USGA PROGRESS REPORT - FALL 1993

PESTICIDE AND FERTILIZER FATE IN TURFGRASSES MANAGED UNDER GOLF COURSE CONDITIONS IN THE MIDWESTERN REGION

University of Nebraska - Lincoln

Garald L. Horst, Project Coordinator
Associate Professor of Turfgrass Physiology

Patrick J. Shea
Professor of Agronomy-Pesticide Residues

William L. Powers
Professor of Soil Physics

Daniel R. Miller
Res. Tech. and Grad. Res. Assistant

Cindy L. Stuefer-Powell
Research Technologist

Leonard A. Wit
Supervisor, JSA Turfgrass Research Facility

Iowa State University

Nick E. Christians
Professor of Turfgrass Science

A. B. Blackmer
Professor of Soil Fertility

Steven K. Starrett
Graduate Research Assistant

UNL Cooperators

F. P. Baxendale, Assoc. Professor, Entomology
R. E. Gaussoin, Assoc. Professor, Horticulture
T. P. Riordan, Professor, Horticulture
G. Y. Yuen, Assist. Professor, Plant Pathology
J. E. Watkins, Professor, Plant Pathology

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CONTENTS

I. Undisturbed Soil Cores - Field Monitoring (Univ. of Nebraska/Iowa State Univ.)

A. 1991 and 1992 Field Studies

The field sites (Nebraska and Iowa) and treatment variables were detailed in the November 1991 Annual Progress Report. Protocols for 1992 field research at both locations followed those of 1991. Procedures for applying pesticides, excavating soil cores, processing soil cores, and analyzing soil cores for pesticides were similar to 1991. However, potassium bromide was applied on the first day of pesticide application in 1992 to serve as a conservative tracer of water movement in the soil.

Analytical effort has focused on determination of residues of pendimethalin, chlorpyrifos, isazophos and metalaxyl, using the procedure for simultaneous extraction and quantification described previous reports. Only minor modifications in the procedure have been made in the interim. Analysis of the four pesticide residues in turf/soil cores from field monitoring at the University of Nebraska and Iowa State University during 1991 and 1992 has been completed.

B. Residue Distribution between Verdure, Thatch and Soil

The amount of pesticide residue measured in the turf/soil system was often affected by site and climatic factors, as reflected in significant year, location and year x location differences (Table 1). These factors had a greater effect on isazofos residues than on the other pesticides (Tables 1 and 2). Chlorpyrifos levels varied by year and location, with more residue measured in 1992 and at the Iowa site than at the Nebraska site. Pendimethalin residues were lower in the first year, but differences between locations were smaller than observed for isazofos and chlorpyrifos. While more metalaxyl was measured in the Nebraska turf/soil profile in 1991, the Iowa site had more of the fungicide in 1992.

Verdure contained high concentrations of the pesticides immediately after application, but irrigation, rainfall and clipping reduced the amount of pesticide recovered from the plant material with time. The thatch layer was highly retentive of the pesticide residues, and generally contained the greatest amount of residue throughout the monitoring period (Figures 1-4). Relatively little chlorpyrifos, and very low amounts of pendimethalin moved through the thatch layer into the underlying soil.

The low mobility can be attributed to the very low water solubility and high hydrophobicity of the two pesticides (Table A-1). By comparison, metalaxyl was more mobile, with greater amounts penetrating the thatch layer. The relatively higher mobility of metalaxyl can be attributed to decreased retention in thatch because of its higher polarity and greater water solubility.

C. Pesticide Concentrations and Total Residue in the Soil

Pesticide concentrations were much lower in soil than in thatch at all sampling times during the study (Tables 3-6). Soil concentrations were highly skewed in the profile, and, with the exception of metalaxyl, generally were highest at the 0-5 and 5-10 cm depths throughout the monitoring period (Figures 9-22). Metalaxyl concentrations in soil were much higher than those of isazofos, which generally were higher than those of chlorpyrifos and pendimethalin. Metalaxyl moved through the entire soil column and concentration in soil increased up to 28 DAT at the Nebraska location in 1991, otherwise the maximum soil concentration was observed at 14 DAT. The lack of increase in isazofos in soil after 1 DAT suggested rapid degradation in soil in addition to limited mobility. Little chlorpyrifos or pendimethalin was found below a depth of 5 cm, and concentrations remained slightly higher in the top 2.5 cm throughout the sampling period. Soil concentrations of chlorpyrifos and pendimethalin generally did not change much after the first 7 days; however in 1991 maximum concentrations were observed at 28 DAT at both locations. Considering its mass, the soil contained little total pendimethalin or chlorpyrifos compared to the thatch layer. In contrast, a considerable amount of metalaxyl was found in the soil. Isazofos recovery from soil was less than metalaxyl, but generally greater than the amount of chlorpyrifos or pendimethalin measured. More soil residual metalaxyl and pendimethalin at the final (112 DAT) sampling suggested that they were more persistent than isazofos or chlorpyrifos.

There was a trend toward higher metalaxyl, chlorpyrifos and pendimethalin concentrations in the Nebraska soil (Tables 8 and 9). Higher concentrations of the pesticides in the verdure at the Iowa location constituted a higher proportion of the total residue in the turf/soil system than at Nebraska. The more mature turf at the Iowa location had a thicker thatch layer than that at Nebraska, reducing the amount of pesticide reaching the underlying soil. The Nicolett soil at the Iowa location is more porous than the Sharpsburg soil at the Nebraska site. While the difference could cause greater leaching at the Iowa site, the distribution of residues in the soil profile did not suggest significant differences in movement between the two soils.

Greater pesticide residue availability in the Iowa soil could result in greater plant uptake and higher concentrations of metalaxyl and possibly isazofos and chlorpyrifos, in the verdure. However, pendimethalin has very limited translocation in plants, suggesting that less of the herbicide was displaced from the verdure after application at the Iowa location. This could be attributed to differences in the timing and amount of irrigation and rainfall received at the two sites.

D. Pesticide Dissipation in the Turf/Soil Profile

Pesticide dissipation in the turf/soil profile appeared to fit the kinetics of first order or perhaps 3/2 order decay, with an exponential or hyperbolic loss of pesticide residue with time. First-order equations generally provided a better fit to the pendimethalin and chlorpyrifos data than for metalaxyl or isazofos (Table 7). Based on an R^2 value ≥ 0.81, first-order decay estimated DT_{50} values of 14, 14, 15, and 19 days for isazofos, chlorpyrifos, pendimethalin, and metalaxyl in the turf/soil profile. Additional curve-fitting will be required to adequately describe overall dissipation where pesticide residue data deviate significantly from first-order decay. While data for pesticide residues in soil often fit first-order decay for some period after application, it is not unusual for dissipation to be more adequately described by an order between one and two, reflecting the influence of other factors, such as sorption, or availability for degradation. In the turf system this is further complicated by differences in rates of degradation in verdure, thatch and soil, and because the thatch serves as a sustained source of pesticide as it moves into the underlying soil.

II. Undisturbed Soil Columns - Greenhouse Research

A. Initial UNL Greenhouse Study (1991-92)

The initial experiment included columns with porous plates receiving 2.5-cm irrigations, columns without porous plates receiving 2.5-cm irrigations, and columns with porous plates receiving 5-cm irrigations. Each treatment had four replicate columns. Results of the bromide movement through the columns in this study are reported in the attached manuscript.

B. Second UNL Greenhouse Study

The second greenhouse experiment at UNL began in September 1992. The experiment includes soils from the Nebraska and Iowa field sites, with 2.5-cm and 5-cm irrigation treatments. Porous plate assemblies are being used on all turf/soil columns. Four replicates of each treatment were included. All sixteen undisturbed cores were harvested and frozen during the first full week of 4 Jan. 1993. Chemical analysis is in progress.

C. Third UNL Greenhouse Study

The third greenhouse experiment at UNL began in December 1992. The experiment includes soils from the Nebraska and Iowa field sites, with 2.5-cm and 5-cm irrigation treatments. Porous plate assemblies are being used on all turf/soil columns. Four replicates of each treatment were included. All sixteen undisturbed cores were harvested and frozen during the week of 28 June 1993. Chemical analysis is in progress.

III. Publications and Presentations.

The following manuscript from UNL is in press for publication in Crop Science journal.

Horst, G.L., W.L. Powers, D.R. Miller, P.J. Shea, and E.A. Wicklund. 1994. Simulating natural drainage under turfgrass in fate studies. Crop. Sci. 34:Jan/Feb.

A manuscript from UNL and ISU is under preparation and will be submitted to Crop Science journal for review and publication.

Horst, G.L., P.J. Shea, N. Christians, D.R. Miller, C.S. Powell, and S.K. Starrett. 1994. Dissipation of chemicals in turfgrass under fairway management conditions. Crop. Sci. In preparation.

The following papers from UNL and ISU were presented at the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America meetings, 6-12 November 1993.

Luke, S.E., S.K. Starrett, N.E. Christians, and T.A. Austin. 1993. Comparing solute transport in undisturbed and disturbed soil columns under turfgrass conditions. Agron. Abstr. p. 76.

Horst, G.L., W.L. Powers, P.J. Shea, D.R. Miller, and C.L. Stuefer-Powell. 1993. Water and chemical mobility in intact turf/soil columns. Agron. Abstr. p. 144.

Shea, P.J., G.L. Horst, N.E. Christians, D.R. Miller, S.K. Starrett, and C.L. Stuefer-Powell. 1993. Two years of monitoring pesticide fate in established turfgrass. Agron. Abstr. p. 76.

The following papers from UNL and ISU were presented at the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America meetings, 1-6 November 1992.

Horst, G.L., P.J. Shea, D.R. Miller, C.L. Stuefer-Powell, and W.L. Powers. 1992. Turfgrass pesticide mobility in intact soil columns. Agron. Abstr. p. 170.

Miller, D.R., G.L. Horst, P.J. Shea, and W.L. Powers. 1992. A greenhouse system to study solute movement in intact field columns. Agron. Abstr. p. 174.

Shea, P.J., G.L. Horst, N.E. Christians, C.L. Stuefer-Powell, D.R. Miller, and S.K. Starrett. 1992. Monitoring the fate of four pesticides in established turfgrass. Agron. Abstr. p. 176.

Starrett, S.K., N.E. Christians, S.E. Luke, T.A. Austin, and A.M. Blackmer. 1992. Nitrogen movement in undisturbed and disturbed soil columns. Agron. Abstr. p. 176.

Table 1. Analysis of variance (ANOVA) on total pesticide residue in the turf/soil profile (verdure, thatch, soil). Probability of greater F ratio (Pr>F) for years, location, and sampling time.

	Isazafos	Metalaxyl	Chlorpyrifos	Pendimethalin
(Y)ear	.0011	.4910	.0002	.0012
(L)ocation	.0041	.5487	.0309	.2300
Y*L	.0607	.0657	.2283	.9290
(T)ime	.0001	.0001	.0001	.0001
Y*T	.0002	.5966	.0001	.0012
L*T	.0071	.2064	.0016	.1130
Y*L*T	.0069	.0366	.0145	.9722

Table 2. Mean total pesticide residues (g ha^{-1}) in the turf/soil profile (verdure, thatch, soil) by years and locations.

Location	Year	Isazofos	Metalaxyl	Chlorpyrifos	Pendimethalin
Nebraska	1991	53	910	82	273
Nebraska	1992	103	674	280	828
Iowa	1991	86	682	141	447
Iowa	1992	229	796	466	978

[1]Mean, estimated, from 24, 182cm^2 surface area turf/soil profiles 60cm deep and projected to a hectare basis.

Table 3. Total estimated isazofos, metalaxyl, chorpyrifos, and pendimethalin (pesticide) residue (g ha^{-1}) sampled at Mead, Nebraska in 1991.

			Days After Initial Application					
Pesticide	**Profile Component**	**Statistic**	**1**	**7**	**14**	**28**	**56**	**112**
Isazofos	Verdure	Mean[1]	2	1	0	0	0	0
		SD[2]	1	0	0	0	0	0
	Thatch	Mean	89	13	3	1	1	0
		SD	109	4	1	0	2	0
	Soil	Mean	82	83	16	16	4	6
		SD	70	119	12	8	2	1
	Total[3]	Mean	173	97	18	16	5	6
		SD	180	119	13	8	4	2
Metalaxyl	Verdure	Mean	18	14	5	6	1	3
		SD	2	6	2	4	2	4
	Thatch	Mean	438	126	47	7	0	0
		SD	127	43	29	4	0	0
	Soil	Mean	1724	1272	538	1070	124	68
		SD	885	1064	179	843	87	83
	Total	Mean	2179	1412	590	1082	125	71
		SD	855	1099	204	845	86	86
Chlorpyrifos	Verdure	Mean	28	28	6	3	0	0
		SD	15	12	2	1	0	0
	Thatch	Mean	175	64	98	22	4	2
		SD	58	42	56	8	2	1
	Soil	Mean	27	7	6	11	8	5
		SD	29	8	2	4	1	2
	Total	Mean	230	99	110	36	12	8
		SD	44	56	54	12	3	2
Pendimethalin	Verdure	Mean	68	66	12	9	0	0
		SD	10	29	4	5	0	0
	Thatch	Mean	672	239	239	83	13	5
		SD	123	77	113	31	8	1
	Soil	Mean	132	12	5	56	12	17
		SD	208	23	4	27	14	18
	Total	Mean	873	318	256	148	25	22
		SD	127	119	113	56	16	17

[1]Mean, estimated, from 4, 182cm^2 surface area turf/soil profiles 60cm deep and projected to a hectare basis.
[2]SD = sample standard deviation.
[3]Total = combined values of verdure, thatch, and soil.

Table 4. Total estimated isazofos, metalaxyl, chorpyrifos, and pendimethalin (pesticide) residue (g ha^{-1}) sampled at Mead, Nebraska in 1992.

			Days After Initial Application					
Pesticide	Profile Component	Statistic	1	7	14	28	56	112
Isazofos	Verdure	Mean[1]	17	4	1	0	0	0
		SD[2]	5	1	1	0	0	0
	Thatch	Mean	374	111	33	6	2	0
		SD	320	21	13	2	1	0
	Soil	Mean	54	2	4	4	3	0
		SD	31	2	1	4	5	0
	Total[3]	Mean	445	117	37	10	5	1
		SD	316	20	13	3	5	0
Metalaxyl	Verdure	Mean	86	32	21	3	0	0
		SD	16	14	9	3	0	0
	Thatch	Mean	1399	705	391	132	0	0
		SD	824	365	171	59	0	0
	Soil	Mean	95	129	642	317	93	1
		SD	50	50	136	289	52	1
	Total	Mean	1580	866	1054	451	93	1
		SD	847	367	292	264	52	1
Chlorpyrifos	Verdure	Mean	140	69	48	164	1	0
		SD	79	39	17	147	1	0
	Thatch	Mean	445	352	201	232	11	1
		SD	430	145	64	182	3	1
	Soil	Mean	2	3	5	4	2	1
		SD	1	2	3	4	1	1
	Total	Mean	587	424	254	400	13	3
		SD	457	158	75	186	3	2
Pendimethalin	Verdure	Mean	110	85	68	46	7	0
		SD	43	35	16	29	6	0
	Thatch	Mean	1741	1435	824	534	73	7
		SD	1664	381	224	172	15	4
	Soil	Mean	4	3	15	14	0	2
		SD	5	4	18	12	0	4
	Total	Mean	1854	1523	907	594	80	9
		SD	1698	382	225	166	14	7

[1]Mean, estimated, from 4, 182cm^2 surface area turf/soil profiles 60cm deep and projected to a hectare basis.
[2]SD = sample standard deviation.
[3]Total = combined values of verdure, thatch, and soil.

Table 5. Total estimated isazofos, metalaxyl, chorpyrifos, and pendimethalin (pesticide) residue (g ha^{-1}) sampled at Ames, Iowa in 1991.

Pesticide	Profile Component	Statistic	Days After Initial Application: 1	7	14	28	56	112
Isazofos	Verdure	Mean[1]	126	10	0	0	0	0
		SD[2]	53	5	0	0	0	0
	Thatch	Mean	254	43	12	6	3	7
		SD	100	10	6	2	1	11
	Soil	Mean	15	7	7	6	5	15
		SD	11	4	2	1	3	20
	Total[3]	Mean	394	60	19	12	8	22
		SD	98	13	7	2	3	20
Metalaxyl	Verdure	Mean	227	34	7	3	1	2
		SD	185	13	5	2	1	2
	Thatch	Mean	554	296	185	77	15	0
		SD	227	27	103	55	5	0
	Soil	Mean	393	797	922	428	130	24
		SD	506	451	319	172	81	13
	Total	Mean	1173	1128	1114	508	145	26
		SD	481	443	334	186	77	12
Chlorpyrifos	Verdure	Mean	108	33	4	1	1	0
		SD	43	8	1	0	0	0
	Thatch	Mean	235	183	111	56	12	23
		SD	94	39	42	27	5	32
	Soil	Mean	8	10	12	37	7	7
		SD	5	4	13	31	4	2
	Total	Mean	350	226	127	94	19	30
		SD	108	41	47	55	6	32
Pendimethalin	Verdure	Mean	149	87	7	2	0	0
		SD	70	18	2	1	0	0
	Thatch	Mean	731	922	379	217	66	15
		SD	249	263	174	97	24	19
	Soil	Mean	3	26	15	29	22	16
		SD	6	26	29	21	22	22
	Total	Mean	883	1035	400	248	87	31
		SD	232	279	164	107	23	40

[1]Mean, estimated, from 4, $182cm^2$ surface area turf/soil profiles 60cm deep and projected to a hectare basis.
[2]SD = sample standard deviation.
[3]Total = combined values of verdure, thatch, and soil.

Table 6. Total estimated isazofos, metalaxyl, chorpyrifos, and pendimethalin (pesticide) residue (g ha^{-1}) sampled at Ames, Iowa in 1992.

			Days After Initial Application					
Pesticide	Profile Component	Statistic	1	7	14	28	56	112
Isazofos	Verdure	Mean[1]	12	32	1	0	0	0
		SD[2]	10	24	1	0	0	0
	Thatch	Mean	462	475	76	8	8	3
		SD	284	143	81	4	3	1
	Soil	Mean	161	77	48	4	4	8
		SD	37	39	42	3	1	8
	Total[3]	Mean	635	583	125	12	12	10
		SD	296	153	122	4	2	10
Metalaxyl	Verdure	Mean	307	82	8	1	0	0
		SD	129	48	9	1	0	0
	Thatch	Mean	1041	1604	310	53	40	1
		SD	453	984	285	26	80	2
	Soil	Mean	455	278	412	87	87	6
		SD	236	193	399	49	92	5
	Total	Mean	1803	1965	729	141	128	7
		SD	672	962	689	41	133	5
Chlorpyrifos	Verdure	Mean	952	117	17	6	1	0
		SD	310	57	12	4	0	0
	Thatch	Mean	530	850	199	61	17	4
		SD	157	947	36	28	5	3
	Soil	Mean	12	8	4	2	9	3
		SD	7	6	4	1	10	2
	Total	Mean	1495	975	220	70	27	6
		SD	261	984	32	31	13	3
Pendimethalin	Verdure	Mean	130	184	47	22	0	0
		SD	56	101	40	12	0	0
	Thatch	Mean	1761	2355	959	299	68	17
		SD	641	1666	376	54	4	13
	Soil	Mean	7	2	3	8	6	1
		SD	8	2	4	11	9	1
	Total	Mean	1898	2541	1009	330	74	18
		SD	620	1743	362	56	5	13

[1]Mean, estimated, from 4, 182cm^2 surface area turf/soil profiles 60cm deep and projected to a hectare basis.
[2]SD = sample standard deviation.
[3]Total = combined values of verdure, thatch, and soil.

Table 7. Total pesticide residue in verdure, thatch, and soil as a function of sampling time after application. These functions are used for an initial estimate of time to 50 percent dissipation (DT_{50}).

Pesticide	Function Estimates	Mead, Nebraska 1991	Mead, Nebraska 1992	Ames, Iowa 1991	Ames, Iowa 1992
Isazofos	β_1	-0.02	-0.05	-0.02	-0.04
	R^2	0.45	0.81	0.29	0.54
	r	-0.67	-0.90	-0.54	-0.73
	SEYE[†]	1.03	0.98	1.23	1.38
	DT_{50}	30	14	35	19
Metalaxyl	β_1	-0.07	-0.14	-0.04	-0.08
	R^2	0.44	0.77	0.92	0.55
	r	-0.67	-0.88	-0.96	-0.74
	SEYE	3.08	3.07	0.44	2.82
	DT_{50}	10	5	19	9
Chlorpyrifos	β_1	-0.30	-0.05	-0.03	-0.05
	R^2	0.76	0.88	0.65	0.83
	r	-0.87	-0.94	-0.81	-0.91
	SEYE	0.66	0.75	0.74	0.84
	DT_{50}	24	13	27	15
Pendimethalin	β_1	-0.03	-0.05	-0.07	-0.05
	R^2	0.70	0.94	0.48	0.91
	r	0.84	-0.97	0.69	-0.95
	SEYE	0.86	0.51	2.89	0.57
	DT_{50}	21	14	10	15

SEYE[†] is standard error of Y (pesticide residue) estimate.

Table 8. Mean pesticide concentration in soil by year (1991-1992) and location (Mead, Nebraska and Ames, Iowa).

	Isazofos	Metalaxyl	Chorpyrifos	Pendimethalin
1991 - Nebraska	7.10	206.47	2.84	10.29
1992 - Nebraska	2.79	162.15	3.01	4.87
1991 - Iowa	4.10	71.70	0.58	2.24
1992 - Iowa	16.77	75.14	1.40	1.31
Nebraska	4.94	184.31	2.93	7.58
Iowa	10.44	73.42	1.00	1.77
1991	5.60	139.08	1.71	6.27
1992	9.78	118.65	2.21	3.09
TOTAL	7.69	128.86	1.96	4.68

Table 9. Analysis of variance (ANOVA) F probabilities for soil pesticide concentrations presented for application year, location, sampling date (time), and soil profile depth at Mead, Nebraska and Ames, Iowa.

4-WAY COMBINED

Variation Source†	Isazofos	Metalaxyl	Chorpyrifos	Pendimethalin
(Y)ear	.0141	.0001	.0028	.0077
(Location)	.0526	.3247	.0534	.4467
Y*L	.0004	.2541	.8809	.9547
(T)ime	.0001	.0001	.0598	.1859
T*Y	.0001	.0068	.2959	.2362
T*L	.3935	.0585	.9525	.1702
T*Y*L	.0001	.0001	.0098	.2325
(D)epth	.0001	.0001	.0001	.0001
D*Y	.0001	.0001	.0032	.0528
D*L	.0001	.0001	.0842	.5113
D*Y*L	.0001	.1781	.6347	.6358
D*T	.0001	.0001	.0102	.5052
D*T*Y	.0001	.0331	.1054	.2264
D*T*L	.0004	.0002	.1733	.0822
D*T*Y*L	.0001	.0001	.0028	.2454

†Y = 1991 and 1992, L = Nebraska and Iowa, T = Time, D = Depth.

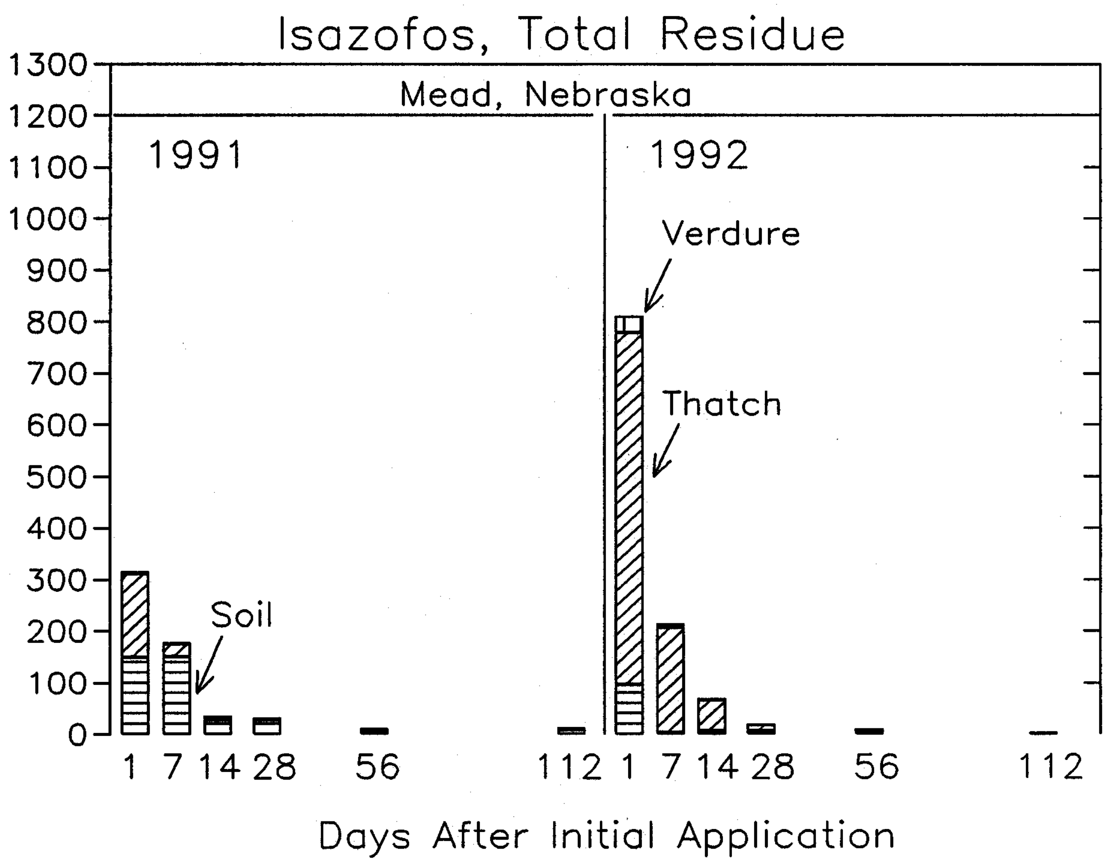

Figure 1. Partitioning of isazofos total estimated residue into verdure, thatch, and soil profile components at 6 sampling dates after initial application on 26 May 1991 and 10 May 1992 at Mead, Nebraska.

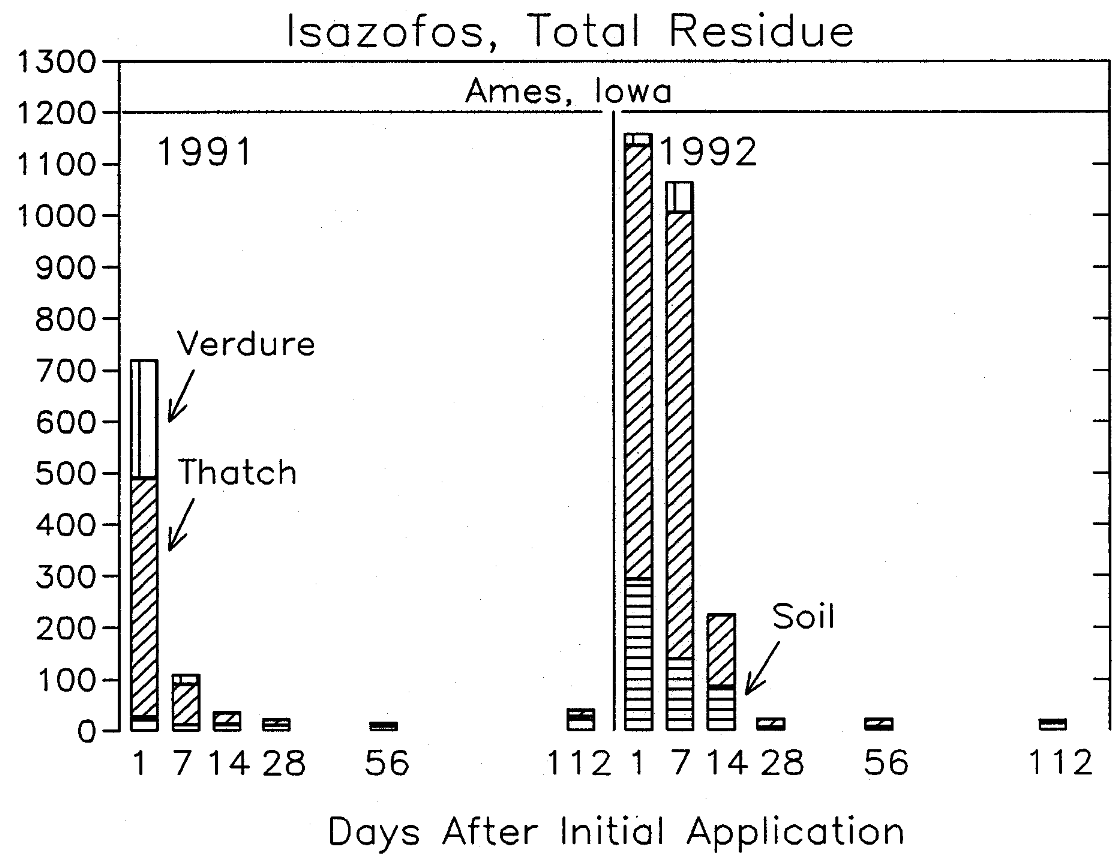

Figure 2. Partitioning of isazofos total estimated residue into verdure, thatch, and soil profile components at 6 sampling dates after initial application on 24 June 1991 and 14 June 1992, at Ames, Iowa.

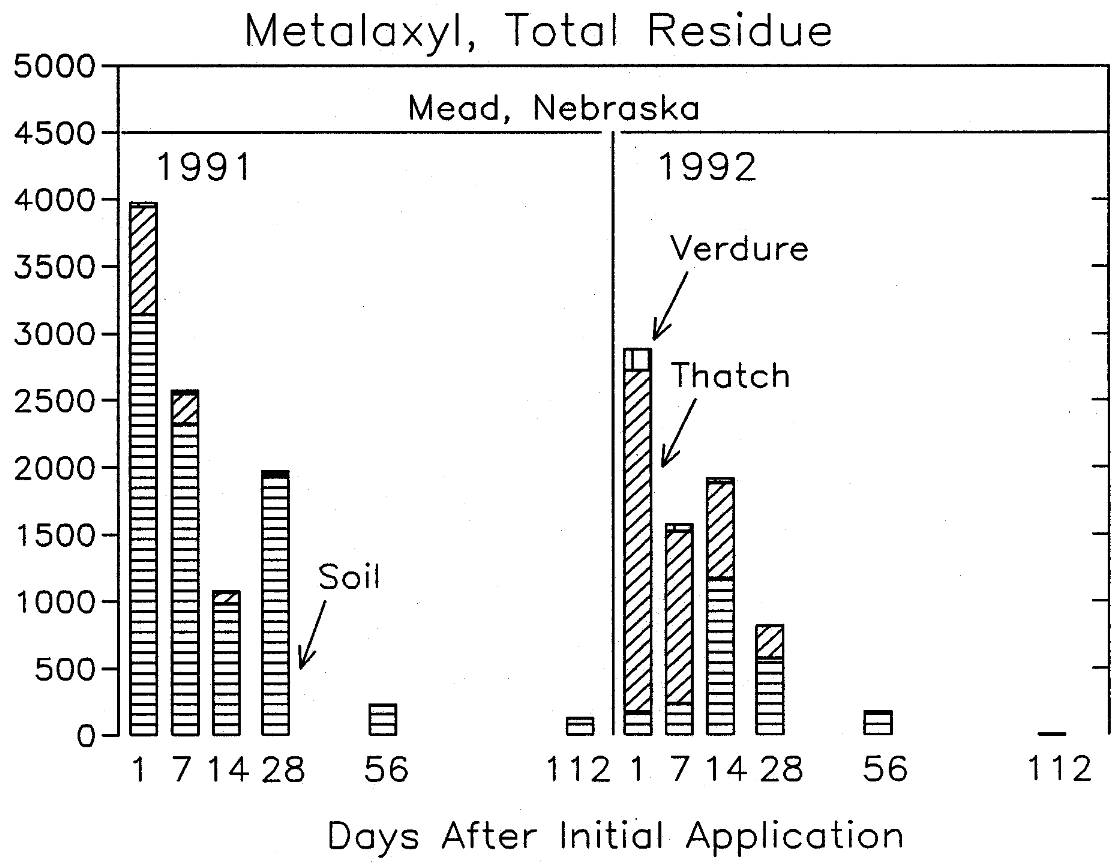

Figure 3. Partitioning of metalaxyl total estimated residue into verdure, thatch, and soil profile components at 6 sampling dates after initial application on 28 May 1991 and 12 May 1992, at Mead, Nebraska.

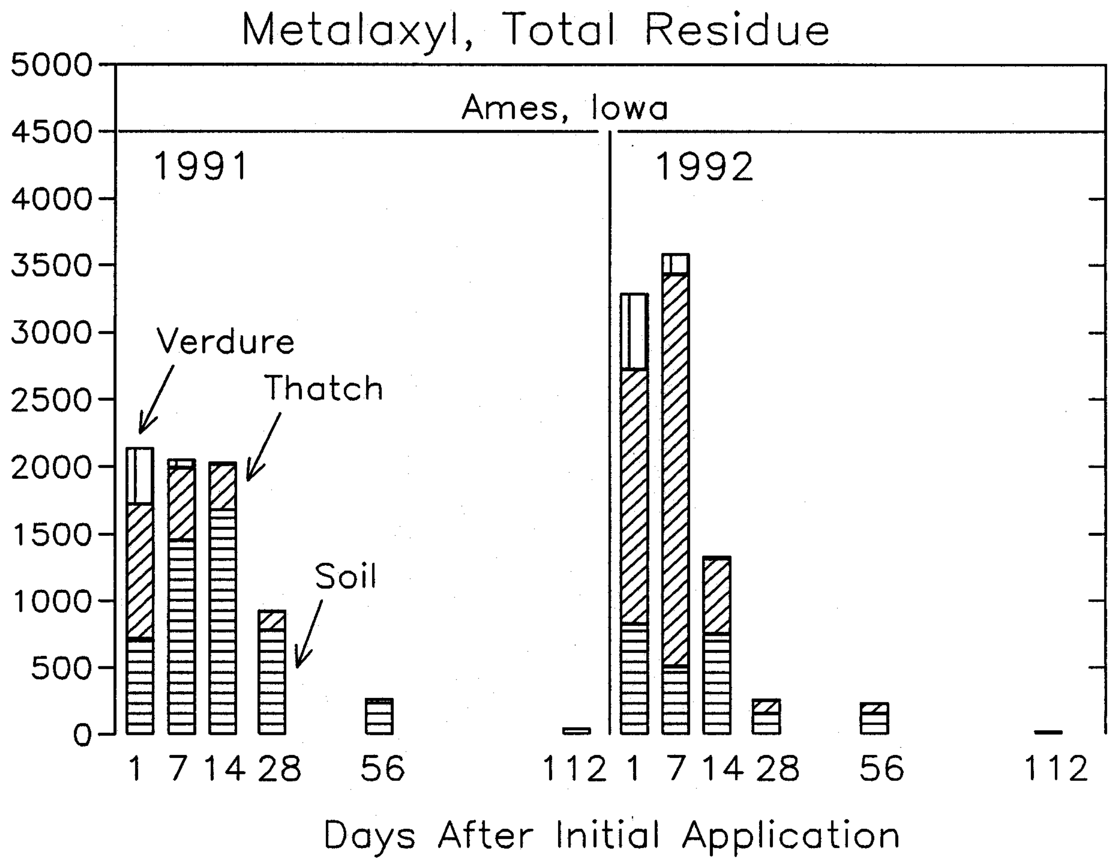

Figure 4. Partitioning of metalaxyl total estimated residue into verdure, thatch, and soil profile components at 6 sampling dates after initial application on 24 June 1991 and 14 June 1992, at Ames, Iowa.

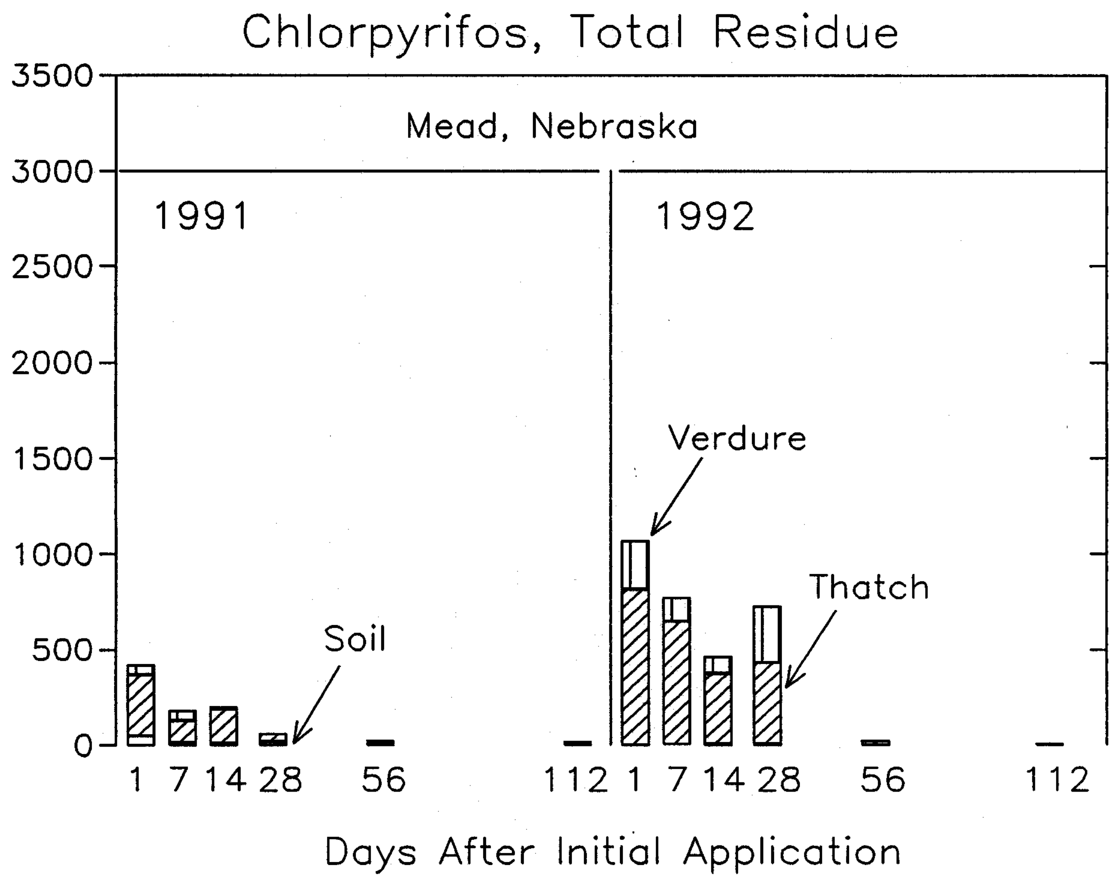

Figure 5. Partitioning of chlorpyrifos total estimated residue into verdure, thatch, and soil profile components at 6 sampling dates after initial application on 27 May 1991 and 11 May 1992, at Mead, Nebraska.

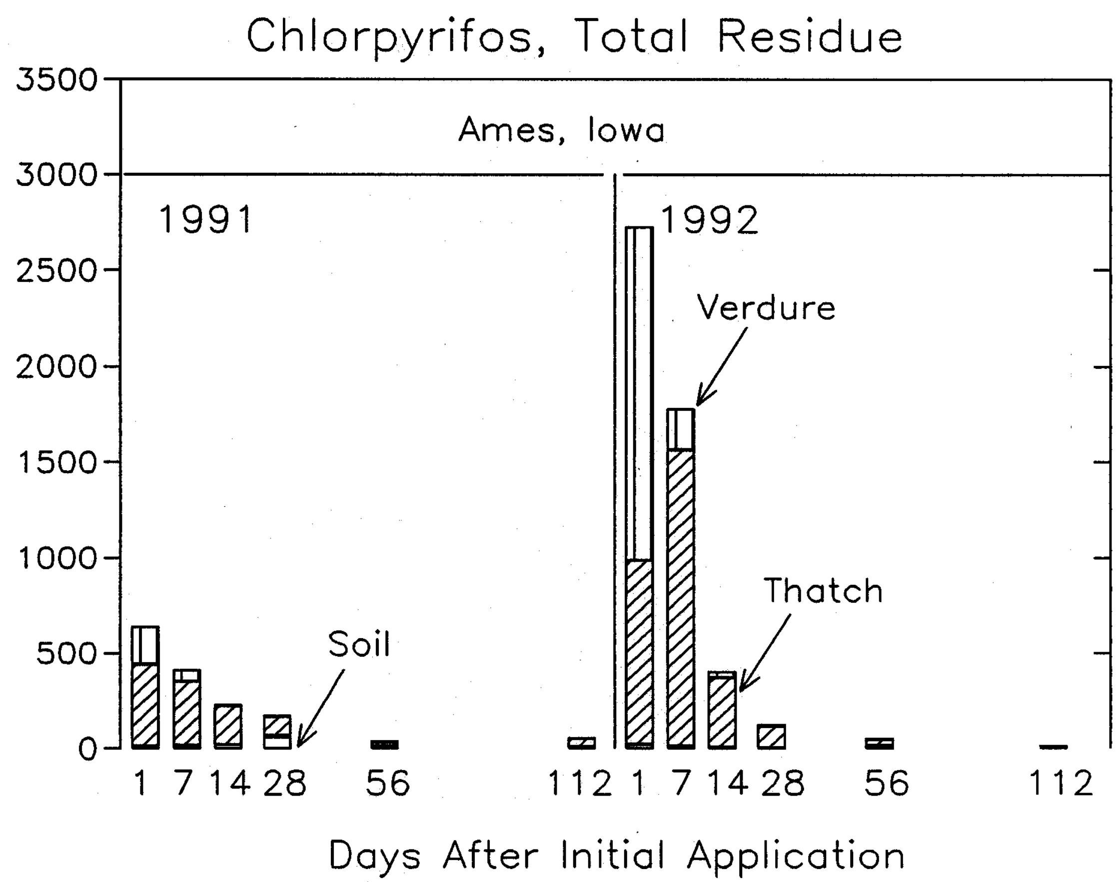

Figure 6. Partitioning of chlorpyrifos total estimated residue into verdure, thatch, and soil profile components at 6 sampling dates after initial application on 24 June 1991 and 14 June 1992, at Ames, Iowa.

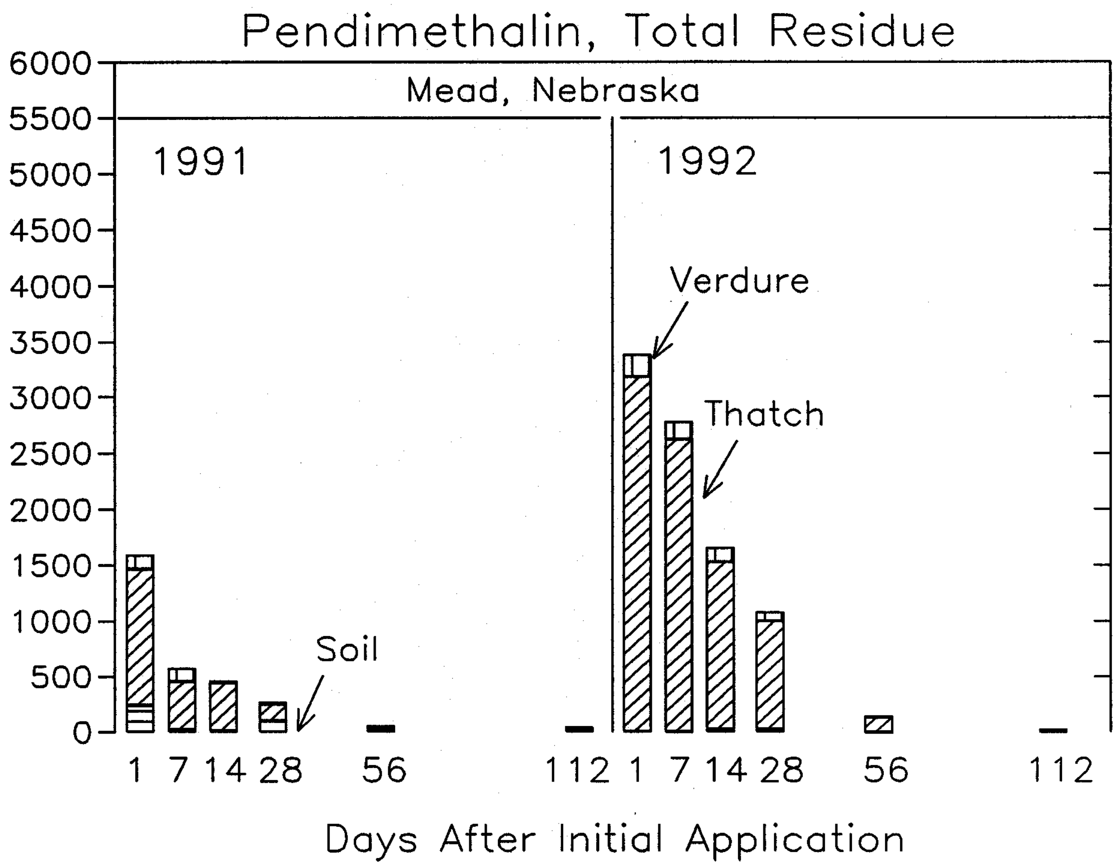

Figure 7. Partitioning of pendimethalin total estimated residue into verdure, thatch, and soil profile components at 6 sampling dates after initial application on 26 May 1991 and 10 May 1992, at Mead, Nebraska.

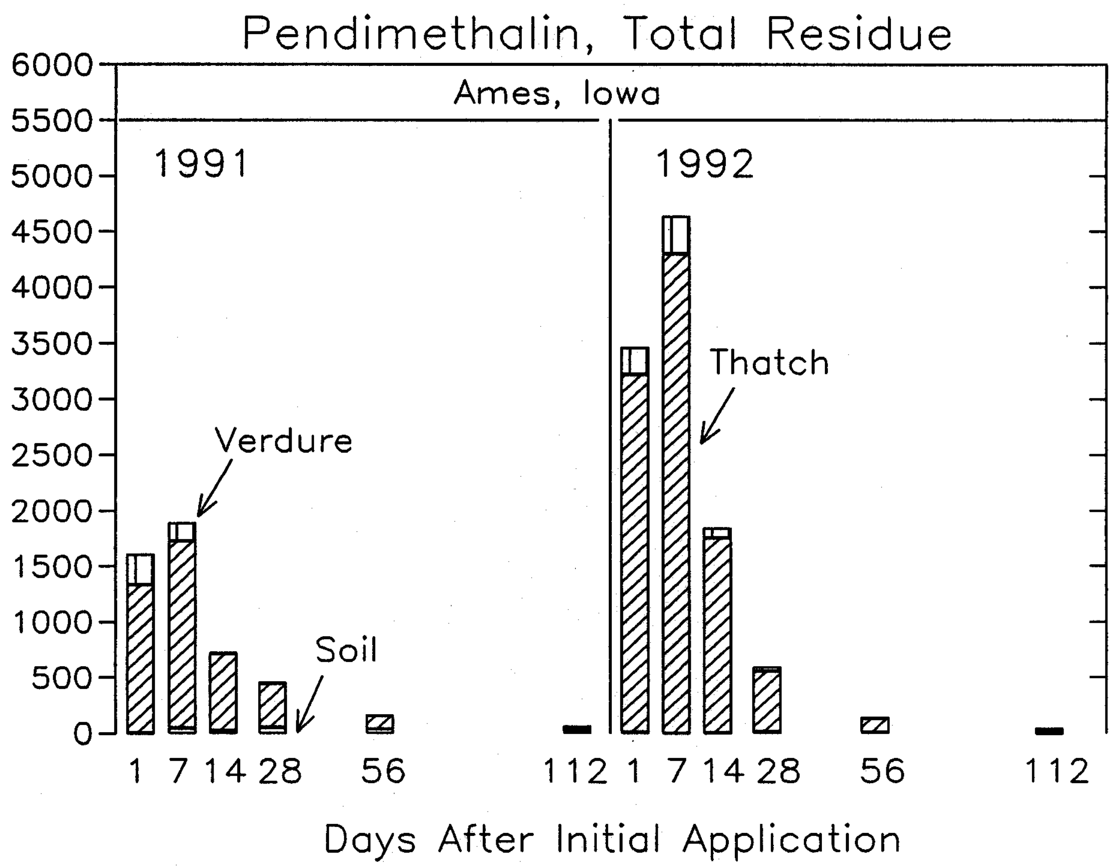

Figure 8. Partitioning of pendimethalin total estimated residue into verdure, thatch, and soil profile components at 6 sampling dates after initial application on 24 June 1991 and 14 June 1992, at Ames, Iowa.

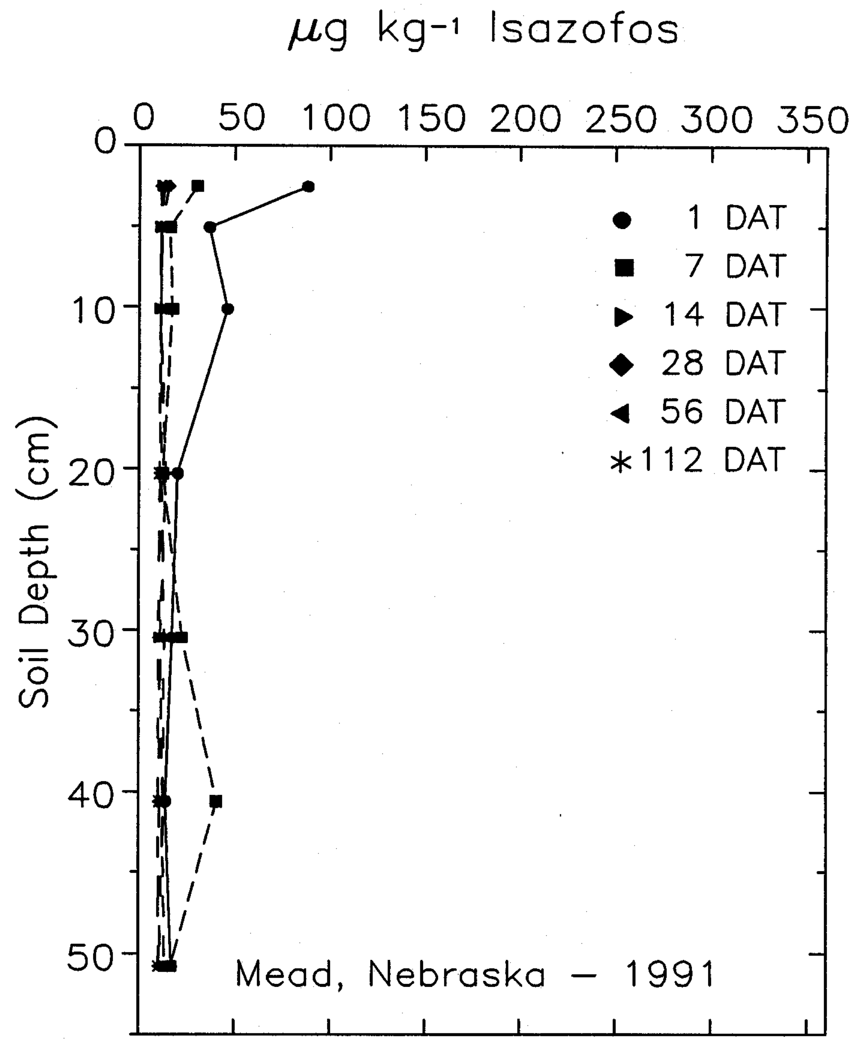

Figure 9. Concentration of isazofos pesticide residue in a soil profile at 6 sampling dates after initial application on 26 May 1991 at Mead, Nebraska.

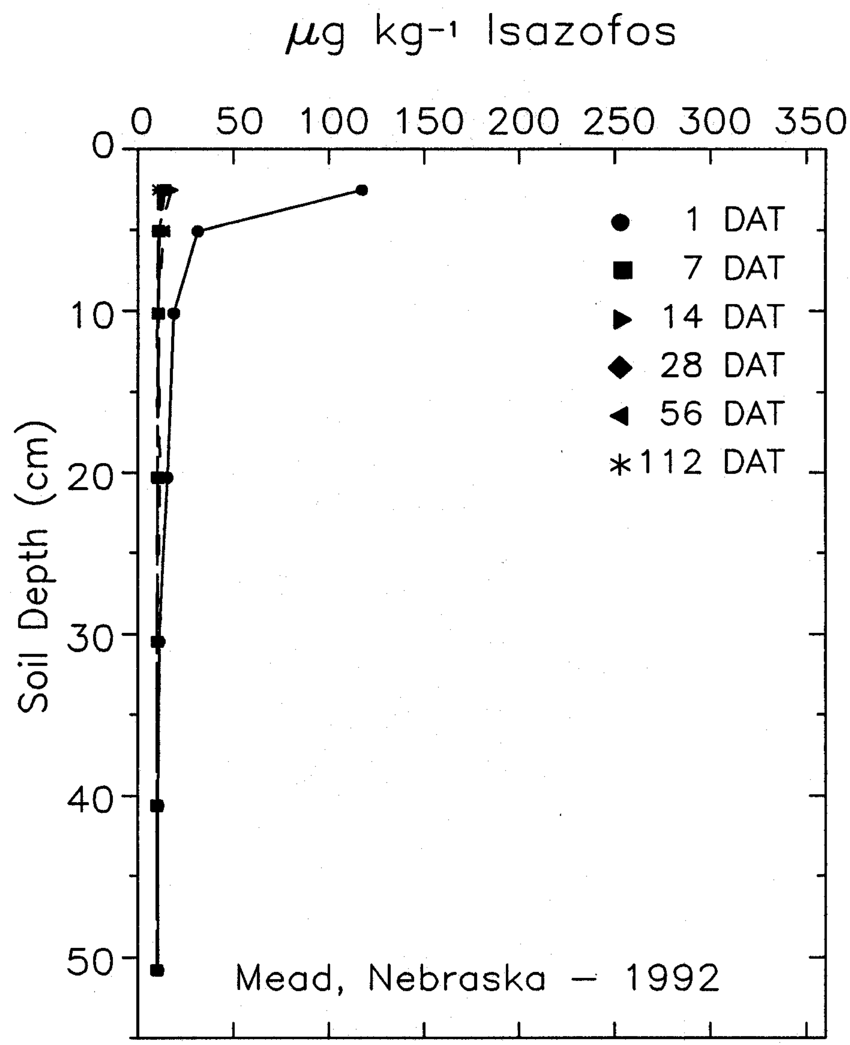

Figure 10. Concentration of isazofos pesticide residue in a soil profile at 6 sampling dates after initial application on 10 May 1992 at Mead, Nebraska.

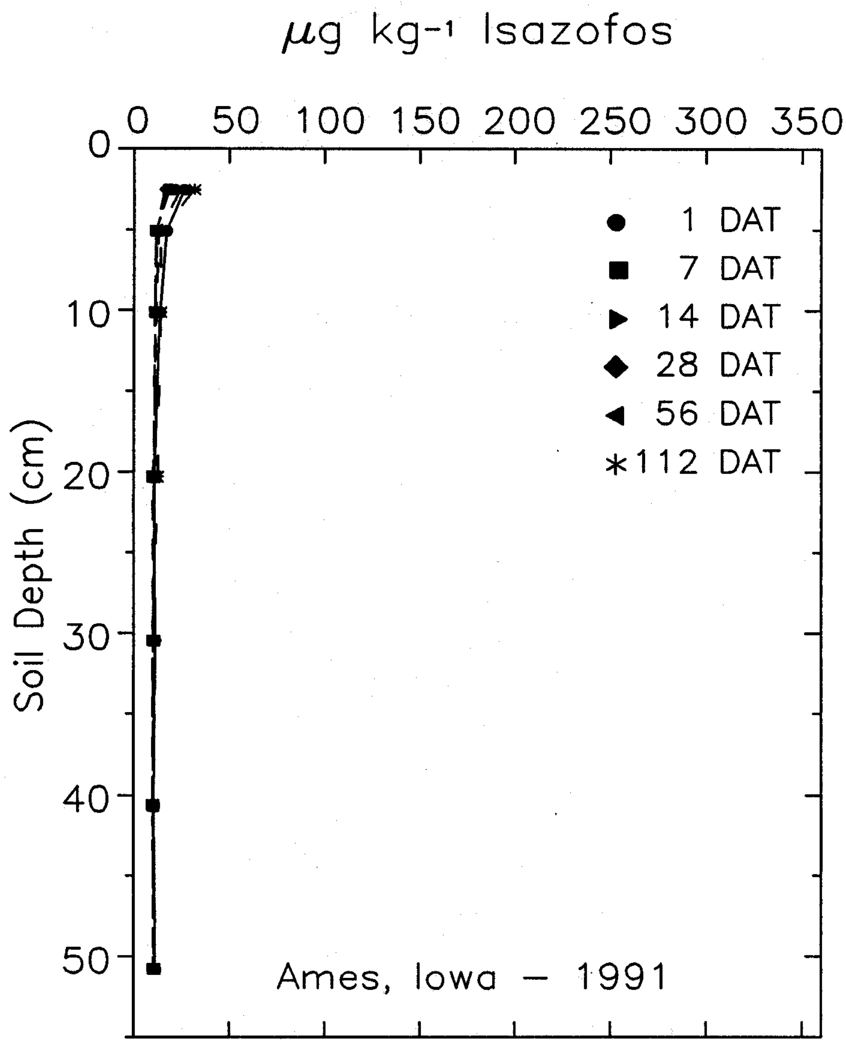

Figure 11. Concentration of isazofos pesticide residue in a soil profile at 6 sampling dates after initial application on 24 June 1991 at Ames, Iowa.

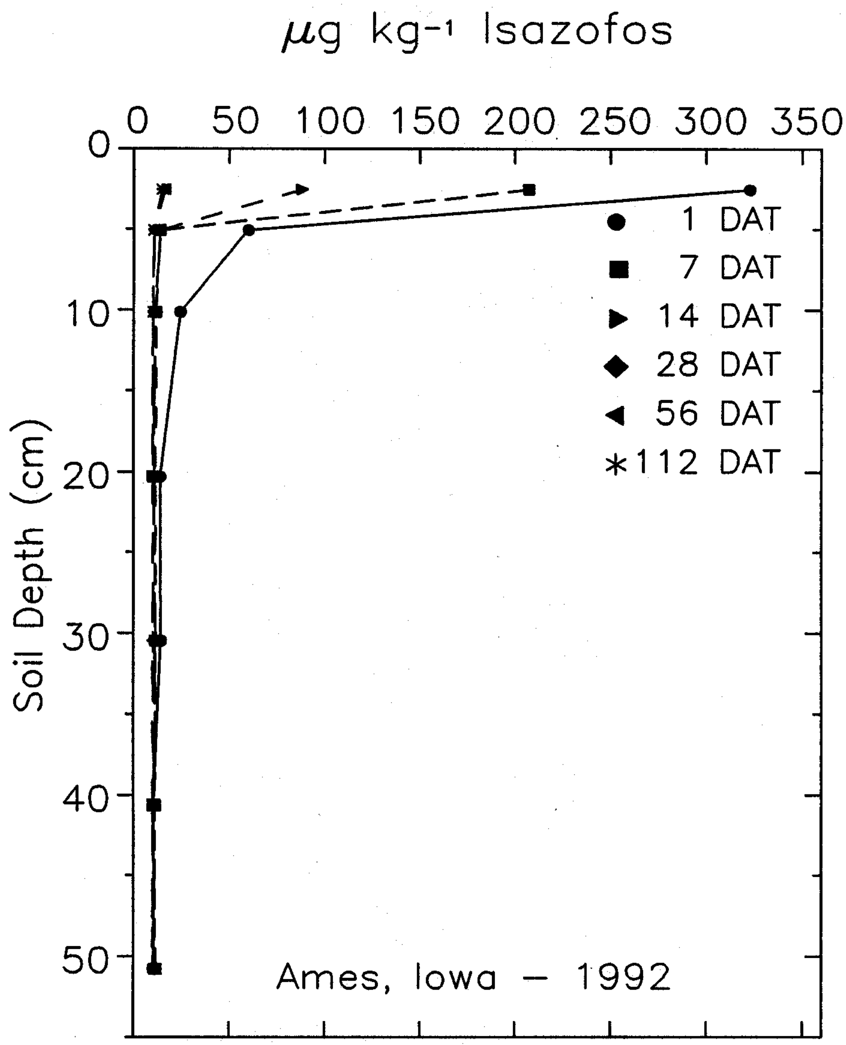

Figure 12. Concentration of isazofos pesticide residue in a soil profile at 6 sampling dates after initial application on 8 June 1992 at Ames, Iowa.

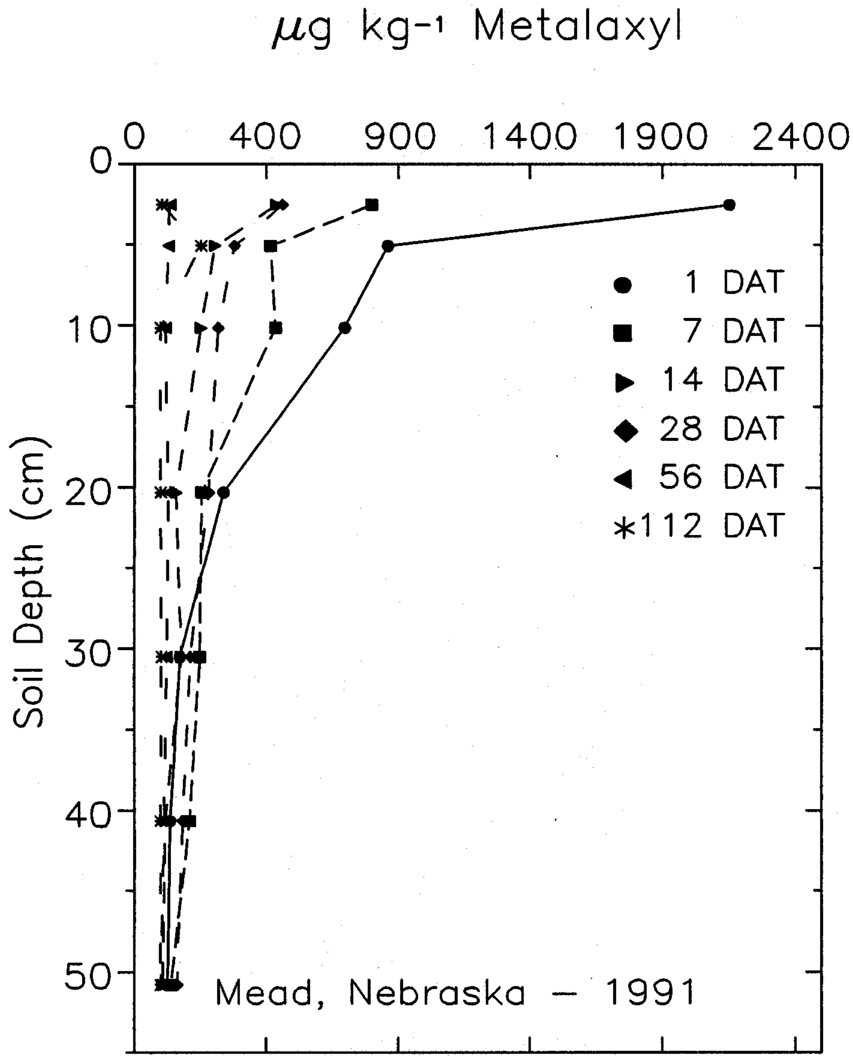

Figure 13. Concentration of metalaxyl pesticide residue in a soil profile at 6 sampling dates after initial application on 28 May 1991 at Mead, Nebraska.

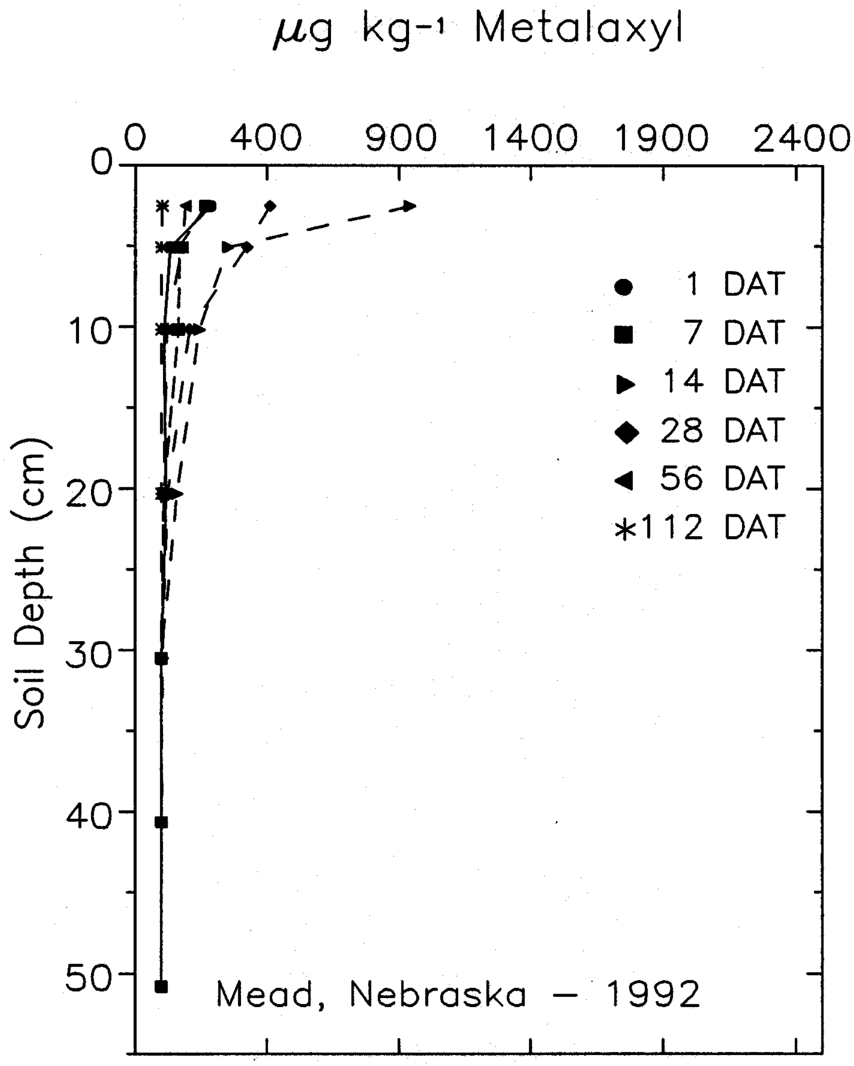

Figure 14. Concentration of metalaxyl pesticide residue in a soil profile at 6 sampling dates after initial application on 12 May 1992 at Mead, Nebraska.

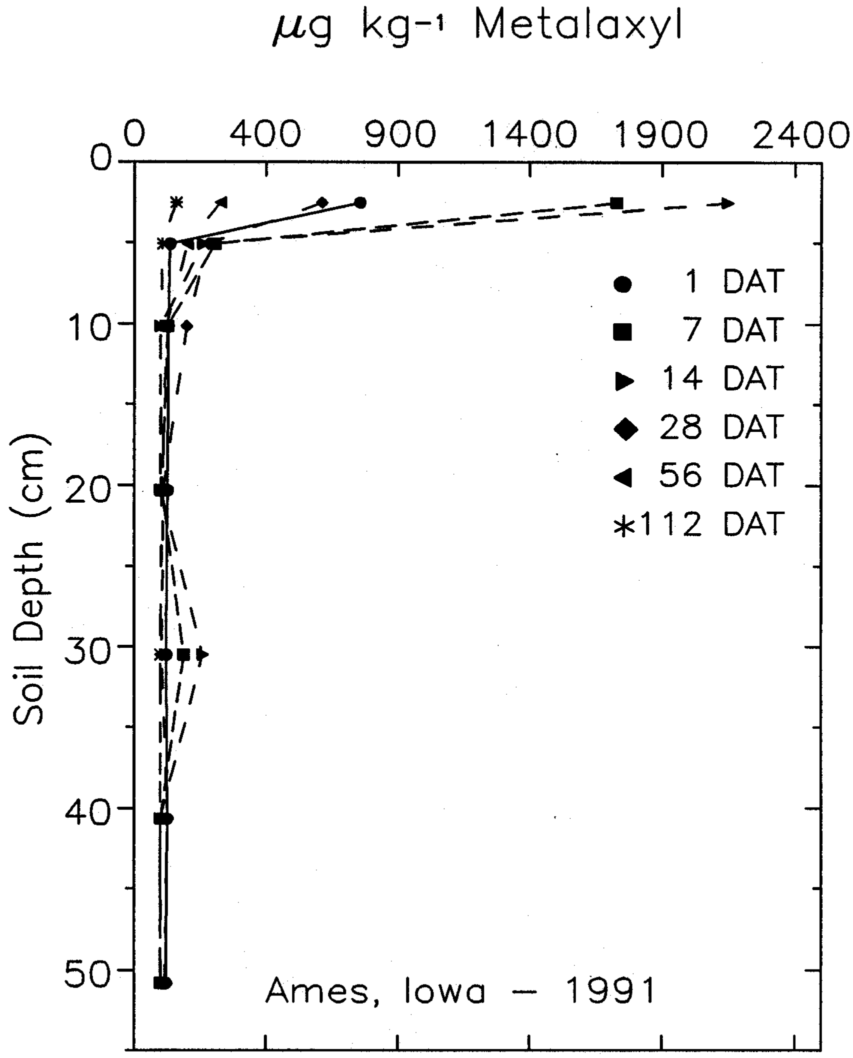

Figure 15. Concentration of metalaxyl pesticide residue in a soil profile at 6 sampling dates after initial application on 24 June 1991 at Ames, Iowa.

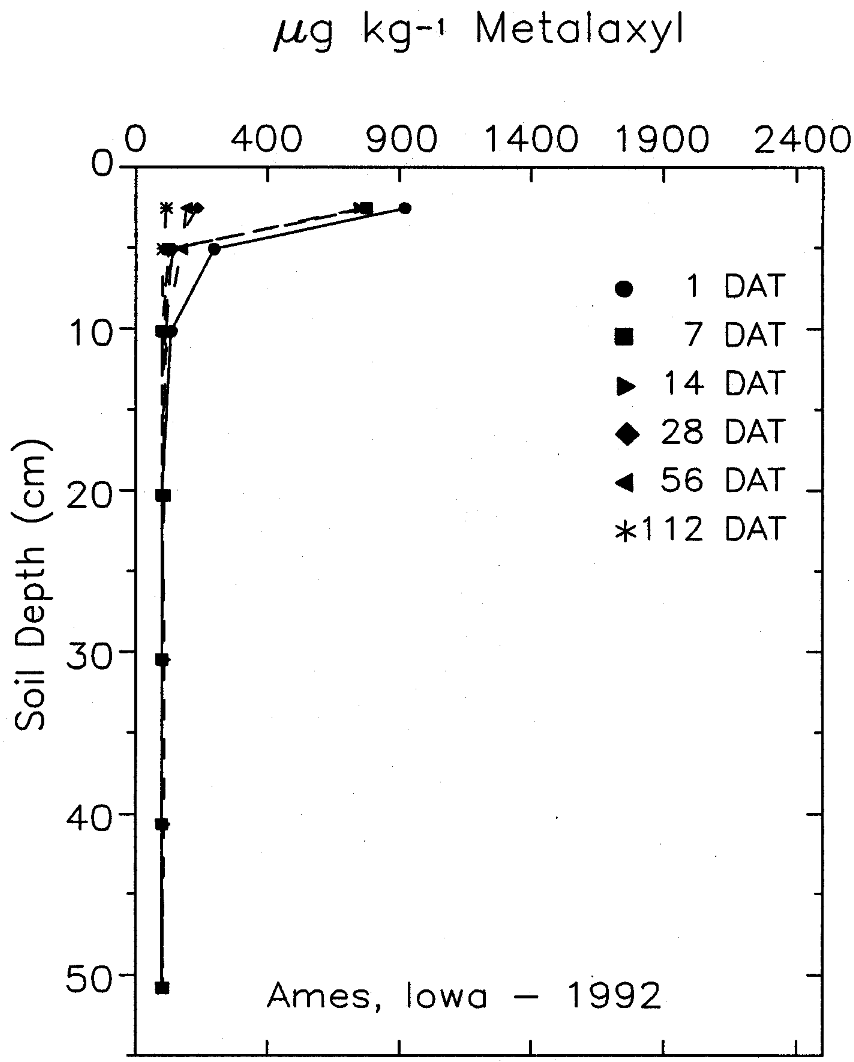

Figure 16. Concentration of metalaxyl pesticide residue in a soil profile at 6 sampling dates after initial application on 8 June 1992 at Ames, Iowa.

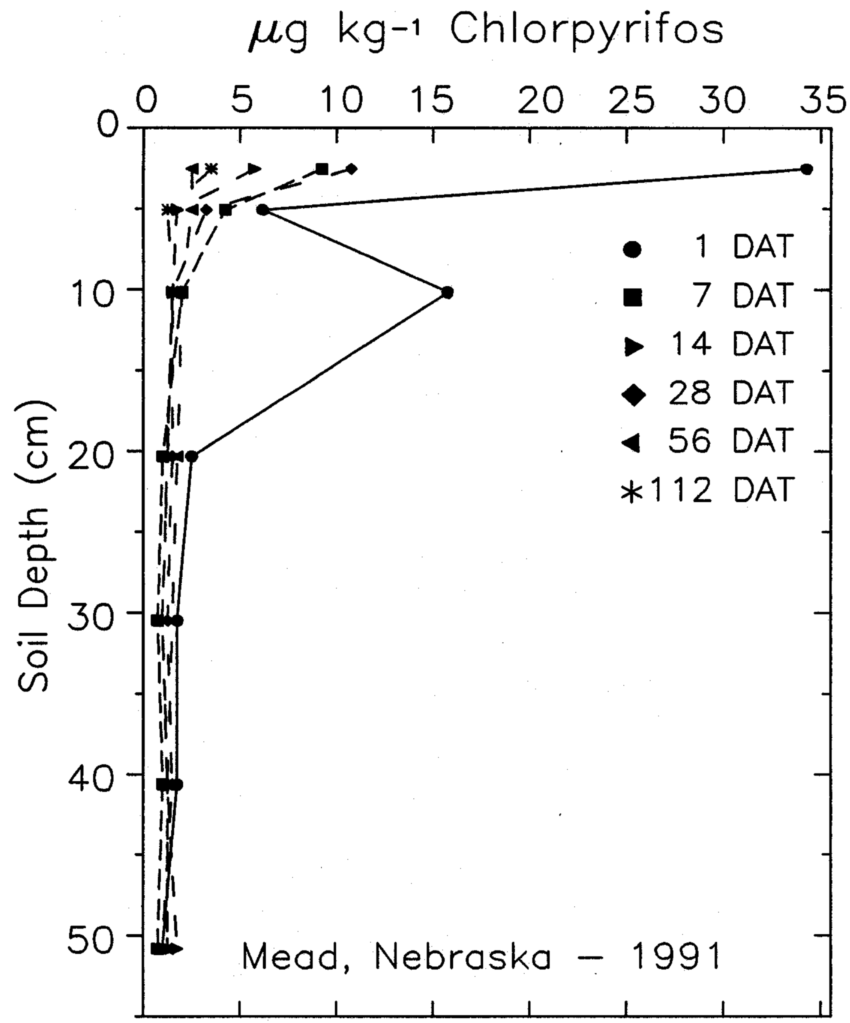

Figure 17. Concentration of chlorpyrifos pesticide residue in a soil profile at 6 sampling dates after initial application on 27 May 1991 at Mead, Nebraska.

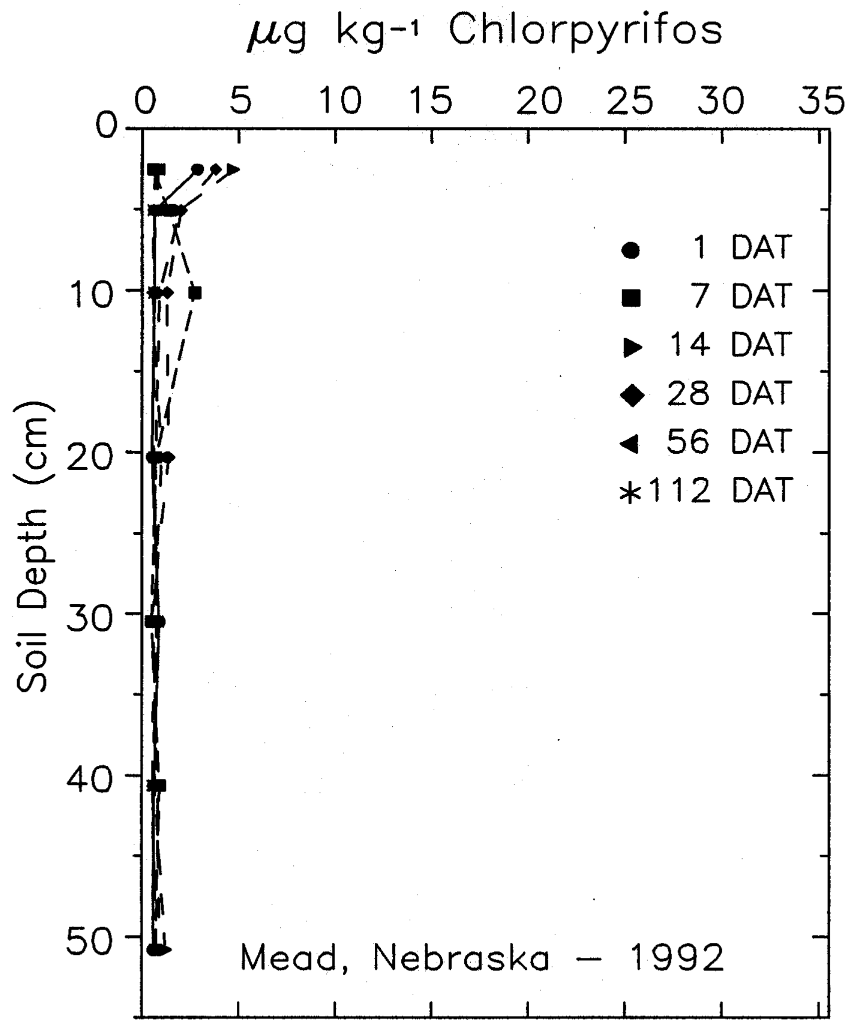

Figure 18. Concentration of chlorpyrifos pesticide residue in a soil profile at 6 sampling dates after initial application on 11 May 1992 at Mead, Nebraska.

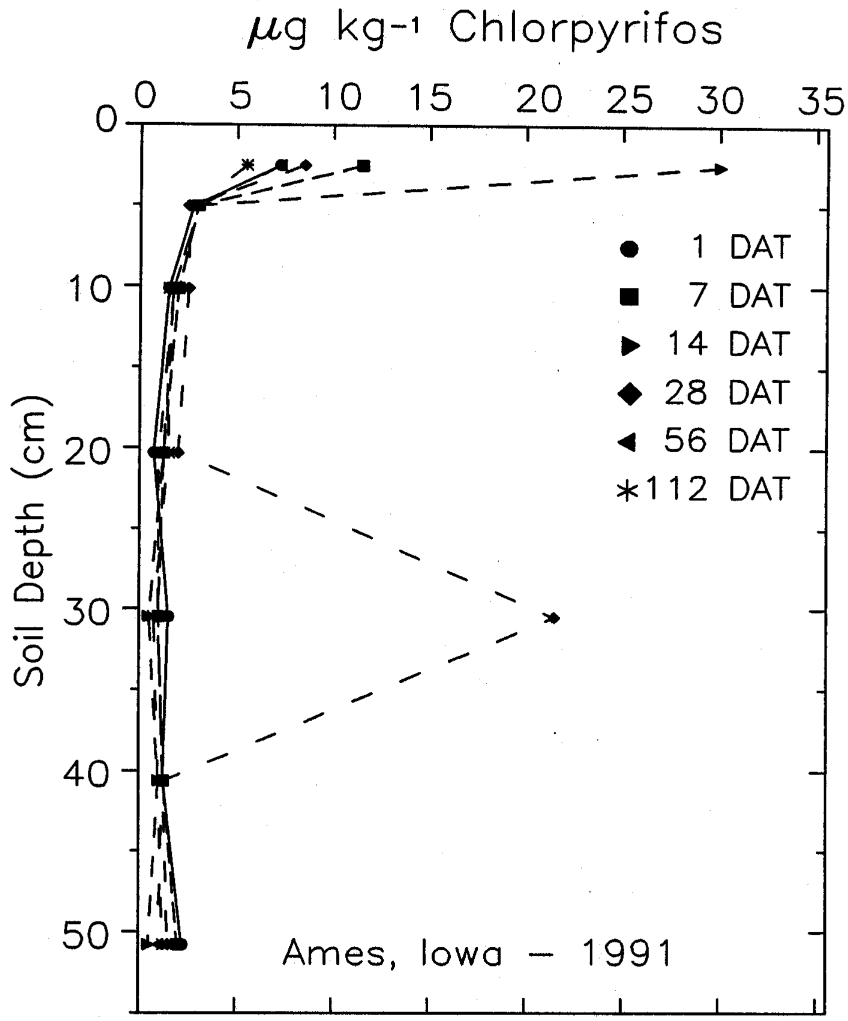

Figure 19. Concentration of chlorpyrifos pesticide residue in a soil profile at 6 sampling dates after initial application on 24 June 1991 at Ames, Iowa.

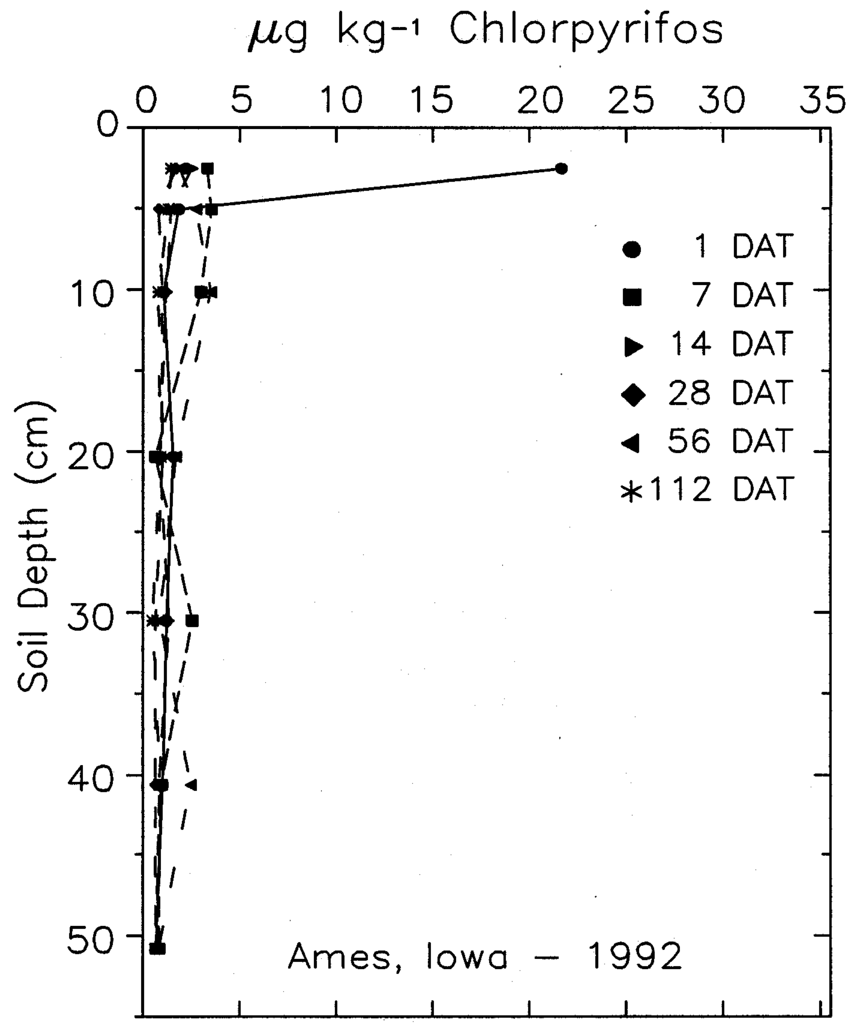

Figure 20. Concentration of chlorpyrifos pesticide residue in a soil profile at 6 sampling dates after initial application on 8 June 1992 at Ames, Iowa.

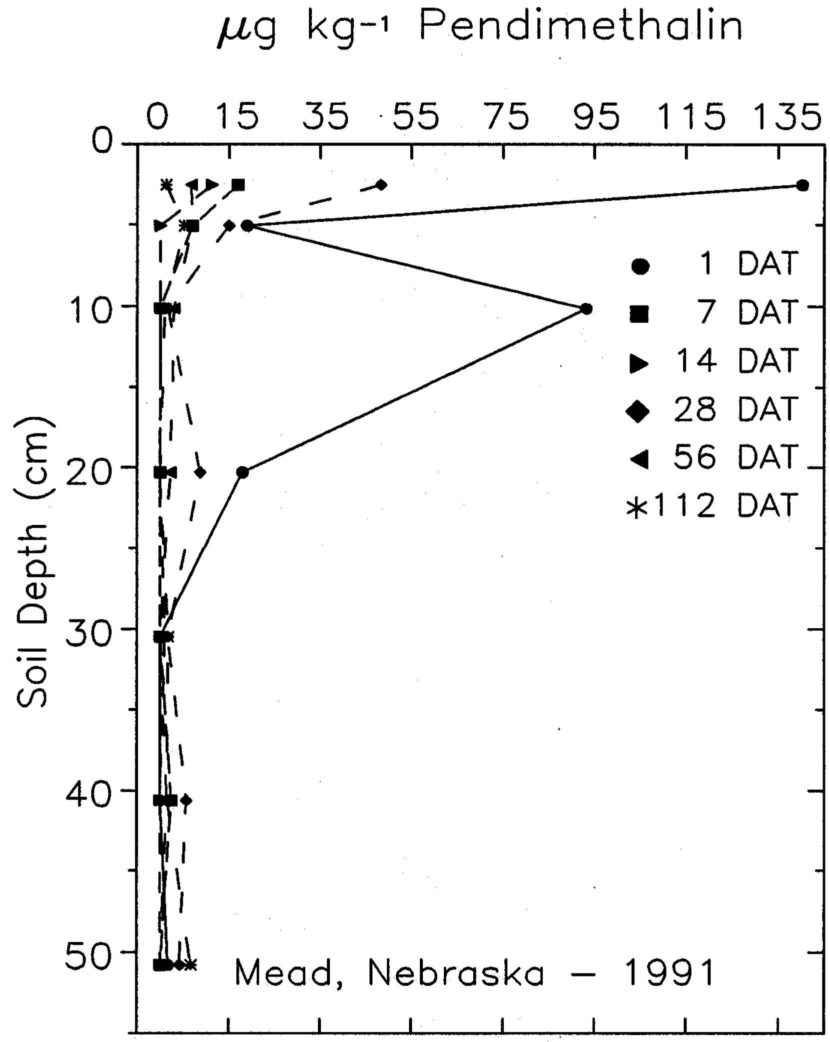

Figure 21. Concentration of pendimethalin pesticide residue in a soil profile at 6 sampling dates after initial application on 26 May 1991 at Mead, Nebraska.

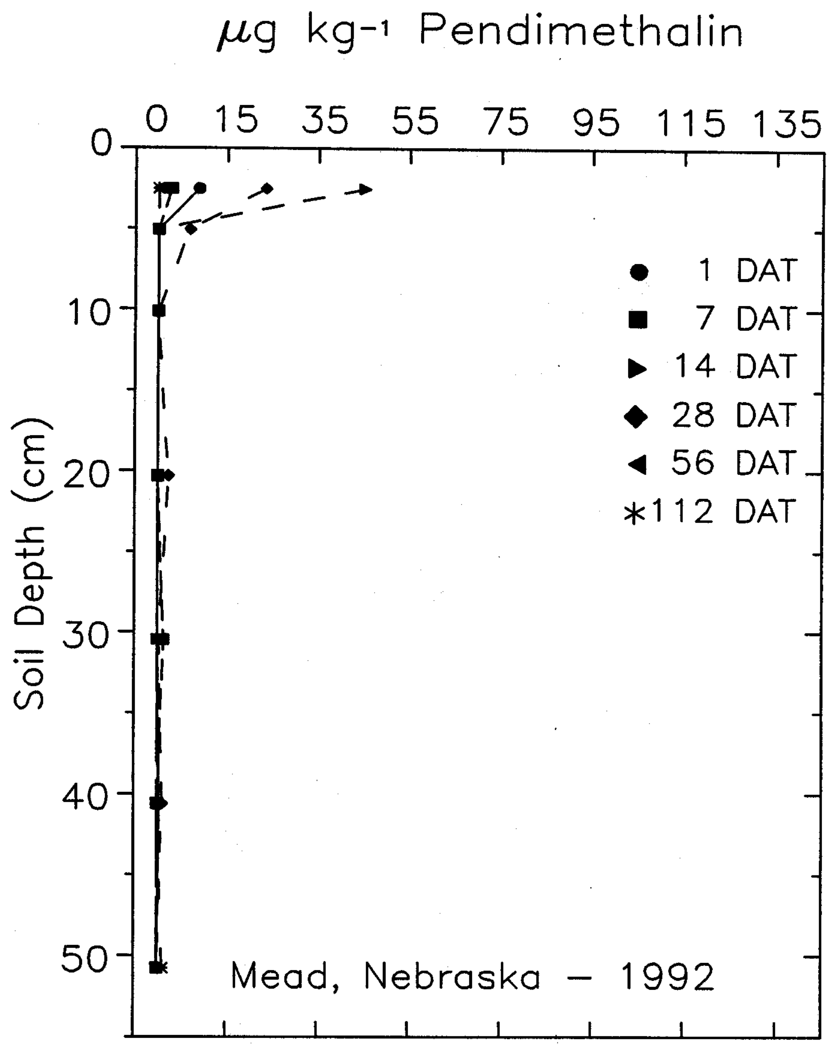

Figure 22. Concentration of pendimethalin pesticide residue in a soil profile at 6 sampling dates after initial application on 10 May 1992 at Mead, Nebraska.

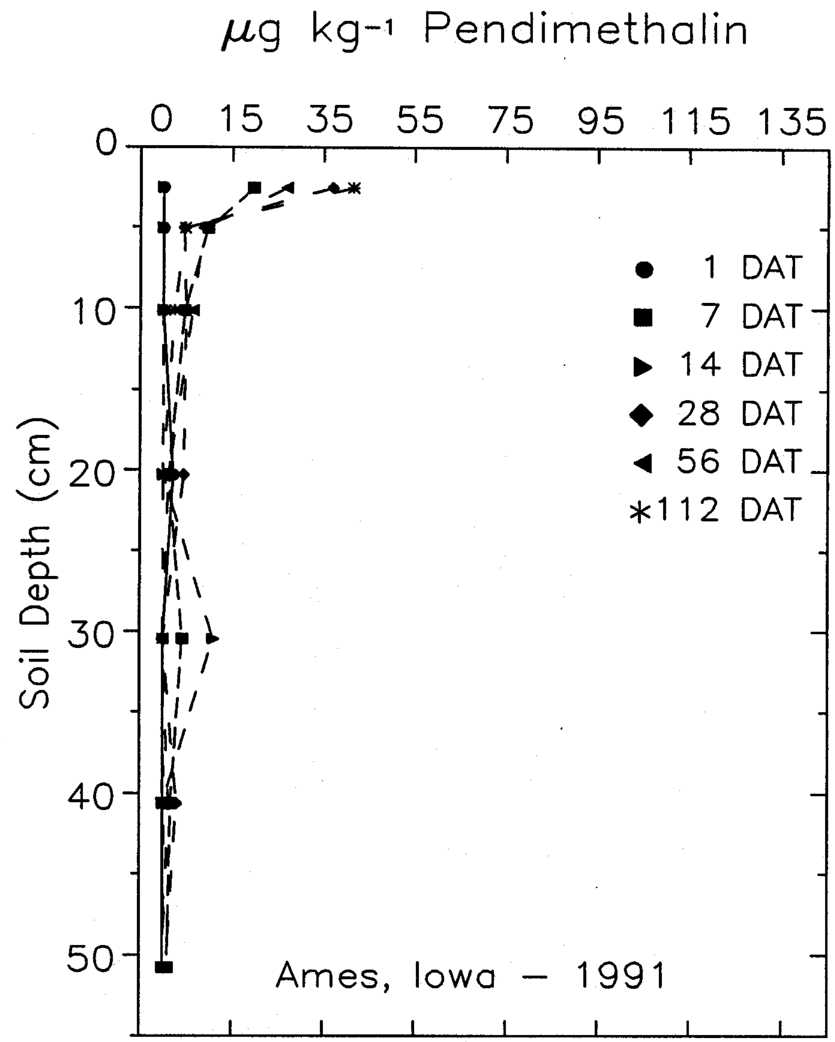

Figure 23. Concentration of pendimethalin pesticide residue in a soil profile at 6 sampling dates after initial application on 24 June 1991 at Ames, Iowa.

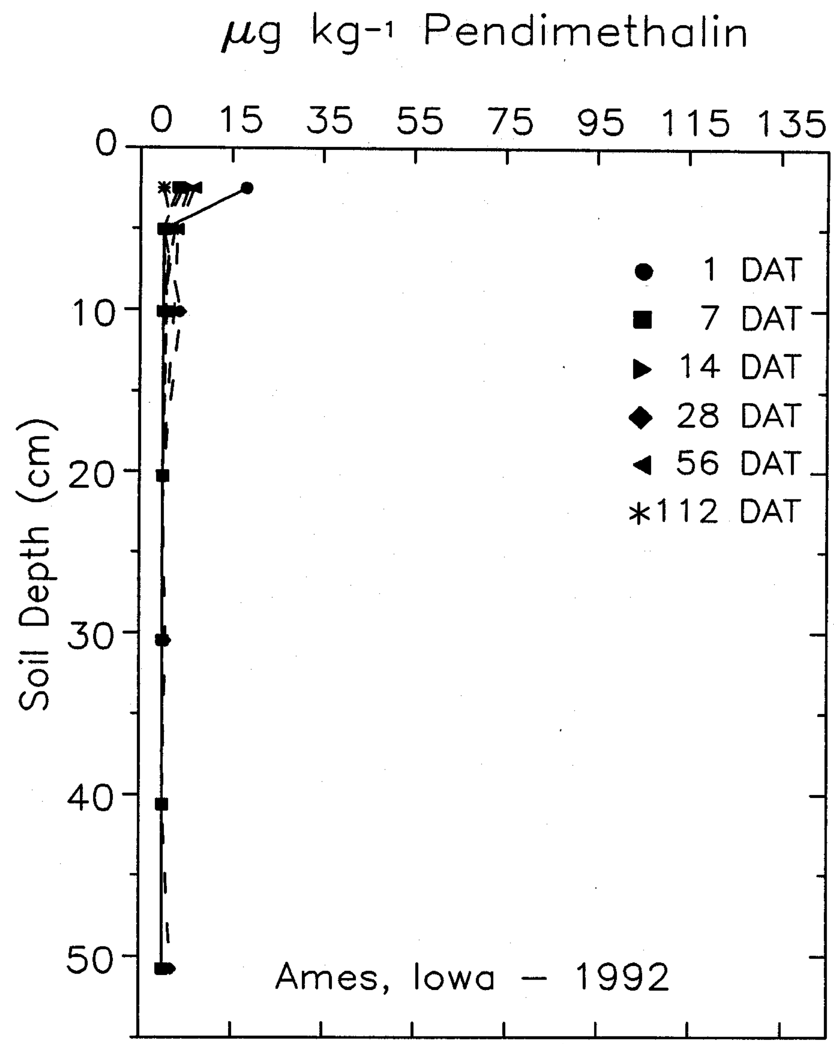

Figure 24. Concentration of pendimethalin pesticide residue in a soil profile at 6 sampling dates after initial application on 8 June 1992 at Ames, Iowa.

APPENDIX A

Table A-1. Properties of metalaxyl, isazofos, chlorpyrifos and pendimethalin.

Pesticide	Water Solubility	K_{ow}	K_{oc}	Half-Life	Vapor Pressure	SCS Rating Leaching	SCS Rating Runoff
	(mg L^{-1})			(days)	(mPa)		
metalaxyl	8400	50	50	70	0.63	Large	Large
isazofos	69	1000	100	34	11.4	Large	Large
chlorpyrifos	2	100000	6070	30	2.5	Small	Small
pendimethalin	0.3	150000	5000	90	3.9	Small	Medium

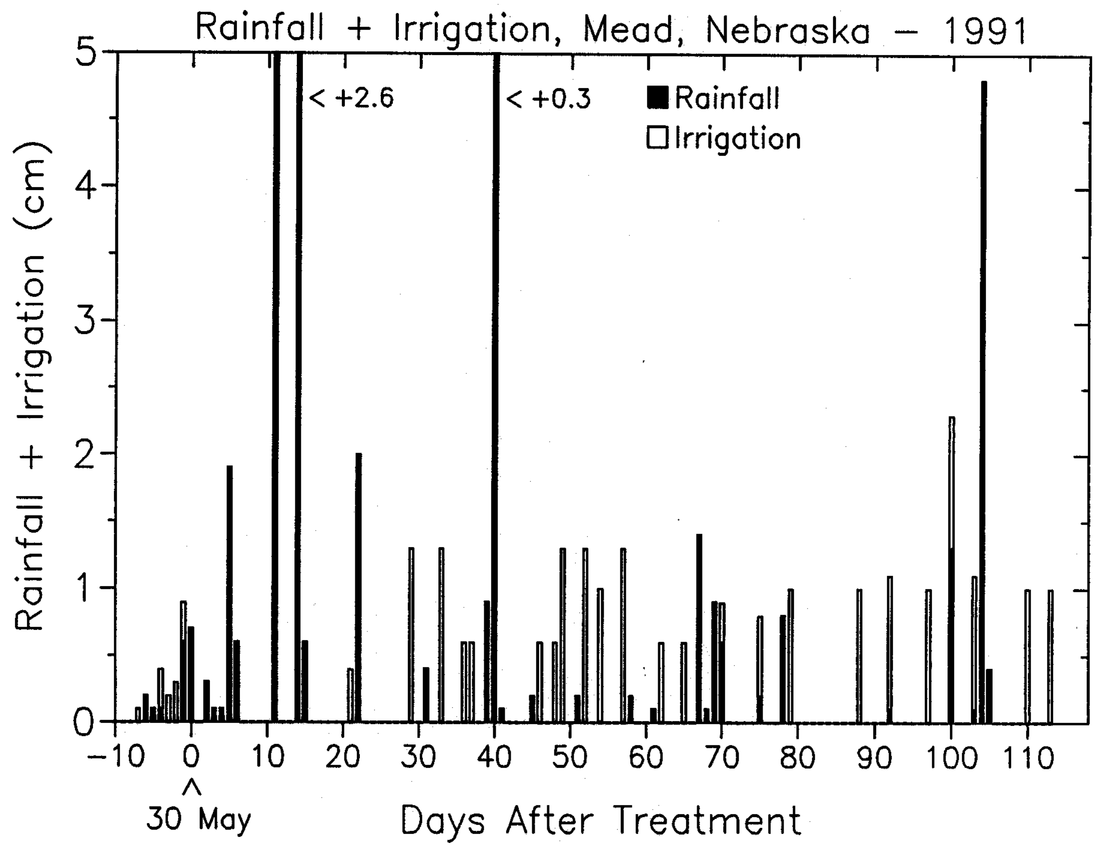

Figure A-1. Rainfall, irrigation events and amounts from 10 days prior to application of pesticides to 112 days after in 1991, at Mead, Nebraska.

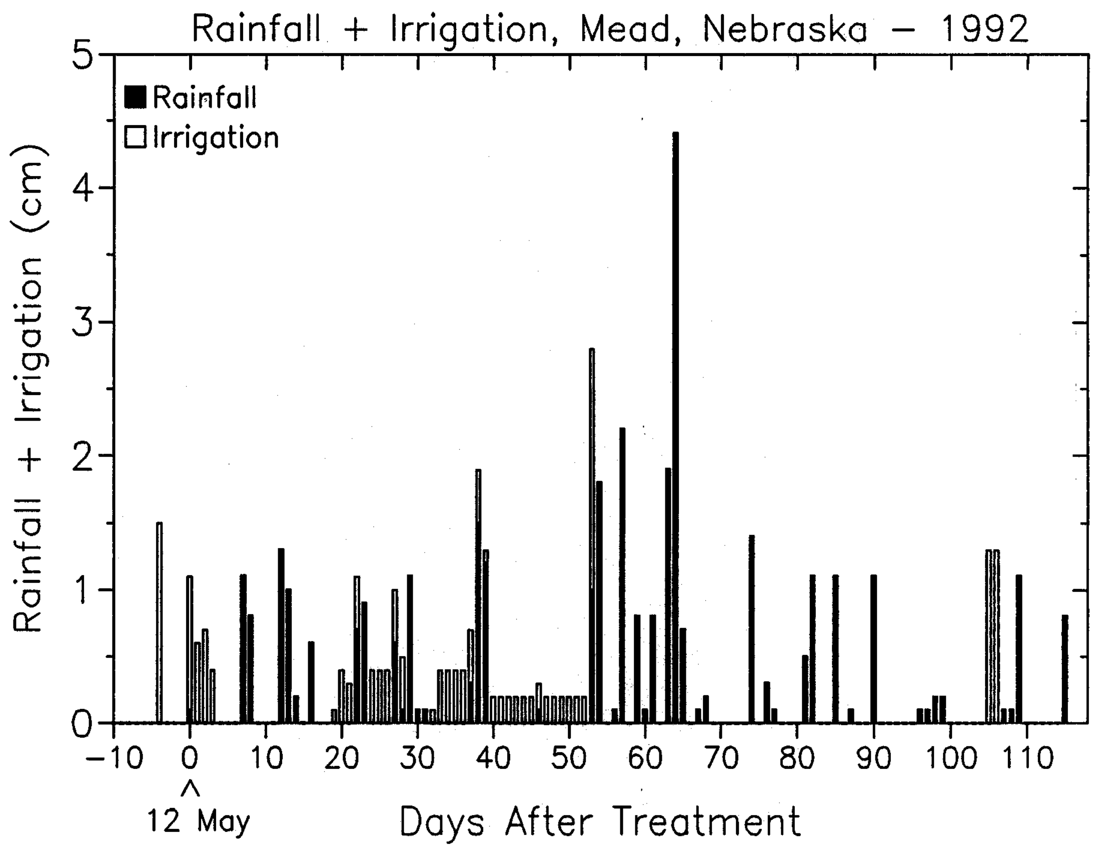

Figure A-2. Rainfall, irrigation events and amounts from 10 days prior to application of pesticides to 112 days after in 1992, at Mead, Nebraska.

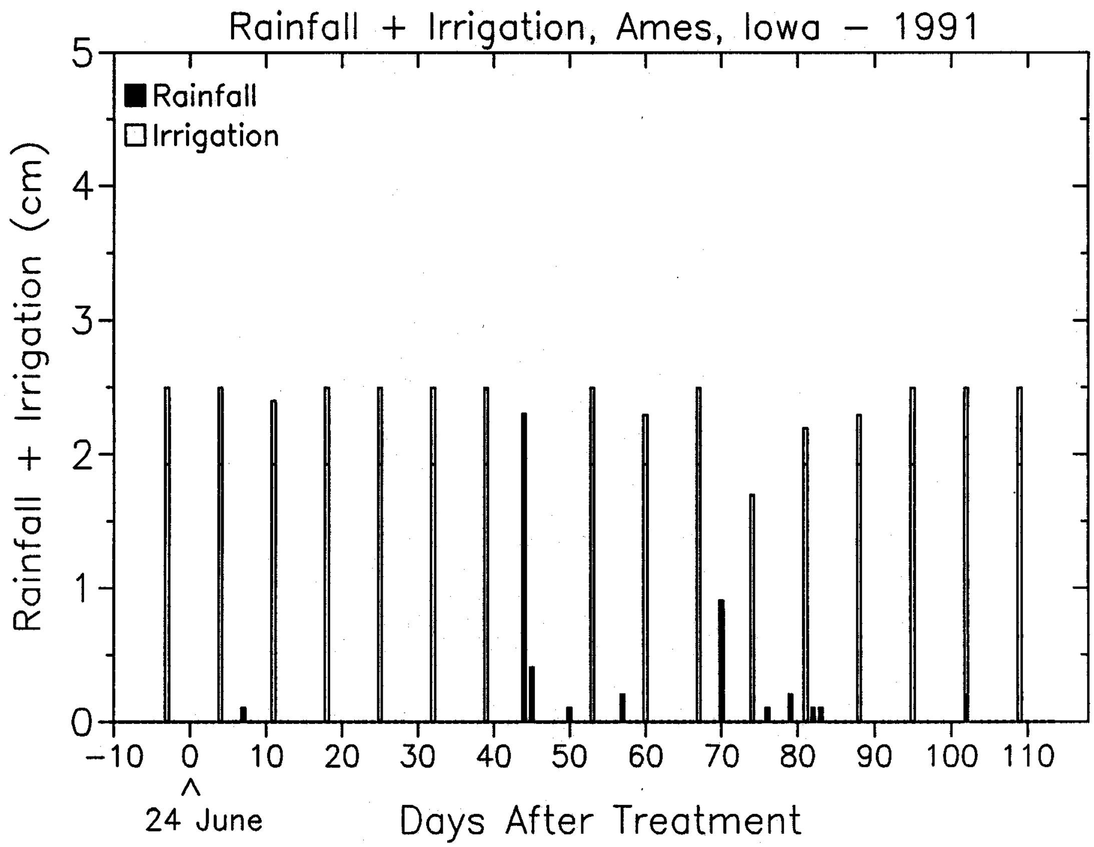

Figure A-3. Rainfall, irrigation events and amounts from 10 days prior to application of pesticides to 112 days after in 1991, at Ames, Iowa.

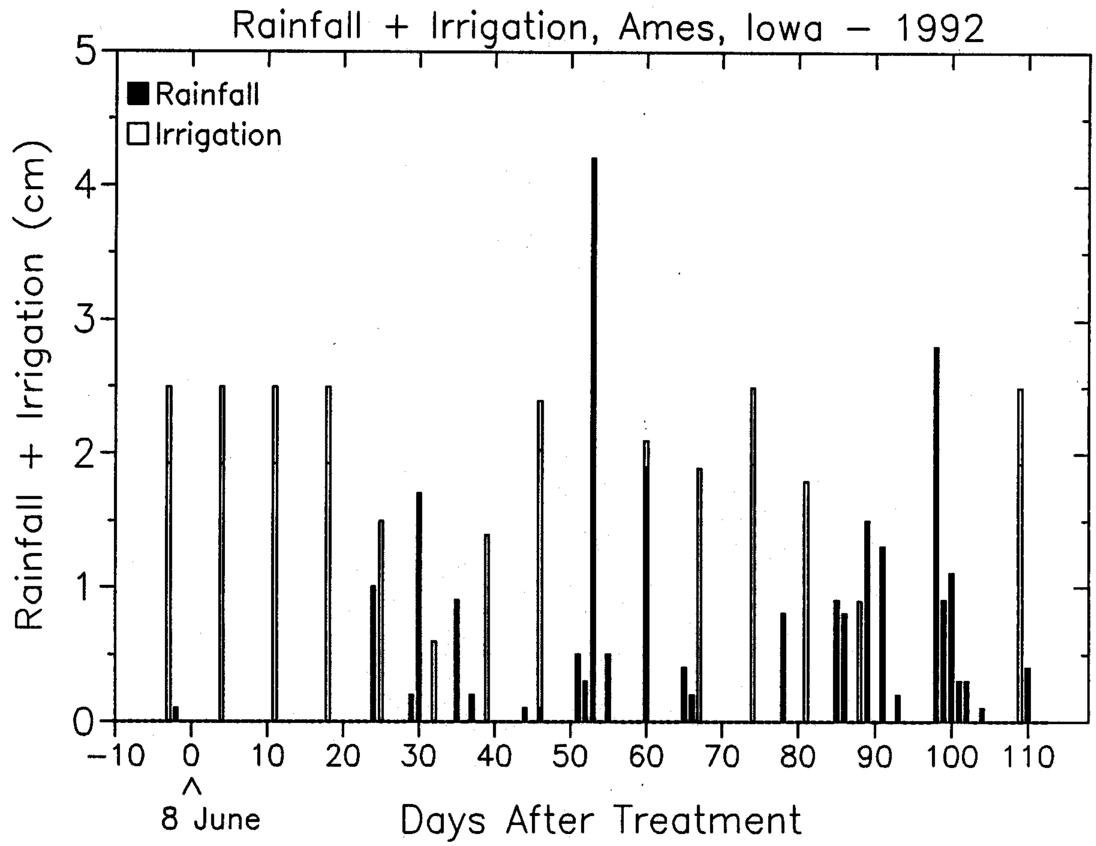

Figure A-4. Rainfall, irrigation events and amounts from 10 days prior to application of pesticides to 112 days after in 1992, at Ames, Iowa.

Summary of Fate of Fertilizers and Pesticides Research
Iowa State University
N.E. Christians, S.K. Starrett, A.M. Blackmer, T.A. Austin

New research that was performed within the last year has produced two papers. A paper entitled, "Comparing Solute Transport in Undisturbed and Disturbed Soil Columns Under Turfgrass Conditions" has been submitted for publication and the paper follows this Report. Also, a paper entitled, "Comparing dispersion coefficients of undisturbed and disturbed soils under turfgrass conditions" is being prepared for publication and an abstract of that work follows.

Progress to Date:

Phase 1: Initiated October, 1990. Completed May, 1992.

Fate of Nutrients in Turfgrass Biosystems

The fate of phosphorus and nitrogen was studied under normal golf course conditions. Fourteen undisturbed soil columns were brought into the greenhouse where the environment could be controlled. Phosphorus and nitrogen was applied to the surface of the soil columns. Two irrigation regimes were used to investigate the effects of management on the movement of the nutrients. At the end of the 7 day test period the soil columns were sectioned into 10 cm layers and tested for phosphorus and nitrogen concentrations. The leachate was also collected and tested. Also, volatilized nitrogen was measured.

Phase 2: Initiated March, 1992.

Fate of Pesticides in Turfgrass Biosystems

The fate of pesticide study consisted of a greenhouse study and a field study. We have completed the research on studying the fate of pendimethalin, MCPP, 2,4-D, dicamba, isazophos, chlorpyrifos, and metalaxyl in the field and in the greenhouse. The fate of these pesticides were studied under normal golf course conditions.

The field study consisted of applying the pesticides to a plot area and collecting soil cores throughout the growing season. Two years of the field study was performed and determination of soil concentrations is nearly complete. The University of Nebraska also performed an identical field study and a joint paper will be completed on the research.

Twelve undisturbed soil columns were brought into the greenhouse where the environment could be controlled. The pesticides were applied to the surface of the soil columns and two irrigation regimes were used to investigate the effects of management on the movement of the nutrients. At the end of the 4 week test period the soil columns were sectioned into 10 cm layers and are being tested for pesticide concentrations. The leachate was also collected and is being tested.

Need for Future Work

The results of our fate of nutrients study does show that golf course management techniques can have an effect of the movement of nutrients and pesticides through a soil profile. Research in the environmental area needs to be continued to advise superintendents how to minimize these adverse environmental effects. A summary outlining our progress and listing our present and future publications follows.

Progress to Date:

Current status:

Field and greenhouse pesticide research completed.
Soil and leachate samples in analytical laboratory being tested.
Plan for Steve Starrett to finish Ph.D. in environmental engineering May, 1994.

Publications, Abstracts, Conference Proceedings, and Seminars:

REFEREED PUBLICATIONS

Fate of ^{15}N Amended Urea in Turfgrass Biosystems by S.K. Starrett, N.E. Christians, and T.A. Austin. Submitted 27 August, 1993 to *Journal of Soil Science*. Currently under review.

Comparing Solute Transport in Undisturbed and Disturbed Soil Columns Under Turfgrass Conditions by S.E. Luke, S.K. Starrett, N.E. Christians, and T.A. Austin. Submitted 27 September, 1993 to *HortScience*. Currently under review.

Comparing Dispersion Coefficients of Undisturbed and Disturbed Soils Under Turfgrass Conditions by S.K. Starrett, N.E. Christians, T.A. Austin, and L.C. Jones. Under preparation for submission to *Journal of Hydrology*.

Fate of Phosphorus in Turfgrass Ecosystems by S.K. Starrett, N.E. Christians, and T.A. Austin. Under preparation for submission to the World Scientific Congress of Golf held July, 1994.

Fate of Pesticides in Turfgrass Biosystem by G.L. Horst, P.J. Shea, N.E. Christians, D.R. Miller, C.L. Stuefer-Powell, and S.K. Starrett. Under preparation.

Fertilizer fate under golf course conditions in the midwest region by Starrett, S.K. 1992. M.S. thesis. Parks Library, Iowa State University. Ames, Iowa 50011.

CONFERENCE PROCEEDINGS

Effects of Management of Nutrient Fate by S.K. Starrett, N.E. Christians, and T.A. Austin. Under preparation for submission to the International Conference & Exposition on Marinas, Parks & Recreation Developments. Milwaukee, Wisconsin. Sponsored by the American Society of Civil Engineering (ASCE), June 1994.

Comparing Solute Transport in Undisturbed and Disturbed Soil Columns under Turfgrass Conditions by S.E. Luke, S.K. Starrett, N.E. Christians, and T. A. Austin. Abstract published November, 1993. American Society of Agronomy Annual Meeting, 1993. Cincinnati, Ohio.

Two Years of Monitoring Pesticide Fate in Established Turfgrass by P. J. Shea, G.L. Horst, N.E. Christians, D.R. Miller, S.K. Starrett, and C.L. Stuefer-Powell. Abstract published November, 1993. American Society of Agronomy Annual Meeting, November 1993. Cincinnati, Ohio.

Nitrogen Transport Characteristics in Undisturbed and Disturbed Soil Columns by S.K. Starrett, N.E. Christians, T.A. Austin, and A.M. Blackmer. Abstract published, American Society of Agronomy Annual Meeting, 1992. Minneapolis, Minnesota.

Monitoring the Fate of Four Pesticides in Established Turfgrass by G.L. Horst, N.E. Christians, P. J. Shea, C.L. Stuefer-Powell, D. R. Miller, and S.K. Starrett. Abstract published, American Society of Agronomy Annual Meeting, 1992. Minneapolis, Minnesota.

Fertilizer Fate in Turfgrasses Managed Under Golf Course Conditions in the Midwestern Region by S.K. Starrett, N.E. Christians, T.A. Austin, and A.M. Blackmer. Abstract published, American Society of Agronomy Annual Meeting, 1991. Denver, Colorado.

CONFERENCE PRESENTATIONS

Comparing Solute Transport in Undisturbed and Disturbed Soil Columns under Turfgrass Conditions. Will present November 1993. American Society of Agronomy Annual Meeting, 1993. Cincinnati, Ohio.

Nitrogen Transport Characteristics in Undisturbed and Disturbed Soil Columns American Society of Agronomy Annual Meeting, 1992. Minneapolis, Minnesota.

Fertilizer Fate in Turfgrasses Managed Under Golf Course Conditions in the Midwestern Region, American Society of Agronomy Annual Meeting, 1991. Denver, Colorado.

Fate of Fertilizer Under Golf Course Conditions in the Midwestern Region, Iowa Turfgrass Institute Annual Conference, 1991. Des Moines, Iowa.

Departmental and College Seminars

Fate of Nitrogen in Turfgrass Areas, Water Resources Seminar Series. April, 1992.

Fate of Nitrogen and Phosphorus in Turfgrass Biosystems, Horticulture Department Seminar Series. October, 1993.

Comparing Solute Transport in Undisturbed and Disturbed Soil Columns Under Turfgrass Conditions

Scott E. Luke
Former Undergraduate Research Assistant, Department of Horticulture, Iowa State University, Present Address, Green Bay Country Club, 2400 Klondike Road, Green Bay, WI 54311

Steven K. Starrett
Department of Civil and Construction Engineering, Iowa State University, Ames, IA 50011

Nick E. Christians
Department of Horticulture, Iowa State University, Ames, IA 50011

T. Al Austin
Department of Civil and Construction Engineering, Iowa State University, Ames, IA 50011

ABSTRACT

Solute transport in undisturbed soil columns with intact macropores were compared to disturbed, repacked columns of the same soil. The total amount of chloride leached was 2.0 times higher for the undisturbed columns than for the disturbed columns, and the total quantity of leachate was 1.4 times higher for undisturbed columns than for the disturbed columns. Total chloride found in layer #2 (6.7 to 13.4 cm) was 1.79 times higher and in layer #3 (13.4 to 20.0 cm) was 2.72 times higher for the disturbed soils than for the undisturbed. For layer #1 (0.0 to 2.0 cm) the opposite was observed, with total chloride in the undisturbed columns 2.4 times higher than in the disturbed columns.

The macropore structure found in an undisturbed soil can have a major impact on water and solute distribution in the profile (Thomas and Phillips, 1979). Infiltration and redistribution of water in soil containing macropores are not adequately described by theories that treat the soil as a homogeneous medium conforming to Darcian principles of water flow (Beven and German, 1982). Starrett (1992) found that macropores played a major role in transport of surface-applied N leached through a 50 cm soil column covered with turf. Practically all the N that leached through during a 7-day period was collected within 1.3 h of application. White (1985) concluded from studies on undisturbed soils that macropores can greatly decrease the time taken for surface-applied, dissolved, and suspended matter to reach subsurface drains or ground water.

Solute movement through soil profiles under turfgrass has been studied using repacked soil columns or other disturbed soils where the macropore structure has been destroyed. The influence of macropores is eliminated when experiments are done in a laboratory using dried, sieved, and repacked soil columns (Evert, 1989). Furthermore, Tindall et al. (1992) stated that while several methods exist for laboratory analysis of column experiments, they deal with disturbed, sieved soil samples and are not typically suitable for intact soil cores because of their basic design and the nature of their construction. Applying the results of studies performed using disturbed soils to situations where undisturbed soils exist may lead to inaccurate conclusions.

The objective of this study was to compare the solute movement characteristics of undisturbed soil columns with those columns containing dried, sieved, and repacked soil under turfgrass conditions. We studied three parameters: total solute leached, total leachate and total solute retained in the soil to compare the differences between undisturbed and disturbed soils.

Four undisturbed soil columns and the soil for four disturbed soil columns were taken from a 1.4-m^2 area at the Iowa State University Horticulture Research Station. The soil in the area was a Nicollet (fine-loamy, mixed, mesic-Aquic Hapludolls) soil with 'Glade' Kentucky bluegrass turf established in 1991 and maintained at a 2.54-cm mowing height. The undisturbed soil columns were collected by modifying the concrete encasement method of Priebe and Blackmer (1989). Soil was excavated from around a 10-cm diameter by 20-cm deep cylindrical soil column. When the columns had been properly shaped, a 15-cm diameter Polyvinyl chloride (PVC) pipe was placed over the columns, and the space between the soil and the PVC was filled with masonary concrete. The concrete was allowed to set for approximately one week. These encased soil columns were then brought to the lab for testing. Numerous earth worm holes were observed during soil column collection.

Disturbed soil columns were made from the soil excavated from around the undisturbed columns. This soil was air dried and ground to pass through a #10 sieve (2.5 mm). When the test period was completed on the undisturbed soil columns, the undisturbed soil was excavated and the concrete/PVC encasement was cleaned by using distilled water and a wire brush. The sieved soil was then placed into the encasement and water-settled. 'Glade' Kentucky bluegrass sod, which was obtained from the same location at the horticulture research station, was placed on top of the soil to form the disturbed soil column. The sod was not given sufficient time to root so the disturbed characteristics of the columns were maintained.

The soil moisture in the columns was brought to field capacity, and the test was conducted for 7 days. Field capacity was attained by submerging the columns in water for 24 h and draining them for an additional 24 h. A permeable membrane was secured to the bottom of the columns to allow leachate movement while retaining the soil in place. A PVC adapter (smooth female end to threaded female end) was placed over the permeable membrane and glued onto the outside of the PVC encasement. A PVC plug with a 1.27-cm drain hole was threaded into the adapter to direct the flow of leachate into collection bottles. The columns were supported by ring stands so that the polyethylene collection bottles could be placed underneath the columns.

The test period started with a 61.0-mg application of chloride in the form of $CaCl_2$. The chloride, which was used as the traceable solute, was applied in a liquid solution with a spray mist atomizer to the top of the sod. After the chloride application, the columns were irrigated with 0.69 cm of distilled water over 15 sec. Some ponding occurred on all soil columns. The distilled water was applied with a Conejet TXVS 4 nozzle (Teejet©, Wheaton, IL). The irrigation regime was continued twice a day (about 0900 h and 1400 h) for 7 days. Leachate samples were collected at approximately 50-ml intervals (gravity flow). At the end of the 7-day test period, the columns were excavated into four sections: layer #1 (plant and thatch) = 0 to 2.0 cm, layer #2 = 2.0 to 6.7 cm, layer #3 = 6.7 to 13.4 cm, and layer #4 = 13.4 to 20.0 cm. The soil was placed on wax paper and allowed to dry at room temperature.

The chloride concentration of the leachate samples and the soil layers was determined by using a chloride-specific-ion electrode (Hach© 1989, model 44510). A liquid sample was extracted from the soil samples to determine soil chloride concentration. The results were analyzed by the analysis of variance factorial method.

The average bulk density for the undisturbed columns was 1.72 Mg m^{-3} (SD=0.07 Mg m^{-3}), which was significantly different ($p<0.001$) from the disturbed columns that had an average bulk density of 1.43 Mg m^{-3} (SD=0.01 Mg m^{-3}).

Forty-eight hours into the experiment the best fit curves for the leachate data started to diverge (Fig. 1). The difference is probably due to preferential flow through the macropores of the undisturbed soil. Ponding did occur allowing the macropores to drain. Differences in the amount of chloride recovered in the leachate started to occur within hours after the experiment had started (Fig. 2). The regression lines indicate that the chloride recovered for the undisturbed soil was reaching a maximum, and chloride recovery was increasing for the disturbed soil at the end of the 7-day test period.

The total amount of chloride leached was 2.0 times higher for the undisturbed columns than for the disturbed columns, and the total quantity of leachate was 1.4 times higher for undisturbed columns than for the disturbed columns (Table 1). There was not a significant difference in total Cl recovered for layer #2 (Table 2). Layer #3 of the disturbed column was 1.79 times higher and layer #4 was 2.72 times higher in the disturbed soil columns than undisturbed soil columns. Layer #1 was the only exception in the four layers where the total chloride recovered was 2.4 times higher for the undisturbed columns than for disturbed columns. The higher chloride concentration in layer #1 of the undisturbed columns is likely due to a vast portion of the applied irrigation water flowing down the macropores leaving Cl in the soil matrix. Irrigation water that was applied to the disturbed soil columns moved through the entire surface area of the column transporting the Cl through the soil column.

It was expected that the water-settling process used to compact the disturbed soil would result in a lower bulk density. The significant difference in bulk density between undisturbed and disturbed columns indicates that the disturbed columns were more porous than the undisturbed columns, which emphasizes the importance of macropore continuity on solute movement and leachate quantities. Thus, we conclude that the increase in total leachate and solute movement as well as the subsequent decrease in retention of chloride in the soil layers is likely due to the macropore structure that existed in the undisturbed columns.

Repacked soil columns are useful in making comparisons of the movement of one solute with the movement of another and in areas where disturbed soil exist. However, applying conclusions from solute movement studies using repacked columns to actual undisturbed field conditions could lead to errors in interpretation because of the effect of the macropore structures.

The results of this study should be taken into consideration when designing future studies where field conditions need to be more closely simulated.

Fig. 1. Averaged percent of total applied irrigation collected as leachate for undisturbed and disturbed soil columns. Bars represent 1 standard deviation.

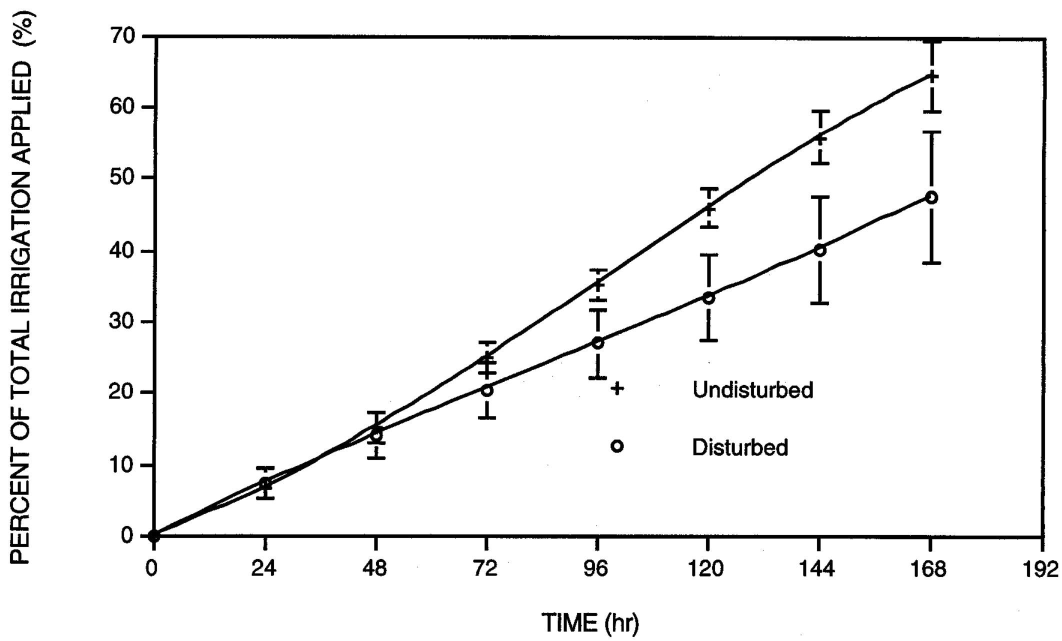

Fig. 2. Averaged percent of total applied chloride collected in leachate for undisturbed and distrubed soil columns. Bars represent 1 standard deviation.

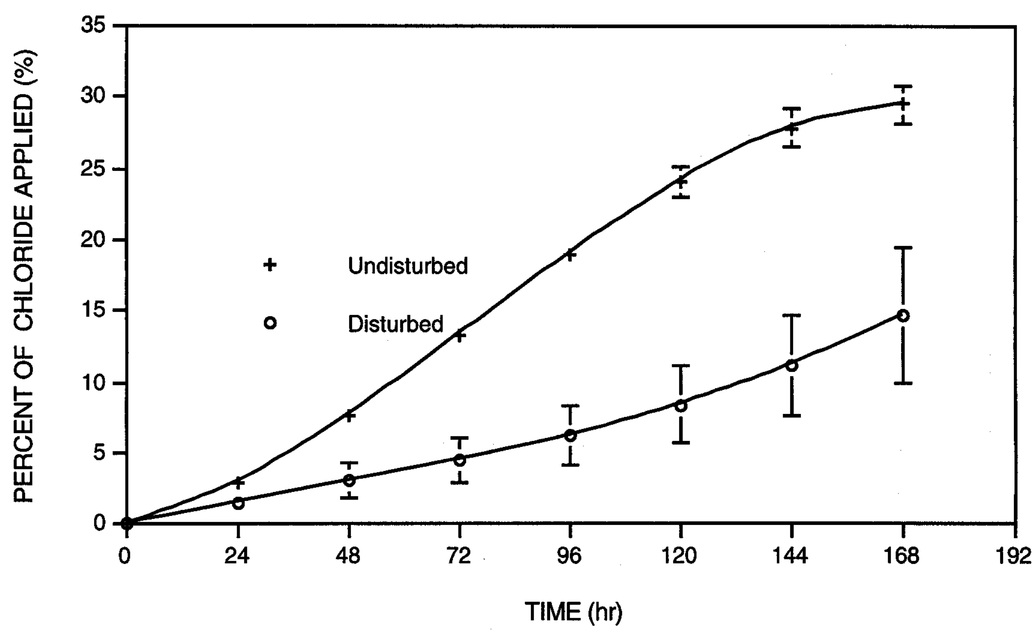

Table 1. Average percentage of applied chloride and irrigation water that leached through 4 replications of undisturbed and disturbed soil columns.

	Undisturbed Soil			Disturbed Soil	
Category	Mean (%)	Std. Dev. (%)	p-value [z]	Mean (%)	Std. Dev. (%)
Chloride	30.0	1.6	0.0017	14.8	5.4
Water recovered	64.5	5.7	0.0335	47.5	11.0

[z] *t* - test, based on the null hypothesis that undisturbed and disturbed are the same.

Table 2. Average percentage of applied chloride in each soil layer for 4 replications of undisturbed and disturbed soil columns.[z]

	Undisturbed Soil			Disturbed Soil		
Layer [z]	Mean (%)	Std. Dev. (%)	p-value[x]	Layer [z]	Mean (%)	Std. Dev. (%)
#1	37.5	4.4	0.0018	T	15.7	1.9
#2	13.0	6.9	0.8733	A	14.0	5.7
#3	19.5	11.8	0.0198	B	35.0	7.4
#4	19.5	2.9	<0.0001	C	53.0	17.6

[z] Layers, #1 = (0.0-2.0 cm), #2 = (2.0-6.7 cm), #3 = (6.7-13.4 cm), #4 = (13.4-20.0 cm).
[x] *t* - test, based on the null hypothesis that undisturbed and disturbed are the same.

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Comparing dispersion coefficients of undisturbed and disturbed soils under turfgrass conditions

S.K. Starrett[a], N.E. Christians[b], T.A. Austin[a], and L.C. Jones[a]
[a]Civil and Construction Engineering Department, Iowa State University, Ames, Iowa 50011, USA
[b]Horticulture Department, Iowa State University, Ames, Iowa 50011, USA
(Received____________________)

ABSTRACT
Starrett, S.K., Christians, N.E., Austin, T.A. and Jones L.C., 1993. Comparing Dispersion Coefficients of Undisturbed and Disturbed Soils Under Turfgrass Conditions. J. Hydrol.,______________.

Research relating to soil leaching properties under turfgrass conditions has often been conducted on repacked soils where the macropore structure has been destroyed. The objective of this study was to compare the solute movement characteristics of undisturbed and disturbed soil columns under turfgrass conditions. We studied the dispersion coefficients and soil chloride concentrations of the undisturbed and disturbed soils and compared the differences. Chloride was used as a conservative tracer to obtain breakthrough curves. Soil columns were excavated into 3 sections. These soil sections were tested for chloride concentrations. The mean bulk density was 1.33 Mg m^{-3} for the undisturbed columns and 1.16 Mg m^{-3} for the disturbed columns. The dispersion coefficient was 3.9 times higher for the undisturbed columns than for the disturbed columns. Chloride concentration found in the; A layer (0 to 6.7 cm) was 2.8 higher, B layer (6.7 to 13.4 cm) was 5.3 times higher, and in the C layer (13.4 to 20.0 cm) was 4.8 times higher for the disturbed soils than for the undisturbed. Applying conclusions from solute movement studies using repacked columns to actual undisturbed field conditions could lead to errors in interpretation because the effect of the macropore structures.