THE UNIVERSITY OF MANITOBA

THE BEHAVIOUR OF TRIAZINE HERBICIDES IN SOME MANITOBA SOILS

BY

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF PLANT SCIENCE

WINNIPEG, MANITOBA

May, 1972

AN ABSTRACT OF THE THESIS OF

JOHN DYSON ELLIOTT presented on February 29, 1972

Title: THE BEHAVIOUR OF TRIAZINE HERBICIDES IN SOME MANITOBA SOILS.

Growth chamber bioassay experiments using oats (*Avena sativa* L. var. Russell) were conducted over a 2 year period using soil from 4 locations. The degree of herbicide movement in the soil profile, the influence of cropping systems on dissipation and the degradation rate of atrazine, SD15418 and S6115 were investigated.

In all cases, the greatest amount of herbicide was retained in the upper 5 cm of soil. As the rate of herbicide application was increased, more herbicide was detected in the lower soil horizons. There appeared to be a greater downward movement of herbicide in the plots containing corn than in fallowed plots.

More herbicide residue was detected at the Winnipeg and Portage la Prairie (Portage) sites (heavy clay soils) than at the Graysville and Carman sites (very fine sandy loam soils). At the Graysville and Carman sites, triazine herbicides appeared to breakdown more rapidly in fallow than in the corn plots. No difference was detected at Winnipeg or Portage between corn and fallow plots.

It appeared that there was a greater percent breakdown of triazine herbicides at high rates than at low rates.

Field bioassay experiments showed that there was more severe injury to oats due to triazine residue at the Winnipeg

and Portage sites than at the Graysville site. At all sites atrazine and S6115 caused a greater degree of oat injury than SD15418.

At the Winnipeg and Portage sites there appeared to be similar triazine injury to oats grown on either corn or fallow plots. At the Graysville site there was less injury to oats grown on the fallow plots than on the corn plots.

ACKNOWLEDGEMENTS

The writer wishes to express sincere appreciation to Dr. E. H. Stobbe, for his assistance throughout the course of this study and for his constructive criticism and suggestions in the preparation of this manuscript.

Grateful acknowledgements are made to Prof. G. M. Young, Dr. G. Racz and Dr. D. E. Schafer for the review of the manuscript and helpful criticism during its preparation.

A special thanks to my wife, Lynn whose understanding, love and sacrifice made my days as a graduate student so much more worthwhile.

A note of thanks to Mr. Scott Reid for permitting me to use the experimental area established by him in 1970.

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INTRODUCTION

The acreage of corn for silage and grain has fluctuated over the past decade in Manitoba. The acreage of silage corn has fluctuated between 20,000 and 65,000 acres, and that of grain corn between 3,300 and 30,000 acres.

Within the last few years, there has been a high industrial demand in Manitoba for at least 1.2 million bushels of grain corn per year, much of which is now imported.

One of the major limiting factors in reaching this potential demand for corn in Manitoba is inadequate control of weeds. Research work done at the University of Manitoba has shown that there are a number of triazine herbicides which will give excellent control of broadleaf and grassy weeds in corn but the residue remaining the following year prevents the growing of susceptible crops in the rotation.

Thus, a study was initiated at the University of Manitoba. The objectives of this study were to obtain the following information on atrazine, SD15418, and S6115:

a) The degree of herbicide movement in the soil horizon,

b) The influence of cropping systems on herbicide dissipation,

c) The degradation rate of atrazine, SD15418 and S6115.

LITERATURE REVIEW

Bioassay of Herbicide Residues in Soil

The bioassay technique to detect herbicide residues is of great use to agriculture researchers. The advantage in using sensitive plants to detect herbicide residues is that they do not require elaborate equipment and can be used to examine a large number of samples. Furthermore, bioassays are often more sensitive than analytical methods. On the other hand, bioassays do not furnish conclusive data for the identification of the herbicide and can only measure the amount of biologically active herbicide in the soil. The total amount of herbicide is not necessarily determined. Finally, bioassays are specific only to specified environments and soil (5, 15).

Bioassay experiments to detect atrazine residues have been carried out using oats, *Avena sativa* L. (32); barley, *Hordeum vulgare* L. (34); Italian rye grass, *Lolium multiflorum* L. (28); sugar beets, *Beta vulgaris* L. (14); cucumbers, *Cucumis sativus* L. (38); and algae, *Chlorella vulgaris* (1).

Measurements recorded to determine herbicidal activity included shoot and root weights, plant height, injury rating and growth inhibition.

Santleman, *et al*. (41), working at 3 locations using oats as a bioassay test plant to detect prometryne found that if uniform procedures and conditions were not adopted assay results varied a great deal, and the percent recovered ranged from 147 percent below to 234 percent above the prometryne actually applied. The adoption of uniform conditions and procedures greatly increased the uniformity of determinations between locations to a range of from 37 percent low to 0 percent high in prometryne applied.

Persistence of Triazine Herbicides in the Soil

Degradation of s-triazine herbicides occurs at a very slow rate in soil (9, 28, 40). When herbicides persist in the soil for more than one growing season susceptible crops cannot be grown the following year in a crop sequence (11, 17, 19, 35).

Fink, *et al*. (17) found that a number of forage grasses and legumes were affected by atrazine residues the following year after application. Tall fescue, *Festuca elatior* var. *arundinacea* and alfalfa, *Medicago sativa* were the most tolerant crops whereas timothy, *Phleum pratense* was susceptible. Red clover, *Trifolium pratense*; Korean lespedeza, *Lespedeza stipulacea*; ladino clover, *Trifolium repens*; and bromegrass, *Bromus inermis* L. were intermediate.

Damage to sugar beets, *Beta vulgaris* was correlated with the method, time and rate of application of atrazine in the previous year. Dilution of the atrazine by plowing in the autumn reduced damage from pre-emergence treatments but not from post-emergence treatments (19).

Peters (35) working in Connecticut found that oats and alfalfa were not injured when the treatment was limited to 2 pounds per acre atrazine applied pre-emergence. When this rate was supplemented in 2 successive corn crops by use of 2 pounds per acre before plowing in the fall, both oats and alfalfa were injured.

Bergstresser (7) working in Manitoba showed that thorough mixing of the upper 2 inches of soil was sufficient to grow oats if atrazine was applied at 1 pound per acre in a 12 inch band (36 inch row spacing). Similar "banding" of 2 pounds per acre atrazine, required thorough mixing of the upper 6 inches of soil to grow oats.

Tolerant crops such as flax may be included in rotation to allow for atrazine dissipation (12).

Adsorption

The factors affecting adsorption of triazine herbicides by soil have been summarized by a number of workers (6, 13, 23, 27, 36, 42). The adsorption of triazine herbicides is influenced by the soil and colloid type, the amount and quality of organic matter, nature of the saturating cation on the exchange site, nature of the formulation, temperature and soil moisture content.

The montmorillonite type clays have very high specific surfaces, high cation exchange capacities and expanding lattices while the kaolinite type clays have low specific surfaces, low cation exchange capacities and non-expanding lattices (48). It has been shown by X-ray technique (13, 36) that organic chemicals may be trapped within the expanding lattices of montmorillonite clays.

Harris, Woolson and Hummer (27) reported that herbicide persistence was directly related to soil organic matter.

Several workers (23, 45) have shown that humic acid played a major role in adsorption. The active sites on the humic acid were alkyl groups. By varying the chain length of the alkyl groups it was found that atrazine adsorption increased logarithmically with increasing chain length.

Anderson and Stephenson (2) studied atrazine activity in southern Ontario soils and Manitoba soils. In Ontario soils they found no relationship between atrazine activity and clay content, organic matter content, or percent initial adsorption. However, in Manitoba soils activity was highly correlated with organic matter content and percent initial adsorption. Desorption studies using these two soil groups indicated that a significant proportion of the initially adsorbed atrazine was recovered from southern Ontario soils but not from Manitoba soils. The different phytotoxicity of atrazine in these two soil groups may be dependent upon the extent of readily reversible adsorption.

By determining the adsorptive capacities of a silt loam soil, Dunigan and McIntosh (16) suggested that the ether and alcohol extractable components of soil organic matter, eg. fats, oils and waxes had a negligible capacity to adsorb atrazine and the hot water extractable materials eg. polysaccharides had a small adsorptive capacity. Protein and nucleic acids had intermediate affinities and humic acid, lignin and quinizarin had high affinities for atrazine. Comparison of adsorptive isotherms of atrazine to lignin and quinizarin suggest that weak chemical bonds may contribute to retention of herbicide by soil organic matter.

Fusi, et al. (21) suggested that herbicide adsorption was inversely related to the degree of soil acidity in acid soils but was not a function of pH in neutral or calcareous soils.

Frissel (20) showed that increasing salt concentration increased adsorption due to salting out of the herbicide. In contrast to Fusi, et al. (21), Frissel found that increasing the H^+ ion concentration enhanced the adsorption of weak bases such as simazine.

Surfactants had no effect on atrazine adsorption (21). Granular formulations persist longer than wettable powders (19).

In soils with a low cation exchange capacity an increase in the water content increased herbicide concentrations in the soil solution (22). The principal effect of soil water content on herbicide phytotoxicity probably is associated with herbicide transport, which is more sensitive to change in water content than is the concentrations of herbicide in soil solution.

The initial water content of a soil influenced the concentration of a herbicide in solution after a 24 hour period (22). Herbicides applied to a wet soil diffused into water filled intra-aggregate pores. Conversely, when herbicides were applied to a dry soil, the herbicide was transported in solution into aggregate pores during the wetting process. The herbicide must diffuse out of the pores in order to participate in any subsequent equilibration.

Harris and Warren (26) suggested that there was no relationship between solubility and adsorption. Adsorption of a herbicide by an artificial anion exchanger bentonite (pH 8.5) was greater at $0^{o}C$ than at $50^{o}C$. In contrast, adsorption by an organic soil was the same at both temperatures.

Harris (24) concluded that the phytotoxicity and movement of herbicides in the soil was inversely related to the extent of adsorption. Harris (25) suggested that by comparing the mobilities of new herbicides with those whose mobility is known, should make it possible to predict the behaviour of new herbicides in the field.

<u>Breakdown by Soil Micro-organisms</u>

McCormick and Hiltbold (31) measured microbial responses to temperature, added energy material and time by evolution of CO_2 from herbicide treated soil samples. Atrazine inactivation was directly related to metabolism of soil organic carbon. Larger amounts of herbicide were inactivated per unit of soil carbon metabolized in a loamy sand than in a clay loam. This difference was associated with less specific surface and consequently greater concentration of the atrazine on the soil particles of the loamy sand than of the clay loam. Addition of microbial energy sources accelerated decomposition of atrazine in both soil types.

Herbicide decomposition was closely associated with repeated additions of energy sources, indicating an incidental or none preferential involvement in microbial breakdown. Decomposition increased with rise in temperature up to 25°C (11, 31, 37, 49).

Talbert and Fletchall (46) suggested that the inactivation of atrazine is most rapid when the soil environment was favourable for the growth of micro-organisms.

Fink, Fletchall and Calvert (18) determined the effect of atrazine residues on fungal and bacterial colonies. Atrazine at 5 pounds per acre had no influence upon the total number of fungal or bacterial colonies, yet variations in species occured. They suggested that high rates of fertilizer in combination with the herbicide increased the number of bacterial colonies.

Burschell (11) concluded that the decomposition of a triazine is largely due to the activity of micro-organisms because with increasing proportions of humus, the intensity of the breakdown process increased.

<u>Photodecomposition</u>

Photodecomposition occured when atrazine remained on the soil surface for extended periods of time (47).

Jordan, <u>et al</u>. (29) showed changes in the ultraviolet absorption spectra for atrazine after exposure to ultraviolet light or sunlight. There were differences between the changes in absorption spectra for herbicides when exposed to sunlight or ultraviolet light. This indicated that different products were being formed under different light conditions.

Chemical Hydrolysis

Armstrong and Chesters (3) suggested that adsorption of atrazine, catalyzed chemical hydrolysis of the herbicide. This enhancement was due to the hydrogen bonding between the adsorbent carboxyl and atrazine ring nitrogen atoms.

Armstrong, Chesters and Harris (4) showed that atrazine is degraded by chemical hydrolysis to hydroxyatrazine in perfusion systems. Atrazine degradation followed first order kinetics in sterilized soil and perfusion systems. Atrazine hydrolysis increased in acid soils which is consistent with the effect of pH on hydrolysis. The rate of hydrolysis of atrazine in sterilized soil was influenced by soil adsorption, pH and organic matter.

Contrary to Burschell (11), a number of workers (22, 30, 33, 44) using labelled atrazine concluded, that the chemical hydrolysis of chloroatrazine to hydroxyatrazine is a major pathway of degradation in soils. Microbial degradation was thought to be of minor importance. This conclusion is based on the fact that atrazine deactivation approached a first order reaction rate. This process also was more closely related to pH.

Influence of Cropping Systems on Dissipation

Sikka and Davis (43) using chemical analysis and bioassay methods reported that corn field plots had less atrazine remaining in the 0 to 6 inch depth than similarily treated fallow plots. Their finding was confirmed by studies conducted under controlled environments. In pot-culture experiments, uptake by corn during a 3 month period accounted for approximately 25 percent of the herbicide initially present.

By use of atrazine-^{14}C, Roeth and Lavey (39) showed that atrazine was taken up by corn roots. Atrazine uptake per gram of plant growth by corn was directly proportional to the concentration of atrazine in the soil. Corn had the greatest rate of uptake during the second and third weeks of growth, thereafter uptake followed closely the growth pattern of corn.

Birk and Roadhouse (8) found appreciably greater atrazine residue remaining in the corn plots than in similarily treated fallow plots, 43.8 percent and 18.3 percent of applied atrazine, respectively. They attributed the difference to a much drier soil which was characteristic of the corn plots during the season.

Nalewaja (32) concluded that atrazine dissipation was greater in the warm, moist soil of fallow plots than by corn roots in corn plots.

<u>Leaching</u>

Under Manitoba conditions, Bergstresser (7) found that a high percentage of the initial atrazine applied remained in the top 0 to 2 inches of soil. These results are in agreement with work done at Guelph, Ontario (8) and North Dakota (32) where atrazine movement was limited.

Burnside, et al. (10) found that atrazine leached down to a 36 inch depth in 6 Nebraska soils during a 4 month period after application. The greatest leaching occured in a very fine sandy loam which received 11 inches of rainfall during this period but approximately 2.5 inches of rain fell within a 2 day period after application. They concluded that increased leaching of the herbicide into the soil profile was an avenue for herbicide dissipation.

Burnside, et al. (9) using an oat bioassay test showed that atrazine leached down into the 12 to 18 inch soil depth after 4 months and the 18 to 24 inch depth or greater after 16 months depending on the soil type and moisture conditions. The greatest leaching occured in the soil exposed to high rainfall. They concluded that once leached into the soil profile, further breakdown is greatly reduced because of the lower soil temperatures and microbial activity.

METHODS AND MATERIALS

Field experiments were established in 1970 at the University of Manitoba, Field Research Laboratory, Winnipeg, Manitoba, Graysville, Manitoba, and at the Elm River Research Farm, Portage la Prairie, Manitoba. In 1971 similar experiments were established at the University of Manitoba and at Carman, Manitoba. Soil characteristics for all sites are given in Table 1.

Corn was seeded at all sites at the rate of 25,000 seeds per acre (in fallow plots corn was removed prior to herbicide treatment). Herbicides were applied post-emergence to crop and/or weeds with a bicycle sprayer and are listed in Table 2.

The experimental design was a split-plot over corn and fallow with 4 replications. The plot size was 8.19 x 18.20 m with the central 6.4 m being treated.

In carrying out the analysis of variance the plot yield was converted to a percentage of check. This was done to reduce errors due to soil factors between corn and fallow plots.

Table 1. Physical and chemical characteristics of soil at 4 locations.

Site	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	Organic matter (%)	Cation exchange capacity (meq/100 g)	Moisture-holding capacity (%)
Winnipeg	0-15	16.5	41.0	42.5	7.7	2.6	31.6	47.3
Graysville	0-15	77.5	9.2	13.3	8.0	2.8	14.5	20.2
Portage la Prairie	0-15	3.1	61.6	35.3	7.9	3.3	31.1	35.2
Carman	0-15	75.9	10.6	13.5	8.1	3.8	18.5	21.8

Table 2. Herbicide treatments applied at all sites 1970-71.

Herbicide	Formulation	Rate (kg/h)
Atrazine	wettable powder	2.24
Atrazine	wettable powder	4.48
SD15418	wettable powder	2.24
SD15418	wettable powder	4.48
S6115	emulsifiable concentrate	1.12
S6115	emulsifiable concentrate	2.24
Check		

Experiment 1. Triazine residue trial, Winnipeg, 1970.

The corn hybrid De Kalb 22 was planted June 10/70. Fertilizer (168.1 kg/h, 14-14-7) was side banded at the time of seeding. The herbicide treatments were applied July 8/70 in a spray volume of 182.4 l/h when the corn was 15 cm in height.

In 1971, the corn stubble was cut and removed from the plot area. On May 6/71 the experimental area was seeded to oats (*Avena sativa* L. var. Russell) directly into the stubble, disturbing the soil surface as little as possible. Fertilizer (56 kg/h, 11-48-0) was applied with the seed, after oat emergence 112.1 kg/h, 14-14-0 was broadcast on the area that was in corn the previous year. Visual ratings were made several times during the year to observe the effect of the herbicidal residue on the oats. The ratings were made on a scale of 0 to 9 where 0 = no crop tolerance and 9 representing complete crop tolerance.

Harvesting of oats was done with a Hege combine, taking 7.32 m^2 from each plot. The sample from each plot was cleaned and weighed.

Experiment 2. Triazine residue trial, Graysville, 1970.

The corn hybrid Morden 67 was planted June 3/70. Fertilizer (224.2 kg/h, 34-0-0) was broadcast and (134.5 kg/h, 11-48-0) was side banded at the time of seeding. The herbicide treatments were applied July 4/70 in a spray volume of 182.4 l/h when the corn was 15-20 cm in height.

In 1971, the corn stubble was removed from the plot area. On May 18/71 the experimental area was seeded to oats. Fertilizer was applied as in Experiment 1. Similar rating, harvesting and analysis was carried out as in Experiment 1.

<u>Experiment 3.</u> Triazine residue trial, Portage, 1970.

The corn hybrid Morden 67 was planted June 2/70 and fertilizer was side banded at a rate of 280.2 kg/h, 23-23-0. The herbicide treatments were applied July 5/70 in a spray volume of 182.4 l/h when the corn was 12-15 cm in height.

In 1971, the corn stubble was removed from the plot area. The area was shallow cultivated in the same direction as the plot length before seeding. On May 31/71 the experimental area was seeded to oats. Fertilizer was applied in a similar manner as Experiment 1. Similar rating, harvesting and analysis was carried out as in Experiment 1.

<u>Experiment 4.</u> Triazine residue bioassay, Winnipeg, 1971.

The corn hybrid Morden 67 was seeded May 10/71. Fertilizer was broadcast (224.2 kg/h, 27-14-0) and 112.1 kg/h, 34-0-0 was side banded at the time of seeding. The herbicide treatments were applied June 2/71 in a spray volume of 191.8 l/h when the corn was 10-12 cm in height.

Experiment 5. Triazine residue bioassay, Carman, 1971.

The corn hybrid Morden 67 was seeded June 3/71 and 67.3, 44.8, 61.6 kg/h of nitrogen (N), phosphorous (P_2O5) and potassium (K_2O), respectively, was spread. The herbicide treatments were applied June 21/71 in a spray volume of 191.8 l/h when the corn was 10-12 cm in height.

Bioassay of soil samples for triazine residues.

In 1970, soil was obtained from the 0-5, 5-10 and 10-15 cm depths from both the corn and fallow plots, 51 days after application. These 1970 samples from the various replicates were bulked in plastic bags and frozen for a 6 month period.

In 1971, soil samples were taken immediately after application (0-5 cm level from the fallow plots), 24 and 67 days after application (0-5, 5-10 and 10-15 cm levels) from both the corn and fallow plots.

The samples from each of the 4 replicates were bulked, dried, ground (20 mesh diameter) and thoroughly mixed. The samples from the 0-5 cm level were mixed with soil from the 0-5 cm level checks, so that the herbicide content was within the range of the standards.

Soil (200 gms) from the field sample was placed in 7 oz plastic cups. Six oat seeds were placed in each cup and the soil watered to field capacity. Fertility levels were maintained using 25 mg/cup of 15-30-15. Each treatment was replicated 5 times and the cups were randomly placed in a growth chamber maintained at 75° F, a 16-hr day length and a light intensity of 2400 ft-c.

The soil was brought up to field capacity every second day. Plants were thinned to 2 uniform seedlings per cup after the oat seedlings emerged. The plants were harvested 3 weeks after planting and dry weights recorded.

Standards of .125, .5, 1.0 and 2.0 ppmw of atrazine, SD15418 and S6115 were prepared using untreated soil from the 0-15 cm depth from each location. The same procedures were carried out on the herbicide standards as for the soil samples from the field plots.

The level of triazine residues remaining in the field samples were calculated from the standard curve, by measuring the percent growth reduction of oats cultured in the field samples.

RESULTS

Standard concentration data for atrazine, SD15418 and S6115

Standard concentration for the herbicides and locations were computed and are presented in Tables 3, 4 and 5. Figure 1 presents the standard curves at each location.

Table 3. Summary of data for atrazine (expressed as a percent of control) at all 4 locations.

Site	Rate of atrazine added (ppmw)					Average effect of site
	0	.125	.500	1.00	2.00	
Winnipeg	100	46.3	13.8	6.7	2.9	33.9[a]
Graysville	100	65.5	15.5	7.1	2.7	38.2
Portage	100	54.5	22.5	6.4	2.8	37.2
Carman	100	52.5	19.5	8.4	3.5	36.8
Average effect of rate applied	100[b]	54.7	17.8	7.2	2.9	

(a) LSD.05 for average effect of site = 3.0.

(b) LSD.05 for average effect of rate applied = 3.3.

Table 4. Summary of data for SD15418 (expressed as a percent of control) at all 4 locations.

Site	Rate of SD15418 added (ppmw)					Average effect of site
	0	.125	.500	1.00	2.00	
Winnipeg	100	72.3	41.2	29.3	4.9	49.5[(a)]
Graysville	100	87.3	73.4	36.5	8.3	61.1
Portage	100	77.5	61.3	22.8	5.7	53.5
Carman	100	82.2	58.6	22.5	7.6	54.2
Average effect of rate applied	100[(b)]	79.8	58.6	27.8	6.6	

(a) LSD.05 for average effect of site = 7.3.

(b) LSD.05 for average effect of rate applied = 8.1.

Table 5. Summary of data for S6115 (expressed as a percent of control) at all 4 locations.

Site	Rate of S6115 added (ppmw)					Average effect of site
	0	.125	.500	1.00	2.00	
Winnipeg	100	65.7	19.4	7.5	4.3	39.4[a]
Graysville	100	61.9	15.5	7.5	4.4	37.9
Portage	100	66.1	25.4	11.4	4.8	41.5
Carman	100	63.5	24.3	10.4	3.8	40.4
Average effect of rate applied	100[b]	64.3	21.2	9.2	4.3	

(a) LSD.05 for average effect of site = 3.4.

(b) LSD.05 for average effect of rate applied = 3.8.

For each increase in concentration of herbicide there was a significant decrease in percent growth reduction. These results show that differences in herbicide levels can be detected between 0 and 2 ppmw. There was very little difference between sites. Differences that appeared (eg. Table 1. Winnipeg and Graysville) may not have been real since each site was evaluated at different times in the growth chamber. Visual observations of oat injury at various rates of atrazine, SD15418 and S6115 are shown on Plates 1, 2 and 3. Since the visual effects were similar for all locations only the standards from the Carman site are illustrated.

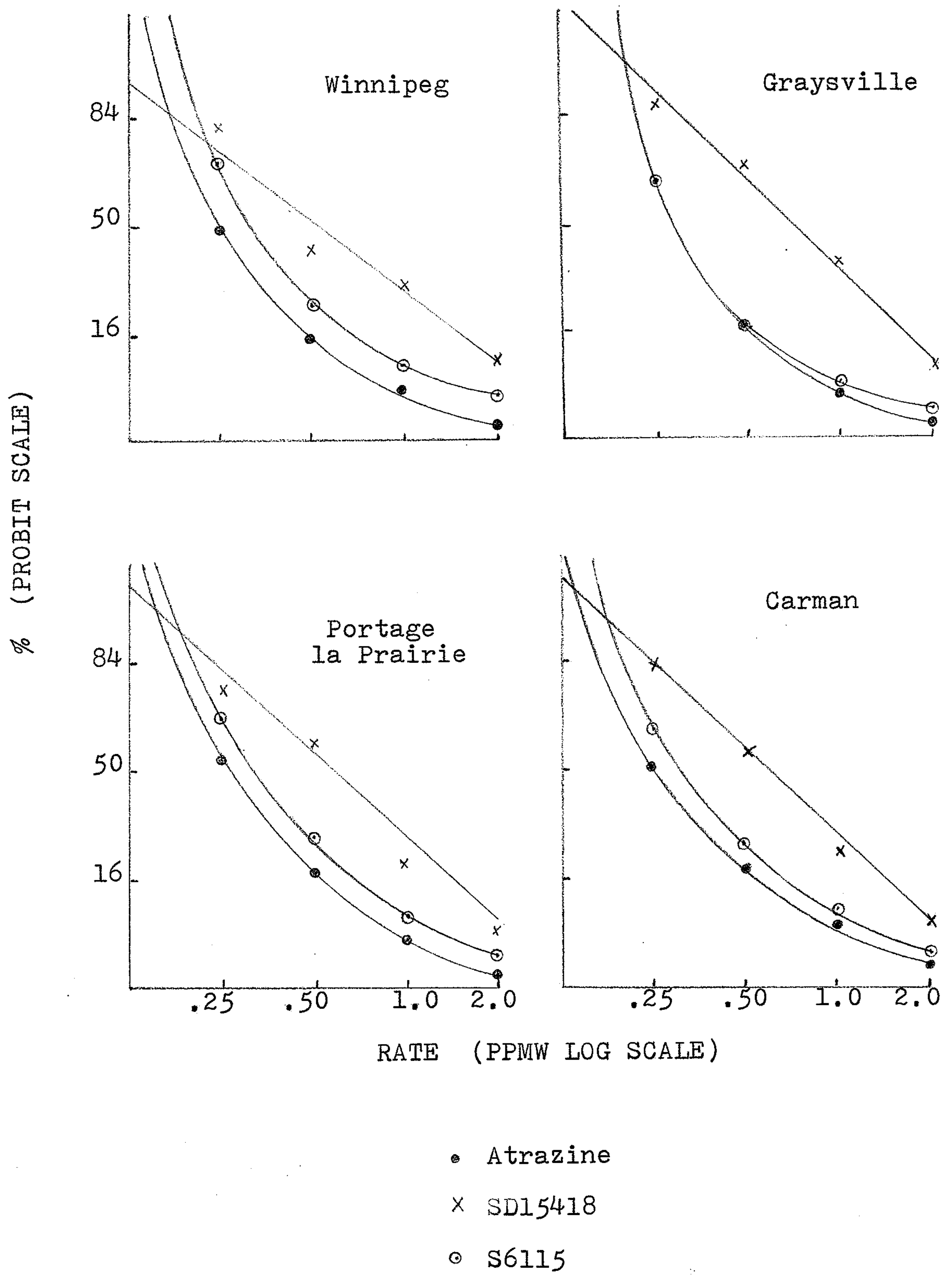

Figure 1. Herbicide standard curve for atrazine, SD15418 and S6115 at 4 locations.

Plate 1. Effect of Atrazine on oats at 0, .125, .500, 1.0, and 2.0 ppmw.

Plate 2. Effect of SD15418 on oats at 0, .125, .500, 1.0, and 2.0 ppmw.

Plate 3. Effect of S6115 on oats at 0, .125, .500, 1.0, and 2.0 ppmw.

Experiment 1. Triazine residue trial, Winnipeg, 1970.

The growth chamber bioassay results showing the percent recovery of atrazine, SD15418 and S6115 51 days after herbicide application are given in Table 6.

Table 6. Percent recovery of atrazine, SD15418 and S6115 at successive depths, 51 days after initial application to corn and fallow (Winnipeg 1970).

a) Atrazine	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	65.0	70.0	75.0	53.5
	5-10	3.0	2.0	3.0	2.0
	10-15	0	0	0	0
	Total	68.0	72.0	78.0	55.5
b) SD15418	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	57.5	66.0	70.0	48.5
	5-10	5.0	3.0	6.0	4.0
	10-15	0	0	0	0
	Total	62.5	69.0	76.0	52.5
c) S6115	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		1.12	2.24	1.12	2.24
	0-5	79.5	75.0	72.5	66.0
	5-10	0	2.0	0	0
	10-15	0	0	0	0
	Total	79.5	77.0	72.5	66.0

In 1971, field bioassays were conducted. Visual observations were averaged for 3 dates and 4 replications and are presented in Table 7. Due to the high degree of variability from plot to plot yield data is presented on a plot basis in Table 8.

Table 7. Degree of oat injury - average of 3 dates and 4 replications (Winnipeg, 1971).

Treatment	Rate (kg/h)	Corn	Fallow
Atrazine	2.24	1.0	1.0
Atrazine	4.48	1.0	0
SD15418	2.24	8.0	8.0
SD15418	4.48	6.0	5.0
S6115	1.12	4.0	3.0
S6115	2.24	0	0
Check		9.0	9.0

Table 8. Grain yield of oats (expressed as a percent of check) Winnipeg, 1971.

Treatment	Rate (kg/h)	Corn 1	2	3	4	Average
Atrazine	2.24	0[a]	0	0	59.5	14.9[b]
Atrazine	4.48	0	28.4	0	0	7.1
SD15418	2.24	99.1	70.6	94.7	98.5	90.7
SD15418	4.48	110.7	63.3	114.7	0	72.2
S6115	1.12	27.0	0	97.8	67.0	48.0
S6115	2.24	21.7	0	0	0	5.4
Check		100	100	100	100	100
		Average oat yield in corn plots				48.3

Treatment	Rate (kg/h)	Fallow 1	2	3	4	Average
Atrazine	2.24	102.3	0	0	0	25.6[b]
Atrazine	4.48	0	75.8	0	0	19.0
SD15418	2.24	106.8	42.7	81.3	77.9	77.2
SD15418	4.48	105.2	53.8	87.5	0	61.7
S6115	1.12	102.1	35.5	0	0	34.4
S6115	2.24	0	0	0	0	0
Check		100	100	100	100	100
		Average oat yield in fallow plots				45.4

(a) 0 signifies that there was no oat growth on that particular plot.

(b) LSD.05 for sub-plot treatments for the same main plot (corn or fallow) = 31.9.

No difference in average oat yield (expressed as a percentage of check) between corn and fallow was observed.

Experiment 2. Triazine residue trial, Graysville, 1970.

The growth chamber bioassay results showing the percent recovery of atrazine, SD15418 and S6115 51 days after herbicide application are given in Table 9.

Table 9. Percent recovery of atrazine, SD15418 and S6115 at successive depths, 51 days after initial application to corn and fallow (Graysville, 1970).

	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
a) Atrazine		2.24	4.48	2.24	4.48
	0-5	47.5	65.0	50.0	46.5
	5-10	6.0	3.0	2.0	2.0
	10-15	0	2.0	0	0
	Total	53.5	70.0	52.0	48.5
b) SD15418	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	43.5	37.5	32.5	23.5
	5-10	7.0	2.0	5.0	3.0
	10-15	0	4.0	0	0
	Total	50.5	43.5	37.5	26.5
c) S6115	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		1.12	2.24	1.12	2.24
	0-5	47.5	55.0	52.5	39.0
	5-10	8.0	5.0	4.0	4.0
	10-15	0	6.0	0	2.0
	Total	55.5	66.0	56.5	45.0

In 1971, field bioassays were conducted. Visual observations were averaged for 3 dates and 4 replications and are presented in Table 10. Yield data is presented on a plot basis in Table 11.

Table 10. Degree of oat injury - average of 3 dates and 4 replications (Graysville, 1971).

Treatment	Rate (kg/h)	Corn	Fallow
Atrazine	2.24	0	3.5
Atrazine	4.48	0	0
SD15418	2.24	9.0	9.0
SD15418	4.48	9.0	9.0
S6115	1.12	6.0	9.0
S6115	2.24	0	1.0
Check		9.0	9.0

Table 11. Grain yield of oats (expressed as a percent of check) Graysville, 1971.

Treatment	Rate (kg/h)	Corn 1	Corn 2	Corn 3	Corn 4	Average
Atrazine	2.24	0[a]	18.7	0	0	4.7[b]
Atrazine	4.48	0	0	0	0	0
SD15418	2.24	95.3	104.6	105.9	102.4	102.1
SD15418	4.48	104.7	102.9	113.7	102.6	106.0
S6115	1.12	94.0	79.5	59.6	47.5	70.2
S6115	2.24	0	39.5	0	0	7.4
Check		100	100	100	100	100
		Average oat yield in corn plots				56.1

Treatment	Rate (kg/h)	Fallow 1	Fallow 2	Fallow 3	Fallow 4	Average
Atrazine	2.24	78.2	36.7	41.8	30.3	46.8[b]
Atrazine	4.48	0	0	0	0	0
SD15418	2.24	109.8	117.2	136.1	93.6	114.2
SD15418	4.48	121.5	100.5	97.6	114.5	108.5
S6115	1.12	86.6	101.2	116.1	118.3	105.5
S6115	2.24	29.6	60.0	12.9	7.6	26.9
Check		100	100	100	100	100
		Average oat yield in fallow plots				71.8

(a) 0 signifies that there was no oat growth on that particular plot.

(b) LSD.05 for sub-plot treatments for the same main plot (corn or fallow) = 13.8.

The grain yield of oats (expressed as a percentage of check) was greater on fallow plots, 71.8, than on corn plots , 56.1, (LSD.05 = 7.5).

Experiment 3. Triazine residue trial, Portage, 1970.

The growth chamber bioassay results showing the percent recovery of atrazine, SD15418 and S6115 51 days after herbicide application are given in Table 12.

Table 12. Percent recovery of atrazine, SD15418 and S6115 at successive depths, 51 days after initial application to corn and fallow (Portage, 1970).

a) Atrazine	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	70.0	67.5	70.0	87.5
	5-10	3.0	2.0	4.0	3.0
	10-15	0	4.0	0	0
	Total	73.0	73.5	74.0	90.5

b) SD15418	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	77.5	65.5	67.2	60.0
	5-10	2.0	4.0	0	0
	10-15	0	0	0	0
	Total	79.5	69.0	67.2	60.0

c) S6115	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		1.12	2.24	1.12	2.24
	0-5	93.0	70.0	90.0	75.0
	5-10	0	4.0	0	4.0
	10-15	0	0	0	0
	Total	93.0	74.0	90.0	79.0

In 1971, field bioassays were conducted. Visual observations were averaged for 2 dates and 4 replications and are presented in Table 13. Due to the high degree of variability from plot to plot yield data is presented on plot basis in Table 14.

Table 13. Degree of oat injury - average of 2 dates and 4 replications (Portage, 1971).

Treatment	Rate (kg/h)	Corn	Fallow
Atrazine	2.24	3.0	4.0
Atrazine	4.48	2.5	2.5
SD15418	2.24	6.5	8.0
SD15418	4.48	3.5	4.5
S6115	1.12	2.5	2.5
S6115	2.24	2.0	1.0
Check		9.0	9.0

Table 14. Grain yield of oats (expressed as a percent of check) Portage, 1971.

Treatment	Rate (kg/h)	Corn 1	Corn 2	Corn 3	Corn 4	Average
Atrazine	2.24	0[a]	95.9	0	56.8	38.2[b]
Atrazine	4.48	0	95.4	0	59.0	38.6
SD15418	2.24	86.8	103.9	99.7	0	72.6
SD15418	4.48	103.8	0	0	90.5	48.6
S6115	1.12	0	75.7	80.2	99.6	63.9
S6115	2.24	67.0	87.4	0	0	38.6
Check		100	100	100	100	100
		Average oat yield in corn plots				66.7

Treatment	Rate (kg/h)	Fallow 1	Fallow 2	Fallow 3	Fallow 4	Average
Atrazine	2.24	114.5	77.7	0	0	48.1[b]
Atrazine	4.48	38.8	71.8	0	33.0	35.9
SD15418	2.24	91.5	104.9	79.8	78.3	88.6
SD15418	4.48	120.2	73.9	0	25.0	54.8
S6115	1.12	0	0	75.4	95.3	42.7
S6115	2.24	0	0	62.5	0	15.6
Check		100	100	100	100	100
		Average oat yield in fallow plots				55.1

(a) 0 signifies that there was no oat growth on that particular plot.

(b) LSD.05 for sub-plot treatments for the same main plot (corn or fallow) = 43.4.

No difference in average oat yield (expressed as a percentage of check) between corn and fallow was observed.

Experiment 4. Triazine residue bioassay, Winnipeg, 1971.

The growth chamber bioassay results showing the percent recovery of atrazine, SD15418 and S6115 immediately, 24 and 67 days after herbicide application are presented in Tables 15, 16 and 17.

Table 15. Percent recovery of atrazine, SD15418 and S6115 from the 0-5 cm depth, immediately after herbicide application to fallow (Winnipeg, 1971).

a) Atrazine	Depth (cm)	Rate of application (kg/h)	
		Fallow	
		2.24	4.48
	0-5	97	107
b) SD15418	Depth (cm)	Rate of application (kg/h)	
		Fallow	
		2.24	4.48
	0-5	100	110
c) S6115	Depth (cm)	Rate of application (kg/h)	
		Fallow	
		1.12	2.24
	0-5	96	110

Table 16. Percent recovery of atrazine, SD15418 and S6115 at successive depths, 24 days after initial application to corn and fallow (Winnipeg, 1971).

	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
a) Atrazine		2.24	4.48	2.24	4.48
	0-5	88.0	93.0	89.0	102.0
	5-10	0	0	0	0
	10-15	0	0	0	0
	Total	88.0	93.0	89.0	102.0
b) SD15418	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	87.0	87.5	92.0	87.0
	5-10	0	0	0	0
	10-15	0	0	0	0
	Total	87.0	87.5	92.0	87.0
c) S6115	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		1.12	2.24	1.12	2.24
	0-5	93.0	94.0	102.0	92.5
	5-10	0	0	0	0
	10-15	0	0	0	0
	Total	93.0	94.0	102.0	92.5

Table 17. Percent recovery of atrazine, SD15418 and S6115 at successive depths, 67 days after initial application to corn and fallow (Winnipeg, 1971).

a) Atrazine	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	62.0	55.0	59.0	51.0
	5-10	6.5	3.0	6.0	4.0
	10-15	0	3.0	0	0
	Total	68.5	61.0	65.0	55.0

b) SD15418	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	59.0	50.0	52.0	47.5
	5-10	0	4.0	0	4.0
	10-15	0	3.0	0	0
	Total	59.0	57.0	52.0	51.5

c) S6115	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		1.12	2.24	1.12	2.24
	0-5	81.0	63.0	74.0	53.0
	5-10	0	4.0	0	4.0
	10-15	0	0	0	0
	Total	81.0	67.0	74.0	57.0

Experiment 5. Triazine residue bioassay, Carman, 1971.

The growth chamber bioassay results showing the percent recovery of atrazine, SD15418 and S6115 immediately, 24 and 67 days after herbicide application are presented in Tables 18, 19 and 20.

Table 18. Percent recovery of atrazine, SD15418 and S6115 from the 0-5 cm depth, immediately after herbicide application to fallow (Carman, 1971).

a) Atrazine	Depth (cm)	Rate of application (kg/h)	
		Fallow	
		2.24	4.48
	0-5	113	111

b) SD15418	Depth (cm)	Rate of application (kg/h)	
		Fallow	
		2.24	4.48
	0-5	96	108

c) S6115	Depth (cm)	Rate of application (kg/h)	
		Fallow	
		1.12	2.24
	0-5	120	95

Table 19. Percent recovery of atrazine, SD15418 and S6115 at successive depths, 24 days after initial application to corn and fallow (Carman, 1971).

a) Atrazine	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	100.0	77.0	88.0	75.5
	5-10	0	5.0	0	0
	10-15	0	0	0	0
	Total	100.0	82.0	88.0	75.5

b) SD15418	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	94.0	88.5	91.5	78.5
	5-10	0	3.0	0	0
	10-15	0	0	0	0
	Total	94.0	91.5	91.5	78.5

c) S6115	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		1.12	2.24	1.12	2.24
	0-5	85.0	81.5	83.0	79.5
	5-10	0	0	0	0
	10-15	0	0	0	0
	Total	85.0	81.5	83.0	79.5

Table 20. Percent recovery of atrazine, SD15418 and S6115 at successive depths, 67 days after initial application to corn and fallow (Carman, 1971).

	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
a) Atrazine		2.24	4.48	2.24	4.48
	0-5	60.0	48.0	53.0	44.0
	5-10	0	3.0	0	2.0
	10-15	0	2.0	0	0
	Total	60.0	53.0	53.0	46.0
b) SD15418	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		2.24	4.48	2.24	4.48
	0-5	55.5	48.0	38.0	33.0
	5-10	0	4.0	0	4.0
	10-15	0	0	0	0
	Total	55.5	52.0	38.0	37.0
c) S6115	Depth (cm)	Rate of application (kg/h)			
		Corn		Fallow	
		1.12	2.24	1.12	2.24
	0-5	56.0	50.0	46.0	32.0
	5-10	0	7.0	0	4.0
	10-15	0	0	0	0
	Total	56.0	57.0	46.0	36.0

DISCUSSION

Growth chamber bioassay

The nature and extent of triazine residues in Manitoba soils dictated the necessity for developing a standard bioassay to determine the soil residue characteristics of atrazine, SD15418 and S6115. The oat plant (*Avena sativa* L. var. Russell) which was sensitive to all herbicides, although showed less phytotoxicity to SD15418 (Figure 1.) than to either atrazine or S6115 was utilized as the bioassay plant.

The sensitivity of the bioassay was considered to be within 10 - 15 percent of the actual amount of herbicide applied. This variability was due to the subjective handling of the bioassay and could also be due to biological variability of the test species.

At all 4 sites investigated, atrazine, SD15418 and S6115 were primarily retained in the top 5 cm of soil. These results are in agreement with Bergstresser (7) and Birk, *et al*. (8) who found very little movement of atrazine in the soil profile. Soil analysis showed that there was no large differences in the organic matter content of soils among sites, but the clay content was variable (Table 1.). Therefore the variations in the cation exchange capacity of the soil can be attributed mainly to variations in clay content. Winnipeg and Portage la Prairie soils, which had the highest cation exchange capacity, had the greatest amount of triazine residue remaining. This is in agreement with McCormick, et al. (31) who found greater atrazine breakdown on sandy loam soils than on clay soils. In contrast, Oliver (34) found that atrazine, SD15418 and S6115 were less persistent on clay soils than on sandy loam soils. The greater amounts of herbicide found on clay soils may be explained on the basis of a slower soil warm up for these soils compared to the lighter textured Graysville and Carman soils. These cooler temperatures would retard microbial activity. Also, greater adsorption of triazine herbicide to the soil colloid or entrappment of the herbicide molecule in the clay lattice may result in less herbicide being available for decomposition in heavy clay soils.

The bioassay results indicate that under normal conditions, the triazine herbicides were not readily leached. At the Winnipeg site more leaching occured during 1971 than 1970; this may be due to the heavy rainfall that occured in July 1971 when 5.28 inches of rain fell. All sites appeared to have the same extent of leaching. This similarity suggests that the clay content (which varied considerably between sites) does not influence the degree of leaching.

Although, there was more herbicide movement in the soil profile with increasing rates initially applied, there was no direct relationship between the amount initially applied and the amount of triazine movement. With the exception of the Winnipeg site in 1970, all herbicides leached to a greater depth under corn than under fallow conditions. This difference may suggest that corn root growth increases the degree of percolation that can occur and as a consequence more leaching can take place. Under fallow conditions no herbicide was detected beyond the 5-10 cm depth except for S6115 at 2.24 kg/h at the Graysville site. It was shown that there is greater dissipation of atrazine, SD15418 and S6115 under fallow conditions in lighter textured Graysville and Carman soils than in clay soils. These results are in agreement with Nalewaja (32) and Birk, et al. (8) who found there was greater breakdown of atrazine under fallow conditions than in plots containing corn. The moisture levels in the corn plots, especially in the 0-5 cm depth where the greatest amount of herbicide remained, would be very low, while in the fallow plots the moisture levels would remain high. This difference would affect the breakdown of the herbicides by soil micro-organisms. These results are in agreement with Talbert, et al. (46) who found there was greater breakdown of atrazine when the soil environment was favourable for the growth of micro-organisms. No difference in dissipation was observed between corn and fallow in the heavy clay soils of Winnipeg and Portage la Prairie. This similarity suggests that under heavy clay soil conditions the moisture levels in the corn plots are maintained and microbial degradation of the herbicide would be similar between corn and fallow plots.

The percent of a triazine recovered generally decreased as the rate of application increased indicating inactivation of greater percentages of large rather than low rates during the same period. This inactivation at high rates suggested that the rate of herbicide dissipation did not follow a 1 st order reaction as Armstrong, et al. (4) concluded but was due largely to the activity of micro-organisms. This conclusion is in agreement with Burschell (11).

The loss of atrazine, SD15418 and S6115 was the least rapid immediately following application. This slow rate of dissipation suggests that the low temperatures in early summer are a factor limiting dissipation. Early summer may also be the period that the micro-organisms are adapting enzyme systems which are capable of breaking down the herbicides. All triazines appeared to dissipate at the same rate up to 24 days after application. After this date differences were observed in the rate of dissipation between the triazine herbicides. It was found that SD15418 degradation occured at a faster rate than either atrazine or S6115 in the sandy loam soils of Graysville and Carman. In the heavy clay soils of Winnipeg and Portage la Prairie, SD15418 dissipation was essentially the same as atrazine or S6115. In comparison, Oliver (34) working at Guelph found that the general order of persistence after 120 days was SD15418 $<$ atrazine $<$ S6115 on clay, loam and sandy loam soils.

Field bioassay

The degree of oat injury in field plots, suggests that there was less SD15418 residue remaining at all sites than atrazine or S6115. It is evident from Figure 1 that SD15418 is less toxic to oats than either atrazine or S6115. Although, a SD15418 plot may have more oat growth it may not be a true indicator of SD15418 residue present. To compare the amounts of triazine residue remaining in the field it would be necessary to find bioassay material that was equally sensitive to all triazines.

Visual observations of oat injury and yield data indicate that atrazine at 2.24 and 4.48 kg/h caused considerable damage to oats at all sites. Winnipeg and Portage la Prairie had no plant growth at 2.24 and 4.48 kg/h in either corn or fallow plots. At the Graysville site there was no plant growth in either corn or fallow plots at 4.48 kg/h. At 2.24 kg/h there appeared to be greater oat growth under fallow conditions compared to oats grown under corn conditions.

SD15418 treatments showed the least amount of oat damage at all sites compared to atrazine and S6115. Winnipeg and Portage la Prairie showed oat injury due to SD15418 even at the lowest rate. At the Graysville site no oat injury was detected in corn or fallow plots with either the 2.24 or 4.48 kg/h rate. In fact, oat yield in the SD15418 plots was greater than the oat yield in the checks. This may be due to the residual weed control that was observed in these plots. Plates 4 and 5 show a representative plot of SD15418 at 4.48 kg/h in fallow and a check showing the residual weed control.

Plate 4. Graysville, Fallow
SD15418 4.48 kg/h

Plate 5. Graysville, Fallow
untreated check

This residue weed control suggests that SD15418 is still present and active in the soil. Green Foxtail (<u>Setaria viridis</u> (L.) Beauv.) may be a better bioassay species for SD15418 than oats. SD15418 may be degraded to some other product which has a phytotoxic effect on green foxtail but not on oats.

S6115 caused extreme damage to oats at the Winnipeg and Portage la Prairie sites. At 1.12 kg/h some plots in both corn and fallow had no oat growth. At the Graysville site there was no detectable oat injury under fallow conditions at 1.12 kg/h but damage to oats was observed under corn conditions. At 2.24 kg/h less oat damage was observed in the fallow plots compared to the corn plots which had negligible plant growth.

The shallow cultivation of the Portage la Prairie plots did not appear to greatly affect the amount of triazine residue remaining. At the Winnipeg and Portage la Prairie sites all treatments showed extreme variability in both corn and fallow plots, either the treated plot showed very little oat damage or there was no oat growth. Yield data analysis showed there was no significant difference between corn and fallow plots.

At the Graysville site the variability between replicates was much less. Yield data analysis showed that there was a significant difference in oat yield (expressed as a percent of check) between corn and fallow plots, with the fallow yielding higher. This percent yield difference suggests that there is less triazine residue remaining under fallow conditions.

CONCLUSIONS

Studies were conducted to determine:

a) the degree of leaching of triazine herbicides,

b) the influence of cropping systems on the herbicide,

c) the degradation rate of atrazine, SD15418 and S6115.

Atrazine, SD15418 and S6115 did not readily leach in the soil horizon and primarily remained in the top 0-5 cm soil depth at all sites. In general there was greater movement of all triazines in corn plots compared to fallow plots. The higher the rate applied, the greater the movement of herbicide in the soil horizon.

In heavy clay soils of Winnipeg and Portage there was no difference in triazine breakdown between corn and fallow. However, in the very fine sandy loam of Graysville and Carman there was greater dissipation of herbicide in fallow than in corn plots.

Under heavy clay soil conditions all triazine herbicides studied appeared to persist to the same degree. In very fine sandy loam soils the general order of persistence was SD15418 $<$ atrazine and S6115 which were similar in their degree of persistence.

The use of atrazine, SD15418 and S6115 for weed control may cause injury to succeeding susceptible crops in heavy clay soils for at least 1 year where no tillage is applied.

In very fine sandy loam soils atrazine and S6115 may cause injury to succeeding susceptible crops a year after application where no tillage is applied. In contrast, the high rate (4.48 kg/h) of SD15418 did not cause injury to oats the following year after application. By using SD15418, susceptible crops could be grown in the rotation the following year.

The use of bioassays are an effective way of estimating the amount of residual triazine herbicide in the soil. However, care should be taken to find a bioassay species that is equally sensitive to all herbicides in the study. This is particularly important in carrying out field residue studies.

Work on the residual behaviour of triazine herbicides should be continued to determine

a) the effect "banding" of triazine herbicides has on residual injury on succeeding crops.

b) the effect of cultivation on triazine residues.

c) the number of years that the herbicide will remain active in the soil.

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APPENDIX A

Physical and chemical properties of atrazine, SD15418 and S6115.

Atrazine - 2-chloro-4-ethylamino-6-isopropylamino-1,3,5,-triazine.

Molecular Weight - 215.7.

Physical State and Colour - Crystalline, White.

Photodecomposition - Stable.

Vapor Pressure - 1.4 x 10^{-6} mm Hg at 30°C.

Solubility - Chloroform - 52000 mg/L at 27°C.

Methanol - 1800 mg/L at 27°C.

Water - 70 mg/L at 27°C.

SD15418 - 2-(4 chloro-6-ethylamino-S-triazine-2-ylamino) -2 methyl-propionitrile.

Physical State and Colour - Crystalline, White.

Photodecomposition - Stable to ultraviolet decomposition.

Vapor Pressure - 1.0 x 10^{-8} mm Hg at 30°C.

Solubility - Water - 160 mg/L at 30°C.

S6115 - 2-chloro-4-cyclopropylamino-6-isopropylamino-1,3,5,-triazine.

Molecular Weight - 227.70.

Physical State and Colour - Crystalline, White.

Photodecomposition - Stable.

Solubility - Insoluble in water.

APPENDIX B

Bioassay Calculations

It was assumed that the soil from .405 h (1 acre) in area and 15 cm deep weighed 2,240,000 kg (2 million lb). Therefore a 1.12 kg/h application was equivalent to .500 ppmw.

$$\frac{1.12 \text{ kg}}{.405 \text{ h}} \times \frac{.405 \text{ h}}{2,240,000 \text{ kg}} = .500 \text{ ppmw}$$

Therefore a .405 h area 5 cm in depth at 1.12 kg/h = 1.5 ppmw. Similarily 2.24 kg/h = 3 ppmw and 4.48 kg/h = 6 ppmw. The percent recovery was obtained by dividing the ppmw detected by the bioassay plants by the ppmw of triazine originally applied.

eg. 1.12 kg/h

$$\frac{\text{ppmw detected}}{1.5 \text{ ppmw}} \times 100 = \% \text{ recovery}$$

Similarily for 2.24 and 4.48 kg/h.

APPENDIX C

Table 1. ANOVA for atrazine (expressed as a percent of check) at all 4 locations.

Source	df	Sum of squares	Mean squares	F
Treatment	19	135740.93	7144.26	263.82*
Herbicide	4	134078.83	33519.71	1237.80*
Site	3	269.91	89.97	3.32*
H x S	12	1392.19	116.02	4.28
Error	80	2166.49	27.08	
Total	99	137907.42		

* Significant at .05 level of probability.

Table 2. ANOVA for SD15418 (expressed as a percent of check) at all 4 locations.

Source	df	Sum of squares	Mean squares	F
Treatment	19	115348.62	6070.98	36.4 *
Herbicide	4	111923.00	27980.75	167.8 *
Site	3	1650.39	550.13	3.29*
H x S	12	1775.23	147.94	.89
Error	80	13345.70	166.82	
Total	99	128694.32		

Table 3. ANOVA for S6115 (expressed as a percent of check) at all 4 locations.

Source	df	Sum of squares	Mean squares	F
Treatment	19	134375.99	7072.42	194.62*
Herbicide	4	133811.41	33452.85	920.55*
Site	3	183.13	55.37	1.52 n.s.[a]
H x S	12	381.45	31.79	.87
Error	80	2906.99	36.34	
Total	99	137282.98		

(a) Non-significant at .05 level of probability

APPENDIX D

Table 1. Grain yield of oats (gms/m^2) Winnipeg, 1971.

Treatment	Rate (kg/h)	Corn 1	Corn 2	Corn 3	Corn 4
Atrazine	2.24	0	0	0	378.3
Atrazine	4.48	0	156.5	0	0
SD15418	2.24	457.8	389.6	376.7	626.8
SD15418	4.48	511.3	349.2	456.3	0
S6115	1.12	124.5	0	389.2	426.4
S6115	2.24	100.3	0	0	0
Check		461.9	551.9	397.8	636.3

Treatment	Rate (kg/h)	Fallow 1	Fallow 2	Fallow 3	Fallow 4
Atrazine	2.24	427.3	0	0	0
Atrazine	4.48	0	387.7	0	0
SD15418	2.24	445.9	218.3	382.9	381.2
SD15418	4.48	439.1	275.4	412.0	0
S6115	1.12	426.4	181.7	0	0
S6115	2.24	0	0	0	0
Check		417.5	511.5	470.8	489.3

Table 2. Grain yield of oats (gms/m^2) Graysville, 1971.

Treatment	Rate (kg/h)	Corn 1	Corn 2	Corn 3	Corn 4
Atrazine	2.24	0	46.9	0	0
Atrazine	4.48	0	0	0	0
SD15418	2.24	237.4	260.7	249.0	206.0
SD15418	4.48	260.9	256.6	267.2	206.4
S6115	1.12	231.9	198.1	140.2	95.6
S6115	2.24	0	98.4	0	0
Check		249.1	249.3	235.1	201.2

Treatment	Rate (kg/h)	Fallow 1	Fallow 2	Fallow 3	Fallow 4
Atrazine	2.24	259.0	109.3	125.6	97.7
Atrazine	4.48	0	0	0	0
SD15418	2.24	363.6	349.6	408.6	301.9
SD15418	4.48	402.5	299.6	293.1	369.3
S6115	1.12	286.9	301.9	348.4	381.3
S6115	2.24	98.1	178.9	38.8	24.5
Check		331.2	298.2	300.2	322.4

Table 3. Grain yield of oats (gms/m^2) Portage, 1971.

Treatment	Rate (kg/h)	Corn 1	2	3	4
Atrazine	2.24	0	246.3	0	173.4
Atrazine	4.48	0	245.1	0	180.2
SD15418	2.24	204.0	266.7	263.5	0
SD15418	4.48	244.1	0	0	276.1
S6115	1.12	0	194.3	211.9	304.1
S6115	2.24	157.4	224.5	0	0
Check		235.1	256.8	264.2	305.2

Treatment	Rate (kg/h)	Fallow 1	2	3	4
Atrazine	2.24	255.1	196.7	0	0
Atrazine	4.48	86.3	181.6	0	78.9
SD15418	2.24	203.8	265.3	229.9	187.2
SD15418	4.48	276.6	187.0	0	59.8
S6115	1.12	0	0	217.1	227.9
S6115	2.24	0	0	180.1	0
Check		222.7	253.0	288.0	239.1

APPENDIX E

Table 1. ANOVA for grain yield of oats (expressed as a percent of check) Winnipeg, 1971.

Source of variation	df	Sum of squares	Mean squares	F
Block	3	5591.7	1863.9	1.162 n.s.[a]
C or F (a)	1	45.5	45.5	.028 n.s.
Error (a)	3	4811.1	1603.7	
Treatment (b)	6	67438.6	11239.8	11.38 *
Interaction	6	1484.2	247.4	.250 n.s.
Error (b)	36	35552.8	987.6	
Total	55	114923.9		

(a) Non-significant at .05 level of probability.

* Significant at .05 level of probability.

Table 2. ANOVA for grain yield of oats (expressed as a percent of check) Graysville, 1971.

Source of variation	df	Sum of squares	Mean squares	F
Block	3	1140.0	380.0	4.9 n.s.
C or F (a)	1	3374.4	3374.4	43.5 *
Error (a)	3	232.8	77.6	
Treatment (b)	6	106607.6	17767.9	96.1 *
Interaction	6	3555.9	592.7	3.2 *
Error (b)	36	6659.2	184.9	
Total	55	121569.9		

Table 3. ANOVA for grain yield of oats (expressed as a percent of check) Portage, 1971.

Source of variation	df	Sum of squares	Mean squares	F
Block	3	5673.4	1891.1	2.30 n.s.
C or F (a)	1	62.4	62.4	.075 n.s.
Error (a)	3	2465	821.7	
Treatment (b)	6	31351.2	5225.2	2.86 *
Interaction	6	2696.2	449.4	.247 n.s.
Error (b)	36	65635.1	1823.1	
Total	55	107883.3		

APPENDIX F

Table 1. Rainfall (inches) at all 4 locations from April thru to September 1970-71.

Site	Year	April	May	June	July	August	September
Winnipeg	1970	1.20	3.23	2.22	3.86	1.05	4.69
Winnipeg	1971	1.40	1.29	2.98	5.28	.89	3.15
Graysville	1970	3.90	2.75	2.26	2.40	1.75	2.21
Portage	1970	3.11	2.44	2.06	2.56	2.23	2.41
Carman	1971	1.42	1.57	3.38	2.95	1.21	3.09