DIVISION S-7—FOREST & RANGE SOILS

Bromide Transport under Contour Hedgerow Systems in Sloping Oxisols

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ABSTRACT

Contour hedgerows promote infiltration, thereby reducing runoff and soil erosion on sloping lands. The increase in infiltration could increase the leaching of mobile chemicals. The objective of this study was to determine the effect of hedgerows on Br^- transport in two Hapludox soils with 21 to 30% slope in the Philippines. In Exp. 1, KBr at the rate of 200 kg Br^- ha^{-1} was broadcast in June 1991 at corn (*Zea mays* L.) planting on (i) the alleyways of plots with pruned hedgerows of *Gliricidia sepium* (Jacq.) Klunth ex Walp. and paspalum (*Paspalum conjugatum* Bergius) (hedgerow treatment) and (ii) open field plots (control). In Exp. 2, KBr was applied at the same rate as in 1991 in strips in the hedgerow and control plots that had not received the KBr application the previous year. After Br^- application, Br^- was analyzed in hand-augered soil samples at increments to 105 cm and in soil solution samples taken with suction lysimeters at the 30-, 60-, and 90-cm depths. Estimated pools of Br^- (kg ha^{-1}) at a given depth were usually less for the suction lysimeter than for soil samples, possibly due to percolating water bypassing Br^- in soil aggregates above the depth of lysimeter sampling. After about 500 mm of rainfall, 50% of the Br^- had leached below the 30-cm depth in the hedgerow plots. Slightly greater lateral, but less vertical, Br^- movement occurred for the control. If NO_3 leaches to or below the observed Br^- leaching depths, it would become unavailable to acid-sensitive food crops displaying shallow rooting depths.

CONSTRUCTION OF CONTOUR HEDGEROWS is a viable soil conservation practice on sloping land in the humid tropics (Kang et al., 1990; Lal, 1991). Food crops are planted in alleys between hedgerows of trees, grasses, or both. Hedgerow plants reduce runoff, filter soil particles, and promote the establishment of terraces between adjacent hedgerows (Nair, 1984). As the steepness and width of the alley decreases, less surface runoff occurs, and infiltration increases (Agus et al., 1997).

With the decreased runoff and increased infiltration in hedgerow systems, it is possible that leaching of mobile nutrients below the root zone will increase. The contour hedge strip at the lower portion of an alley serves as a barrier to slow runoff from that alley, causing solids to settle and allowing greater water infiltration in this region. This infiltrating water may have both downward and horizontal components. Lateral movement occurs if a layer or horizon of soil with lower hydraulic conductivity underlies the surface soil. Thus, both vertical and horizontal solute transport are expected.

Another reason for lateral flow near the hedgerows is that the elevation gradient is steep at the hedgerow location. Over time, a "bench" terrace forms as sediment removed from the upper portion of an alley is deposited in the lower portion of the alley (see Fig. 1B). This process is promoted by the presence of the hedgerow. The steep gradient near the hedgerow gives rise to a sizeable horizontal gradient. To our knowledge, solute transport in soils with contour hedgerows has not been investigated. Knowledge about the leaching process could assist in timing the application of mobile fertilizer nutrients such as NO_3.

Direct measurement of the NO_3 leaching in soil is complicated because NO_3 undergoes biochemical transformations in addition to physical interactions with soil and water (Stevenson, 1982). For this reason, Br^- is often used to evaluate the leaching process of anionic species (Smith and Davis, 1974). Bromide moves in the soil like NO_3, but unlike NO_3, Br^- does not undergo chemical transformations in the soil (Bowman, 1984). Moreover, the natural Br^- concentration in most soils is commonly about two orders of magnitude less than for Cl^-, another common ion used to study transport processes (Davis et al., 1980).

The concentration of a solute in the soil can be determined by either extracting the chemical from soil samples and analyzing its concentration in the soil extract, or measuring its concentration in soil solution extracted from the soil. The solute concentration measured in soil samples includes solute from exchange sites and from the mobile and the immobile phases of the soil water. Suction lysimeters provide an estimate of the concentration of solute in the larger pores of the soil, but probably do not provide an accurate assessment of the movement of the total mass of a solute through the soil. The suction-lysimeter technique provides an estimate of the solute concentration in low-tension waters held at suctions less than that applied to the porous cup sampler (Magid and Christensen, 1993). For soil samples, the volume of soil in which the solute concentration is measured is known, whereas the volume of the bulk soil represented by the solution sample obtained from suction lysimeters is unknown.

Lateral transport of Br^- within soils on slopes has been demonstrated on Ultisols in the Piedmont region in the USA (Bruce et al., 1985; Bathke et al., 1992; Afyuni et al., 1994). In cropped fields, Afyuni et al. (1994) found 225-cm lateral transport of Br^- within Ultisols on 5 to 10% slopes receiving 1460 mm of rainfall during a 15-mo period. The presence of an argillic horizon with a lower hydraulic-conductivity value than overlying horizons may contribute to lateral flow. This condition is not present in Oxisols.

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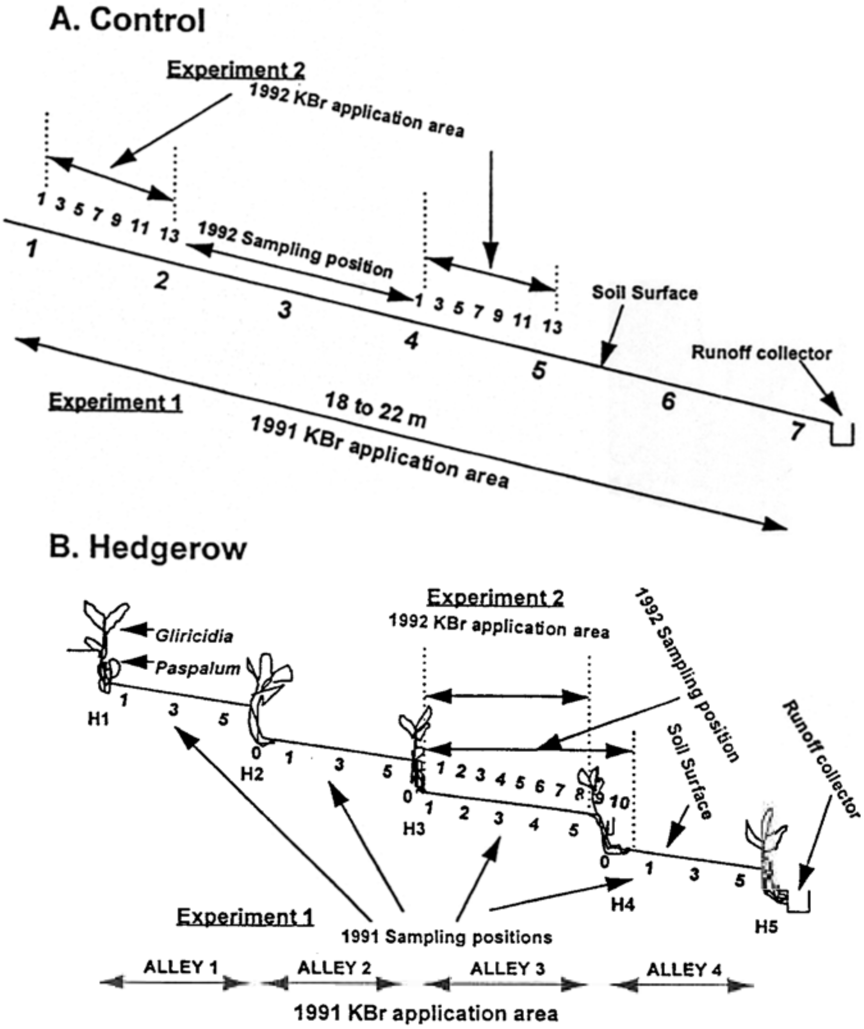

Fig. 1. Schematic representation for KBr application areas and sampling positions on (A) control and (B) gliricidia–paspalum hedgerow plots. Experiments 1 and 2 were conducted on different splits of the main plots.

The objective of this study was to determine the effect of a contour hedgerow system on vertical and horizontal Br^{-1} transport on sloping Oxisols in the humid tropics. Such information could be useful in developing management strategies for fertilizer applications in high rainfall environments.

MATERIALS AND METHODS

Two privately owned farm fields (Compact and Cabacungan) with acidic upland soils were used for the study. Both are located near the outreach station of the International Rice Research Institute (IRRI) in Claveria, Mindanao, the Philippines (8°38′N, 124°55′E). The soils at the Compact site (500 m elevation and 1880 mm annual rainfall) are classified as a very-fine, halloysitic, allic, isohyperthemic, Typic Hapludox. The soils at the Cabacungan site (200 m elevation and 1200 mm annual rainfall) are classified as a very-fine, kaolinitic, isohyperthemic, Rhodic Hapludox. Clay content generally decreases with depth at both sites, but is 10% by mass higher in the profile at Cabacungan (Table 1). Bulk density to the 2-m depth is between 0.9 and 1.1 Mg m^{-3} at both sites. Prior to hedgerow establishment in 1988, both fields had annual corn–fallow rotations.

Two replicates of contour hedgerow and control plots were installed at each site in 1988. The width of each main plot along the contour was 15 m while its length downslope ranged from 18 to 22 m, depending on slope that ranged from 21 to 30%. The control treatment was the conventional cultivation system in the area and consisted of plowing and disking on the contour. Hedgerows were not present in control plots.

The hedgerow-treatment plots had five hedgerows and four alleys (Fig. 1). Average hedgerow width was 0.8 m and average alley width was 4.7 m. Each hedgerow consisted of one row of gliricidia trees and one row of paspalum planted on the contour. The row of paspalum was 30 cm downslope from the row of gliricidia. The distance between adjacent hedgerows was based on a 1-m change in elevation and on the average, was 5.5 m. Thus, about 15% of the total land area was devoted to hedgerows. Further details on contour hedgerow establishment are provided by Agus et al. (1997).

The gliricidia was pruned four times each year. Pruned biomass was placed on the soil surface in the alley to serve as mulch and to recycle plant nutrients. Plant residues not harvested from each food crop were retained in the plot area. Paspalum was not pruned because it reached a maximum height of only 40 cm.

From the time of hedgerow establishment in 1988 until our solute transport study began in 1991, two rice (*Oryza sativa* L.) and two corn crops were grown. May through September and October through February represent the local dry and wet seasons, respectively. The alleys for hedgerow plots and the entire control plots were plowed twice with an oxen-pulled

Table 1. Selected soil profile properties at the Compact and Cabacungan sites (after Subagjo et al., 1993).

Depth	Horizon	CEC†	Al saturation	pH(1:1) H_2O	Sand	Clay	Bulk density	Saturated hydraulic conductivity
cm		cmol$_c$ kg^{-1}	%		%	%	Mg M^{-3}	m s^{-1}
Compact								
0–14	A	7.17	33	4.5	3	75	1.09	3.1×10^{-5}
14–31	AB	6.66	70	4.7	2	71	1.05	2.2×10^{-5}
31–59	Bo1	6.37	89	4.8	2	72	1.00	3.5×10^{-6}
59–85	Bo2	6.35	94	4.7	2	74	0.95	–
85–111	Bo3	6.49	93	4.6	2	70	0.90	–
111–143	Bo4	6.42	96	4.7	2	69	0.96	–
143–174	Bo5	6.66	93	4.8	3	60	0.95	–
174–203	Bo6	6.59	83	4.8	4	60	1.04	–
Cabacungan								
0–6	A	8.19	22	4.8	2	82	0.91	–
6–25	AB	5.68	63	4.5	2	88	1.04	–
25–54	Bo1	5.22	62	4.6	1	89	1.09	–
54–83	Bo2	5.42	67	4.9	1	88	1.08	–
83–116	Bo3	5.84	72	5.0	1	50	1.03	–
116–151	Bo4	5.96	90	5.3	1	84	1.03	–
151–184	Bo5	6.58	86	5.3	2	79	1.10	–
184–216	Bo6	6.87	87	5.2	2	76	1.07	–

† Cation exchange capacity calculated as the sum of Ca, K, Mg, Na, and Al extracted with 1 *M* NH_4OAc at pH 7

one bottom moldboard plow and harrowed once with an oxen-pulled wooden harrow before planting each crop. Rice (cv. IR-30716-B-1-B-1-1-2) was drill-seeded in 30-cm rows. Corn (cv. Pioneer 3274) was planted in rows 60 cm apart. Each main plot was split. One half of the plot was used for Exp. 1 and the other half for Exp. 2.

Experiment 1

Corn was planted on 10 Oct. 1991 and the following rice crop was planted 1 June 1992 at Compact. At Cabacungan, corn was planted 29 Oct. 1991, followed by rice on 2 June 1992. Potassium bromide was broadcast at a rate of 200 kg Br^- ha^{-1} during corn planting. In hedgerow plots, only the four alley areas received KBr, whereas it was applied to the full length of the control (Fig. 1, Table 2).

Soil Samples

Soil samples for Br^- concentration analysis were taken three times. Cumulative rainfall and the soil sampling dates are given in Table 2. Samples from three replicate transects were collected. Soil samples were taken at 15-cm depth increments to a depth of 105 cm using a 6-cm-diameter hand auger. Samples in the control were taken at seven equally spaced positions, 3 m apart (Fig. 1A). Samples in hedgerow plots were taken from Positions 1, 3, and 5 in Alleys 1, 2, and 4 and from Positions 1 through 5 in Alley 3 (Fig. 1B). Samples were also taken at the center of hedgerow positions H2, H3, and H4 which subsequently were called Position 0.

The soil samples were oven dried at 105°C for 24 h, and ground to pass a 2-mm sieve. Fifty milliliters of distilled water and 1 mL of 5 *M* $NaNO_3$ (total ionic strength adjustment buffer solution) were added to a 10-g subsample. The suspension was shaken 30 min and the unfiltered suspension analyzed with an Orion model 94-35A Br^- specific ion electrode and Orion reference electrode model 90-01 (Orion Research Inc., Cambridge, MA). The detection limit of the Br^- selective electrode was 0.5 mg L^{-1}. Based on this limit, along with several analyses of untreated soils, the background Br^- concentration in the soil was taken as 1 mg kg^{-1}.

Using the bulk density values in Table 1, we converted the mass of Br^- in each sample to kg Br^- ha^{-1}. The depth to the center of Br^- mass was determined by graphical integration as the centroid of the plot of the mass of Br^- vs. soil depth curve.

Suction Lysimeters

Suction lysimeters were installed at the 30-, 60-, and 90-cm depths only at Compact. They were constructed using 5.4-

Table 2. Chronological sequence of activities for Experiments 1 and 2 related to KBr application, Br^- analysis in soil samples, and the depth of the Br^- center of mass.

	Compact				Cabacungan			
			Depth to Br^- center of mass				Depth of Br^- center of mass	
Activity	Date	Cumulative rainfall	Hedgerow	Control	Date†	Cumulative rainfall	Hedgerow	Control
			cm	cm		mm	cm	cm
Experiment 1								
1991 KBr	10 Oct 91	0	–	–	29 Oct 91 (0)	0	–	–
First Br^- sampling	25 Oct 91	257	29	26	23 Dec 91	43	17	19
Corn harvest	13 Jan 92	–	–	–	14 Jan 92	–	–	–
Rice planting	1 June 92	–	–	–	2 June 92	–	–	–
Second Br^- sampling	9 June 92	510	37	37	15 June 92	204	20	19
Rice harvest	28 Sep 92	–	–	–	5 Oct 92	–	–	–
Third Br^- sampling	1 Oct 92	1626	51	49	12 Oct 92	1075	38	35
Experiment 2								
1992 KBr	22 June 92	0	–	–	23 June 92 (0)	0	–	–
Soil sampling	24 Aug 92	530	31	27	27 Aug 92	541	27	21

† Numbers in parentheses are the numbers of days since KBr application.

cm-long by 2.2-cm-diameter cups (Model 655X1-B1M1, Soil Moisture Equipment Corp., Santa Barbara, CA) epoxied to a section of 12.7-mm (½-inch) polyvinyl chloride (PVC) pipe. A rod the diameter of the suction sampler was driven vertically into the soil to the desired depth and manually withdrawn. After the suction lysimeter was inserted, the upper 5 cm of soil at the soil–PVC tubing interface was compacted. Flexible nylon tubing was attached to the PVC pipe and was connected to 350-mL collection bottles. Each bottle was connected to a manifold for applying suction as described by Rhoades and Oster (1986). Suction lysimeters were installed at Positions 1, 3, 5, and 7 in the control (Fig. 1A), and at Positions 0 (H3 and H4), 1, 2, 3, 4, and 5 of Alley 3 in the hedgerow plots (Fig. 1B). Cups were installed only at the 30- and 60-cm depths at the H3 and H4 positions.

To extract soil solution, a suction equivalent to −40 to −70 kPa was applied to the porous cups with a hand-operated vacuum pump. Suction was applied only when the soil water pressure at the depth of interest was greater than −15 kPa, as measured by tensiometers installed at the 15-, 30-, and 45-cm depths. Data were treated as missing if the volume of soil solution collected was <25 mL. Distilled water was added to solution sample volumes between 25 and 50 mL to bring the volumes to 50 mL. A 50-mL sample of the solution was analyzed with a Br^- specific ion electrode after adding 1 mL of 5 *M* $NaNO_3$ ionic strength adjuster.

Surface Water Runoff and Soil Sediment

A metal barrier of galvanized sheet metal was constructed around a 5-m-wide soil strip running the full length of the plots for both treatments. The lower border of the 5-m-wide strip plot was instrumented with a gutter, tipping bucket, mechanical counter, fluid splitter, and 24-L-capacity runoff collector. During some rainfall events, runoff water and suspended solids flowed into the gutter. Runoff water and any suspended solids not trapped in the gutter flowed into a tipping bucket and the number of tips was recorded. About 3% of the runoff water flowed into the splitter and then to the runoff sampler. The volume of runoff, calculated from the tipping bucket data, and the oven-dry mass of suspended material were determined for each rainfall event. Bromide concentration in the sediment and runoff-water samples was measured using the Br^- electrode.

Experiment 2

On 22 and 23 June 1992 (3 wk after planting rice at Compact and Cabacungan, respectively), 200 kg Br^- ha^{-1} was broadcast in selected regions in the half of the plot that did not receive a KBr application in Exp. 1. For the control, KBr was applied to two 2.1-m-wide strips (equivalent to the distance occupied by several rows of rice) running 5 m across the contour (Fig. 1A). The KBr was applied only to Alley 3 of the hedgerow plots (Fig. 1B).

Soil Samples

Soil samples in the control were taken from rice Rows 1, 3, 5, 6, 9, 11, and 13 (Fig. 1A). Rows 1, 3, 5, and 7 were within the KBr application area, and Rows 9, 11, and 13 were outside and down slope from the KBr application area. Soil samples in the hedgerow plots were taken from seven equidistant positions on Alley 3 (Fig. 1B). Samples were also taken at Position H4, at 20 and 60 cm down slope from the edge of the third alley (Position 8 and 9), and at the first rice row of the fourth alley (Position 10).

Experiments 1 and 2 included two main plots (hedgerow and control) replicated two times at each of two locations (Compact and Cabacungan). Analysis of variance to assess differences in Br^- concentration at different sampling positions was performed. Other variables such as crop yield, Br^- concentration in biomass, and runoff were evaluated by analysis of variance for location and main plot effects.

RESULTS AND DISCUSSION

Vertical Bromide Transport Based on Soil Samples

The depth of the center of Br^- mass in the soil profile for the hedgerow and control treatments for three dates for Exp. 1 and one date for Exp. 2 are presented in Table 2. In addition, the mean Br^- mass vs. soil depth in Oct. 1992 for both treatments at both sites is shown in Table 3. At a given location, the depth to Br^- center of mass was similar for both treatments. The tendency was for the Br^- center of mass at Compact to be deeper than at Cabacungan. This difference was expected due to higher rainfall (Table 2) and probably to a lower evaporation rate at Compact.

In general, the center of Br^- mass at both sites was near or above the 50-cm depth through the third sampling date, which corresponded to 1626 and 1075 mm of cumulative rainfall after KBr application at Compact and Cabacungan, respectively. These depths to the Br^- center of mass are similar to those for a Piedmont soil (clayey, kaolinitic, thermic Typic Hapludult) in the USA receiving a comparable amount of rainfall (Afyuni et al., 1994).

The depth to which the center of Br^- mass was found may indicate a permanent loss to root uptake of anions in soils with high subsoil acidity. Root systems of Al-sensitive annual crops do not extend below depths of 20 to 30 cm (Ritchey and Carter, 1993; Menzies et al., 1994). Few corn or rice roots extended below the 30-cm depth at either site in this study. Inspection of Table 2 shows that after the soil had received about 200 and 500 mm of rainfall, 50% of the Br^- had leached below the 20- and 30-cm depths, respectively. It is common for this quantity of rainfall to occur early in the wet season in some tropical regions. If planting is delayed beyond the first rains, or if soluble nutrients are applied in higher quantities than needed by the crop, the Br^- movement data suggest it is likely that much of the NO_3 mineralized or applied at the beginning of the season would leach below the root zone in a short time.

Table 3. Mean Br^- mass in October 1992 vs. soil depth for the control and hedgerow treatments at Compact and Cabacungan.

	Compact		Cabacungan	
Depth	Control	Hedgerow	Control	Hedgerow
cm	kg ha^{-1}			
0–15	12.5	13.0	21.1	21.7
15–30	21.1	18.5	41.0	36.6
30–45	37.5	26.8	39.0	31.8
45–60	34.0	30.1	21.0	21.8
60–75	26.2	32.3	11.6	10.5
75–90	17.3	15.6	8.7	6.0
90–105	9.3	10.0	6.7	4.4

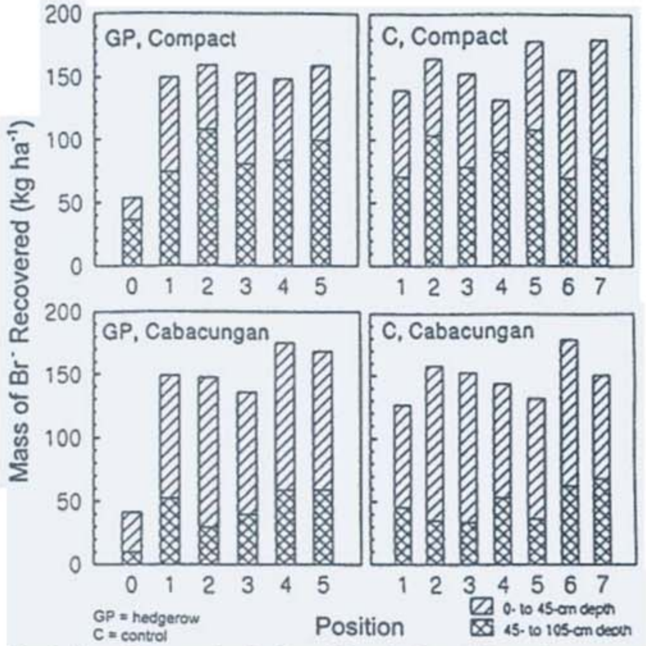

Fig. 2. Bromide mass in the 0- to 45- and 45- to 105-cm depths as a function of sampling position for the third sampling in October 1992 (Exp. 1). For the hedgerow treatment, Positions 1 to 5 are equally spaced positions in the alley of mean width of 4.5 m. Position 0 is the hedgerow position. See Fig. 1 for exact location of each position.

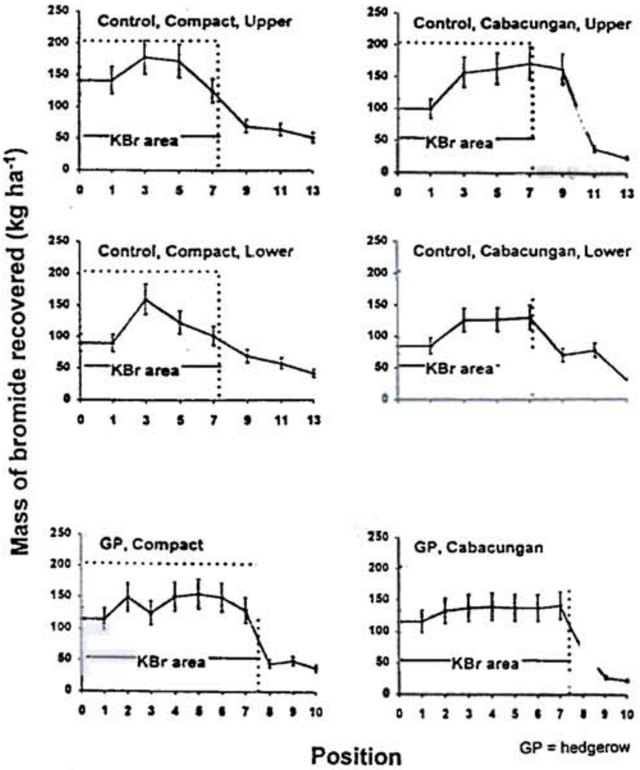

Fig. 3. Bromide mass (Exp. 2) in the 0- to 105-cm depth as a function of position for the hedgerow and the upper and lower slope positions of the control. Positions 9, 11, and 13 for the control and Positions 8, 9, and 10 for the hedgerow plots are down slope from the KBr application area. See Fig. 1 for exact location of each position. The area of the rectangles formed by the dotted line and the axes represents 100% of the applied Br.

Lateral Bromide Transport Based on Soil Samples

Lateral transport of KBr in the control in Exp. 1, due either to runoff or subsurface flow, was evaluated by regressing Br^- concentration vs. distance down slope of the equally spaced positions. Analysis of variance (not shown) for the position effect showed no evidence of lateral movement ($P = 0.29$ and 0.76 for Compact and Cabacungan, respectively).

For the hedgerow plots in Exp. 1, down slope movement of Br^- was detected at Position 0 (40 cm down slope from the lower boundary of the area where KBr was applied, see Fig. 1B); 54 and 41 kg Br^- ha^{-1} were detected in the 0- to 105-cm depth for the Compact and Cabacungan sites, respectively (Fig. 2). These Br^- levels are significantly higher than the background Br^- level ($P = 0.01$, *t*-test). This result indicates that some of the Br^- applied on the alley moved down slope to the hedgerow position.

The use of strip applications of Br^- in Exp. 2 illustrates more clearly the lateral Br^- movement for both treatments (Fig. 3). Positions 9, 11, and 13 for the control were 45, 105, and 135 cm, respectively, down slope from the lower boundary of the KBr application area. Positions 8, 9, and 10 for the hedgerow plots were 20, 60, and 100 cm down slope, respectively. Lateral Br^- transport was not detected in the control in Exp. 1 because KBr was applied along the entire hill slope rather than at distinct areas separated by areas where no KBr was applied. Less lateral Br^- movement for the hedgerow plots occurred because the hedgerow plots had a gentler slope and less runoff than the control (Table 4). This result is consistent with the Br^- center of mass data in Table 2. The hedgerows reduced the amount of solute transported laterally through runoff.

The areas bounded by the axes and the dotted line in Fig. 3 represents 100% of the applied Br^- and its distribution on the soil surface after Br^- application in Exp. 2. Integration of the area below the measured Br^- curves gives an estimate of the percentage of Br^- recovery. It ranges from nearly 100% for "Control, Compact, Upper" to ≈80% for "Hedgerow, Compact". The percentage of Br^- recovery probably would have been even greater if soil samples had been collected and analyzed for Br^- from a few more positions down slope.

Soil Solution Samples

Soil solution samples were taken only for Exp. 1 at Compact. Soil solution samples were collected in 1991

Table 4. Rainfall, number of rainy days, and runoff for the control and hedgerow treatments in Compact and Cabacungan.†

Site	Total rainfall	Days with rainfall	Treatment	Slope	Total runoff
	m			%	mm
Compact	1520	121	Control	23	143
			Hedgerow	21	111
Cabacungan	1249	76	Control	30	66
			Hedgerow	27	53

† Measurement period is 1 Dec. 1991 through 30 Nov. 1992.

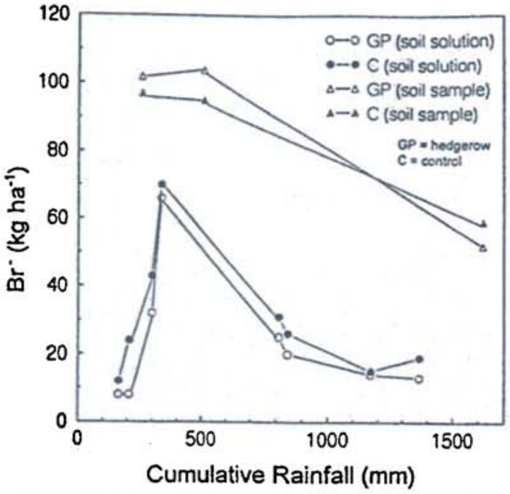

Fig. 4. Bromide mass in the soil and water samples in the 15- to 45-cm depth for the two treatments at the Compact site as a function of cumulative rainfall.

on 17, 18, 25, and 30 October. Cumulative rainfall for these dates after KBr application was 163, 207, 298, and 335 mm, respectively. Samples in 1992 were collected on 22 and 25 June, 27 July, and 22 August, which correspond with cumulative rainfall amounts of 810, 845, 1170, and 1367 mm, respectively.

The ability to collect soil solution samples was dictated by the hydraulic properties of the soil. Because too little soil solution was collected when soil water pressure was less than −50 kPa, no samples were collected between November 1991 and June 1992. Hence, soil solution samples for Br^- analysis were collected shortly after heavy rains. Based on four sampling dates each year, the peak Br^- concentration at the 30-cm depth was detected at the fourth sampling (Fig. 4). Bromide concentration for the fifth sample decreased dramatically. Bromide was not detected at the 60- or 90-cm depths at the time the dry period began.

Bromide pools (kg ha^{-1}) were estimated from soil solution Br^- concentrations based on the measured Br^- concentration, the soil water content at field capacity, and the measured bulk density.

The Br^- concentration calculated from the soil solution samples was lower than that for the solid phase (Fig. 4). Bromide measured in the soil samples included Br^- in both the immobile and mobile phases, but complete recovery of Br^- from these samples may not have been obtained because the samples were oven dried. Bromide measured in the soil solution extracted by the suction lysimeter came only from the mobile water fraction (Barbee and Brown, 1986). Drying promotes the movement of Br^- into small pores within soil aggregates. This intra-aggregate Br^- is often not in equilibrium with the mobile phase of percolating water soon after rainfall.

Table 5. Bromide concentration and amount removed in rice grain and straw harvested 5 Oct. 1992 in Compact. Potassium bromide was applied 11 mo earlier.

Bromide	Mean	Standard deviation
Concentration in plant components		
Grain (mg kg^{-1})	205	183
Straw (mg kg^{-1})	909	802
Biomass pool (kg ha^{-1})		
Grain (kg ha^{-1})	1010	55
Straw (kg ha^{-1})	3030	–
Amount removed		
Grain (kg ha^{-1})	0.2	0.2
Straw (kg ha^{-1})	3.0	3.0

Bromide Concentration in Runoff and Soil Sediment Samples

The Br^- concentration in the runoff water was usually <1 mg L^{-1} and for the soil sediment was <1 mg kg^{-1} soil. Potassium bromide applied to the soil surface dissolved in the first rain water. Infiltration of the KBr-laden water occurred before runoff began. Runoff occurred when the rainfall intensity and time period were sufficiently high to exceed the infiltration capacity. Thus, little Br^- remained at the soil surface when runoff began.

Bromide in Biomass

The mean Br^- concentration for rice grain at the Compact site in 1992 was 205 mg kg^{-1} and for straw was 909 mg kg^{-1} (Table 5). The concentration in the grain was 22% of that in the straw. Even though the Br^- concentration in the plants was high, when multiplied by the standing biomass yields (Table 5), the total amount removed by the rice crop was small, and its effect on the mass balance of Br^- was <2%.

SUMMARY

We evaluated the effect of hedgerows on the lateral and vertical transport of Br^- under high rainfall conditions at two Oxisol sites in the Philippines. Both vertical and lateral transport were observed. Vertical movement exceeded a depth of 105 cm, but the centers of Br^- mass were 51 and 49 cm deep for the hedgerow and control treatments, respectively, after 1626 mm of rain at the Compact site. Depth to the centers of Br^- mass at the Cabacungan site were 38 and 35 cm for the hedgerow and control treatments, respectively, after 1075 mm of rain. The observed differences in depth of Br^- transport between the control and hedgerow treatments were only 2 or 3 cm. From the agronomic viewpoint we believe any increase in solute leaching that might occur under the hedgerow treatment due to increased infiltration is probably more than offset by reductions in soil erosion. For example, soil loss from December 1991 to November 1992 at Compact was 63 and 20 Mg ha^{-1} for the control and hedgerow treatments, respectively.

This work allows us to predict that a mobile anion, such as NO_3, if not taken up soon by plant roots, is subject to leaching below the 30-cm-deep rooting zone in this environment. If NO_3 or other mobile solutes moves below the maximum rooting zone for all plants except highly acid-tolerant ones, it becomes inaccessible to the plant and represents a major loss, especially in developing tropical countries where an application of 30 or 40 kg N ha^{-1} represents a major economic investment.

Only a minor difference in surface water runoff and Br^- leaching depth between the conventional and contour-hedgerow systems was found. The amount of rainfall had a greater influence on runoff and Br^- leaching than tillage system for the 2 yr investigated.

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