29	+	532.17	(65.3)	86.12	6.41	7.46
120	752.69	+	518.08	(68.8)	97.64	2.36	0.00
150	467.88	+	425.77	(91.0)	79.55	3.33	17.13
180	525.04	+	244.47	(46.5)	69.16	5.27	25.57
270	260.19	+	154.83	(59.5)	74.15	10.58	15.27
360	436.75	+	177.72	(40.6)	68.32	6.14	25.54

APPENDIX 1.2 CARNATION CREEK SOIL RESIDUE DATA - GLYPHOSATE  
 SAMPLING LOCATION - MIDDLE WATERSHED (STATIONS 4,6)

Time (days)	Total residue ( $\mu\text{gs}$ )		Distribution of residues (%)		
	(0-30 cm core)		0-5 cm	5-15 cm	15-30 cm
0	484.00	-----	91.05	9.95	0.00
3	379.76	-----	100.00	0.00	0.00
6	172.18 $\pm$ 217.39	(126.2)	88.97	11.03	0.00
9	369.65 $\pm$ 370.68	(100.2)	94.65	5.35	0.00
12	147.01 $\pm$ 96.94	(65.9)	87.61	12.39	0.00
15	125.97 $\pm$ 2.45	(1.9)	50.00	50.00	0.00
18	113.93 $\pm$ 73.58	(64.5)	100.00	0.00	0.00
21	182.32 $\pm$ 126.05	(69.1)	100.00	0.00	0.00
30	92.40 $\pm$ 60.28	(65.2)	100.00	0.00	0.00
37	56.79 $\pm$ 6.57	(11.5)	100.00	0.00	0.00
45	57.82 $\pm$ 32.02	(55.3)	100.00	0.00	0.00
60	70.25 $\pm$ 4.94	(7.0)	85.50	0.00	20.50
75	82.71 $\pm$ 44.68	(54.0)	100.00	0.00	0.00
90	102.21 $\pm$ 36.71	(35.9)	100.00	0.00	0.00
120	54.70 $\pm$ 59.69	(109.1)	100.00	0.00	0.00
150	34.08 $\pm$ 14.40	(42.2)	100.00	0.00	0.00
180	35.10 $\pm$ 2.84	(8.1)	100.00	0.00	0.00
270	8.29 $\pm$ 11.73	(141.4)	100.00	0.00	0.00
360	28.98 $\pm$ 4.22	(14.5)	100.00	0.00	0.00

APPENDIX 1.3 CARNATION CREEK SOIL RESIDUE DATA - GLYPHOSATE  
 SAMPLING LOCATION - UPPER WATERSHED (STATIONS 1,2,3)

Time (days)	Total residue ( $\mu\text{gs}$ )			Distribution of residues (%)		
	(0-30 cm core)			0-5 cm	5-15 cm	15-30 cm
0	1476.96	+ 376.25	(25.5)	89.02	7.97	2.01
3	878.16	+ 567.78	(64.6)	96.09	3.91	0.00
6	1410.93	+ 1238.64	(87.7)	96.21	3.79	0.00
9	926.39	+ 983.53	(106.1)	81.82	18.18	0.00
12	992.08	+ 1552.66	(156.5)	61.17	38.83	0.00
15	809.63	+ 882.92	(109.0)	96.00	4.00	0.00
18	1140.02	+ 1048.37	(91.9)	89.79	6.06	4.16
21	709.89	+ 472.23	(66.5)	86.37	9.65	3.99
24	1313.89	+ 1048.25	(79.7)	91.15	8.85	0.00
27	669.76	+ 560.39	(83.6)	93.94	6.06	0.00
30	668.25	+ 226.16	(33.8)	97.44	0.00	2.56
37	408.28	+ 282.19	(69.1)	84.08	15.92	0.00
45	1004.85	+ 1182.40	(117.6)	99.58	0.42	0.00
60	238.99	+ 174.70	(73.1)	100.00	0.00	0.00
75	483.30	+ 44.22	(9.1)	95.89	4.11	0.00
90	522.29	+ 130.66	(25.0)	97.68	2.32	0.00
120	533.29	+ 486.51	(91.2)	83.45	16.55	0.00
150	782.87	+ 523.55	(66.8)	73.40	15.56	11.04
180	157.71	+ 82.23	(52.1)	87.29	12.71	0.00
270	394.36	+ 332.45	(84.3)	80.95	19.05	0.00
360	198.07	+ 116.21	(58.6)	100.00	0.00	0.00

APPENDIX 2.1 CARNATION CREEK SOIL RESIDUE DATA - AMPA  
 SAMPLING LOCATION - LOWER WATERSHED (STATIONS 7,8,9)

Time (days)	Total residue ( $\mu\text{g/s}$ )		Distribution of residues (%)		
		(0-30 cm core)	0-5 cm	5-15 cm	15-30 cm
0	101.24	+ 68.52 (67.68)	100.00	0.00	0.00
3	181.44	+ 78.25 (43.13)	95.28	2.51	2.20
6	163.56	+ 70.24 (42.95)	100.00	0.00	0.00
9	238.59	+ 20.68 ( 8.67)	92.72	7.28	0.00
12	342.58	+ 213.01 (62.18)	92.76	7.24	0.00
15	274.70	+ 130.11 (47.36)	96.02	3.98	0.00
18	334.51	+ 197.41 (59.02)	84.75	12.48	2.78
21	299.13	+ 119.41 (39.92)	81.99	8.59	9.42
24	391.22	+ 66.67 (17.04)	91.87	6.36	1.78
27	588.42	+ 47.93 ( 8.15)	78.94	10.10	10.96
28	561.67	+ 0.00 ( 0.00)	69.15	14.43	16.43
30	350.53	+ 56.84 (16.22)	94.07	5.93	0.00
37	186.30	+ 56.53 (30.34)	100.00	0.00	0.00
45	369.53	+ 201.56 (54.55)	100.00	0.00	0.00
60	389.49	+ 199.36 (51.19)	90.30	9.70	0.00
75	474.77	+ 370.03 (77.94)	100.00	0.00	0.00
90	530.51	+ 183.35 (34.56)	87.94	6.13	5.92
120	281.64	+ 154.54 (54.87)	96.77	3.23	0.00
150	342.28	+ 106.88 (31.23)	87.06	7.22	5.73
180	470.50	+ 308.24 (65.51)	73.66	15.45	10.89
270	614.96	+ 304.59 (49.53)	81.02	12.16	6.82
360	583.37	+ 372.03 (63.77)	66.99	5.83	27.18

## APPENDIX 2.2 CARNATION CREEK SOIL RESIDUE DATA - AVPA

## SAMPLING LOCATION - MIDDLE WATERSHED (STATIONS 4,6)

TIME (DAYS)	TOTAL RESIDUE (UGS)		DISTRIBUTION OF RESIDUES (%)		
	(0 - 30 CM CORE)		0-5 CM	5-15 CM	15-30 CM
0	62.13	+ 37.56 (60.46)	100.00	0.00	0.00
6	77.13	+ 34.09 (44.20)	100.00	0.00	0.00
9	139.04	+ 5.36 ( 3.86)	93.41	6.59	0.00
12	166.33	+ 235.23 (141.42)	64.18	22.75	13.07
15	121.07	+ 115.06 (95.04)	50.00	50.00	0.00
18	122.12	+ 80.43 (65.86)	92.63	7.37	0.00
21	95.59	+ 16.28 (17.03)	100.00	0.00	0.00
30	87.31	+ 63.95 (73.25)	100.00	0.00	0.00
37	73.31	+ 68.09 (92.88)	100.00	0.00	0.00
45	82.94	+ 42.98 (51.82)	100.00	0.00	0.00
60	83.49	+ 78.58 (94.12)	100.00	0.00	0.00
75	126.41	+ 51.23 (40.52)	100.00	0.00	0.00
90	167.46	+ 21.71 (12.96)	100.00	0.00	0.00
120	64.93	+ 63.11 (97.20)	100.00	0.00	0.00
150	113.09	+ 40.87 (36.14)	100.00	0.00	0.00
180	107.52	+ 66.24 (61.60)	100.00	0.00	0.00
270	38.86	+ 32.07 (82.53)	100.00	0.00	0.00
360	144.84	+ 204.84 (141.42)	77.41	22.59	0.00

## APPENDIX 2.3 CARNATION CREEK SOIL RESIDUE DATA - AMPA

## SAMPLING LOCATION - UPPER WATERSHED (STATIONS 1,2,3)

TIME (DAYS)	TOTAL RESIDUE (UGS)		DISTRIBUTION OF RESIDUES (%)		
	(0 - 30 CM CORE)		0-5 CM	5-15 CM	15-30 CM
0	64.98	+ 59.49 (91.55)	87.16	12.84	0.00
3	148.03	+ 99.96 (67.53)	90.60	9.40	0.00
6	239.82	+ 23.98 (10.00)	96.97	3.03	0.00
9	236.97	+ 214.26 (90.42)	85.99	14.01	0.00
12	145.99	+ 153.54 (105.18)	56.58	43.42	0.00
15	320.34	+ 123.41 (38.52)	93.27	6.73	0.00
18	369.90	+ 176.29 (47.66)	85.80	14.20	0.00
21	448.62	+ 270.28 (60.25)	82.08	12.51	5.40
24	391.57	+ 187.21 (47.81)	87.74	11.01	1.26
27	363.23	+ 252.93 (69.63)	90.59	9.41	0.00
30	307.27	+ 128.93 (41.96)	98.73	1.27	0.00
37	426.39	+ 136.46 (32.00)	88.64	11.36	0.00
45	255.44	+ 42.02 (16.45)	94.12	5.88	0.00
60	240.43	+ 40.75 (16.95)	92.69	7.31	0.00
75	359.93	+ 233.64 (64.91)	96.55	3.45	0.00
90	320.98	+ 80.12 (24.96)	92.71	7.29	0.00
120	347.99	+ 38.65 (11.11)	61.66	38.34	0.00
150	588.14	+ 230.23 (39.15)	76.28	17.02	6.70
180	359.84	+ 140.37 (39.01)	77.87	22.13	0.00
270	284.75	+ 221.38 (77.75)	68.71	18.05	13.24
360	248.96	+ 100.47 (40.36)	98.03	1.97	0.00

# Proceedings of the Carnation Creek Herbicide Workshop

December 7 - 10, 1987

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March 1989

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ECONOMIC & REGIONAL DEVELOPMENT AGREEMENT

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Partial funding for the research project and the cost of printing this publication was provided by the Canada-British Columbia Forest Resource Development Agreement - a five year (1985-90) \$300 million program cost-shared equally by the federal and provincial governments. Additional funding was provided by Monsanto Canada.

### Canadian Cataloguing in Publication Data

Carnation Creek Herbicide Workshop (1987 : Nanaimo, B.C.).

Proceedings of the Carnation Creek Herbicide Workshop

(FRDA Report, ISSN 0835-0752 ; 063)

Issued under Forest Resource Development Agreement  
Co-published by B.C. Ministry of Forests.

"Canada/BC Economic & Regional Development Agreement".

ISBN 0-7726-0917-9

1. Glyphosate. 2. Herbicides - Environmental aspects - British Columbia - Carnation Creek. 3. Herbicides - British Columbia - Carnation Creek - Toxicology. I. Reynolds, P.E. (Phillip E.), 1947-. II. Canada. Forestry Canada. III. British Columbia. Ministry of Forests. IV. Forest Resource Development Agreement (Canada) V. Canada/BC Economic & Regional Agreement VI. Title. VII. Series

SB952.G58C37 1989 632:954 C89-092067-2

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Province of British Columbia

This is a joint publication of Forestry Canada  
and the British Columbia Ministry of Forests.

Produced and distributed by the Ministry of  
Forests, Research Branch.

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