Cover Crop Effects on Bromide Tracer Recovery and Soil Nitrate Distribution

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Short Title – Cover Crop Effects on Bromide and Soil Nitrate

ABSTRACT

A conservative tracer was used to test the hypothesis that the mechanism by which cover crops scavenge residual nitrate (NO_3^-) is through uptake and retention during the winter with redistribution to the soil surface in spring. Bromide (Br^-) was applied in December 2000 to plots planted in summer vegetable plots with (called H plots) and without (called C plots) winter cover crop management. Three fertilizer treatments (N0 for no fertilizer, N1 for half and N2 for vegetable crop recommendation) were managed at the subplot level. During winter, H plots had a common vetch (*Vicia Sativa*) / triticale (*Tritcosecale X* L. var. Celia) mix cover crop while C plots were left fallow. Snap beans (*Phaseolus vulgaris* L. cv. Oregon 91G) were planted on plots during the summer of 2001. Twenty-six passive capillary samplers (PCAPS), each with a collection area of $0.26m^2$, were installed at 1.2 meters depth. Flux concentrations of Br^- within percolating soil water were measured. Soil was sampled to 1.2 meters depth during May, September, and December of 2001 using a hand auger and extracted to determine vertical Br^- and NO_3^-- N concentration profiles under the various treatments. PCAPS recovered peak Br^- concentrations were 14.3 and 23.1 mg L^{-1} while fitted peak concentrations were 10.9 and 14.7 mg L^{-1} for H and C plots, respectively. Average Br^- collection efficiencies from PCAPS below H and C plots were 35 and 47 % of the applied mass, respectively. Cover crop treatment had a significant effect on Br^- collection efficiency (*P*-value of 0.02). Vertical concentration profiles of Br- and NO_3^-- N between H and C plots showed evidence of cover crop uptake, retention and mineralization of both chemicals. PCAPS collected and soil extracted Br^- mass were added after the May auger sampling to calculate an 83% and 95% tracer recovery for the cover cropped and fallow fields, respectively. Through uptake and retention, cover crops can assimilate NO_3^- and therefore reduce the amount of NO_3^- available to leaching processes.

INTRODUCTION

The use of winter cover crops is a strategy that has potential as a best management practice (BMP) for nitrogen (N) as well as soil fertility and conservation. Winter cover crops that are incorporated into the ground before spring planting protect the soil surface, add organic matter, smother weeds, and improve soil tilth (Sattell et al., 1998). Cover crops maintain organic matter content, reduce erosion on slopes and impede the formation of crust layers due to raindrop effects on bare earth, improving infiltration and water-holding capacity during dry summer months. Besides improving soil quality, cover crops scavenge excess N left in the soil after fall harvest, reducing NO_3^- leaching to groundwater. (Meisinger et al., 1991; Brandi-Dohrn et al., 1997; Staver and Brinsfield, 1998; McCracken et al., 1994).

Despite the effectiveness of cereal crops to accumulate N, research findings question the ability of disked cereal rye residue to provide available N to the summer crop. Burket et al. (1997) measured crop yields harvested from plots managed under fallow treatment, cereal rye and clover. Consistent with other studies such as McCracken et al. (1989), Mitchell and Teel (1977) and Raimbault et al. (1991), Burket et al. (1997) found no yield improvements for corn grown in cereal cover plots versus fallow plots, suggesting that mineralization was not enhancing crop growth.

Leguminous winter cover crops such a crimson clover, winter pea, and vetch are appealing because while scavenging NO_3^- from the previous crop, additional N may be supplied to the system. In a three year study by Ranells and Wagger (1997) comparing grass cover crops and legume monocultures, the top 90 cm of soil contained more total inorganic N in the legume plots. Other studies showing higher inorganic N concentration after legume cover crop cultures include Sainju et al., (1998) and Brown et al., (1993).

Bromide$^-$ is often used as a surrogate tracer for NO_3^- because it is easily analyzed, has low background concentrations and is not reactive or adsorbed in soils (Kung, 1990). Hargrove and Bausch (1973) used leaching rates of Br^- to compare leaching rates from N fertilizers. The ability of plants to take up Br^- from soil water is well recorded (Chao, 1966; Owens et al., 1985; Kung, 1990; Schnabel et al., 1995). Plants passively assimilate Br^- while taking up soil water. Because of crop uptake, the ability of Br^- as a tracer describing water movement has been questioned. Tracer breakthrough characteristics in soil can be modified if Br^- is taken up by plants and redistributed on the surface through plant decay, leaf fall, or ingestion by grazing animals (Owens et al., 1985; Kung, 1990). Plant uptake of Br^- in surrogate studies could result in overestimation or underestimation of leaching depending on the reactivity and absorption qualities of the modeled chemical (Kung, 1990).

The objectives of this study were to 1) Quantify the mass recovery of a surface applied Br^- tracer under cover cropped and fallow plots 2) Observe Br^- and NO_3^-- N concentration profiles attained through manual soil sampling from cover cropped and fallow plots 3) Describe the effect of cover crop uptake and mineralization on the distribution of Br^- and NO_3^- in the vadose zone.

METHODS

Site Description

The study site was at the North Willamette Research and Extension Center (NWREC) located near Aurora, Oregon (45° 17' N and 122° 45' W). The Willamette Valley has a Mediterranean climate characterized by wet winters and dry summers. Weather records from 1963 to 1990 give an annual average precipitation total of 103.6 cm (40.8 inches) (Oregon

Climate Service, 2003). During the dry, sunny summer months, potential evapotranspiration (ET) far exceeds rainfall.

Soils located within the 0.98 hectare study site are slightly sloped towards the south (<3%). The soil is classified as a Willamette silt loam and is of glaciolacustrine genesis. Description of organic carbon, pH, bulk density, particle size distribution, saturated hydraulic conductivity and moisture retention characteristics for the NWREC study plot are described in Brandi-Dohrn et al. (1996). Soil bulk density measurements were repeated in 2001.

Summer vegetables grown on the experimental plots were irrigated using a hand move sprinkling system. Irrigation sets took place once per week. Water was applied for variable set times according to the time of the year; however a quantitative model of evapotranspiration was not used to fine tune irrigation amounts. Irrigation procedures were consistently managed by the same person throughout the study.

During the two winters included in this analysis, cover cropped (H) plots were planted in a biculture of common vetch (*Vicia Sativa*) and the cereal crop triticale (*Tritcosecale X* L. var. Celia) while C plots were left fallow. Plots were in corn (*Zea mays* L. cv. Jubilee) during the summer of 2000 preceding this analysis and snap beans (*Phaseolus vulgaris* L. cv. Oregon 91G) were planted on all plots during the summer of 2001.

Instrumentation and Sample Processing

Passive Capillary Samplers (PCAPS) were used to continuously sample soil water flux. Twenty-six PCAPS were located throughout the 0.98 ha field. A detailed description of PCAPS design, installation and operation at the NWREC is detailed in Brandi-Dohrn et al. (1996).

Water was pumped from the PCAPS after cumulative rainfall between sampling events neared 2.5 cm, at which point the collection vessels would be reaching capacity. The procedures for PCAPS generated sample processing and flow weighting calculations are provided in Feaga, (2003).

Tracer Application

A Br^- tracer was applied on December 12, 2000. The fall planted common vetch / triticale mix cover crop was already well established on H plots. In order to remain consistent with previous studies, a 29.6 g/L Br^- solution was used for the tracer application (Hess, 1995). The total amount of Br^- applied over the 31 x 84.5 cm^2 PCAPS surface dimensions was 3877 mg. The tracer solution was prepared by dissolving KBr in water. The tracer solution was pressurized to 414 kPa using CO_2 and applied to the field using a three meter wide manually mobilized sprayer mounted to a bicycle wheel. A 0.5 mm depth of the solution was sprayed above each pair of PCAPS from a height of one meter. The total spray area was 6m x 7.5m. Figure 1 shows the spray pattern for the Br^- application.

Soil Sampling

Following the Dec 12th, 2000 application of the Br^- tracer at the NWREC, manual soil sampling was used to observe spatial concentrations of the Br^- plume. Dates for the three sampling events were the 5th and 6th of May 2001, 5th-7th of September 2001, and the 15th of December 2001, respectively. For each sampling event, two holes were augured (1 ¼" diameter) on each of the subplots (N0, N1, N2) equipped with working PCAPS. All augured holes were well within the area of tracer application and about 1.5 meters from the buried samplers (Figure 1). It was imperative to sample far enough from the PCAPS to prevent any hydrologic changes that could result from destructive sampling. Each of the 40 holes was augured to 1.2 meters, the same depth as the flux plane of the PCAPS collection wicks. Each augured hole was divided into six layers, each 20 cm deep. All layers from the soil profile were separately pulled to the surface, removed from the auger, placed into heavy duty freezer bags and stored in a cooler containing dry ice to stop microbiological action in the soil. Holes were back filled with bentonite to ensure that the remaining auger hole did not serve as a conduit for preferential flow. Samples were stored frozen until they could be analyzed.

The last two sampling events were identical to the first except that each 1.2 meter hole was divided into twelve layers (instead of six), each 10 cm deep. This change was made so that the Br^- plume and resident concentrations of NO_3^-- N within the soil water could be determined with better resolution. The upper 30 cm were not represented during the September sampling event due to large quantities of decaying bean crop left from the recent mowing and a dry, uneven soil surface that was deemed difficult to characterize using an auger sampling tool. Samples were not taken from fallow plots containing PCAPS 21 and 22 in both September and December. In September the soil was too compacted to sample, while in December the area was ponded with water.

Soil Extractions and Processing

After thawing, soil samples were manually homogenized within the bag. Bromide and NO_3^--N concentrations may be variable over small distances, so this mixing step was important to ensure that each sample removed from each layer for extraction was representative of the entire layer. A sub sample was taken from each of the bags to yield approximately 20 grams of oven dry soil.

Soil Br^- and NO_3^- were extracted from each of the oven dried sub samples using the method used by Dick and Tabatabai (1979). The clear extract was stored frozen until it could be analyzed with a Dionex AS4A-SC separator column and an AG4A-SC guard column (Dionex Corp. Sunnyvale, CA) for Br^- and NO_3^- content. Concentrations of Br^- and NO_3^-- N within the extracted solution were used to back calculate the concentrations of these ions in the soil water and to determine the percent of original applied tracer mass recovered.

To compute the total mass recovery, the average Br^- content from each 20 cm depth unit of the augured soil sample was converted to a mass Br^- / mass soil basis. This ratio was applied to the soil mass in the corresponding soil volume below the PCAPS. The soil mass in each of the volumes below the PCAPS was estimated using the bulk density measurements with depth and the volume of soil contained in a cube with a length and width equal to the dimensions of the PCAPS surface panel and a depth of 10 or 20 cm as defined by the soil sampling depth units.

Bromide collection efficiency data were tested by analysis of variance (ANOVA) with a general linear model as a randomized complete split-plot block design over tracer application years with winter cover crop treatment as main plots and N rate as subplots. A separate ANOVA analysis was also made for each tracer application year.

RESULTS

Br^- Tracer Breakthrough and PCAPS Mass Recovery

Rainfall characteristics during the period following the application of the Br^- tracer are given in Figure 2. Water year 2001 (measured from October 2000 to September 2001), received only 58% of the average rainfall. Winter 2001 was somewhat wetter than average with 108% of the typical water year accumulation. Winter 2002 received 100% of the average at the time of this analysis with four months yet to be measured in water year 2003. Several rain events during December and January of water year 2002 resulted in saturated conditions and overland flow on some of the plots. Though matrix flow was the dominant flow regime, preferential flow existed at the site and was an important process in chemical transport and dispersion (Feaga, 2003).

An average concentration was fit to the flow-weighted average Br^- concentration calculated from the 14 samplers under C plots and the 12 samplers under H plots (Figure 3b). The best fit line was determined using Microsoft Excel's solver package to minimize the sum of squared differences between measured data and the Advection Dispersion Equation (ADE) modeled solution. This analysis of tracer breakthrough is qualitatively based; a quantitative description of transport parameters generated using the ADE is provided in Feaga, (2003).

Figure 3b shows that the real and fitted concentrations were higher below fallow plots than cover cropped plots. PCAPS measured peak Br^- concentrations were 14.3 vs. 23.1 mg L^{-1} and fitted peak concentrations were 10.9 vs. 14.7 mg L^{-1} for H and C plots, respectively. Figure 3a shows the cumulative mass recovery of Br^- collected by PCAPS after 2.8 pore volumes of water were collected. Overall average mass recovery in percent for the 2000 Br^- application was 41%. Individual samplers measured recovery efficiencies that ranged between 56 and 18 % (Figure 4). Mass recoveries were 35 and 47% for the H and C plots, respectively. Analysis of variance showed that cover crop treatment had a significant effect (*P*-value = 0.02) on Br^- collection efficiency (Table 1). Though crop analysis was not made to determine the Br^- content within the biomass, uptake of Br^- by the common vetch / triticale mix cover crop is the most probable explanation for the observed differences in tracer recovery.

Using a water balance, it was possible to find the water collection efficiency for PCAPS. In Feaga (2003), an average collection efficiency of 76% was calculated over three seasons spanning the eleven years of PCAPS operation. Brandi-Dohrn et al. (1996) also found an average water collection efficiency of 76% over the first 566 days of PCAPS operation at the same site. Assuming 76% collection efficiency during this period of Br^- recovery, average Br^- collection efficiencies would be increased to 46 and 61% for the H and C plots, respectively.

With time, Br^- tracer recovery under cover cropped plots could reach unity with fallow plots as the process of crop assimilation and mineralization will eventually relinquish Br^- to the soil water and leach to sampler depth. Recycling of Br^- through mineralization aside, it is possible that recovery ratios calculated using PCAPS may increase in the future if considerable diffusion of Br^- occurred into small pores of the soil matrix. This would have the effect of creating a long tail on the Br^- breakthrough curve (Haggerty et. al., 2000). This may be hard to measure, however, as Br^- concentrations drop to near the detection limit defined by the chromatograph analysis technique.

Cover Crop Effects on Soil NO_3^- and Br^- Concentration Profiles

Extraction of soil samples showed differences in chemical distribution between fallow and cover cropped treatments. Bromide and NO_3^-- N concentration profiles were drawn for at least 36 different 1.2 meter holes for the months of May and September 2001. The May sampling was one month after the incorporation of the cover crop into the soil by disking the plots. Bromide concentration profiles for plots of similar cover crop treatment were averaged for each sampling date and are shown in Figure 5. For NO_3^-- N profiles, concentrations correlated with fertilizer inputs, however only N2 plots are shown (Figure 6). Extraction analysis of soil samples from mid-December 2001 indicated that heavy rains in November and early December moved the Br^- and NO_3^- - N pulses past the 1.2 meter level. Considerable differences were not seen between May profiles and September profiles, and can be explained by the lack of deep percolation during the dry summer months.

The May and September destructive tracer recovery events indicated that the cover cropped fields had much higher concentrations of NO_3^- - N and Br^- near the ground surface, evidence that the common vetch triticale mix cover crop had successfully scavenged dissolved chemicals from the soil water during the winter months. It appeared that the elevated concentration levels of soluble Br^- and NO_3^-- N and at the time of sampling were attributed to redistribution of these chemicals through decomposition and mineralization of the cover crop in the soil (Kung, 1990). It is possible that a portion of the N mineralized from the common vetch came from fixed atmospheric N. Nitrogen contents in the plant and N fixing rates were not quantified; therefore it is impossible to positively identify the source of elevated N concentrations in the upper soil.

The lack of a NO_3^--N or Br^- pulse under cover cropped plots versus a clearly defined pulse peaking at around 50 cm under fallow fields supports the hypothesis that the legume cereal mix successfully scavenged N. The higher NO_3^-- N concentrations were at a depth of around 70 to 80 cm, while Br^- pulse was at a depth of 40 to 50 cm. The NO_3^-- N plume originated as post harvest NO_3^- remaining in the soil after the fall 2000 corn harvest, while the Br^- tracer was not applied until Dec 12th.

It is probable that the redistributed NO_3^- and Br^- remaining under the cover cropped plots were available for uptake by the following summer bean crop. Nitrate and Br^- in the fallow plots would be incapable of assimilation the following summer as a large proportion of their mass was below root depth.

Adjusted Br^- Mass Balance at a Point in Time

PCAPS tracer recoveries during the 2000 Br^- application were expanded to include mass recovered through soil extraction. Tracer recovery was calculated only for the May 2001 sampling event because the September 2001 event did not include the upper 30 cm of the profile. The May soil sampling recovered an average of 82% and 92% of the applied Br^- mass in the cover cropped and fallow plots, respectively. The recoveries calculated by PCAPS collection were much lower than the soil sampling mass recovery ratios. At the time of the May soil sampling, some Br^- mass had already been collected by the PCAPS at 1.2 meters of depth. The average cumulative mass of Br^- collected by PCAPS between the date of tracer application and the 4th of May (the day before soil sampling) was 71 mg and 97 mg (of the total 3877 mg applied over each PCAPS cross sectional area) for the cover cropped and fallow plots, respectively.

The PCAPS collected Br^- mass and the mass collected through soil collection and extraction were added together to calculate a total Br^- balance for the 6th of May 2001. This adjusted Br^- mass recovery was 83% and 95% for the cover cropped and fallow plots, respectively. Jaynes et al. (2001) also recorded high total recovery ratios for a Br^- tracer when masses from soil residue extractions and tile effluent losses were added. The high recovery ratios of soil extracted Br^- versus PCAPS collected Br^- can be explained by rainfall patterns. Little rain fell following tracer application during the winter of 2000, minimizing leaching and allowing the Br^- to stay in a well defined plume that was well-represented by the soil sampling design.

CONCLUSIONS

Recovery of NO_3^- and an applied Br^- tracer indicate that the common vetch / triticale mix cover crop assimilated Br^- and NO_3^- during the winter of 2000. The retention of Br^- and NO_3^- within the upper soil profile illustrated the process by which cover crops reduce leaching of applied chemicals. Statistically significant cover crop effects on Br^- collection efficiency suggest scavenging by the cover crop.

ACKNOWLEDGEMENTS

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Figure

6 Nitrate - N concentration in soil water during May 2001 (left) and September 2001 (right). The difference between cover cropped and fallow treatments are evidence that NO_3^- -N was retained by the cover crop during the winter.

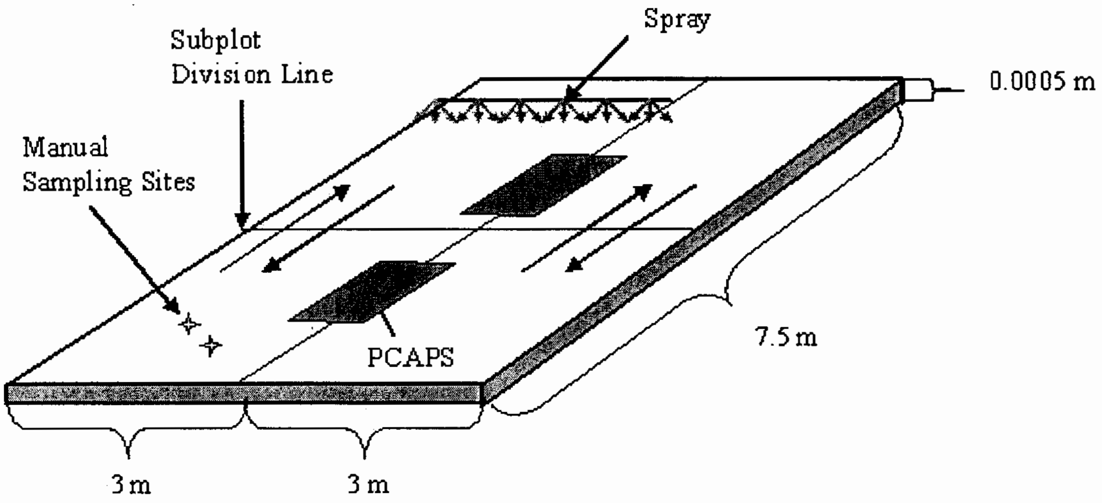

Spray
Subplot Division Line
0.0005 m
Manual Sampling Sites
7.5 m
PCAPS
3 m
3 m

Figure 1

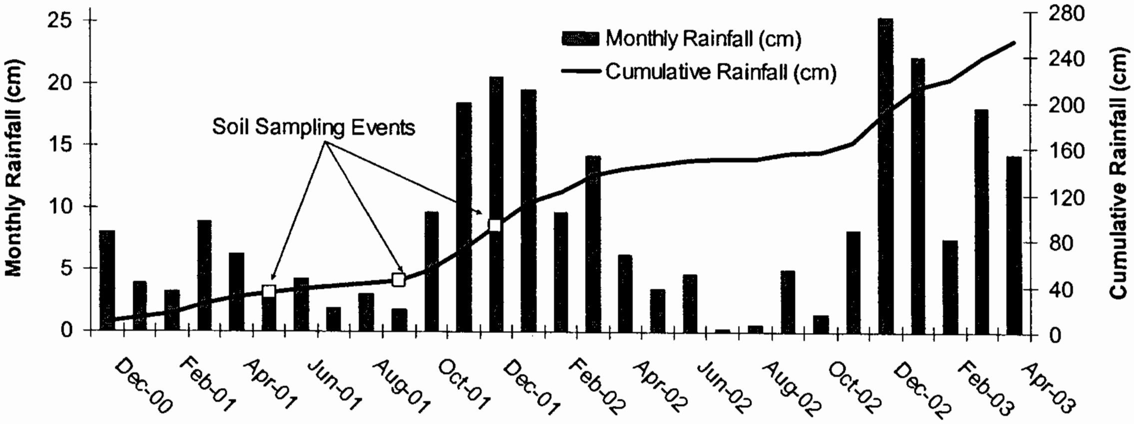

Monthly Rainfall (cm)
Cumulative Rainfall (cm)
Soil Sampling Events
25
20
15
10
5
0
280
240
200
160
120
80
40
0
Dec-00
Feb-01
Apr-01
Jun-01
Aug-01
Oct-01
Dec-01
Feb-02
Apr-02
Jun-02
Aug-02
Oct-02
Dec-02
Feb-03
Apr-03

Figure 2

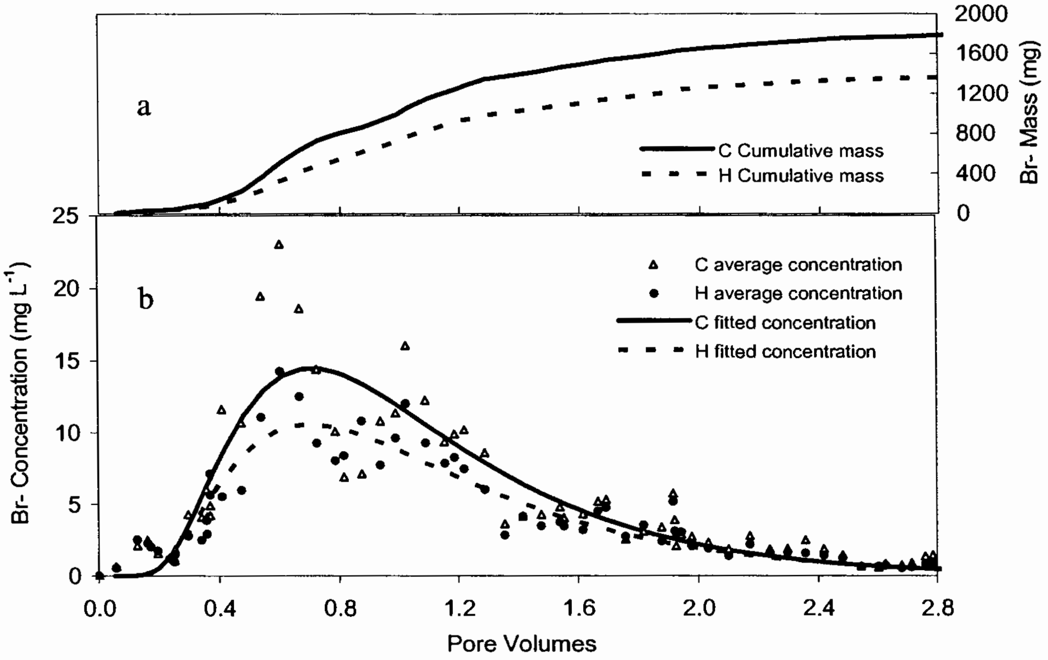

a
C Cumulative mass
H Cumulative mass
Br- Mass (mg)
2000
1600
1200
800
400
0
b
C average concentration
H average concentration
C fitted concentration
H fitted concentration
Br- Concentration (mg L^{-1})
25
20
15
10
5
0
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Pore Volumes

Figure 3

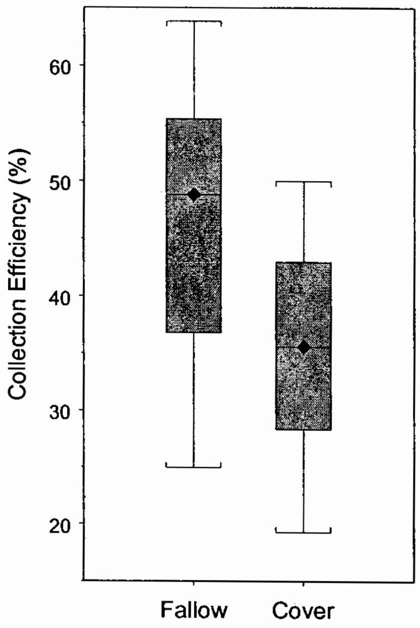
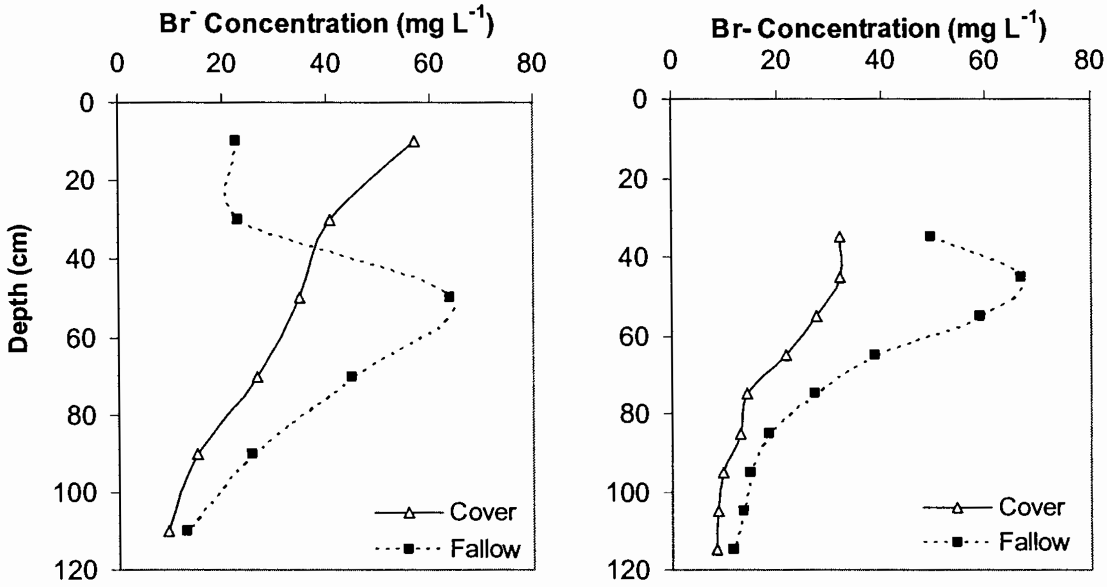


Figure 4



Br⁻ Concentration (mg L⁻¹)
0
20
40
60
80
Depth (cm)
0
20
40
60
80
100
120
Cover
Fallow
Br- Concentration (mg L⁻¹)
0
20
40
60
80
0
20
40
60
80
100
120
Cover
Fallow

Figure 5

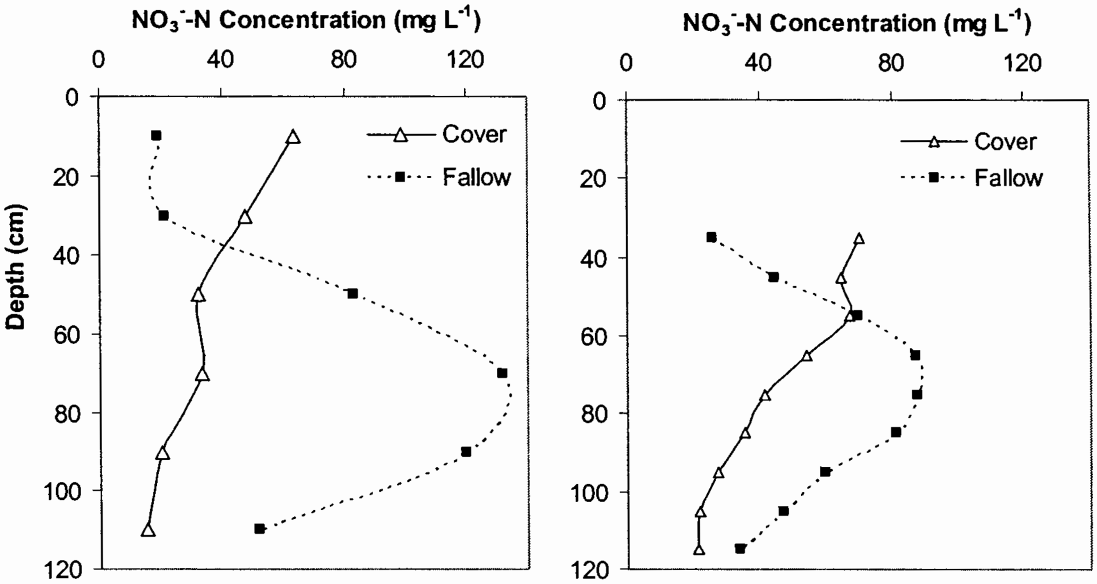

NO$_3^-$-N Concentration (mg L^{-1})
0
40
80
120
Depth (cm)
0
20
40
60
80
100
120
Cover
Fallow
NO$_3^-$-N Concentration (mg L^{-1})
0
40
80
120
0
20
40
60
80
100
120
Cover
Fallow

Figure 6

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Table

Table 2 Summary of analyses of variance showing the sources of effects on Br- collection efficiency by PCAPS following the December, 2000 tracer application.

Time Period	**Source of Variation**	**Br^- Collection Efficiency**	
		df	***P*-value**
2000 Br^- tracer application	Cover crop	1	0.0214
	N fert. rate	2	0.4489
	Block	3	0.2140
	Cover * N fert. rate	2	0.9635