Crop rotations effects on leaching potential and groundwater quality. [DNR-080] 1993?

Posner, Joshua L.; Bubenzer, Gary; Madison, Frederick William, 1937-
Madison, Wisconsin: Wisconsin Department of Natural Resources, 1993?

https://digital.library.wisc.edu/1711.dl/5EFOP2KSOWHZU8T

Crop Rotations Effects on
Leaching Potential and
Groundwater Quality

Crop Rotations Effects on Leaching Potential and Groundwater Quality

Principal Investigators:

J. L. Posner, Assoc. Professor - Dept. of Agronomy, UW-Madison
G. D. Bubenzer, Professor - Dept. of Ag Engineering, UW-Madison
F. Madison, Assoc. Professor - Dept. of Soil Science, UW-Madison

Research Assistant

T. K. Iragavarapu, Graduate Student - Dept. of Agronomy, UW-Madison

Period of Contract: July 1, 1990 - December 31, 1992

Table of Contents

Table of contents (continued)

Abstract

MONITORING THE ENVIRONMENTAL IMPACT OF

ALTERNATIVE CROPPING SYSTEMS:

STUDIES ON WATER MOVEMENT, FALL SOIL NITRATE LEVELS, AND

PHOSPHORUS AND POTASSIUM NUTRIENT BUDGETS

Tammiraj Kumar Iragavarapu

Under the supervision of Associate Professor Joshua L. Posner

at the University of Wisconsin-Madison

A large-plot crop rotation study was initiated at two locations in southern Wisconsin in 1990 to compare the productivity, profitability, and environmental impact of contrasting cropping systems. Three studies were conducted from 1990 to 1992 to monitor the environmental impact of different cropping systems.

Study 1. Leaching of agricultural chemicals to ground water is a function of the amount and type of chemicals used and the amount of water percolating through the soil profile. Field testing with a bromide (Br^-) tracer indicated that breakthrough times to a shallow (1 m) groundwater table took less than one growing season, regardless of the cropping system. The rapidity of Br^- leaching and inability to identify a leaching front with repeated soil sampling indicated that preferential flow dominated piston flow under natural rainfall conditions under all the rotations on this prairie-derived silt loam soil.

Study 2. Fall soil nitrate (NO_3^-) levels are a measurement of synchrony between nitrogen availability and uptake by the crop. Excess NO_3^- in the fall in the upper midwest is liable to leaching below the root zone prior to the next cropping season. Pre-planned contrasts and combined analysis across years (1991 and 1992) and locations indicated that fall NO_3^- under the corn phase of the rotations were significantly greater than the pure legume phases. Legume phases had significantly greater fall NO_3^- than the intercrop (soybean/wheat, wheat/red clover, oats/alfalfa) phases. Also, the addition of wheat after soybean significantly reduced fall NO_3^- levels compared to no fall seeding after soybean harvest.

Study 3. An important component of long-term agricultural stability is the maintenance of soil fertility. Neither buildup nor continual draw-down are acceptable. Nutrient budgets for phosphorus (P) and potassium (K) were constructed for six rotations. Due to high initial fertility, no P or K fertilizers were used. Nutrient balance after three cropping seasons indicated a deficit of P in the cash grain rotations and a large deficit of K in the forage rotations. Soil testing in the fall of the third cropping season indicated a consistent drop in available P and exchangeable K to a depth of 90 cm.

Approved: ________________________

Date: ________________

General Introduction

Agriculture in Wisconsin and the nation is facing ever increasing challenges. The 1980's have been especially stressful to many farmers, and the farm population has continued to shrink (Felstehausen, 1986). Two issues of primary concern are declining farm profitability and the increasing awareness of the impact of farming on the environment (Chesters and Schierow, 1985; Hallberg, 1987). A number of critics of current agricultural practices are proposing low-input cropping systems as a partial solution to these problems (Goldstein and Young, 1987; Kansas State University, 1987; Olson et al., 1986). Their contention is that well managed low-input systems result in good profit margins and in less negative impact on the environment.

A key component of this strategy is the use of crop rotations where, biologically fixed nitrogen and alternating crops of different growth habits are used to minimize the need for fertilizers and pesticides as well as reduce the risk of movement of agricultural chemicals to the groundwater (Heichel, 1987; Power, 1987: Voss and Shrader, 1984). Critics of this approach argue that good management of chemical inputs, not their replacement, result in better profit margins and more vigorous crops that cause less damage to the environment (Hoeft and

Nafziger, 1988; Holt, 1989).

Regardless of the approach, a critical issue in production agriculture is nutrient management. The twin goals of high yields and environmentally sound agronomic practices are not contradictory. Achievement of these goals requires good management which synchronizes nutrient availability with crop need.

In order to partially address the question of optimal nutrient management, a large cropping systems trial (Wisconsin Integrated Cropping Systems Trial-WICST) was initiated at Arlington Research Station (ARS) and the Lakeland Agricultural Complex (LAC) sites in southern Wisconsin (Figure 1) in 1990. The trial contrasts different enterprise types and production strategies. Three rotations relate to cash grain production, and three other rotations focus on forage production. In both enterprise types, reduction in purchased inputs will be achieved by using rotations with greater cereal-legume interactions (Table 1). For example, in the cash grain rotations, R_1 is continuous corn while R_3 is only 33% corn and includes soybeans and a wheat/green manure during the three year cycle. With the forage rotations, R_4 has 3 years of alfalfa then one year of corn while R_6 has the legume (red clover) and bromegrass/timothy growing simultaneously. The mean energy input is the greatest for the high-input system

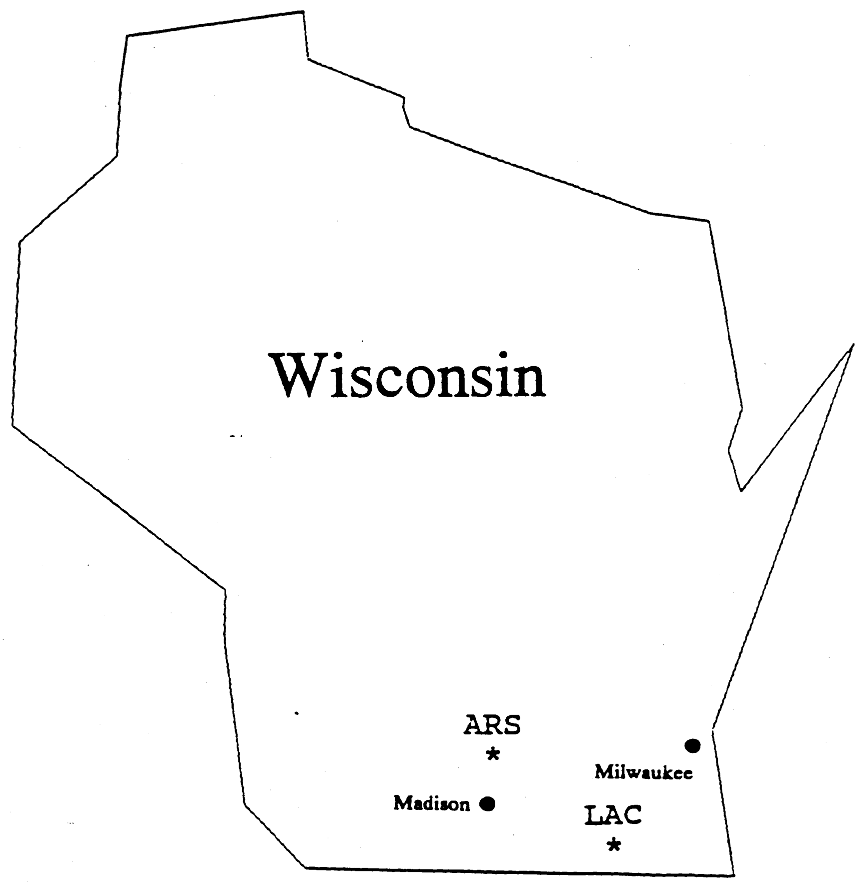

Figure 1. Location of Arlington Research Station (ARS), and the Lakeland Agricultural Complex (LAC) sites.

Table 1. Projected productivity and level of inputs in the Wisconsin Integrated Cropping Systems Trial, 1989.

Rotation	Predicted Yield (Mg ha^{-1})	Mean above ground productivity[1] Mg ha^{-1} yr^{-1}	Mean energy input[2] Kcal ha^{-1} yr^{-1}	Variable[3] Costs \$ ha^{-1} yr^{-1}	Chemical inputs: Fert N kg ha^{-1}	Chemical inputs: Herbicide AI kg^{-1} ha^{-1}	Chemical inputs: Insecticide AI kg^{-1} ha^{-1}
R_1							
Cont. Corn	9.4	17.7	4,663,360	346	179	Atrazine 2.2	Counter 1.6
						Alachlor 2.2	
R_2							
Drilled soybean	3.7	14.0	3,003,520	257	134	Bladex 2.8	--
corn	10.0					Alachlor 2.8	
						Sencor .6	
						Treflan 1.7	
R_3							
Row soybean	2.7	11.2	1,328,860	124	0	--	--
wheat/straw	4.0/4.5						
corn	75						
R_4							
Seeding alfalfa	6.7	12.0	3,509,870	272	11	Eptam 3.2	Lorsban 1.1
hay I	11.2					Bladex 2.2	
hay II	11.2					Alachlor 2.8	
corn	10.0						
R_5							
Oats/alfalfa	2.4/4.5	10.6	2,405,780	111	11	--	--
hay I	9.0						
corn	7.5						
R_6							
Rotational grazing	9.0	9.0	318,630	40	na	--	--

1. Mean above ground productivity: dry matter biomass production per hectare per year. Calculated based on the following harvest indices: Corn = .45; soybean = .35; wheat = .42; oat = .45
2. Mean energy input includes only seed, fertilizer, lime, manure, pesticides, and fuel. Based on Pimentel, D. 1980 Handbook of Energy Utilization in Agriculture, CRS Press Inc.
3. Variable costs include seeds, fertilizer, pesticides, drying, fuel, and labor. Costs are based on 1988 Wisconsin Crop Budgets. R. Klemme and L. Gillespie.

followed by medium-input and the smallest for the low-input system in both cash grain and forage enterprises (Table 1). Also, in the high-and medium-input systems, weed control is achieved by chemical means, whereas in the low-input cash grain system, the weeds are controlled mechanically. The trade-off between chemical and mechanical inputs is reflected in the variable costs for each of the six systems.

In evaluating alternative production strategies in the 1990's it is important to go beyond only the classical performance criteria of production (yield) and economic returns ($/hectare). This thesis reports on three ecological impact studies that were initiated in 1990. The three studies are:

1. Effect of contrasting cropping systems on leaching. Since water is the vehicle that carries dissolved nutrients to the ground water, water movement through the root zone was studied both in the presence and absence of crops.
2. Synchrony of N availability and N uptake as reflected by the amount of fall NO_3-N. Fall NO_3-N levels as an indicator of potentially leachable NO_3^- were measured under all the phases of different cropping systems.

3. Long-term maintenance of soil fertility as indicated by soil test levels of available P and exchangeable K. Nutrient (P and K) inputs and outputs were monitored. Change in soil fertility status (between 1990 and 1992) was measured in the fall of the third cropping season.

References

Chesters, G., and L.J. Schierow. 1985. A primer on non point pollution. Journal of Soil and Water Conservation 40: 14-18.

Felstehausen, H. 1986. Decline of farming in Wisconsin. Wisconsin Academy Review: 45-49.

Goldstein, W.A., and D.L. Young. 1987. An agronomic and economic comparison of a conventional and a low-input cropping system in the Palouse. American Journal of Alternative Agriculture 2 (2): 51-56.

Hallberg, G.R. 1987. Agricultural chemicals in groundwater. Extent and implications. Am. J. Alter. Agric.2: 3-15.

Heichel, G.H. 1987. Legumes as a source of nitrogen in conservation tillage systems. In J.F. Power (ed) The role of Legumes in Conservation Tillage Systems Ankeny, Iowa: Soil Conservation Society of America. p. 29-35

Hoeft, R.G., and E.D. Nafziger. 1988. Sustainable agriculture. Better crops with Plant Food 72(2): 9-11.

Holt, D. 1989. A love affair with LISA. Better crops with Plant Food 73(3): 4-7.

Kansas State University. Cooperative Extension Service. 1987. The annual Report: 1987 Management Information, Kansas Farm Management Associations. Manhattan, Kansas. Kansas State University.

Olson, K.D., E.J. Weness, D.E. Talley, P.A. Fales, and R.R. Lopnow. 1986. Southwestern Minnesota Farm Business Management Association. Economic Report ER87-4. St.Paul, MN: University of Minnesota.

Power, J.F. 1987. Legumes: Their potential role in agricultural production. Am. J. Alter. Agric. 2(2): 69-73.

Voss, R.D., and W.D. Shrader. 1984. Rotation effects and legume sources of nitrogen for corn. In D.F. Bezdicek and J.F. Power (eds.) Organic Farming: current technology and its role in sustainable agriculture, special publication No.46. ASA, CSA, SSCA. pp. 61-68.

Chapter 1

Study of Water Movement Through Soil Using Bromide Tracer

Introduction

The long-term sustainability of American farms is of concern to both farm and urban communities. It is estimated that by the year 2000 the number of U.S. farms will decline from 2.2 million to 1.2 million (Office of Technological Assessment, 1986). This change is the result of the tremendous economic pressure on the farming community. Additional stress is generated by the growing concern that farmers are causing serious environmental degradation. At the Federal level, the 1985 Farm Bill included several provisions to encourage farmers to reduce soil erosion (Myers, 1988). At the state level, there is an increasing concern over the effect of agrichemicals on water quality (WDATCP, 1989).

Agricultural activities are the main source of ground water contamination in Wisconsin, followed by municipal landfills, underground storage tanks, abandoned hazardous waste sites and spills (WDNR, 1992). The most common agricultural ground water contaminants are nitrates (NO_3^-) and pesticides. Of the agricultural sources, nitrate is the most problematic.

Leaching of surface-applied chemicals to ground water is a function not only of the amount of chemical in the root zone but also the amount of water percolating through it (Bolton et al., 1970).

This study was aimed at estimating the volume of water leaching through the profile under the six rotations in the cropping systems trial. The leaching volume was initially estimated using GLEAMS (Ground water Loading Effects of Agricultural Management Systems) simulations (Leonard et al., 1987). Other objectives included were: a) to determine the importance of piston versus macropore flow using a bromide tracer, and b) to estimate the breakthrough time to ground water of surface-applied chemicals.

Literature Review

To estimate the percolating water through the root zone, it is important to have an understanding of a water balance model and its various components. Also, a knowledge of actual water movement through the soil is important since water is the vehicle that carries agrichemicals to ground water.

This literature review is organized into three parts: a) an initial discussion of the water balance equation, b) a description of GLEAMS (Ground water Loading Effects of Agricultural Management Systems), and c) a review of water movement studies using anion tracer methodology.

Water balance equation

Introduction: The volume of deep percolation is often estimated by a water balance model (Rice et al., 1986). Water balance models consist of three major components: a) water added (irrigation + precipitation), b) water lost (evapotranspiration (ET), runoff, and deep percolation), and c) water stored (change in soil storage). Evapotranspiration is the water lost from the land surface by transpiration and evaporation. Runoff is that portion of the precipitation that appears in surface streams. Deep percolation is the downward movement of water beyond the root zone. Hillel (1982) provided the following root zone water balance model:

(Change in soil storage) = (gains) - (losses) ..... [1]

$$(\Delta S + \Delta V) = (P + I + U) - (R + D + E + T) \quad \text{.....} \quad [2]$$

Where,

ΔS = change in root zone soil moisture storage

ΔV = increment of water incorporated in the plants

P = precipitation

I = irrigation

U = capillary flow into the root zone

R = runoff

D = drainage out of the root zone (percolation)

E = evaporation

T = transpiration

Since the components V and U are small (Hillel, 1982), they are not considered for the purpose of this discussion. For unirrigated conditions, equation 2 can be simplified as:

Deep percolation = Precipitation - (ET + Runoff + Δ Soil storage) .... [3]

The various components of the water balance model (equation 3) are discussed briefly in the following paragraphs.

Precipitation: Long-term precipitation data at the Arlington Research Station (ARS) (Table 1.1A) and at Lake Geneva near the Lakeland Agricultural Complex (LAC) (Table 1.1B) sites are readily available. Average annual precipitation at Lakeland Agricultural Complex is about 1001 mm, and exceeds Arlington Research Station (857 mm) by 144 mm. Fifty-five percent and 48% of the yearly precipitation is received during the growing season (May-September) at ARS and LAC, respectively, and the remainder from late fall to early spring (October-April). This remaining 45 - 52% is subject to either runoff, soil storage or deep percolation, since ET is low during those cool months.

Evapotranspiration (ET): This is the largest component of

Table 1.1A. Average monthly precipitation at Arlington (1948- 1983)

Month	Rainfall (mm)	Snow (mm)	# of days of precip.
Growing season			
May	84	0	8
June	103	0	7
July	112	0	6
August	77	0	7
September	96	0	6
Total:	472	0	34
Off season			
October	58	0	5
November	45	36	4
December	34	188	3
January	28	185	3
February	25	145	3
March	42	183	5
April	77	25	7
Total:	309	762	30
Yearly Total	781	762	64

Source: Palm, R. S and A. R. deSouza 1983. Wisconsin Weather

Conversion from snow to rainfall = 10:1 (25.4 mm snow = 1 mm rainfall)

Table 1.1B. Average monthly precipitation at Lake Geneva[†] (1945- 1983)

Month	Rainfall (mm)	Snow (mm)	# of days of precip.
(Growing season)			
May	79	3	7
June	106	0	7
July	89	0	6
August	116	0	7
September	90	0	6
Total	480	3	33
(Off season)			
October	65	3	5
November	54	76	5
December	55	267	6
January	46	285	5
February	33	180	4
March	64	274	6
April	93	48	7
Total:	410	1133	38
Yearly Total	888	1135	71

[†] Lake Geneva is the nearest weather station (7 miles) to Elkhorn.
Source: Palm, R. S and A. R. deSouza 1983. Wisconsin Weather; Conversion factor, 25.4 mm snow = 1 mm rainfall)

water balance equation and difficult to measure directly. Evapotranspiration is estimated by three common methods: a) direct, b) indirect, and c) computer simulation (Hatfield, 1990). For direct methods, the widely used approaches are: a) measurement with weighing lysimeters, and b) portable chambers. The indirect methods include : a) inferring ET from a hydrologic balance model as in equation 2, and b) micro-meteorological in approach (i.e., profile, Bowen ratio, aerodynamic methods like Penman, etc). Computer simulation models use climatological algorithms, and agronomic and soil conditions to estimate ET.

Lysimeter measurements are the most accurate of all methods (Hatfield, 1990). Weighing-type lysimeters are more precise in that they are equipped with a scale for accurate measurement. Change in weight over a given period of time represents water lost through ET from the lysimeter. However, these lysimeters may not be reliable if the soil is disturbed or the planting density in the lysimeter does not represent actual field conditions (Hillel, 1982).

Researchers have reported seasonal ET values for different crops (Table 1.2). Some of these ET values were derived using a water balance approach in irrigation replenishment studies. In these, after taking initial moisture measurement, water was added to bring the soil

Table 1.2. Evapotranspiration of different crops

Crop	Location	Seasonal ET (mm)	Yield (Mg ha^{-1})	Source
Corn[a]	Manhattan, KS	561	8.0	Hattendorf et al.(1988)
Corn[b]	Tribune, KS	568	7.0	Hattendorf et al. (1988)
Corn[b]	Ames, Iowa	405	8.0	Hamlett et al. (1988)
Corn[c]	Coshocton, OH	645	8.4	Chichester & Smith, (1978)
Soybean[a]	Manhattan, KS	590	3.3	Hattendorf et al. (1988)
Soybean[b]	Tribune, KS	490	2.7	Hattendorf et al. (1988)
Soybean[a]	Stuttgart, AR	382	1.9	Scott et al. (1987)
Soybean[b]	Stuttgart, AR	497	2.7	Scott et al. (1987)
Alfalfa[b]	Alberta, Canada	660	11.6	Sonmor, (1963)
Alfalfa[b]	Colorado	609	9.0	Peterson, (1972)

[a] = ET derived using water balance model without irrigation
[b] = ET derived using water balance model with irrigation
[c] = Weighing lysimeter study

moisture to field capacity (Hattendorf et al., 1988). It was assumed that the amount of precipitation/irrigation plus deficit in soil moisture between two sampling dates (beginning and end of growing season) was due to evapotranspiration.

Alfalfa has a greater seasonal water requirement compared to other crops (Table 1.2). This is due to its vigorous growth nearly six to eight months in a year and complete ground cover (Sonmor, 1963). Also, the deep root system of alfalfa removes water from deeper horizons. Mathers et al. (1975) reported that alfalfa uses water from 180 cm and 360 cm depth during the first and second years, respectively. On the other hand, corn planted in rows (76 cm) and having a shorter period of active growth has a lower water requirement.

Sonmor (1963) grouped crops into three main classes in descending order of their total water requirement: a) close-seeded perennials, b) close-seeded annuals, and c) annual row crops. From ET values given in Table 1.2, it can be inferred that at yields common in Wisconsin, the seasonal ET of row crops like corn and soybean is approximately 120% of the precipitation received during the same period of time. Since the crop demand for water (ET) exceeds the amount of precipitation, the leaching losses are minimal in the summer.

<u>Runoff:</u> The extent of runoff depends on several factors, e.g., type of tillage, soil, length of slope, percent slope, rainfall pattern, etc. (Steinhart, 1984). Tillage affects directly infiltration and surface storage of the soil, and therefore, the volume of runoff (Mueller et al., 1981). Most past research on runoff has focussed on the effect of different tillage practices on runoff in row crops (corn and soybean). Conservation tillage systems decrease the amount of runoff by reducing the raindrop impact and creating a rough surface (Johnson et al., 1979; Baker et al., 1978; etc). On a runoff plot study in Illinois, Siemens and Oshwald (1978) reported that of the 127 mm of total water applied, runoff was only 12% in a chisel plowed field compared to 33% in a conventional tillage. Chisel plowing reduced runoff and soil loss by 75% and 89%, respectively, compared to conventional tillage (Mueller et al., 1981). Steinhart (1984), in her review of tillage studies conducted in the upper midwest, concluded that runoff is negligible under conservation tillage practices on 0-2% slopes.

<u>Soil storage:</u> Texture and depth are important factors affecting potential water storage in soil. The greater the clay content in general, the greater will be the total water retention of the soil. For example, sandy soils

retain only about 25 mm of available water per foot of soil. On the other hand, medium-textured silt loam soils retain about 56 mm of available water in the top 30 cm of soil profile (Martin et al., 1991). In early spring, in the upper midwest, silt loams are usually fully charged and hold about 168 mm of available water in the top 90 cm of the soil profile. This stored water supplements incoming rainfall to meet the crops' seasonal ET requirement. Short-term changes in soil storage are important during the growing season for two reasons: a) water demand by the crops, and b) rainfall replenishment pattern during the season. However, for an annual budget, the change in soil storage will be small because ET plus drainage will be approximately equal to the rainfall (Hillel, 1982).

<u>Deep percolation:</u> Percolation may be estimated by differences by measuring all other terms in the equation 3 or by direct field measurements. Percolation is measured under field conditions by two methods: a) lysimeters, and b) tile drains. Lysimeters are enclosed systems equipped with a drainage system to collect water lost through the root zone. Tile drains form sub-surface drainage systems for poorly drained agricultural lands (Logan et al., 1980). The amount of water that flows in a tile is a function of crop ET, precipitation, soil factors like infiltration,

hydraulic conductivity, slope, and texture (Logan et al., 1980). The tile flow represents a portion of the water percolating below the root zone.

Studies on measured percolation in lysimeters (Table 1.3) indicate that at Coshocton, Ohio, the percentage of rainfall lost as percolation is more under corn (33-34%) than alfalfa (11%).

Percolate volumes were markedly different when lysimeters were compared to tile drains. For example, Bergstrom (1987), in a study in Sweden, observed 269 mm (47%) percolate under alfalfa from lysimeters as compared to 69 mm (12%) using tile drains. The difference in drainage volumes by the two methods results from all the percolating water being collected in a closed lysimeter system, while in the tile drain system only a portion is captured (Bergstorm, 1987).

Although lysimeters give accurate measurements, they are measurements in a disturbed system (except monolith types). Lysimeters, for example, will overestimate percolation if their catchment is larger than the size of the lysimeter, or crop production within the lysimeter is reduced. Tiles underestimate absolute percolation, although the setting is less disturbed.

Nevertheless, both lysimeters and tile drains are used to compare between treatments or for sampling the quality

Table 1.3. Amount of percolation measured with lysimeters and tile flow under different crops

Crop	Site	Soiltype	Rainfall (mm)	Percolate (mm)	Reference
Corn[¶]	Coshocton, OH	Silt loam	1185	525 (44.3)	Owens (1990)
Corn[¶]	Coshocton, OH	Silt loam	1073	358 (33.4)	Chichester (1977)
Corn[§]	Charles City, IA	Loam	650	118 (18.2)	Logan et al. (1980)
Corn[§]	Waseca, MN	Clay loam	760	88 (11.6)	Logan et al. (1980)
Corn[§]	Ames, Iowa	Loam	883	193 (21.8)[†]	Kanwar et al. (1988)
Corn[§]	Ames, Iowa	Loam	883	272 (31.9)[‡]	Kanwar et al. (1988)
Corn[§]	Ames, Iowa	Silt loam	811	131 (16.2)	Baker and Johnson (1981)
Soybeans[§]	Hoytville, OH	Clay	810	243 (30.0)	Logan et al. (1980)
Meadow[¶]	Coshocton, OH	Silt loam	990	108 (10.9)	Owens (1990)
Alfalfa[¶]	Kjettslinge,Sweden	Clay loam	576	269 (47.0)	Bergstorm (1980)
Alfalfa[§]	Kjettslinge,Sweden	Clay loam	576	69 (12.0)	Bergstorm (1980)
Alfalfa[§]	Ohio	Silt loam	264[ǀ]	48 (18.2)[ǀ]	Logan et al. (1980)
Oats[§]	Ames, Iowa	Silt loam	943	100 (10.6)	Baker and Johnson (1981)

¶ Lysimeter studies
§ Tile drain studies
ǀ April-May 1972, and March-April 1973

† conventional tillage
‡ no-tillage

Numbers in parentheses are percentage of incoming rain of percolating water.

Temporal factor: Lysimeter studies (Owens, 1990; Chichester and Smith, 1978) to determine the time of percolation revealed that regardless of the type of crop greatest amounts of percolation occurred during the winter and early spring months (November through April). Similarly, Bolton et al. (1970), in a 7-year tile drain study with various cropping systems, reported peak effluent flows during the months of October through March. In the upper midwest regions where soil freezes during winter, the soils are thawed by April 1, but crop ET will not offset the precipitation until mid-June. As a result, most of the deep percolation losses occur during the period of April 1-mid June (Schepers, 1988).

Conclusions: Evapotranspiration is the major component of the water balance model. On a yearly basis, depending on the type of the crop, ET accounts for 60-75% of the incoming precipitation (see Tables 1.1A, B and 1.2). Measured deep percolation varied between 10-20% of incoming rainfall under tile drains, and as high as 33-44% under lysimeters.

In areas where runoff is small (Steinhart, 1984) and change in soil storage on a yearly basis is negligible

(Hillel, 1982), the annual water balance equation 3 can be simplified to:

$$\text{Deep percolation} = \text{Rainfall} - \text{ET} \quad \ldots\ldots\ldots\ldots \quad [4]$$

GLEAMS hydrology component

Introduction: Recent concerns about ground water contamination by nutrients and pesticides has resulted in the development of mathematical models to assess the impact of agricultural management practices on ground water quality (Leonard et al., 1987). In 1980, CREAMS (Chemicals, Runoff, and Erosion From Agricultural Management Systems) was developed to evaluate non-point source pollutant loads from field size agricultural areas (Knisel, 1980). In order to include vertical movement of pesticides, a modified version of CREAMS, called GLEAMS (Ground water Loading Effects of Agricultural Management Systems), was developed by Leonard et al. (1987). The GLEAMS model consists of three separate components: hydrology, erosion, and pesticides (version 1.8.55). This study focusses only on the hydrology component of the model. A brief overview of the hydrology component is given here. Detailed description of the model is given by Leonard et al. (1987).

Water balance: The hydrologic component uses daily climatic data to calculate water balance in the root zone using the equation:

$$M_t = M_0 + P_t - Ru_t - ET_t - R_t \text{ ....} [5]$$

where, M_0 is the initial soil moisture, M_t is soil moisture at day t, P_t is precipitation, Ru_t is runoff, ET_t is evapotranspiration, and R_t is percolation below root zone between the initial day and t.

Precipitation: To calculate water balance, GLEAMS uses daily precipitation data as water-equivalent depth from a stored precipitation file.

Runoff: Daily rainfall is partitioned between surface runoff and infiltration using Soil Conservation Service (SCS) curve number (CN) procedure (USDA, 1972). In determining a curve number, variables like storm type, antecedent moisture condition, hydrologic soil group, soil conservation practices, slope, and land use are considered. Runoff volume is calculated by:

$$Q = (P - 0.2S)^2/(P + 0.8S) \text{ ......} [6]$$

where, Q = runoff volume; P = precipitation;
S = (1000/CN)-10, which is a retention parameter related to the curve number.

Snowmelt: Precipitation that occurs during days having freezing air temperatures is accumulated as "snowpack". When the mean daily air temperature rises above freezing, snowmelt is calculated by equation [7] until the "snowpack" is depleted.

$$SMT = 4.57T \qquad [7]$$

where, SMT is snowmelt in mm per day, and T is the mean daily temperature in degrees Celsius (Knisel, et al., 1985). When the soil is frozen, this water is lost as runoff. Mean daily temperature and December solar radiation data (a proxy for the depth of freezing) are used to estimate duration of frozen soil conditions during the spring melt period.

$$DFS = 35.4 - 0.154\ R \qquad [8]$$

where, DFS = number of days with frozen soil after mean daily temperature first rises above freezing, and R is December solar radiation in gm-cal cm^{-1} day^{-1}. Snowmelt goes into soil storage, percolation, and runoff. Although this method is quite simplistic, it does account for snowmelt under frozen conditions (Knisel et al., 1985) . Snowmelt during March and April primarily contributes to runoff.

Evapotranspiration: Soil evaporation and plant transpiration are estimated with modified Penman equation (Ritchie, 1972). Evaporation based on heat flux is a function of daily net solar radiation and mean daily temperature, which are interpolated from a Fourier series fitted to a mean monthly radiation and temperature (Smith and Williams, 1980). Soil evaporation is calculated in two stages. When the soil is wet, soil evaporation is limited only by available energy and is equal to potential soil evaporation. As the surface soil dries, evaporation depends on transmission of water through the soil profile to the surface and time elapsed since stage two began.

Plant transpiration is computed as a function of evaporation and leaf area index (LAI). When soil moisture tension falls below 1.5 MPa, plant growth is stopped by holding LAI constant until water becomes available. This allows an interaction between rainfall data and LAI to account, in an approximate manner, for plant-water stress conditions.

<u>Percolation:</u> The model uses a soil storage routing technique to predict flow of water through the root zone (Williams and Hann, 1978). The root zone is divided into three to 12 computational layers depending on the rooting depth for water routing. This storage routing technique assumes that water moves downward in the soil in a piston-like fashion . Once the upper layer reaches field capacity, excess water is drained into the next layer. The

routing equation is:

$$R = G\,[F + (STO/dT)],\quad [F + (STO/dT)] > FC \;....[9]$$

where, F is the infiltration or inflow rate, STO is the storage volume, G is the storage coefficient, and dT is the routing interval (1 day), FC is field capacity.

If inflow plus storage does not exceed field capacity, percolation will not occur. The storage coefficient is computed by

$$G = 2dT/(2T + dT) \;...............[10]$$

where, T is the travel time through a storage layer. Travel time is estimated by

$$T = (SM - FC)/r \;..................[11]$$

where, SM is soil water storage, and r is the saturated conductivity of the soil.

<u>Model testing:</u> The GLEAMS model has been tested primarily for pesticide runoff and leaching to the bottom of the root zone (Johnson, 1978; Smith et al., 1978). Johnson (1978) conducted a study on pesticide (Cyanazine and Alachlor) runoff on two watersheds near Lincoln, IA during 1976-78. The author compared observed runoff and sediment yields with GLEAMS simulations. Although the model simulations did not agree with the observed runoff volumes, the sediment yield comparisons were reasonable. In a study conducted in Georgia, both simulated and observed data indicated

movement of atrazine to 15 cm depth (Smith et al., 1978).

Owens et al. (1985) used bromide (Br^-) to simulate pesticide leaching in a study at Coschocton, OH. In this study, 168 kg Br^- ha^{-1} was broadcast on three lysimeters in 1980. The authors used Br^- to evaluate the water balance/solute transport components of GLEAMS. The GLEAMS simulations were run using three different rooting depths (74 cm, 102 cm, and 240 cm). Observed Br^- leaching under the three lysimeters at the end of four years ranged from 61 to 138 kg ha^{-1}, compared to the simulated Br^- leaching amounts of 108 to 142 kg ha^{-1} over the same period of time.

Limitation of the model: The storage routing technique (equation 9) in the hydrology component of GLEAMS assumes that water moves through the computational layers in the soil in a piston-like fashion. The following discussion suggests that piston flow is not the only mechanism of downward movement of water and, therefore, the assumption of piston flow may limit the applicability of the GLEAMS model.

Movement of water through soil

Introduction: Currently two types of models describe the movement of water through the soil: (a) piston-type flow, where, percolating water displaces resident water as it moves down, and (b) macropore flow, where, a portion of the water bypasses the bulk of the soil and moves through macropores (Thomas and Phillips, 1979). In the past it was thought that downward movement of water was by simple piston flow mechanism (Bodman and Colman, 1943); but recent field studies indicated that piston flow is not the only mechanism by which water and solutes move through soil.

Macropore flow: Beven and Germann (1982) reviewed the importance of macropores on water flow in soils. According to these authors, macropores can be formed by earthworms, decaying roots, cracks and fissures, etc. Soil type and tillage practices affect macropore formation. Cracks are formed in clay soils due to shrinking and swelling depending on soil moisture.

Conservation tillage is recommended to reduce pesticide contamination of surface water through runoff (Baker and Johnson, 1979). On the other hand, since plowing is minimized under conservation tillage, there are more continuous macropores from the surface deep into the subsoil, potentially increasing water flow through macropores. For example, Kanwar et al. (1988) reported 31% of incoming precipitation as tile flow under no-tillage compared to 21% under conventional tillage (see Table 1.3).

Greater tile flow under no-tillage in this study could be due to macropore flow. Increased infiltration rates (37 mm h^{-1}) were also reported under no-till plots compared to 16 mm h^{-1} under moldboard plow conditions. This increased infiltration under no-till was attributed to the combined effect of surface cover and macropores in a study conducted on sandy clay loam soils in Georgia (Radcliffe et al., 1988).

Old root channels can contribute significantly to preferential flow of water. Barley (1959) reported that water infiltration rates increased following death of corn plants as decaying roots created channels that conducted water. Increased infiltration rates (2- to 3-times) were also observed due to water flow through dead alfalfa root channels in a 3-year study (Meek et al., 1989).

Abundance of earthworms is considered desirable in field situations. Increased earthworm populations were reported in alfalfa and red clover fields compared to corn fields (Shipitalo et al., 1988). An increase in earthworm channels was found under no-till cultivation compared to conventional tillage (Ehlers, 1975). Earthworms promote significant changes to the soil by improving its physical and chemical conditions for plant root growth and crop yield (Syers and Springett, 1983). On the other hand, macropores caused by earthworms increase the water infiltration and percolation rates through the soil.

The extent of macropore flow has been estimated in different ways. Watson and Luxmoore (1986) in a tension infiltrometer study estimated that 73% of water flux was conducted by macropores which occupied only 0.04% of the soil volume. Macropore was defined as a pore having >0.05 cm radius and drained at < 3 cm water tension. They calculated macropore flow as the difference between ponded infiltration rate and infiltration rate at 3 cm tension.

Jabro et al. (1991) studied the spatial variability of pore size distribution and Br^- concentration. They observed considerable variation (1.2 cm hr^{-1} to 33.5 cm hr^{-1}) in infiltration rates, and Br^- concentrations (56-172% CV) due to the spatial variability of the pore-size distribution in the soil profile. The authors attributed this large variation to the presence of macropores in the soil.

The extent of macropore flow has also been determined by comparing the actual deep percolation rate with deep percolation calculated from mathematical equations (Rice et al., 1986). The authors calculated Darcy velocity as the product of the water content and tracer velocity. Actual Br^- tracer velocity was five times greater than determined from a water balance. The authors attributed this discrepancy between the tracer and water balance rates to preferential flow of the water and solute in the field situation.

As a result of this preferential flow, water and surface-applied solutes bypass the bulk of the soil and move faster and farther in the soil than would be expected based only on piston flow (Quinsberry and Phillips, 1978).

Work conducted with bromide (Br^-) as a tracer of water and solutes has indicated that preferential flow is an important mechanism of water and solute movement through the soil. However, most of the past research on macropore flow was conducted under continuously flooded conditions where the surface-applied water and chemicals leached rapidly below 100 cm (Shuford et al., 1977; Jabro et al., 1991; etc).

Most studies that reported solute transit times using Br^- as a tracer have focused on coarse-textured soils with supplemental irrigation. Saffigna et al. (1977), for example, reported that 610 mm of water (irrigation + precipitation) moved Br^- to >3 m depth within 205 days on an irrigated sandy soil in Wisconsin. Similarly, Rice et al. (1986) reported that Br^- had moved to 2 m depth in 126 days after a 290 mm application of water on a sandy loam soil in Arizona. It is not clear, however, what role macropore flow would have on finer-textured agricultural soils under natural rainfall conditions (Bowman and Rice, 1984).

<u>Conclusions:</u> The above literature suggests that macropore flow plays a major role in the downward movement of water and chemicals. Earthworms, dead root channels, and cracks and fissures can contribute to macropore flow under field conditions. In no-tillage, due to the lack of disturbance of the surface soil, macropores may promote transportation of surface-applied chemicals to ground water.

Use of tracers to study water movement

Tracers have been used to follow the movement of percolating water (Rice et al., 1986; Shuford et al., 1977; etc). A wide range of tracers have been used to follow the path of water and solute movement. Davis et al. (1980) gave a brief review of commonly used tracer types. Of all the tracers, anions like chloride (Cl^-) and bromide (Br^-) are most widely used. Several workers (Carlan et al., 1985; Shuford et al., 1977; Jabro et al., 1991; etc.) have used anion tracers. Anions are more common because they are not adsorbed to the negatively charged clay particles in the soil. These selected anions have been found to faithfully mimic water movement in soil once a correction is made for the volume of exclusion. This is the volume of soil pore space unavailable to negatively charged ions as they are repelled by clay surfaces (Smith, 1972). As a result of this repulsion, these anions tend to move slightly faster than water (Smith and Davis, 1974). Due to this anion exclusion phenomenon, Br^- has been found to move 15% faster than water (Rice et al., 1986).

It has been demonstrated that Br^- has desirable characteristics for use as a tracer under field conditions. It is easily detected and unlikely to contaminate the environment (Onken et al., 1977). Although Br^- can be toxic to animals at greater (> 7 ppm) levels, it is not toxic to plants (Martin, 1966). Except in surface soils (0-15 cm), where, microbial activity affects the movement of nitrates (Smith and Davis, 1974), movement of bromide in the soil is similar to nitrates.

Water balance study with GLEAMS

This study was developed to simulate water balance for the six rotations in the Wisconsin Integrated Cropping Systems Trial. Long-term (1975-1986) precipitation and temperature data at both the Arlington Research Station (ARS), and the Lakeland Agricultural Complex (LAC) were used for simulations.

Materials and Methods

In order to simulate water balance using the GLEAMS model, climatic, soil, and crop management data are required. Model inputs used in this study are listed in Table 1.4. Daily precipitation, mean daily temperature, and monthly mean solar radiation data were obtained from State Climatologist. The soil profile was partitioned into two horizons. Water retention, pore space, and saturated hydraulic conductivity values assigned to these horizons were obtained from GLEAMS Users' Manual Soil Series database (Davis et al., 1990). Measured organic matter content at both the sites was assigned to the two horizons. The original plot size at the two locations was selected as a physical unit for water balance simulation. Separate

Table 1.4. Inputs for GLEAMS hydrology component

Variable	Value	Unit
Climatic		
Daily precipitation	Variable	inches
Mean monthly solar radiation	Variable	langleys/day
Daily mean air temperature	Variable	^0F
Soil (silt loam):		
Effective saturated conductivity	0.22	in/hr
Field capacity	0.35	in/in
Wilting point	0.18	in/in
Organic matter	4-5	%
Initial water content (fraction of available water)	1.00	in/in
Soil evaporation parameter	4.50	
Porosity	0.46	in/in
SCS curve number for moisture condition II†	61 - 74	
Hydraulic slope	0.02	ft/ft
Surface residue cover	0.5 - 0.8	
Bulk density	1.5	gm/cm^3
Plant		
Crop duration	variable	Julian days
LAI	see Appendix I.A	
Planting date	variable	Julian days
Harvest date	variable	Julian days
Effective rooting depth‡	34-60	inches
Management practice	Good	

† SCS curve number 61 for alfalfa, and 74 for corn
‡ Effective rooting depth 34" for corn; 60" for alfalfa
Same values were used for both the sites

runs were made for each of the six rotations at each site. The simulations were done for 12 years (1975-1986), in which the R_2 (2-yr rotation) had 6 cycles, R_3 and R_5 (3-yr rotations) had four cycles, and R_4 (4-year rotation) had three cycles. Rotations 1 and 6 are continuous corn and continuous pasture, respectively. Within each run, temperature, winter cover factor, and leaf area index parameters (LAI) were updated each year. LAI values were modified by the crop and by planting and harvest dates (Appendix I.A). In the years where alfalfa was companion seeded with oats, LAI was modified after oat harvest to account for emerging alfalfa crop. Similarly, LAI was also modified for winter cover crop (winter wheat) in R_3. Good management practices were assumed for all crops, as management also affects LAI.

Results

Water balance results averaged over 12 years for the six rotations (R_1 through R_6) are given in Table 1.5.

<u>Precipitation:</u> Average annual precipitation for LAC is 131 mm more than the ARS (Table 1.5). Growing season rainfall is 60% of total precipitation at ARS and 51% at LAC (Table 1.6). This indicates that over winter precipitation is

Table 1.5. Water balance calculations using GLEAMS: 12 year averages (1975-1986)

Rotation	Precipitation (mm)	ET (mm)	Runoff (mm)	Percolation (mm)
		Arlington Research Station (ARS)		
R_1.C-C-C	830	679 (82)	101 (12)	50 (6)
R_2.Sb-C-Sb	830	679 (82)	104 (12)	47 (6)
R_3.Sb-W/rc-C	830	716 (86)	74 (9)	40 (5)
R_4.A-A-A-C	830	705 (85)	81 (10)	44 (5)
R_5.O/A-A-C	830	702 (85)	82 (10)	46 (5)
R_6.P-P-P	830	748 (90)	75 (9)	7 (1)
		Lakeland Agricultural Complex (LAC)		
R_1.C-C-C	961	745 (78)	119 (12)	97 (10)
R_2.Sb-C-Sb	961	742 (77)	121 (13)	98 (10)
R_3.Sb-W/rc-C	961	805 (84)	97 (10)	59 (6)
R_4.A-A-A-C	961	762 (79)	105 (11)	93 (10)
R_5.O/A-A-C	961	763 (79)	105 (11)	93 (10)
R_6.P-P-P	961	833 (87)	101 (11)	27 (2)

Numbers in parentheses are percentage of total precipitation.

C=corn;Sb=soybean; W=winter wheat; rc=red clover; O/A=oats and alfalfa companion seeded; A=sole seeded alfalfa; P=pasture (50% red clover + 25% brome grass + 25% timothy). Simulations were run on a 2% slope. Rooting depths of 34", 34",60", 60" and SCS runoff curve numbers of 74, 75, 61, and 60 were used for corn, soybeans, alfalfa, and pasture, respectively.

Table 1.6. Long-term (1965-89) growing season rainfall and simumulated evapotranspiration values GLEAMS

Month	ARS Rainfall (mm)	ARS ET (mm)	LAC Rainfall (mm)	LAC ET (mm)
May	75	63	82	69
June	103	81	105	87
July	101	120	107	130
August	117	144	120	157
September	102	83	77	91
Total	498	491	491	534

ARS= Arlington Research Station
LAC= Lakeland Agricultural Complex

more at LAC, indicating a greater potential for percolation losses at this site.

Evapotranspiration: Evapotranspiration was 6% higher (Table 1.5) in the close-canopy forage rotations (R_4, R_5, and R_6) compared to row crop cash grain rotations (R_1 and R_2). Even though R_3 is a cash grain rotation, the large ET in this rotation is due to the longer growing season due to winter wheat. Similarly, R_4 and R_5 have alfalfa growing for 6-8 months/year which contributes to more ET. The values in Table 1.5 indicate that regardless of the type of crop ET is the major component of the water balance equation (79-90% of incoming precipitation). However, during the crop season for example, ET in corn accounts for most of the precipitation (Table 1.6), and during the peak period of crop growth (July-August) ET is more than rainfall. The values for seasonal ET of corn simulated by GLEAMS (Table 1.6) are within the range reported in the literature (Table 1.2). Annual ET values are generally 63-85 mm higher at LAC than ARS due to higher (131 mm) rainfall, resulting in less predicted drought stress. The remaining water was partitioned between runoff and percolation.

Runoff: Runoff was 17-23% lower (Table 1.5) under forage rotations (R_4, R_5, and R_6) compared to row crops (R_1 and R_2).

Due to the winter wheat and red clover in R_3, the runoff losses were 23-36% lower than from continuous corn. Regardless of the type of the crop, maximum runoff was estimated to occur during March and April due to snow melt and storms received during these two months. For example, in the continuous corn rotation 73-89% runoff was estimated during these two months.

Percolation: Estimated annual percolation losses under the rotations were generally low (Table 1.5). Percolation losses accounted for 1-6% of incoming rainfall at Arlington Research Station and 2-10% at the higher rainfall LAC site. Percolation losses were maximum under continuous corn, followed by soybean-corn rotation. Low ET values coupled with shallow root systems (86 cm) in these two rotations resulted in more percolation losses. On the other hand, in R_3 due to the presence of winter cover crop, the ET values were at a maximum, lessening the water available for percolation. In general, as the length of growing season increased, percolation losses were reduced due to an increase in ET. In case of monocropping (R_1), the amount of percolation increased with increasing precipitation. In forage rotations in which 1 year of corn was included after 2-3 hay years, percolation was usually more during the corn year compared to hay years. In all the rotations, irrespective of the type of the crop, percolation was more during late fall and early spring months than during the summer or winter period. For example, in continuous corn, 69% of the total percolation occurs during the October-May period.

<u>Conclusions:</u> The values for ET, runoff, and percolation were estimated to be greater at LAC compared to ARS due to greater amounts of precipitation. Growing season ET values predicted by the model are within the range of the reported values in the literature. Evapotranspiration values are greater under closed canopy crops (R_3 and R_6) compared to row crops (R_1 and R_2).

Estimated runoff losses were low and not too important and in agreement with Steinhart (1984) on these level fields. Runoff was higher under row crops compare to sod crops. Most of the runoff occurred during the snow melt periods of March and April.

Percolation losses simulated by the model were much lower than reported values in the literature (Table 1.3). This may be due to the piston-type percolation model used in the hydrology component of GLEAMS. Due to this piston-type model, GLEAMS may overestimate the actual water stored in the soil, consequently lowering percolation losses. The majority of the percolation simulated by the model occurred in late fall and early spring periods as suggested by the literature.

Leaching frame study

During the summer of 1990, a preliminary monitoring study was conducted using potassium bromide (KBr) to trace water movement in the prairie-derived medium textured (Griswold silt loam) soil profile in Southeast Wisconsin. In this experiment, the Br^- concentration was monitored to one meter depth by periodic sampling.

Objectives

1. To evaluate the application method, sampling procedure and the detection method of Br^- as a conservative tracer on silt loam soils.

2. To determine the relative importance of piston versus macropore flow in a prairie-derived silt loam soil.

3. To determine the breakthrough times with which surface-added chemicals move beyond the root zone to ground water in these soils.

Materials and Methods

Site description: The experimental site is on a Griswold silt loam (Aquic Argiudoll, Fine-loamy, Mixed, Mesic), mottled subsoil variant, on a 0-3% slope. The variants from the normal Griswold soils are moderately deep, dark-colored, somewhat poorly drained soils. In a typical profile, the surface layer is a black silt loam about 30 cm thick. The underlying material is calcareous, yellowish-brown, friable sandy loam that is mottled with a strong brown color. The soil is saturated at 0.3 to 0.9 m during wet periods. At the nearby (1 km) sludge plots, the ground water is quite shallow and fluctuates between 1-5 m. Ground water flow is north to south at the rate of 0.02 to 0.2 m yr^{-1} (Postle, 1984).

Treatments: Three different treatments were selected for study during the summer of 1990. The hypotheses was that if piston flow dominated, depth to the peak of bromide concentration band would be predominately determined by the amount of water added (Gish and Jury, 1982). On the other hand, if macropore flow dominated, the partitioning of the rainfall would be more important than the total amount; i.e., a greater percent of total rainfall would move by macropore flow during infrequent intense showers than frequent small events. If the former model of water transport was correct, the depth of Br^- concentration band would indicate leaching volume. If however, the latter model was correct, the Br^- tracer could no longer be used to estimate leaching volumes but only to identify breakthrough times to ground water. The three treatments were:

1. 12.7mm water twice a week without plants
2. 50.8 mm water every 14 days without plants
3. Natural rainfall without plants

These treatments were replicated three times in a completely randomized design (CRD). Treatments were selected to represent Wisconsin's cropping season average rainfall of 102 mm per month.

In treatment 1, 12.7 mm water was applied twice a week through the drop-forming rainfall simulator. The leaching frames in this treatment were covered after the water was applied to prevent natural rainfall from entering.

In treatment 2, 50.8 mm water was applied every two weeks, and these frames were also covered to protect against natural rainfall.

In treatment 3, the leaching frames were exposed to natural rainfall.

<u>Leaching frame installation:</u> Nine 90 cm x 90 cm metal

leaching frames (3 treatments x 3 replications) were used as experimental units. These metal frames (Fig 1.1) were installed 15 cm deep to prevent runoff losses of water and bromide salt.

Rainfall simulator: A drop-forming rainfall simulator, made of plexiglass, with holes spread 2.5 cm apart, was used to simulate artificial rainfall. The rainfall simulator was placed on top of the leaching frame (Fig 1.2) while applying the water.

Bromide salt application: Potassium bromide (KBr) was surface-applied at the rate of 300 kg ha^{-1} (198 kg ha^{-1} of Br^-) to each of the nine leaching frames in 12.7 mm water on June 25, 1990. Twenty five grams of KBr was dissolved in 2 liters of water and applied through the rainfall simulator; then the remaining quantity of water was added.

Soil sampling: Soil sampling took place during June, August, and November of 1990 (Table 1.7). Initial sampling of all frames was made two days after the bromide was applied to determine the uniformity of application. The second sampling (August) took place after the frames had received 188 mm and 152 mm of rain under natural and simulated rainfall treatments, respectively. Final

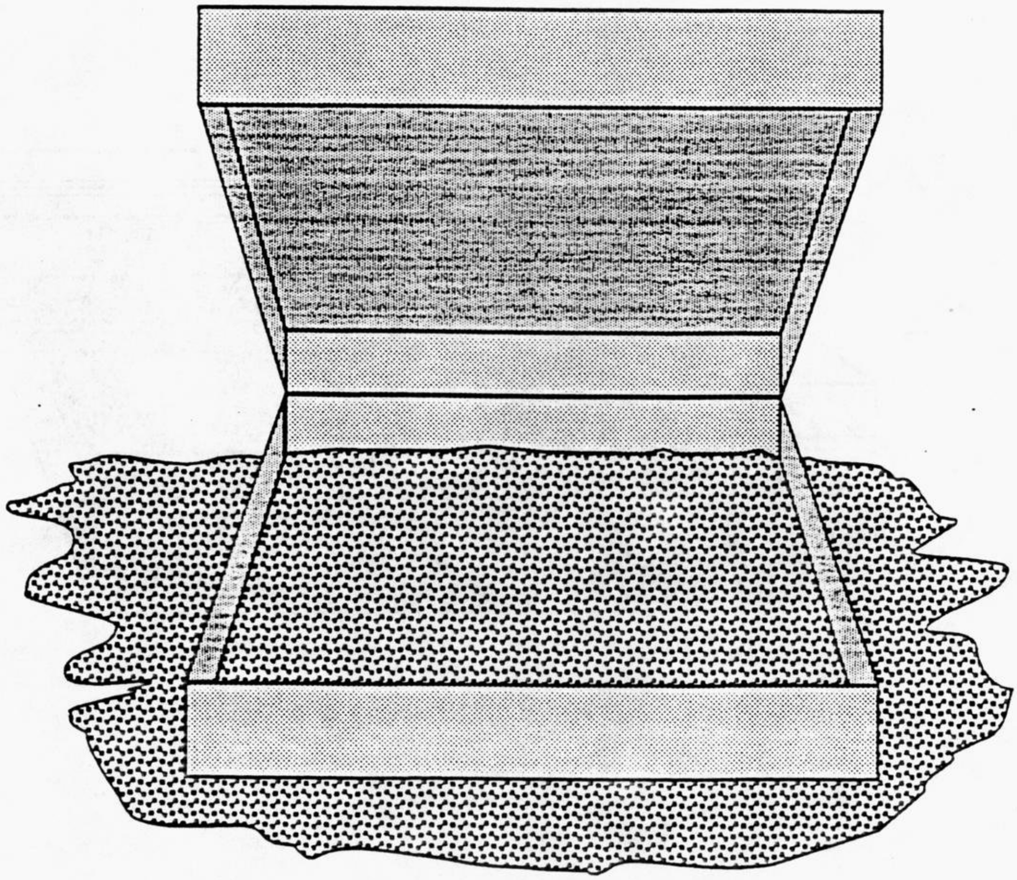

Figure 1.1. Metal frame (90 cm x 90 cm) used in the leaching frame study, 1990.

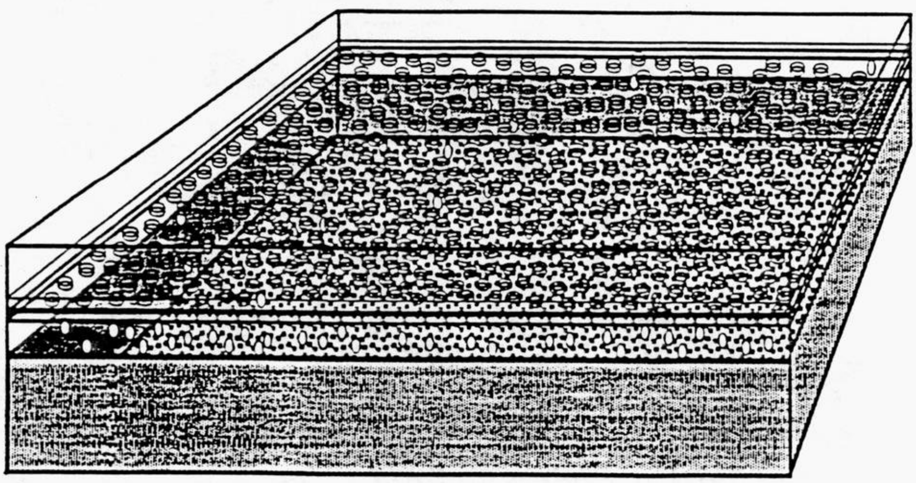

Figure 1.2. Drop-forming rainfall simulator used in the leaching frame study, 1990.

Table 1.7. Leaching frame soil sampling schedule, 1990

Treatment	Sample 1		Sample 2		Sample 3	
	Date	Cumu. rain (mm)	Date	Cumu. rain (mm)	Date	Cumu. rain (mm)
1. 12.7 mm twice a week	6/27	12.7	8/9	152.0	11/8	457.0
2. 50.8 mm every 15 days	6/27	12.7	8/9	152.0	11/8	457.0
3. Natural rainfall	6/27	12.7	8/23	188.0	11/8	328.0

sampling (November) took place after the natural and simulated rainfall treatments had received a total of 328 mm and 457 mm, respectively.

Each leaching frame was subdivided into four quadrants and a random core was drawn from each quadrant. Soil cores were collected to a depth of 100 cm with a 1.9 cm diameter probe. The top 20 cm of soil column was subdivided into four 5-cm sections, and the bottom 80 cm column was divided into four 20-cm sections (20-40, 40-60, 60-80, and 80-100). The holes were then filled with a bentonite + soil mixture to prevent preferential movement of water and Br^- through these holes. After taking gravimetric soil moisture measurements, the eight sections from each core were analyzed for Br^-.

Percent Br^- recovery is the amount of Br^- detected in the soil profile with our sampling procedure to one meter depth divided by Br^- applied. Since runoff was eliminated, and no plants were growing, percent recovery gave an indication of how much of the surface-applied Br^- has drained beyond a depth of 1 m with a given rainfall amount and time. Measured concentrations by sampling horizon were corrected for bulk density (B.D.) and sample volume and summed to give total Br^- recovery: $\sum [Br^-]_{mg/kg} \times B.D._{g/cc} \times Volume_{cc}$.

Bromide analysis: Bromide was extracted from five-gram subsamples of soil with 50 ml of 0.001 M $SrCl_2$. Bromide was determined using an Orion Model 94-35 electrode and a Model 90-01 single junction reference electrode (Onken et al., 1975). To reduce potential interference, an ionic strength adjuster of 5 M $NaNO_3$ was added at the rate of 2% by volume. The tip of the electrode was cleaned frequently with polishing strips. A new working standard solution of 0.001 M $SrCl_2$ was prepared every week. A known standard was run between every ten samples.

Results and Discussion

Uniformity sampling: Soil sampling took place to a depth of 20 cm in four 5-cm increments two days after Br^- application to evaluate uniformity of application. Br^- was found in all the cores, indicating water got distributed to the entire leaching frame through the drop-forming rainfall simulator. However, the CV of Br^- concentration ranged from 48% at 0-5 cm to 112% at 15-20 cm depth. The high CVs at lower depths indicate that Br^- had already started moving in preferential paths just after an application of only 12.7 mm of water. On this sampling date, 110% of the applied Br^- was recovered in the 20 cm soil profile (Fig 1.3). More than 100% recovery could be due to sampling errors,

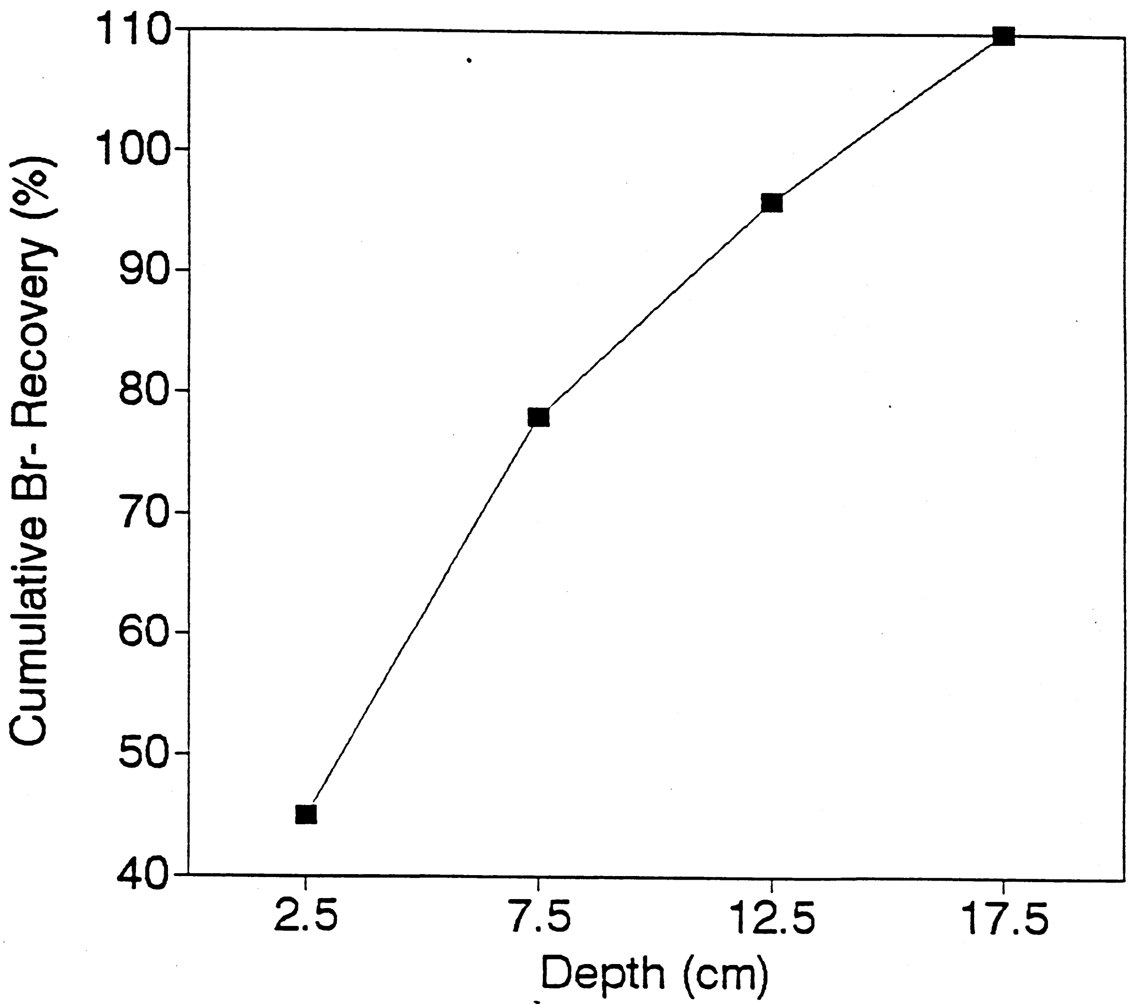

Figure 1.3. Cumulative Br^- recovery on the uniformity sampling date (6/27/1990) in the leaching frame study, 1990

incorrect sample volume and variability in soil bulk density. Eighty percent of the applied Br^- was recovered in the top 10 cm of the soil profile.

Bromide distribution in soil (sampling date 8/9/90)

Treatment 1: (12.7 mm twice a week): After an accumulation of only 152 mm of rain, Br^- was already distributed throughout the soil profile (1 m) with a peak at 7.5 cm depth (Fig. 1.4A). The arithmetic means for bromide concentrations in soil are 17.9, 12.9, 12.6, 10.5, 10.6, 10.8, and 11.8 mg kg^{-1} at 0-5, 5-10, 10-15, 15-20, 20-40, 40-60, 60-80 cm, and 80-100 cm depth, respectively, with coefficients of variation (CV) 56, 48, 79, 85, 39, 37, 42, and 38 %, respectively. The CV was expected to be less in the top 20 cm as plowing mixes the plow layer (Jabro et al., 1991). However, variation was high in the top 20 cm (67%) compared to (39%) at 20-100 cm depth. This may be because no tillage operation was carried out on this piece of land prior to leaching frame installation, and macropores might be present even in the top 20 cm. Also, there was no mechanical mixing of the soil in the leaching frames after Br^- application. Eighty five percent of the applied bromide was recovered on this date. The mean recovery in each core was 97.8 mg/kg of Br^-, with a CV of

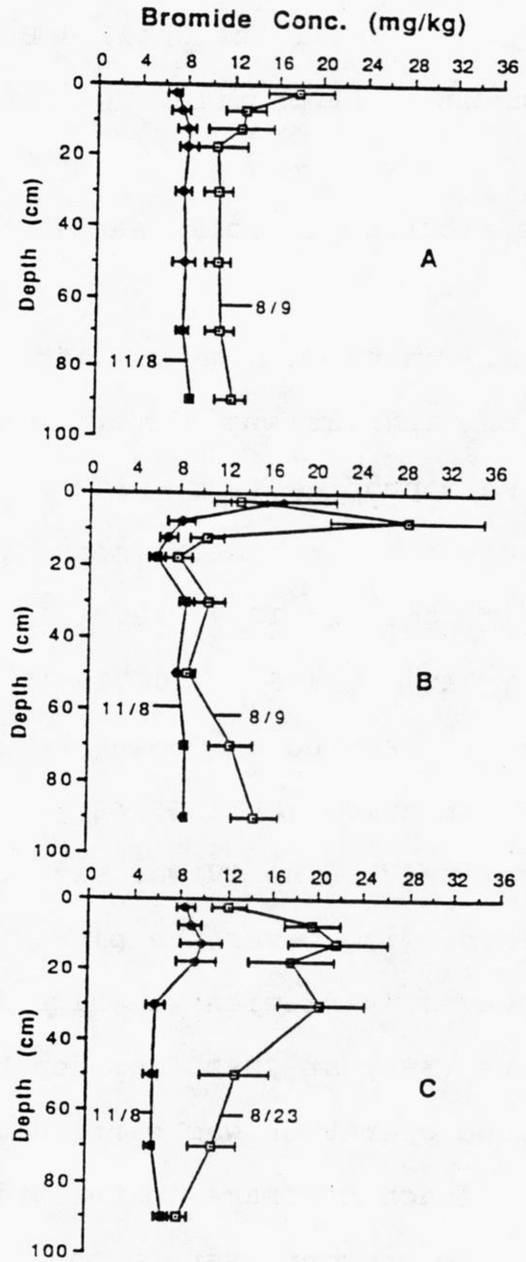

Figure 1.4. Bromide distribution in the soil profile in treatment 1 (12.8 mm twice a week) (A); treatment 2 (50.8 mm every 15 days) (B); and treatment 3 (natural rainfall) (C) in the leaching frame study, 1990. Horizontal lines indicate SE around the mean.

30%. The moisture curve (Fig. 1.5A) indicates more moisture in the top 30 cm compared to the bottom 80 cm. This could be due to frequent application of water, and to the fact that the frames were kept covered to prevent rainfall from striking the plots. The entire profile (1 m) was above field capacity on this sampling date as well as through out the duration of the trial. Any excess application of water may have created a positive pressure above the wetting front and resulted in water moving to macropores (Beven and Germann, 1982).

Treatment 2: (50.8 mm every 15 days): In this treatment also, Br^- was found down to the 100-cm depth. Unlike treatment 1, the Br^- distribution had a clear peak (Fig. 1.4B) at top 10 cm. Bromide concentrations in the soil were: 13.3, 28.4, 10.3, 7.9, 10.5, 8.7, 12.6, and 14.8 at 0-5, 5-10, 10-15, 15-20, 20-40, 40-60, 60-80, and 80-100 cm depths, respectively. More Br^- was recovered (94%) in this treatment compared to treatment 1, indicating that most of the bromide remained in the 100 cm of the soil profile. This suggests that additional flow of water was through macropores resulting in more uniform distribution of Br^- in the soil profile. Our hypothesis is that Br^- got distributed in the soil profile initially, and the water applied subsequently, bypassed the bulk of the soil and moved

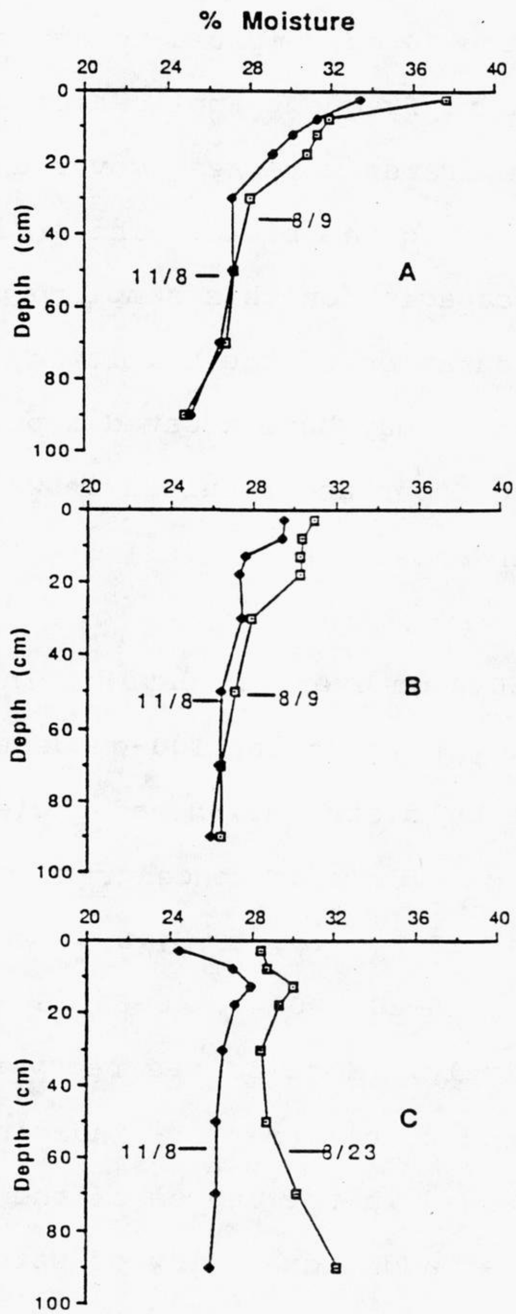

Figure 1.5. Gravimetric moisture content in the soil profile under treatment 1 (12.8 mm twice a week) (A); treatment (50.8 mm every 15 days) (B); and treatment 3 (natural rainfall) (C) in the leaching frame study, 1990

through macropores. The soil moisture content (Fig.1.5B) was greater in the upper 20 cm compared to the lower depths. However, in this treatment also, the entire profile was above field capacity.

Treatment 3: Rainfall distribution during the 1990 season is given in Figure 1.6. Most of the storms were low intensity, and 70% of the total rainfall fell in storms of < 20 mm. A cumulative rainfall of 188 mm was received by 8/23/90. Under natural rainfall Br^- was also detected over the entire profile (1 m), with small peaks in the top 30 cm (Fig.1.4C). Highest concentrations of Br^- remained in the top 30 cm of the profile. The arithmetic means for Br^- concentrations in the soil were 12.1, 19.5, 21.7, 17.6, 20.3, 12.7, 10.9, and 7.9 mg kg^{-1} 0-5, 5-10, 10-15, 15-20, 20-40, 40-60, 60-80 cm, and 80-100 cm depth, respectively. The CV for Br^- concentration at various depths ranged from 39% to 121%. All the Br^- (103%) was recovered over the 1-m profile on this sampling date. Soil moisture content ranged from 28% to 32% over the entire profile at this sampling date (Fig. 1.5C).

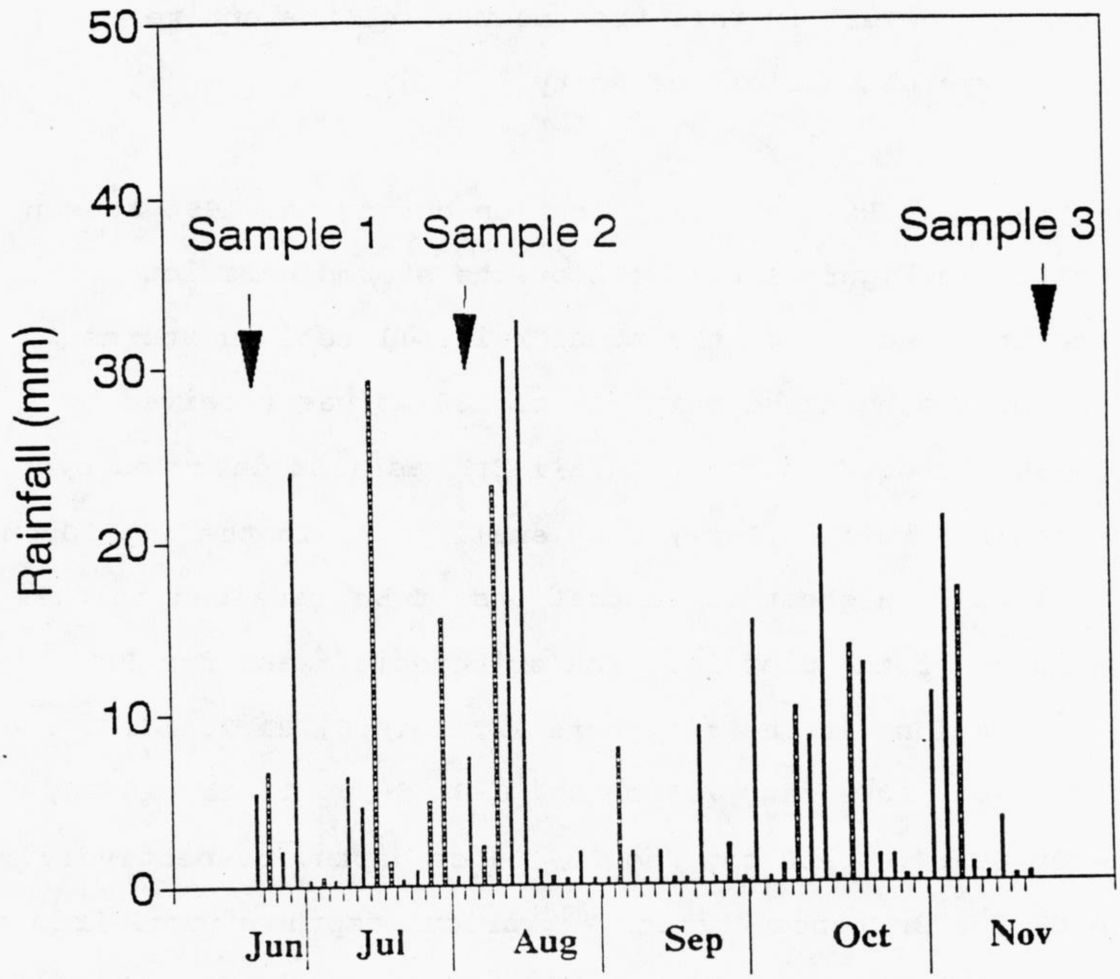

Figure 1.6. Daily rainfall distribution at the Lakeland Agricultural Complex after Br^- application in the leaching frame study, 1990.

Sampling date 11/6/90

Treatment 1: Bromide distribution in the entire profile on 11/6/90 was similar to the distribution on 8/9/90, except in the top 20 cm (Fig 1.4A). This indicates little displacement of Br^- even after leaching with an additional 305 mm of water. The recovery was 58%, indicating that 27% of applied Br^- was lost between August and November. This suggests that leaching occurs when small quantities of Br^- diffuse from smaller pores (soil matrix) to the surface of macropores and then Br^- moves through the entire profile. Moisture content (Fig 1.5A) was similar to August sampling with the top 20 cm containing more moisture than the lower depths.

Treatment 2: Bromide distribution was similar to that at the August sampling date. Thirty-five percent of the applied Br^- was lost between these two sampling dates (65% recovery) with 305 mm of applied water. Bromide concentration was highest near the soil surface. Variance was greater in the upper 40 cm (27-97%) of the profile. The moisture distribution (Fig 1.5B) looks similar to that at the August sampling date.

Treatment 3: By this sampling date, 328 mm of cumulative rainfall was received. Bromide content decreased considerably from August sampling date (140 mm received between the two sampling dates). Fifty percent of the Br^- was lost between these two sampling dates. Bromide content in the soil was 8.4, 8.8, 9.7, 9.3, 5.9, 5.6, 5.6, and 6.6 mg kg^{-1} at 8 depths (0-5, 5-10, 10-15, 15-20, 20-40, 40-60, 60-80, and 80-100 cm, respectively). Bromide content was slightly greater in the top 20 cm compared to the bottom 80 cm. The moisture content of the profile (Fig. 1.5C) was lower compared to August sampling date, due to evaporation losses.

The drop-forming rainfall simulator facilitated uniform water distribution. However, the application of water whether 12.7-mm or 50.8-mm increments (treatments 1 and 2), was rapid, resulting in ponding, which promoted preferential flow.

Conclusions

Bromide concentration varied greatly by depth. Overall percent recovery in the top 1 m, however, was less variable (Fig.1.7-1.9). Except for two major outliers, the percent Br^- recovery in each of the 12 cores was relatively uniform. In general, the variation in percent recovery was

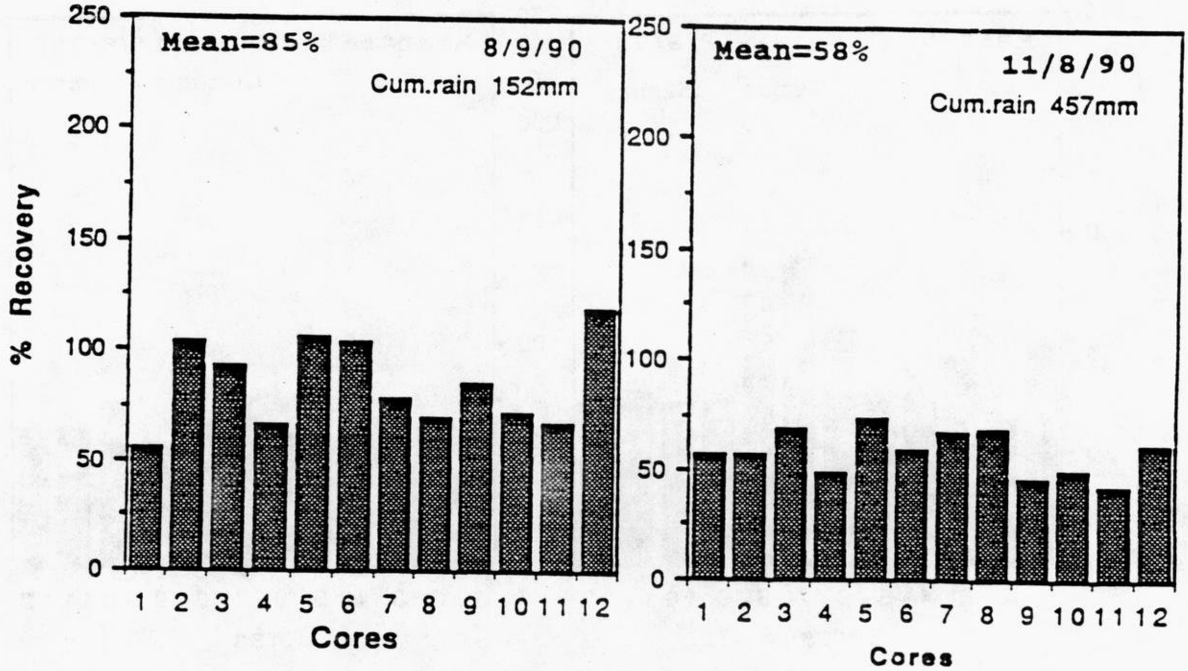

Figure 1.7. Percent Br^- recovery in the top 100 cm in each of the 12 cores under treatment 1 (12.8 mm twice a week) in the leaching frame study, 1990

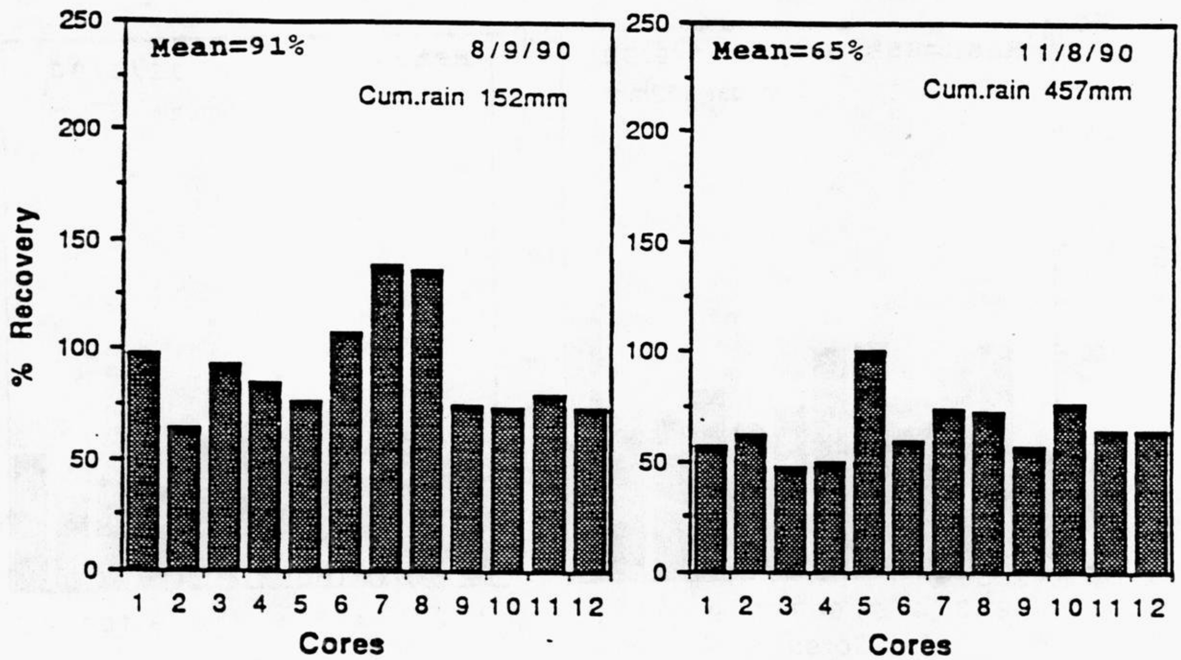

Figure 1.8. Percent Br^- recovery in the top 100 cm in each of the 12 cores under treatment 2 (50.8 mm every 15 days) in the leaching frame study, 1990

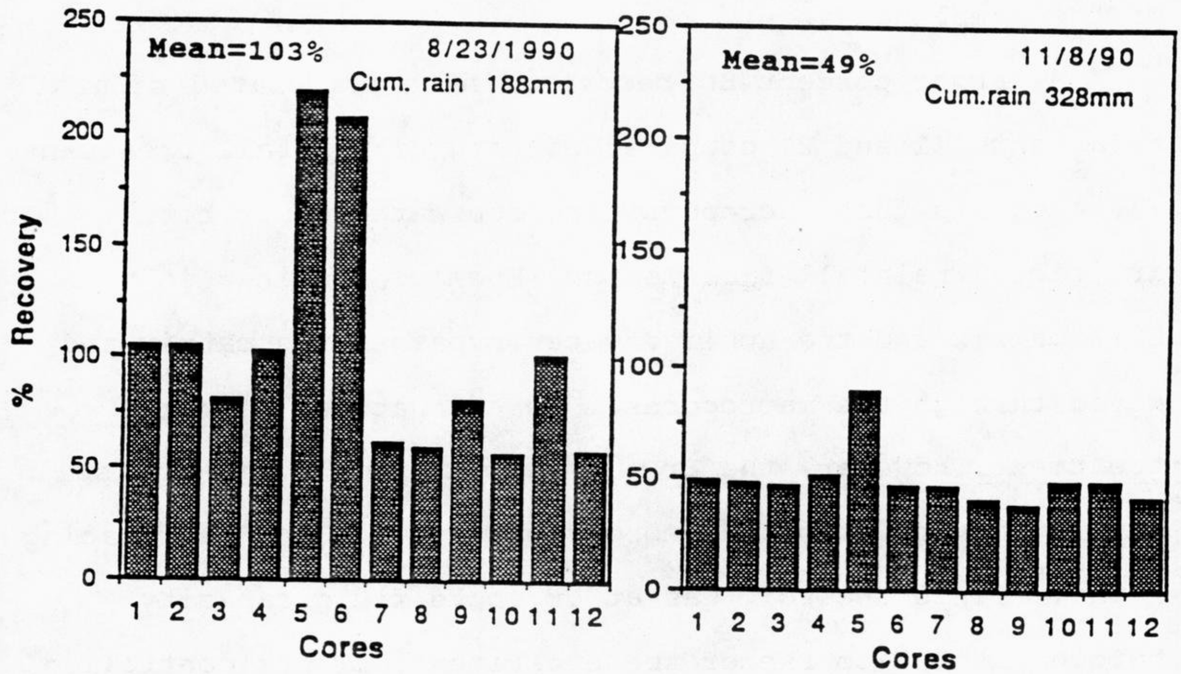

Figure 1.9. Percent Br^- recovery in the top 100 cm in each of the 12 cores under treatment 3 (natural rainfall) in the leaching frame study, 1990

greater in August sampling compared to November. This uniform recovery of Br^- in each of the 12 cores indicates that our sampling procedure accounted for most of the Br^- in the soil profile.

The lack of a high Br^- concentration band, descending with time, indicates macropore flow was important in the movement of Br^- under all of the three treatments at either of the sampling dates.

A larger percent Br^- recovery in the simulated rainfall treatments (1 and 2) compared to natural rainfall treatment (3) suggests that macropore flow dominated under both artificial rainfall treatments. Bromide remained in the soil matrix and the applied water bypassed the matrix and moved through the macropores. In the natural rainfall treatment, however, the Br^- was redistributed into the soil matrix, moving downwards more steadily with the percolating water. Since the soil was at or above field capacity throughout the course of the experiment, ET was controlled and runoff was eliminated in treatments 1 and 2, all the applied water must equal percolation. If the water moves by simple piston-type flow, assuming 50 % pore volume, the Br^- front should move to 30 cm by the August sampling date (152 mm water added). However, Br^- was found to the 1 meter depth by the August, indicating that Br^- did not move by simple piston-type flow under these two treatments conditions.

Nevertheless, only 50% recovery in November in treatment 3 indicates that preferential flow is also important even under natural conditions.

It can be concluded from this preliminary study that macropore flow of water dominated piston-type flow under these conditions, and Br^- moved beyond one meter depth in the soil in one growing season.

Crop rotation study

Introduction: The preliminary leaching frame study conducted on bare soil indicated that preferential flow is the dominant mechanism of downward movement of water and solutes. However, in this preliminary study the conditions were artificial i.e., plants were not growing, water was added too rapidly, and all season the soil profile was above field capacity. It was decided in summer of 1991 to verify the findings of the 1990 leaching frame study under natural field conditions. The objective of this study was to determine the time for a surface-applied chemical to move through the root zone in the presence of vegetation under natural field conditions.

Materials and Methods

<u>Treatments:</u> The five rotations that were compared are: 1) R_1 - Continuous corn, 2) R_2 - Soybean-corn, 3) R_3 - Soybean-wheat/red clover-corn, 4) R_4 - Alfalfa-alfalfa-alfalfa-corn, and 5) R_5 - Oats/alfalfa-alfalfa-corn. Bromide salt was surface-applied to the first phase of each of these five rotations, e.g., the soybean plots in R_2 (<u>sb</u>-c-sb), and the companion seeded alfalfa plots in R_3 (<u>o/a</u>-a-c). Corn was the previous year's crop for all the treatments. Pasture plots in R_6 were not included in this study since Br^- could affect the grazing animals' health.

<u>Plot lay-out:</u> The plots were laid out in a randomized complete block (RCB) design with four repetitions in the WICST (Fig 1.10 A and B). Each repetition consists of 14 treatments. Plots are of 0.33 ha in size. This study was conducted in the first three of the four replications in the large trial.

<u>Well installation:</u> In early spring 1991, one monitoring well was installed in each of the five rotations (R1,T1), (R2,T3), (R3,T6), (R4,T6), and (R5,T12). Although not part of the Br^- study, wells were also installed in the pasture plots (R_6,T_{14}). Two check wells (4.0 m and 8.5 m deep)

101 R1 T1 Cont. Corn ●	201 R5 T13 Filler Corn	301 R4 T10 Filler Corn	401 R1 T1 Cont. Corn
102 R4 T8 D.S. Alfalfa ●	202 R4 T7 Est. Alf. I	302 R4 T9 Filler Corn	402 R4 T8 D.S. Alfalfa
103 R4 T7 Est. Alf. I	203 R2 T2 NR Soybean ●	303 R1 T1 Cont. Corn ●	403 R4 T10 Filler Corn
104 R6 T14 Pasture ●	204 R3 T4 Filler Corn	304 R2 T2 NR Soybean ●	404 R3 T4 Filler Corn
105 R5 T12 Oats/Alfalfa ●	205 R3 T5 Wheat/R Clov.	305 R4 T8 D.S. Alfalfa ●	405 R5 T13 Filler Corn
106 R5 T11 Est. Alf. I	206 R2 T3 Corn	306 R3 T6 WR Soybeans ●	406 R3 T5 Wheat/R Clov.
107 R3 T5 Wheat/R Clov.	207 R5 T12 Oats/Alfalfa ●	307 R3 T5 Wheat/R Clov.	407 R3 T6 WR Soybeans
108 R2 T2 NR Soybean ●	208 R3 T6 WR Soybeans ●	308 R3 T4 Filler Corn	408 R6 T14 Pasture
109 R3 T4 Filler Corn	209 R4 T8 D.S. Alfalfa ●	309 R5 T12 Oats/Alfalfa ●	409 R2 T2 NR Soybean
110 R4 T9 Filler Corn	210 R1 T1 Cont. Corn ●	310 R4 T7 Est. Alf. I	410 R2 T3 Corn
111 R3 T6 WR Soybeans ●	211 R5 T11 Est. Alf. I	311 R2 T3 Corn	411 R4 T7 Est. Alf. I
112 R4 T10 Filler Corn	212 R4 T9 Filler Corn	312 R5 T11 Est. Alf. I	412 R5 T12 Oats/Alfalfa
113 R2 T3 Corn	213 R6 T14 Pasture ●	313 R5 T13 Filler Corn	413 R5 T11 Est. Alf. I
114 R5 T13 Filler Corn	214 R4 T10 Filler Corn	314 R6 T14 Pasture ●	414 R4 T9 Filler Corn

Figure 1.10A. Plot lay-out at the Lakeland Agricultural Complex (LAC) in 1991. Plots marked with dots have monitoring wells installed in the spring of 1991.

101 R1 T1 Cont. Corn ●	201 R5 T13 Oats/Alfalfa	301 R4 T10 Filler Corn	401 R1 T1 Cont. Corn
102 R4 T8 Est. Alf. I ●	202 R4 T7 Est. Alf. II	302 R4 T9 D.S. Alfalfa	402 R4 T8 Est. Alf. I
103 R4 T7 Est. Alf. II	203 R2 T2 Corn ●	303 R1 T1 Cont. Corn ●	403 R4 T10 Filler Corn
104 R6 T14 Pasture ●	204 R3 T4 WR Soybean	304 R2 T2 Corn ●	404 R3 T4 WR Soybean
105 R5 T12 Est. Alf. I ●	205 R3 T5 Corn	305 R4 T8 Est. Alf. I ●	405 R5 T13 Oats/Alfalfa
106 R5 T11 Corn	206 R2 T3 NR Soybean	306 R3 T6 Wheat/R Clov.●	406 R3 T5 Corn
107 R3 T5 Corn	207 R5 T12 Est. Alf. I ●	307 R3 T5 Corn	407 R3 T6 Wheat/R Clov.
108 R2 T2 Corn ●	208 R3 T6 Wheat/R Clov.●	308 R3 T4 WR Soybean	408 R6 T14 Pasture
109 R3 T4 WR Soybean	209 R4 T8 Est. Alf. I ●	309 R5 T12 Est. Alf. I ●	409 R2 T2 Corn
110 R4 T9 D.S. Alfalfa	210 R1 T1 Cont. Corn ●	310 R4 T7 Est. Alf. II	410 R2 T3 NR Soybean
111 R3 T6 Wheat/R Clov.●	211 R5 T11 Corn	311 R2 T3 NR Soybean	411 R4 T7 Est. Alf. II
112 R4 T10 Filler Corn	212 R4 T9 D.S. Alfalfa	312 R5 T11 Corn	412 R5 T12 Est. Alf. I
113 R2 T3 NR Soybean	213 R6 T14 Pasture ●	313 R5 T13 Oats/Alfalfa	413 R5 T11 Corn
114 R5 T13 Oats/Alfalfa	214 R4 T10 Filler Corn	314 R6 T14 Pasture ●	414 R4 T9 D.S. Alfalfa

Figure 1.10B. Plot lay-out at the Lakeland Agricultural Complex (LAC) in 1992. Plots marked with dots have monitoring wells installed in the spring of 1991.

adjacent to the plots were also installed to monitor depth to ground water during growing season. One check well was installed deeper than the other to determine the ground water pressure distribution. Wells were constructed using 38 mm i.d. PVC pipes. These PVC pipes have a 1.5 m screen at the bottom in the water. Wells were 4.0 m deep in the northern end of the field and 3.0 m deep in the south due to the proximity of the water table in the southern end of the field. Wells were placed in the southeast corner of the plots to capture the ground water flow, which is in a southeast direction (Postle, 1984). Wells were kept covered 46 cm below the soil surface during the growing season to facilitate field operations and were brought to the soil surface during the remainder of the year. While buried, the top of the capped wells are covered with aluminum cans sitting on a metal plate surrounding the tube for protection while uncovering the wells. Description of the well, and their placement is shown in Figures 1.11 and 1.12.

Bromide application: On May 22, a one-time application of potassium bromide (KBr) salt was surface-applied uniformly to a 5m x 5m subplot surrounding the monitoring well at the rate of 300 kg ha^{-1} (197 kg ha^{-1} of Br^-). Seven hundred and fifty grams of KBr was dissolved completely in 5 liters of

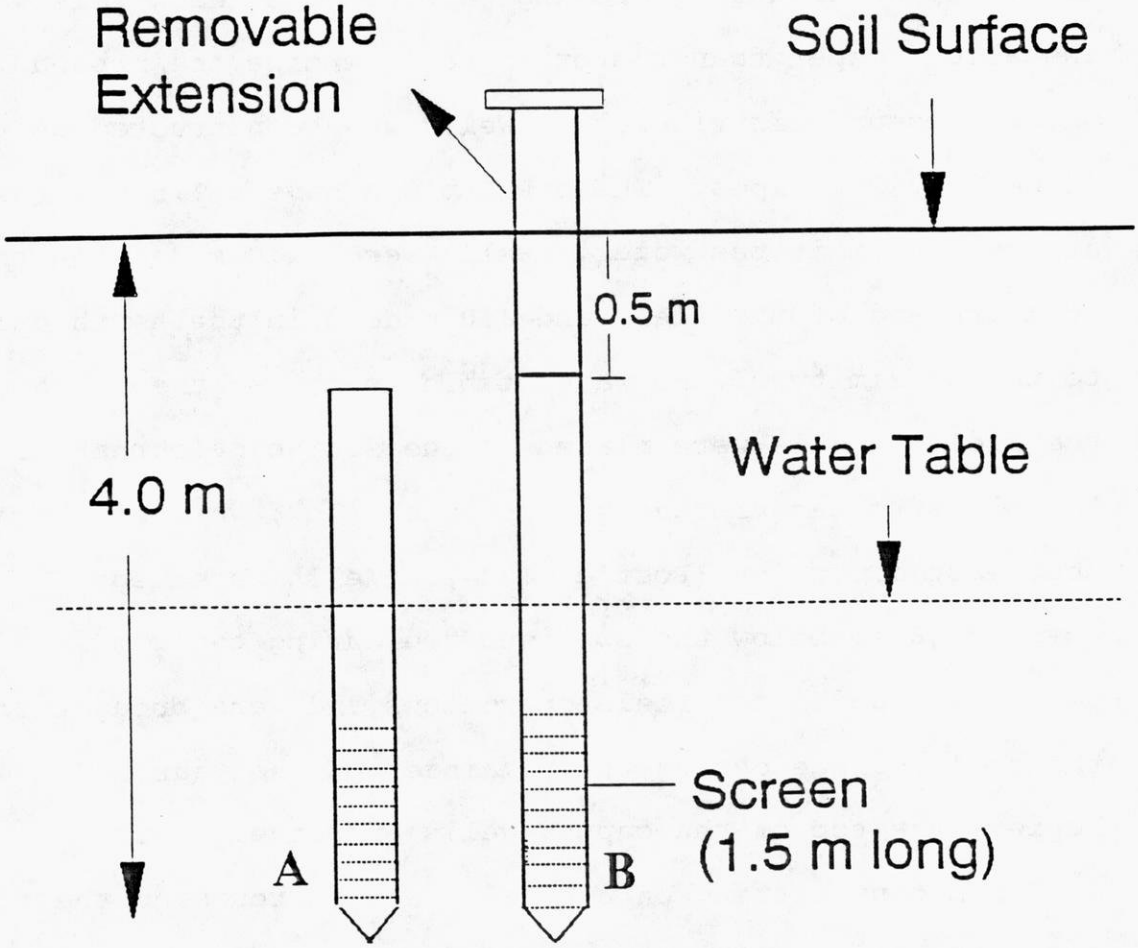

Figure 1.11. Description of the monitoring well installed in the early spring of 1991 at the Lakeland Agricultural Complex (LAC) in the crop rotation study, 1991. Buried well during the growing season (A), and opened well for sampling (B).

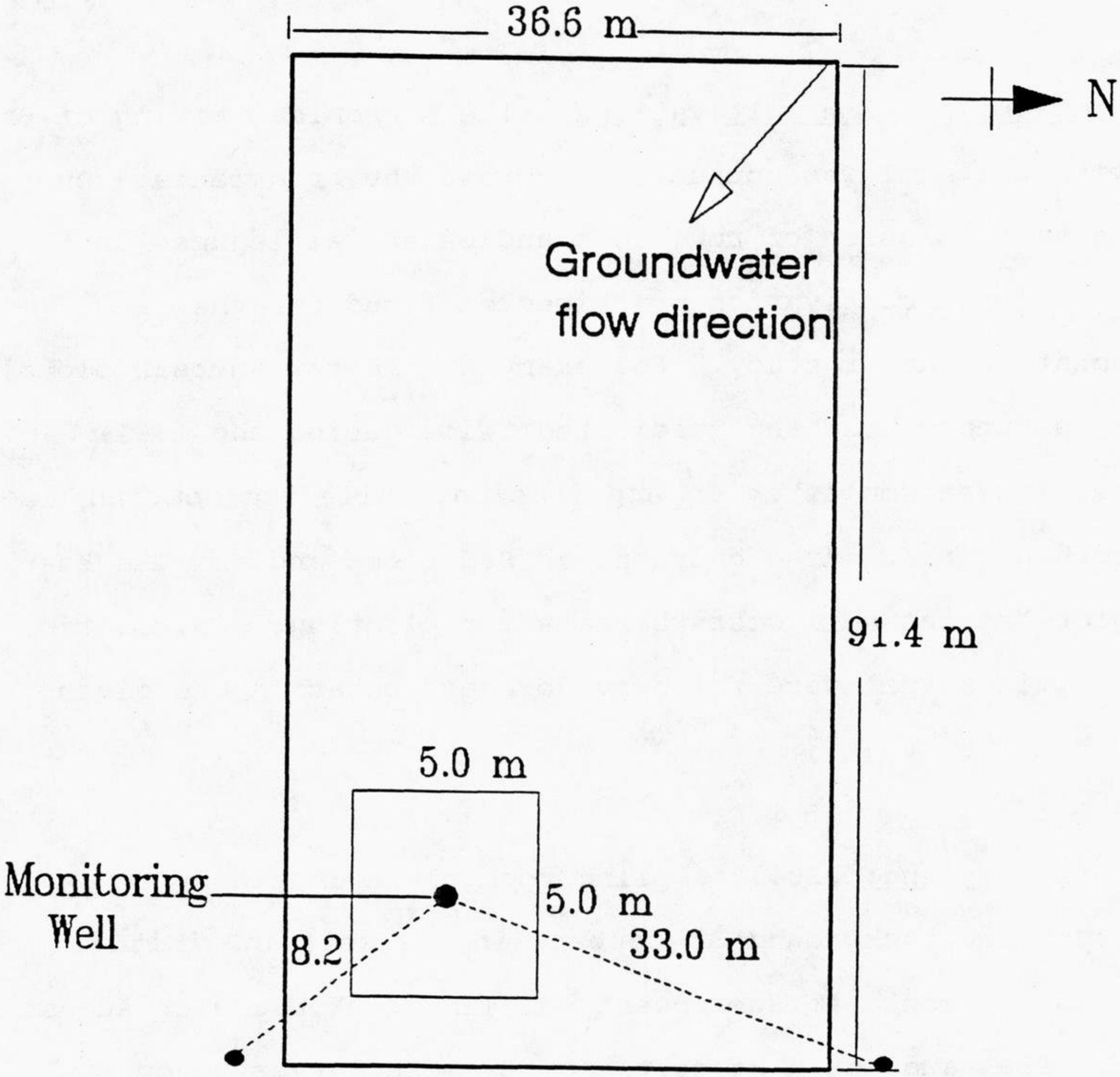

Figure 1.12. Location of the monitoring well in the plot in the crop rotation study, 1991

water and sprayed onto the plot area using a sprayer with four spray nozzles attached to the boom.

Post-application cultivations: The mechanical mixing of Br^- with the soil was not uniform across the treatments. Due to the inclusion of row crops and perennial legumes in the rotations, cultivation practices differed for the rotations under study. For example, the row soybean plots were rotary hoed and cultivated twice during the 1991 growing season after Br^- application, while the continuous corn was cultivated only once. Sod crops and drilled beans plots had no soil disturbance after planting. Cultivation practices that were followed for each rotation are given in Table 1.8.

Soil sampling: Soil sampling took place initially to determine background Br^- content in the soil and initial moisture content. Subsequent sampling took place on August 13, 1991 and again after the crops were harvested on November 16, 1991 to determine Br^- distribution under different crops. Soil samples were also collected the following spring (April 29, 1992) to determine over-winter changes in Br^- distribution in the soil profile. Eight cores were taken from each plot. Four cores were drawn to a depth of 100 cm in six increments (0-10,10-20,20-40,40-60,

Table 1.8. Tillage practices followed on bromide-treated plots

Rotation	Fall 1990	Spring tillage	Rotary hoe	Culti vation	Fall tillage	Spring tillage	Rotary hoe	Culti vation	Fall tillage
		1991				1992			
1. C-C-C	Chisel	TD Landoll	None	None	Chisel	Tilloll	None	Once	Chisel
2. Sb-C-Sb	Chisel	TD Landoll	None	None	No Till	None	None	No-till	Chisel
3. Sb-W/rc-C	Chisel	TD Landoll	Twice	Twice	No Till	None	None	None	None
4. A-A-A-C	Chisel	TD Landoll	None	None	None	None	None	None	None
5. O/A-A-C	Chisel	TD Landoll	None	None	None	None	None	None	Chisel

Bromide was applied on May 22, 1991 before 1st rotary hoeing
TD = Tandom Disk
c=corn
sb=soybean
w=wheat
rc=red clover
A=alfalfa
O/A=oats/alfalfa

60-80, and 80-100 cm), and the other four to a depth of 20 cm in 10 cm increments. Due to dry soil conditions in August, soil samples were collected only to 80 cm depth. All 32 samples were analyzed separately.

Ground water sampling: Wells were drained three times using a bail (0.6 cm i.d. x 61 cm h) and allowed to recover to ensure that the water sampled was representative of surrounding water (Smith et al., 1990). Initial water samples were collected to determine background Br^- concentrations. Ground water samples were analyzed for Br^- at the UW-Plant and Soil Analysis Laboratory. Water samples were collected twice a year (spring and fall) during 1991 and 1992.

Tissue sampling: Tissue samples were collected from the bromide-treated subplots to determine crop uptake of Br^-. Corn and soybean grain samples were collected at physiological maturity, and, forage legumes were grab sampled from the bromide-treated area each time a cut was taken.

Analytical methods:

Soil analysis: The Br^- analysis procedure was the same as in the leaching frame study.

Tissue analysis: One-half to 1 g of dried plant material was placed in a flask of a high speed homogenizer, and 49 ml of distilled water and 1 ml of ionic strength adjuster ($NaNo_3$) were added. After homogenizing the sample for 3 minutes, the supernatant was filtered, and Br^- determination was made on the filtrate using the solid state Orion electrode (Abdalla and Lear, 1975).

Water analysis: Br^- concentrations in the water samples were quantified using high pressure liquid chromatography (HPLC) consisting of a Dionex QIC analyzer and a Spectra Physics 4270 Integrator.

High pressure liquid chromatography (HPLC) utilizes resins in separator columns which are very specific to separate a particular type of constituent over time. Bromide anions were separated using a column and then identified by the retention time (time between sample injection and peak elution). Under constant liquid pressure and flow rates, the retention time is characteristic of the anion. Integration of peak area and comparison with peaks from samples of known concentration enables quantification of Br^- in the sample solution.

Results and Discussion

Soil analysis

Precipitation: Daily rainfall distribution from initiation (May, 1991) of the trial to the November, 1991 sampling date is given in Figure 1.13. Below-normal precipitation was recorded during June, July, and August at this site. This dry weather early in the growing season resulted in the formation of deep cracks in the field. Rainfall was heavy during September (126 mm) and October (158 mm).

Considerable fluctuation in the water table elevation was observed during 1991 and 1992 (Fig 1.14). The water table dropped from 0.5 m below the soil surface in May to 2.6 m below the soil surface in August, 1991 due to the dry weather coupled with the high crop water demand. By December, the water table had risen to 1 m due to heavy post-season rainfall.

Bromide distribution in the soil (August, 1991)

A cumulative total of 170 mm of rainfall was recorded by the August sampling date after Br^- application. Similar to the leaching frame study in 1990, detectable amounts of Br^- were found to 80 cm in all the treatments in August.

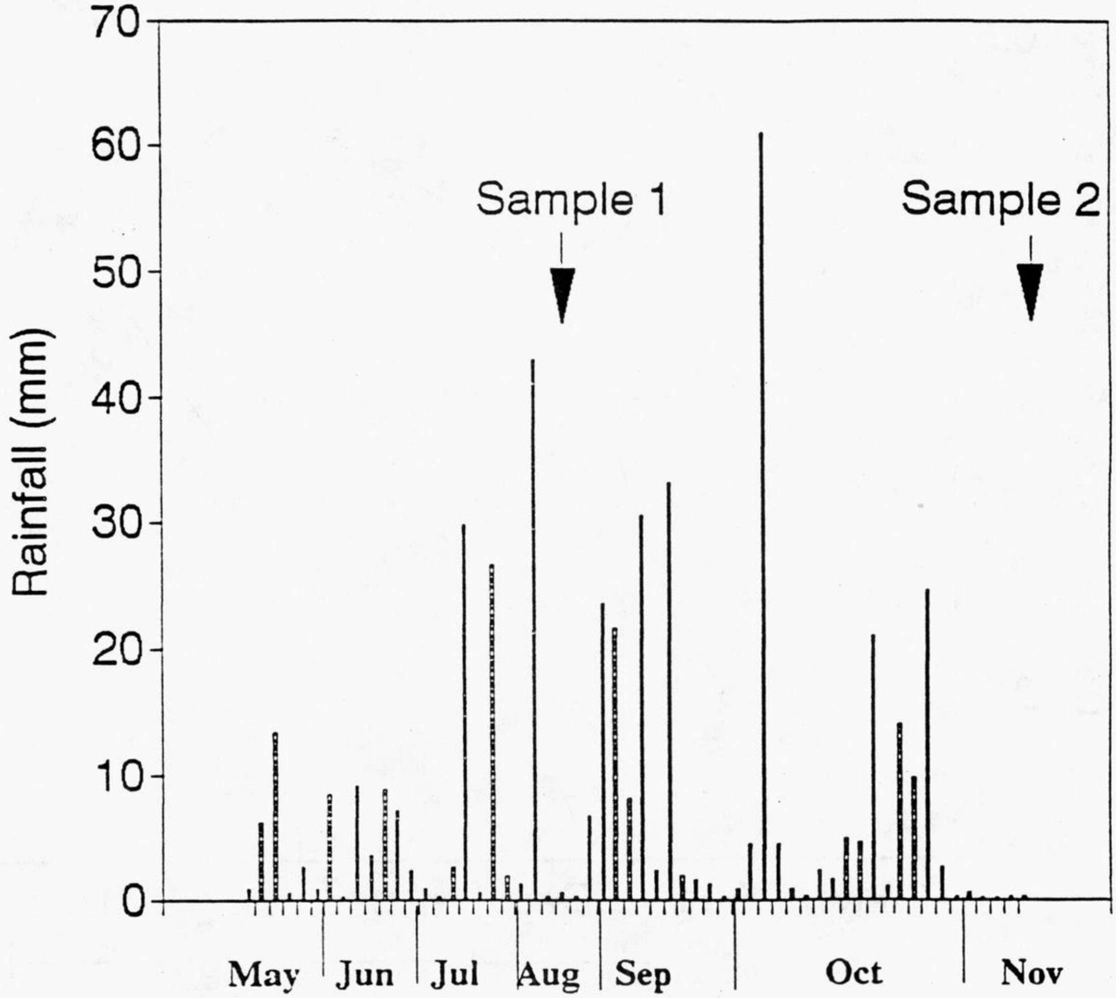

Figure 1.13. Daily rainfall distribution at the Lakeland Agricultural Complex after Br^- application until the November sampling date in the crop rotation study, 1991.

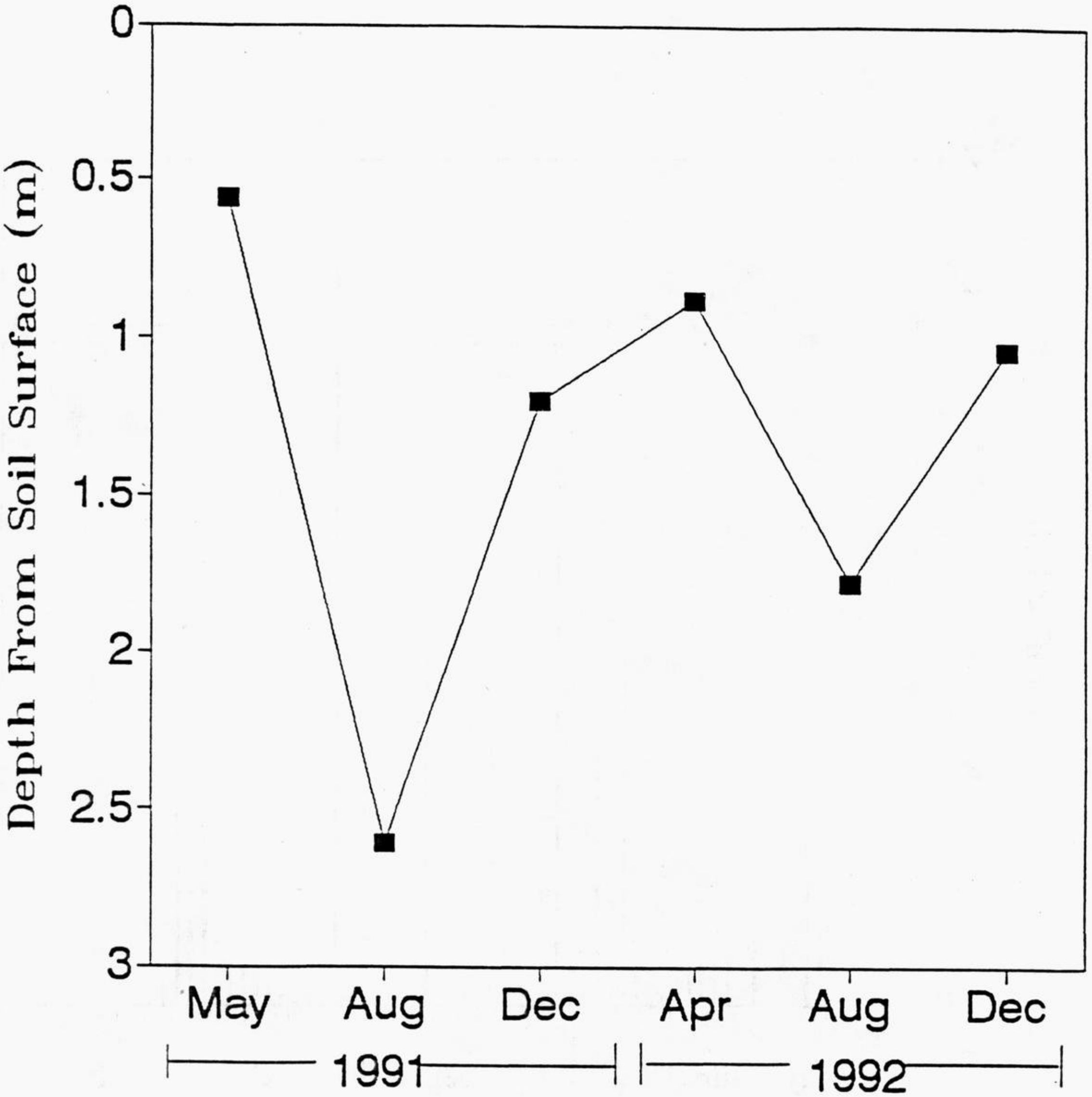

Figure 1.14. Water table elevation in the check wells at the Lakeland Agricultural Complex during 1991-92.

<u>Corn:</u> Bromide remained concentrated in the top 20 cm of the soil profile (Fig 1.15A). The mean Br^- concentrations were 30, 8, 3, 3, and 3 mg kg^{-1} at 5, 15, 30, 50, and 70 cm depths, respectively, with the CV for Br^- concentration of 83, 158, 157, 144, and 147 % at the five depths. Sporadic heavy rainfall in July and August at this location might have moved Br^- through the soil cracks. The high CV at all depths could be due to the channelization of Br^- in the soil profile.

<u>Drilled soybeans:</u> Similar to the other treatments, highest concentrations of Br^- remained in the top 30 cm of the profile under drilled soybeans (Figure 1.15B). The mean Br^- concentrations were 30,32,14,12, and 15 mg kg^{-1} at 5, 15, 30, 50, and 70 cm depths, respectively. The CV of Br^- concentration ranged from 89 to 156% on this sampling date.

<u>Row soybeans:</u> Bromide concentrations were low under wide-row soybeans compared to narrow-row soybeans (Figure 1.15C). The mean Br^- concentrations were 17, 15, 17, 12, and 9 mg kg^{-1} at 5, 15, 30, 50, and 70 cm depths, respectively. The CV of Br^- concentration ranged from 97 to 130% at various depths.

<u>Alfalfa:</u> Similar to corn plots, Br^- was distributed over

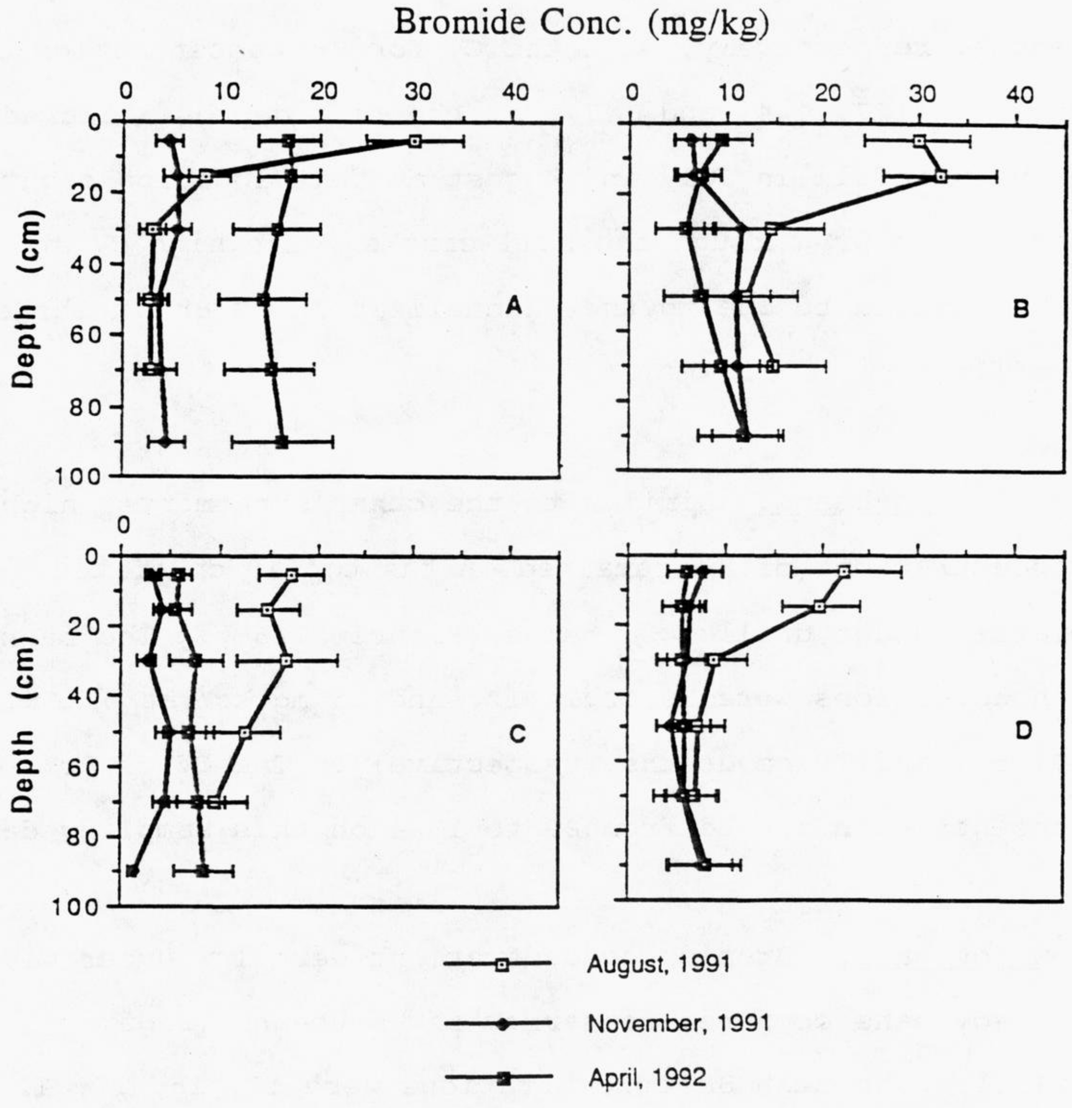

Figure 1.15. Bromide distribution in the soil profile at three sampling dates under different crops:corn (A), drilled soybeans (B), row soybeans (C), and solo-seeded alfalfa (D), in the crop rotation study, 1991. Horizontal lines indicate SE around the mean.

the entire profile, with the highest concentrations remaining in the top 30 cm of the profile (Figure 1.15D). The mean Br^- concentrations were 22, 20, 9, 7, and 7 mg kg^{-1} at 5, 15, 30, 50, and 70 cm depth, respectively. The CVs for Br^- concentration ranged from 99 to 134%.

Oats/alfalfa: Oats/alfalfa had the highest concentrations of Br^- compared to the other four treatments over the entire profile on this sampling date. The mean Br^- concentrations were 42, 31, 26,24, and 56 mg kg^{-1} at 5, 15, 30, 50, and 70 cm depths, respectively. The CV of Br^- concentration ranged from 86 to 222%.

After Br^- application, there was no disturbance of the surface soil in corn, drilled soybeans and alfalfa plots. However, the row beans were rotary hoed and cultivated twice resulting in slightly smaller CVs compared to other treatments.

Bromide distribution in November, 1991

By November, Br^- concentration decreased markedly (Figure 1.15A-D) in the top 20 cm compared to the August sampling date under all the crops. Between the two sampling dates 303 mm of rainfall was received. In general, the CV of Br^- concentration was higher on this sampling date compared to August in all the treatments. These high CVs could be due to channelization of Br^- by November. Most of the Br^- had leached between August and November sampling dates under all crops. Heavy late-season rainfall in September and October might have leached Br^- deeper from the surface layers.

Bromide distribution in April, 1992

Little change in the Br^- content in the profile was noticed between Nov 17-April 29 (Figure 1.13A-D) in all the treatments except corn. This indicates that Br^- got distributed in the soil matrix and the moving water bypassed the soil matrix. Variations (CVs) similar to November sampling were noticed on this sampling date also.

<u>Moisture content of the profile:</u> Moisture content of the profile is given in Fig 1.16 A-D. Moisture content was statistically similar under all the treatments at all depths in August, 1991; November, 1991; and April, 1992, except at 40-60 and 60-80 cm depth on the November, 1991 sampling date. Soil moisture distribution for August, 1991 indicates that drilled soybeans and companion-seeded alfalfa plots had slightly higher moisture content compared to corn and alfalfa plots.

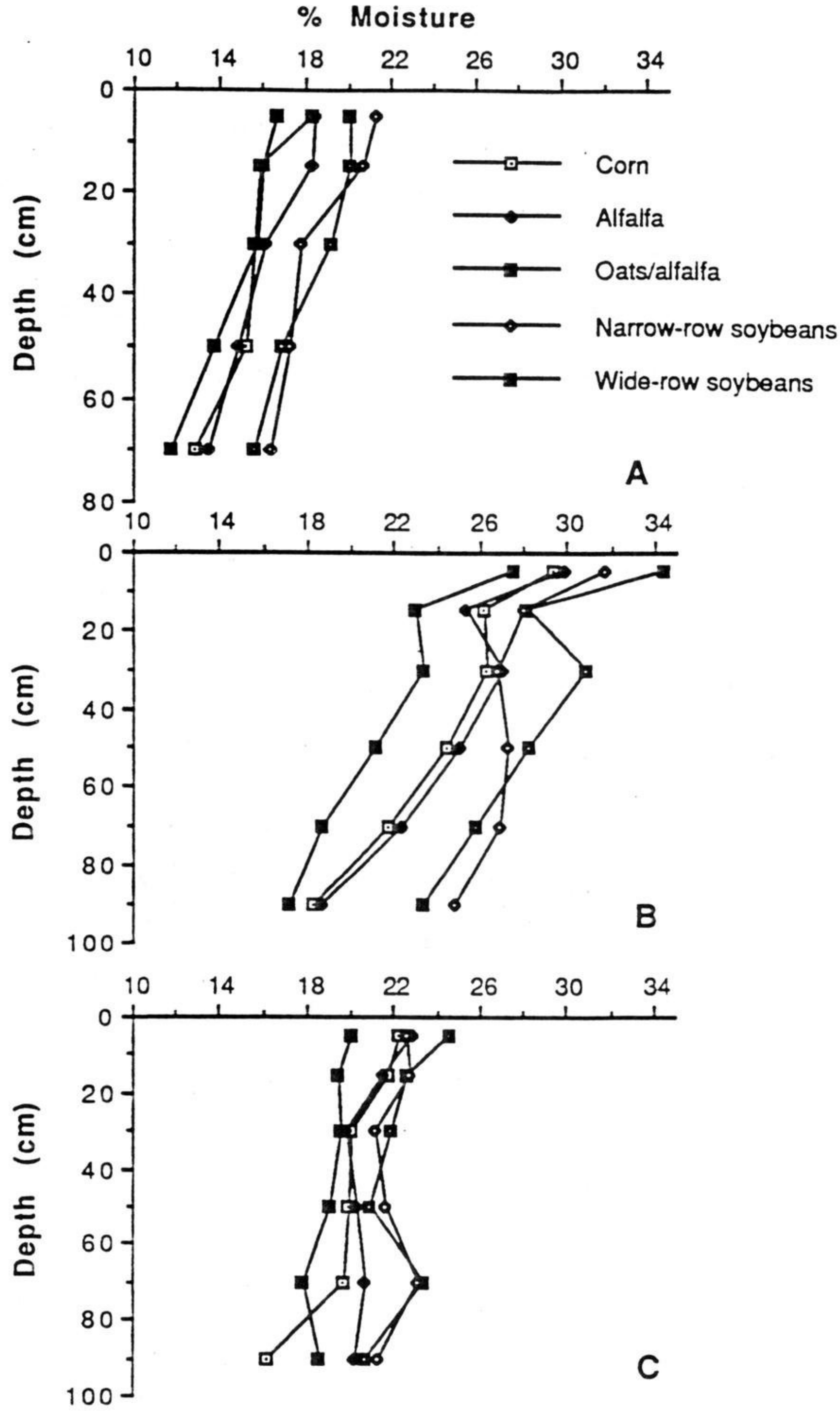

Figure 1.16. Gravimetric moisture content in the soil profile under different crops at three sampling dates: August, 1991 (A), November,1991 (B), and April, 1992 (C) in the crop rotation study, 1991-92.

Moisture content was slightly greater in the upper 30 cm of the profile compared to the rest of the profile. Moisture content was lowest in August under all crops compared to that of November and April, 1992 due to the dry weather that prevailed early in the growing season.

Soil moisture content was greater in November, 1991 in all the treatments due to the heavy post-season rainfall (284 mm) in September and October months. Moisture content of the profile was near field capacity under all the treatments by the following spring of 1992.

Most of the Br^- leaching occurred between August and November sampling dates due to the heavy post-season rain received in September and October (284 mm). Little change in Br^- content between late fall (1991) and early spring of 1992 in the profile also indicates that the water moving through the profile did not leach Br^- and bypassed the bulk of the soil matrix.

Comparison with GLEAMS simulations

Field observations were compared with the GLEAMS simulations. The GLEAMS simulations were compared to Br^- leaching under corn since corn had the greatest percolation losses in the 12-year simulation study and also represents the worst case scenario. Daily precipitation, mean daily temperature, maximum and minimum temperature data for 1991 at LAC site were used for simulations. Simulations were run using rooting depths of 30, 45, and 60 cm to estimate how far Br^- would move by piston-type flow. According to GLEAMS simulations, Br^- should move only to 45 cm by September 22, and 60 cm by November 5 in the corn profile. However, Br^- was found to a depth of 80 cm under all the crops by the August sampling date. This disagreement between GLEAMS simulations and field observations provides another indication that Br^- did not move by piston-type flow as used in the GLEAMS model. The GLEAMS predicted percolation losses below 90 cm depth by November. Heavy post-season rains in September and October in 1991 brought the soil profile (1 m) to field capacity as shown in Figure 1.16 B, and percolation losses could occur by piston-type flow. This indicates that Br^- could have moved beyond 1 m depth even by piston-type flow due to heavy post-season rainfall in 1991.

Ground water analysis

Background Br^- concentrations taken in May, 1991 were zero in all but one of the 16 wells tested. By December, however, Br^- was detected in all wells. Bromide concentration under solo-seeded alfalfa was 29.9 mg/L, and was significantly greater than the other four treatments (Fig 1.17). Earthworms were most abundant in this treatment (520 m^{-2}). Bromide might have moved through these earthworm channels and ultimately to the ground water. Another possible explanation could be that Br^- moved preferentially through the root channels of the previous corn crop. The treatments did not differ in the Br^- concentrations on the April, 1992 sampling date. However, Br^- concentrations on this date were significantly lower in a paired T-test compared to those of December, 1991. In April, 1992, the five treatments did not differ statistically in the Br^- concentration. Bromide concentration decreased over time (Fig 1.17) in all the treatments due to dilution in the ground water.

Tissue analysis

Bromide concentration and uptake under different crops is given in Table 1.9. Most of the Br^- accumulated by the

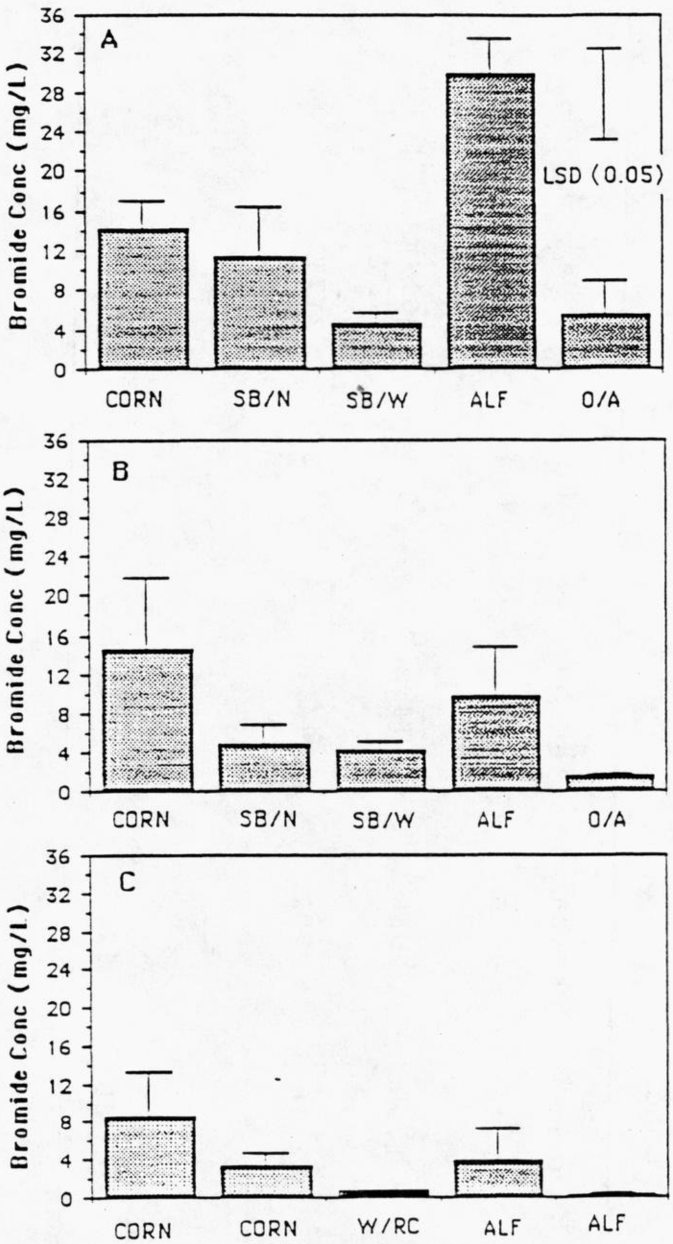

Figure 1.17. Bromide concentration in the monitoring wells under different crops at three sampling dates:December, 1991 (A), April, 1992 (B), and December, 1992 (C) in the crop rotation study, 1991-92. Vertical lines indicate one-half SE around the mean.

Table 1.9. Bromide concentration and uptake by different crops

	Conc.	Uptake DM	Uptake	Conc.	Removal DM	Removal
	$g\ kg^{-1}$	$kg\ ha^{-1}$	$kg\ ha^{-1}$	$g\ kg^{-1}$	$kg\ ha^{-1}$	$kg\ ha^{-1}$
1. Corn	1.89	9580	17.2	0.4	6607	2.8
2. Drilled soybeans	1.80	7950	14.3	0.3	3619	1.3
3. Row soybeans	2.10	7051	14.8	0.3	3173	1.0
4. Oats (straw+grain)	--	--	--	1.0	4503	4.7
5. Direct seeded alfalfa	5.60	1156	6.50	--	--	--

corn plant was stored in the stover. Negligible amounts of Br^- was removed from the system in the harvested portion of the crops during 1991 season. Less than 2% of the applied Br^- was removed in the harvested portion of both corn and soybeans, and only 3% of the applied Br^- was removed by the single cut of alfalfa taken in 1991.

Conclusions

By August, 1991 after only 170 mm of accumulated rainfall, bromide moved to a depth of 80 cm under all rotations.

The speed with which Br^- moved deep in the profile and ultimately to the ground water indicates that macropore flow is the dominant mechanism even under natural field conditions.

Surface-applied chemicals could reach ground water within one growing season irrespective of the cropping system under these field conditions.

References

Abdalla, N.A., and B. Lear. 1975. Determination of inorganic bromide in soils and plant tissue with bromide selective ion electrode. Commun. Soil Sci. Plant Anal. 6:489494.

Baker, J.L., J.M. Laflen, and H.P. Johnson. 1978. Effect of tillage systems on run-off losses of pesticides. A rainfall simulation study. Trans. ASAE 21: 886-892.

Baker, J.L., and H.P. Johnson. 1981. Nitrate-nitrogen in tile drainage as affected by fertilization. J. Environ. Qual. 10: 519-522.

Baker, J.L., and H.P. Johnson. 1979. The effect of tillage systems on pesticide in runoff from small watersheds Trans ASAE 22: 554-559.

Barley, K.P. 1954. Effects of root growth and decay on the permeability of a synthetic sandy soil. Soil Sci. 78: 205-210.

Bergstrom, L. 1987. Nitrate leaching and drainage from annual and perennial crops in tile-drained plots and lysimeters. J. Environ. Qual. 16(1): 11-18.

Beven, K., and P. Germann. 1982. Macropore and water flow in soils. Water Resources Research, 18(5): 1311-1325.

Bodman, G.B., and E.A. Colman. 1943. Moisture and energy conditions during downward entry of water into soils. Soil Sci. Soc. Am. Proc. 8: 116-122.

Bolton, E.F., J.W. Aylesworth, and F.R. Hore. 1970. Nutrient losses through tile drains under three cropping systems and two fertility levels on a Brookston clay soil. Can. J. Soil Sci. 50: 275-279.

Bowman, R.S., and R.C. Rice. 1984. Chemical Tracers Their use in measuring deep percolation rates. Proc Third Deep Percolation Symp., Scottsdale, AZ. 7 Nov. Arizona Department of Water Resources, Phoenix.

Carlan, W.L., H. F. Perkins, and R.A. Leonard. 1985. Movement of water in a plinthic Paleudult using a bromide tracer. Soil Sci. 139(1): 62-66.

Chichester, F.W. 1977. Effects of increased fertilizer rates on nitrogen content of runoff and percolate from monolith lysimeters. J. Environ. Qual. 6(2): 211-217.

Chichester, F.W., and S.J. Smith. 1978. Disposition of 15-N labeled fertilizer nitrate applied during corn culture in field lysimeters. J. Environ. Qual.7(2):227-232.

Davis, S.N., G.M. Thompson, H.W. Bentley, and G. Stiles. 1980. Ground water Tracers A short review. Ground Water 18(1): 14-23.

Davis, F.M., R.A. Leonard, and W.G. Knisel. 1990. GLEAMS User Manual version 1.8.55. USDA-ARS southeast watershed research laboratory, Tifton, Georgia. 45 pp.

Edwards, W.M., M.J. Shipitalo, L.B. Owens, and L.D. Norton. 1989. Water and nitrate movement in earthworm burrows within long-term no-till corn fields. J. Soil and Water Cons. 44: 240-243.

Ehlers, W. 1975. Observations of earthworm channels and infiltration on tilled and untilled loess soil. Soil Sci. 119 (3): 242-249.

Entz, M.H., and D.B. Fowler. 1989. Influence of crop water environment and dry matter accumulation on grain yield of no-till winter wheat. Can. J. Plant Sci. 69: 367-375.

Gish, T.J., and W.A. Jury. 1982. Estimating solute travel times through a crop root zone. Soil Science. 133:124-130.

Hammlett, J.M., J.L. Baker, and D. Timmons. 1988. Water balance and movement under a corn crop in field lysimeter. ASAE paper 88-2528.

Hatfield., J.L. 1990. Methods of estimating evapotranspiration. In B. A. Stewart., and D. R. Nielsen (eds), Irrigation of agricultural crops. Agronomy series No.30. Amer. Soc. Agronomy, Madison, WI.

Hattendorf, M.J., M.S. Redelfs, B. Amos, L.R. Stone, and R. E. Gwin. 1988. Comparative water use characteristics of six row crops. Agron. J. 80:80-85.

Hillel, D. 1982. Introduction to soil physics. Academic Press, pp. 304-319.

Jabro, J.D., E.G. Lotse, K.E. Simmons, and D.E. Baker. 1991. A field study of macropore flow under saturated conditions using a bromide tracer. J. Soil and Water Cons. 46: 376-380.

Jaynes, D.B., R.S. Bowman., and R.C. Rice. 1988. Transport of a conservative tracer in the field under continuous flood irrigation. Soil Sci. Soc. Am. J. 52: 618-624.

Johnson, H. P. 1978. Development and testing of mathematical models as management tools for agricultural non-point pollution control. Annual Report 1977-78. Dept of Ag Engineering, Iowa State University. Ames. Unpublished. 645 pp.

Johnson, H.P., J.L. Baker, W.D. Shrader, and J.M. Laflen. 1979. Tillage systems effects on sediment and nutrients in run-off from small watersheds. Trans. ASAE 22: 1110-1114.

Kanwar, R.S., J.L. Baker, and D.G. Baker. 1988. Tillage and split N-fertilization effects on subsurface drainage water quality and crop yields. Trans ASAE 31(2): 453-461.

Knisel, W.G. 1980. CREAMS: A field-scale model for Chemicals, runoff, and erosion from agricultural management systems. U.S.Dept. of Agriculture, Science and Education Administration, Conservation Research Report No. 26, 643 pp

Knisel, W.G., D.C. Moffitt, and T.A. Dumper. 1985. Representing seasonally frozen soil with the CREAMS model. Trans. ASAE 28(5):1487-1493.

Laflen, J.M. 1982. Effect of tillage on soil erosion and nutrient losses p. 76. In. C. E.Steinhart (ed.). An assessment of conservation tillage in Wisconsin.

Leonard, R.A., W.G.Knisel, and D.A. Still. 1987. GLEAMS Ground water Loading Effects of Agricultural Management Systems. Trans ASAE 30(5):1403-1418.

Logan, T. J., G.W. Randall, and D.R. Timmons. 1980. Nutrient content of tile drainage from cropland in the North Central Region. Ohio Agric. Res. Dev. Cent., Research Bulletin #1119.

Martin, J.P. 1966. Bromine (chapter 5). In H.D. Chapman (ed.) Diagnostic criteria for plants and soils. Univ. of Calif Press, Berkeley, CA. p. 62-64.

Martin, D.L., J.R. Gilley, and R.W. Skaggs. 1991. Soil water balance and management In R.F. Follett, D.R. Keeney, and R.M. Cruse (eds.). Managing nitrogen for ground water quality and farm profitability. Soil Sci. Soc. Am. Madison, WI.

Mathers, A.C., B.A. Stewart., and B. Blair. 1975.Nitrate-nitrogen removal from soil profiles by alfalfa. J. Environ. Qual. 4(3): 403-405.

Meek, B.D., E.A. Rechel, L.M. Carter, and W.R. De Tar. 1989. Changes in infiltration under alfalfa as influenced by time and wheel traffic. Soil Sci.Soc. Am. J. 53:238-241.

Mueller, D.H., T.C. Daniel, and R.C. Wendt. 1981. Conservation tillage: Best management practice for non-point run-off. Environ. Management 5(1): 33-53.

Myers, P.C. 1988. Conservation at the crossroads. J.of Soil and Water Cons. 43:1:10-13.

Office of Technological Assessment. 1986. Technology, public policy and the changing structure of agriculture. OTA-F-285. Washington DC.

Onken, A.B., R.S. Hargrove, C.W. Wendt, and O.C. Wilke. 1975. The use of a specific ion electrode for determination of bromide in soils. Soil Sci. Soc. Amer. Proc. 39:1223-1225.

Onken, L.B., C.W. Wendt, R.S. Hargrove, and O.C. Wilke. 1977. Relative movement of bromide and nitrate in soils under three irrigation systems. Soil Sci.Soc.Amer. J. 41:50-52.

Owens, L.B., R.W. Wan Keuren, and W.M. Edwards. 1985. Ground water quality changes resulting from a surface bromide application to a pasture. J. Environ. Qual. 14(4): 543-548.

Owens, L.B. 1990. Nitrate-nitrogen concentrations in percolate from lysimeters planted to legume-grass J. Environ. Qual. 19: 131-135.

Palm, R.S., and A.R. DeSouza. 1983. Wisconsin weather. Burgess Publishing Company, Minneapolis, MN.

Peterson, H.B. 1972. Water relationships and irrigation p. 469-480. In C. H. Hansomn (ed.). Alfalfa Science and Technology. American Society of Agronomy. Madison, WI.

Postle, J.K. 1984. A field study of the agricultural use of waste water sludge. Masters thesis. Soil Sci. Dept. UW-Madison

Priebe, D.L., and A.M. Blackmer. 1989. Preferential movement of oxygen-18-labelled water and nitrogen-15-labelled urea through macropores in a Nicollet soil. J. Environ. Qual. 18: 66-72.

Quisenberry, V.L., and R.E. Phillips. 1978. Displacement of soil water by simulated rainfall. Soil Sci. Soc. Am. J. 2: 675-679.

Radcliffe, D.E., E.W. Tollner, W.L. Hargrove, R.L. Clark, and M.H. Golabi. 1988. Effect of tillage practices on infiltration and soil strength of a Typic Hapludult soil after ten years. Soil Sci. Soc. Am. J. 52:798-804.

Rice, R.C., R.S. Bowman, and D.B. Jaynes. 1986. Percolation of water below an irrigated field. Soil Sci. Soc. Am. J. 50: 855-859.

Ritchie, J.T. 1972. A model for predicting evaporation from a row crop with incomplete cover. Water Res. Res. 8(5): 1204-1213.

Robbins, J.S., and H.R. Haise. 1961. Determination of consumptive use of water by irrigated crops in the Western United States. Soil Sci. Soc. Am. Proc 25: 150-154.

Saffigna, P.G., D.R. Keeney, and C.B. Tanner. 1977. Lysimeter and field measurements of chloride and bromide leaching in an uncultivated loamy sand. Soil Sci. Soc. Am. J. 41: 478-482.

Schepers, J.S. 1988. Role of cropping systems in environmental quality: Ground water nitrogen. In Cropping Strategies for Efficient Use of Water and Nitrogen. American Society of Agronomy Special Publication Number 51.

Scott, H.D., J.A. Ferguson., and L.S. Wood. 1987. Water use, yield and dry matter accumulation by determinate soybean grown in a humid region. Agron J. 79:870-875.

Shipitalo, M.J., R. Protz, and A.D. Tomlin. 1988. Effect of diet on the feeding and casting activity of Lumbricus terrestris and L. Rubellus. Soil Biol. Biochem. 20: 233-237.

Shuford, J.W., D.D. Fritton, and D.E. Baker. 1977. Nitrate-nitrogen and chloride movement through undisturbed field soil. J. Environ. Qual. 6:255-259.

Siemens, J.C., and W.R. Oshwald. 1978. Corn-soybean tillage systems: Erosion control, effects on crop production, costs. Trans ASAE 21: 293-302.

Smith, S.J. 1972. Relative rate of chloride movement in leaching of surface soils. Soil Sci. 114(4): 259-263.

Smith, S.J., and R.J. Davis. 1974. Relative movement of bromide and nitrate through soils. J. Environ. Qual.3(2): 152-155.

Smith, C.N., R.A. Leonard, G.W. Langdale, and G.W. Bailey. 1978. Transport of agricultural chemicals from small upland Piedmont watersheds. U.S.EPA Research Service, Watkinsville, GA. Final Report on Interagency Agreement No. D6-0381. Publ No. EPA 600/3-78-056. 363 pp.

Smith, M.C., D.L. Thomas, A.B. Bottcher, and K.L. Campbell. 1990. Measurement of pesticide transport of shallow ground water. Trans ASAE 33(5): 1573-1582.

Smith, R.E., and J.R. Williams. 1980. Simulation of the surface water hydrology. In W.G. Knisel (ed.). CREAMS: A field-scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. U.S. Dept of Agriculture, Conservation Research Report no. 26, 640 pp.

Sonmor, L.G. 1963. Seasonal consumptive use of water by crops grown in Southern Alberta and its relationship to evaporation. Can. J. Soil Sci. 43: 287-297.

Steinhart, C.E. 1984. An assessment of conservation tillage in Wisconsin.

Syers, J.K., and J.A. Springett. 1983. Earthworm ecology in grassland soils. In J.E. Satchell (ed). Earthworm ecology: From Darwin to vermiculture. Chapman and Hall, New York. pp. 67-83.

Thomas, G.W., and R.E. Phillips. 1979. Consequences of water movement in macropores. J. Environ. Qual. 14:87-91.

Tompkins, D.K., D.B. Fowler., and A.T. Wright. 1991. Water use by no-till winter wheat: Influence of seed rate and row spacing. Agron. J. 83(4): 766-769.

U.S.D.A. Soil Conservation Service. 1972. National engineering handbook, Hydrology, section 4, 1972. 548 pp

Watson, K.W., and R.J. Luxmoore. 1986. Estimating macroporosity in a forest watershed by use of a tension infiltrometer. Soil Sci. Soc. Am. J. 50: 578-582.

WDATCP. 1989. Nutrient and Pesticide Best Management Practices for Wisconsin Farms. Tech Bull ARM-1 and UW-Ext Bull A-3466.

WDNR 1992. Wisconsin water quality assessment report to congress. Publ-WR254-92-REV.

Williams, J.R., and R.W. Hann. 1978. Optimal operation of large agricultural watersheds with water quality constraints. Texas Water Resources Institute, Texas A&M University, Tech Report No.96, 152pp.

Appendix I.A

Leaf Area Index† (LAI) Table

Corn		Sb		Sb/w		Alfalfa		Oats/alf		Pasture	
Date	LAI	Date	LAI	Date	LAI	Date	LAI	Date	LAI	Date	LAI
1	0.00	1	0.00	1	0.00	1	0.00	1	0.00	1	0.00
125	0.00	130	0.00	130	0.00	115	0.10	110	0.00	105	0.00
140	0.07	145	0.12	145	0.12	130	0.38	119	0.27	120	0.38
156	0.16	160	0.33	160	0.33	145	1.55	127	0.47	135	1.60
171	0.19	174	1.58	174	1.58	160	2.55	136	0.72	150	2.61
186	0.41	189	2.16	189	2.16	165[1]	0.10	144	0.92	155[1]	0.38
202	0.96	204	2.49	204	2.49	180	0.36	153	1.27	170	1.60
217	2.47	219	2.46	219	2.46	195	1.50	162	1.86	185	2.61
232	2.49	234	2.42	234	2.42	215	2.50	170	2.47	195	2.65
247	2.26	248	1.91	248	1.91	220[2]	0.09	179	2.46	200[2]	0.38
263	1.52	263	0.95	263	0.95	235	0.38	187	2.36	215	1.60
278	0.00	278	0.41	278	0.41	250	1.55	196[1]	1.15	230	2.61
366	0.00	366	0.00	292	0.30	265	2.50	210	1.50	245	2.60
				322	0.30	270[3]	0.15	230	2.46	250[3]	0.38
				351	0.30	300	0.10	235[2]	0.35	265	1.60
				366	0.30	330	0.10	250	1.46	300	0.14
						366	0.10	264	2.46	366	0.14
								366	0.10		

† square meter leaf surface/square meter soil surface

Note: The underlined julian dates correspond to planting and harvesting dates for row crops
[1], [2], [3] correspond to first, second, and third forage cuts. In case of Oats/alfalfa, first cut is oats harvest

University of Wisconsin-Madison

College of Agricultural and Life Sciences
Department of Agronomy
1575 Linden Drive
Madison, Wisconsin 53706-1597
Phone: 608-262-1390/1391
FAX: 608-262-5217

Improving Agriculture Through Crop Biotechnology, Genetics and Production Research

June 30, 1993

David Lindorff
Groundwater Management Section
Bureau of Water Resources
Department of Natural Resources

Dear David,

Please find inclosed three copies of chapter I of Raj Kumar Iragavarapu's thesis. In this chapter he reports on the work he did using the GLEAMS model to estimate percolation volumes (based on mass flow assumptions). The second section covers his preliminary Leaching Frame Study (1990) where we created different rainfall patterns without crops and monitored bromide movement into the soil profile. As you can imagine, we found that GLEAMS did a poor job of estimating bromide movement and it appears that preferential flow is very important. The third section in the chapter deals with the field testing (1991, 1992) where we applied bromide to five different crop rotations* and monitored breakthrough times to the groundwater. As in the preliminary Leaching Frame Study, we found that bromide moved rapidly and was in the groundwater by the end of the first cropping season under all five rotations.

In addition to the work on water movement under the different crop rotations, we took advantage of the PVC wells that were installed to monitor background triazine levels and nitrite plus nitrate levels in the water. As the attached table shows, triazine and nitrate levels are high at the Lakeland Agricultural Complex. The jump in triazine levels for the fourth date of sampling is due to the change in analytical techniques from the immuno assay to gas chromatography. Twelve of the twenty wells exceed the Enforcement Standard of 3.5 ppb for triazines. Nitrate levels in the groundwater suggest that best management practices have resulted in improved water quality. Nitrate + Nitrite concentrations were above the safe limit (45 ppm) in 6 wells in May 1991 and three wells in both December '91 and April '92. Only one well exceeded the safe limit in December 1992.

----

* In rotation terminology "-" separates years, and "/" means in the same year. As a result rotation 3 is sb/w-w/rcl-c (soybeans in year one with winter wheat planted in the fall after soybean harvest. In year two the wheat has red clover frost seeded into it in March. In year three, corn is planted. By the same token in rotation 5 we have oats planted as a companion crop with alfalfa, in year two there is alfalfa hay and in year three corn is planted (o/a-a-c)

A final activity undertaken with DNR funding was the initiation of a preliminary study using PVC well screening to construct horizontal wells to measure the leachate as it leaves the rooting zone. The 22 wells were installed using tile laying equipment, some at 0.75 m, others at 1.5 m. This was done in July 1992 and a cover crop was established. In May of 1993 we have planted corn over this "tube" garden and applied different levels of nitrogen fertilizer. We are now monitoring the leachate captured in the tubes to see if this approach can be used on the large crop rotation plots. At this point we have no data to report.

I would like to thank the Department of Natural Resources in general and the Bureau of Water Resources in particular for the funding we received. I hope that the research we have done and reported at a number of meetings, as well as the infrastructure we have built will serve the Department and Wisconsin farmers in the future.

Sincerely Yours,

Joshua L Posner

Joshua Posner
Agronomy Department

Table 29. Atrazine and Nitrate concentrations in the monitoring wells at Lakeland Agricultural Complex in 1991 and 1992

Field ID	Treat-ment#	Well #	Triazine Concentration 5/20/91†	12/10/91†	4/23/92†	12/9/92‡	Nitrite + Nitrate Concentrations 5/20/91	12/10/91	4/23/92	12/9/92
			ppb				ppm			
101	1	EC361	0.4	1.3	0.7	10.3	80.8	41.5	40.2	39.7
210	1	EC371	0.1	0.4	0.2	3.6	52.8	48.5	46.1	44.2
303	1	EC373	0.1	1.9	0.6	1.7	34.9	21.3	38.5	36.4
Mean							56.2	37.1	41.6	40.3
108	2	EC365	0.2	0.5	0.3	7.9	70.8	60.5	55.9	47.8
203	2	EC367	0.3	0.4	0.2	7.6	11.4	14.0	26.0	20.0
304	2	EC374	0.1	0.4	0.2	4.7	12.8	20.1	28.1	20.1
Mean							31.7	31.5	36.7	29.3
111	6	EC366	0.3	0.3	0.3	11.3	60.8	43.8	9.1	18.4
208	6	EC369	0.2	0.5	0.4	11.7	37.3	28.6	14.9	38.4
306	6	EC376	0.1	0.3	0.2	4.7	28.8	42.3	9.4	23.8
Mean							42.3	38.2	11.3	26.9
102	8	EC362	0.2	0.3	0.1	0.5	38.7	15.1	12.5	4.84
209	8	EC370	0.4	0.5	0.3	4.5	48.8	6.8	14.9	14.4
305	8	EC375	0.1	0.2	0.2	1.8	34.8	10.3	8.5	5.73
Mean							40.8	10.7	12.0	8.3
105	12	EC364	0.1	0.2	0.1	1.2	16.5	15.4	21.8	10.8
207	12	EC368	0.2	0.3	0.3	5.2	69.6	49.7	3.9	38.7
309	12	EC377	0.1	0.2	0.1	2.7	11.9	7.3	56.1	8.34
Mean							32.7	24.1	27.3	19.3
104	14	EC363	0.1	0.3	0.2	5.4	24.7	21.3	2.8	21.4
213	14	EC372	--	0.2	0.1	1.3	--	2.2	29.6	2.84
314	14	EC378	--	0.2	0.2	5.5	--	63.2	--	30.0
Mean							24.7	28.9	16.2	18.1
1S[1]	-	EC379	--	0.1	0.1	0.2	--	31.1	2.8	2.07
1D[2]	-	EC380	--	0.2	<DL	0.3	--	6.9	29.6	10.6

[1] Check well #1 13 feet deep | Located in the northern end of
[2] Check well #2 28 feet deep | the field
DL = detection limit
Treatment codes in 1991:
1 = continuous corn (C-C-C)
2 = narrow-row soybean phase of soybean-corn-soybean (Sb-C) rotation
6 = Wide-row soybean phase of soybean-wheat/red clover-corn (Sb-W/rc-C) rotation
8 = Seeding year alfalfa phase in alfalfa-alfalfa-alfalfa-corn (A-A-A-C) rotation
12= Companion seeded alfalfa phase in oats/alfalfa-alfalfa-corn (O/A-A-C) rotation
14= Continuous pasture.
† Immuno Assay Method
‡ Gas Chromatography method