Mobility of herbicides used for weed control in maize in lysimeter experiments

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ABSTRACT

The transport of chemicals from agricultural fields to groundwater bodies is mainly due to water infiltration through soil. Evaluation of the leaching phenomenon of chemicals is often difficult because of the spatial heterogeneity in the natural soil profile. This heterogeneity is frequently due to the preferential flow phenomenon, a term which describes several physical non-equilibrium flow processes. This phenomenon is critical for herbicide leaching and groundwater contamination since significant amounts ofherbicide may by-pass the biologically and chemically active topsoil.

Quantitative evaluation studies on the extent of preferential movement are scarce in the literature. In this investigation, transport of herbicides terbuthylazine, alachlor, metolachlor, linuron and monolinuron were studied in an experimental site equipped with lysimeters. The field site is located at Treviglio (BG) in a cereal crop tillage area, particularly vulnerable to groundwater contamination. Three different rainfall situations were simulated: in the first campaign a constant water seal was applied to reach the interstitial water saturation in the more superficial soil horizons; in the second one an intermittent rainfall simulation condition (30 mM/day of rain) was applied; in the third one natural precipitation was followed.

The temporal trend of herbicide concentrations in the leachates collected from the installed lysimeters allowed the description of the breakthrough curves at different depths (30-60-80-100-180 cm). The herbicide degradation was followed analyzing their main metabolites in leachates and in the groundwater samples. Results showed significant differences both between the three sampling campaigns and with each simulation. A constant water seal ensured infiltration rates and herbicide concentrations reached the maximum contamination levels because much of the soil adsorption capacity was by-passed. In all the campaigns, the results showed two main processes of herbicide transport: in the first pattern the herbicide flow was mainly due to water infiltration through macropores; in the second one, the transport was driven through the soil by matrix flow. Metolachlor and monolinuron were considered as the most mobile herbicides.

INTRODUCTION

The transport of chemicals from agricultural fields to the groundwater bodies is mainly due to water infiltration through soil. The evaluation of the leaching phenomenon of chemicals often causes difficulty because of the spatial heterogeneity in the natural soil profile. This heterogeneity is frequently due to a preferential flow phenomenon, a term which describes several physical non-equilibrium flow processes (Kamra, 1996).

In fine textured soils, large and discontinuous macropores consisting of shrinkage cracks, earthworm channels or root holes operate as preferential flow pathways and can cause rapid movement of chemicals through the unsaturated zone. Preferential flow is not confined solely to heavy clay soils, although they represent the worst case. The phenomenon is critical for herbicide leaching and groundwater contamination since significant amounts of herbicide may bypass the biologically and chemically active topsoil (Ghodrati & Jury, 1992; Harris *et al.*, 1994).

Quantitative evaluation studies on the extent of preferential movement are rare in the literature. In this investigation, transport of chloride and the herbicides terbuthylazine, alachlor, metolachlor, linuron and monolinuron were studied in an experimental site equipped with lysimeters. The experimental field is located at Treviglio (BG) in a maize crop tillage area, particularly vulnerable to groundwater contamination.

METHODS AND MATERIALS

The studied area is located in the Eastern Lombardy plane between Oglio and Adda rivers, at 120 m a.s.l. on an 80 m thickness Würm fluvial-glacial deposit consisting of gravel, sand and conglomerates. The experimental site pertains to the fundamental level of the Po plane. The field is located at the South-East of Treviglio (BG). The watertable is surficial and flows between 5-9 meters of depth in NE-SW direction. Soil is Typic Hapludalf (USDA Soil Taxonomy) and its texture is loamy from topsoil to 120 cm of depth, silty clay loamy from 120 to 150 cm and sandy loamy from 150 to 480 cm with 50% of gravel. The soil is carbonated, the organic carbon content decreases from the topsoil value of 2.7% to 0.02% in the deepest layer (more than 200 cm of depth). The maximum clay content is 26-27% and was measured in the 70-106 cm soil layer. The area is classified as highly vulnerable to groundwater pollution, having a good water drainage.

Suction cup (0.5 L) lysimeters in Teflon (called T) and in ceramic (called C) material (Timco, USA) were installed in the plot (20 m^2 area) to collect water samples from soil pores at 30, 60, 80, 100 and 180 cm of depth (Figure 1). Manometer type tensiometers were installed at the same depth of lysimeter cups, to monitor water saturation conditions of the different soil horizons.

The commercial Aresin (Hoechst Schering AgrEvo, Germany), Siolcid SC (SIAPA, Italy), Lasso Microtech (Monsanto, Italia) and Primagram TZ products (Ciba Geigy, Switzerland) containing monolinuron (41.5 %), linuron (37.6%), terbuthylazine (15%), alachlor (48%) and metolachlor (30%) respectively were used in the three experiments for the herbicide application during 1997-1999 years with one exception: in the second one only Lasso Microtech and Primagram TZ were applied.

The herbicide solution was applied by using a water reservoir with tube irrigation system, with the aim of obtaining a good uniformity in herbicide distribution on the experimental plot. Three experimental campaigns were undertaken in different hydraulic conditions, in order to assess the influence of soil humidity and permeability on herbicides transport pathways. In the first campaign a constant water seal was applied to reach the interstitial water saturation in the more superficial soil horizons, the added water amount varied from 600 L/day to 1,200 L/day; in the second one an intermittent rainfall simulation condition (30 mm/day of rain for 21 days) was applied and in the third one no artificial water was supplied, except for the 600 L solution used for herbicides application, the natural precipitation events were recorded by the installed rain gauge.

The herbicides analyses were conducted by concentrating water samples on 200 mg Lichrolut EN column (Merck, Germany) and analysing the extracts with HPLC Diode-Array 1050 (Hewlett Packard, USA) equipped with an automatic sampler and Lichrospher 5100 C18 column (25 cm x 4.6 mm) (Guzzella *et al.*, 1998 and 2000).

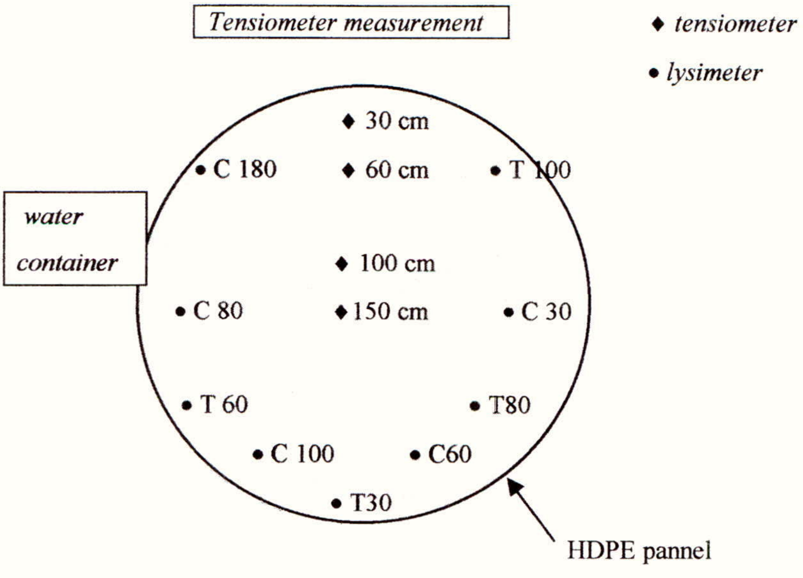

Figure 1. Schematic diagram of the experimental plot showing relative locations of instruments.

RESULTS AND DISCUSSION

Results showed significant differences both between the three sampling campaigns and with the different simulations (Figures 2, 3 and 4). The constant water seal and the natural precipitation experiments enhanced infiltration rates and herbicide concentrations reached the maximum values (Figures 2 and 4). The results showed two main process of herbicide transport: the herbicide flow was mainly due to water infiltration through macropores and therefore the herbicide concentrations were very high as in the C30 and T80 lysimeters in the first experiment and in the T30, C80 and T80 lysimeters in the third experiment; the transport was driven through the soil by matrix flow and the herbicide concentrations were lower in the C60 and C80 lysimeters in the second experiment and the T30, C60 and T100 lysimeters in the third experiment .

In both the experiments the herbicides were partially retained by soil as showed by the attenuated and delayed response of leachate concentrations. The phenomenon is particularly evident for terbuthylazine and linuron which were characterized by the highest value of K_{oc} and the lowest solubility with respect to monolinuron, metolachlor and alachlor.

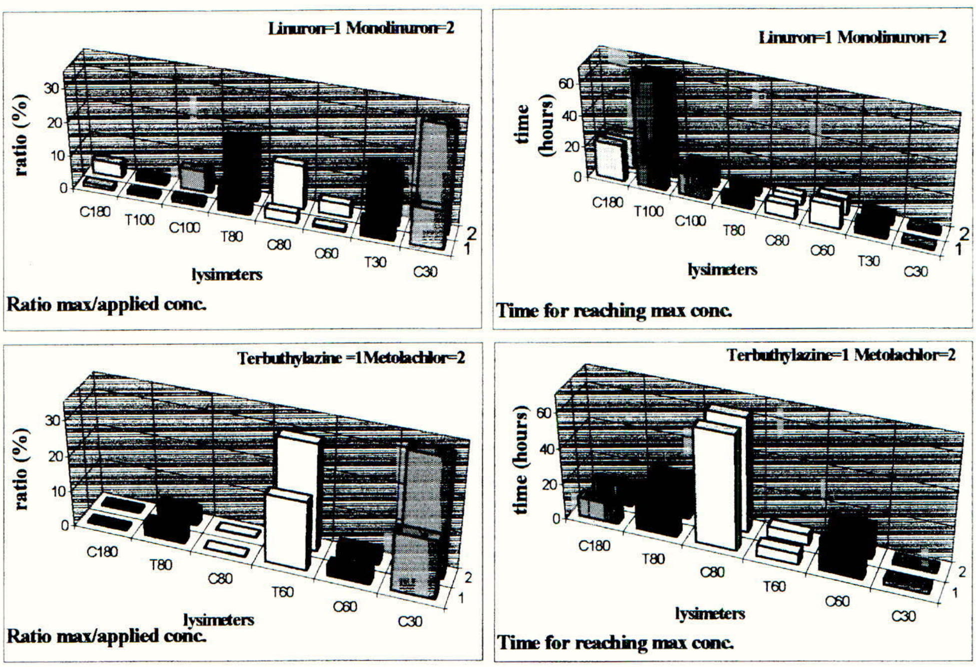

Figure 2. Time necessary for reaching the maximum concentration and ratio of maximum value to applied concentrations of herbicides in the first campaign.

In the second experiment (Figure 3) the herbicide maximum concentrations were generally lower that those measured in the other two studies, the time necessary for reaching the maximum concentrations were greater and therefore preferential water flow was less relevant.

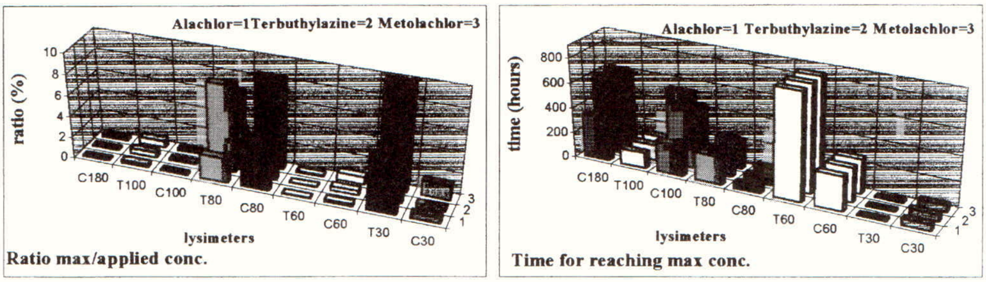

Figure 3. Time necessary for reaching the maximum concentration and ratio of maximum value to applied concentrations of herbicides in the second campaign.

The greatest herbicide concentrations were detected in the more surficial lysimeter (T30) and at 80 cm of depth where a consistent clay soil horizon was present. Considering the herbicides applied in the second experiment, metolachlor showed the highest leaching capacity in all the installed lysimeters. In fact, the highest metolachlor concentrations were measured in the leachates due to its chemo-dynamic properties that it indicate high water solubility. On the contrary, the pattern of alachlor did not follow its chemo-dynamic properties: alachlor mobility profile showed a great similarity to the terbuthylazine one. An explanation of this phenomenon may be found in the preparation of the commercial product; the alachlor in microencapsuled formulate will reduce the leaching from soil.

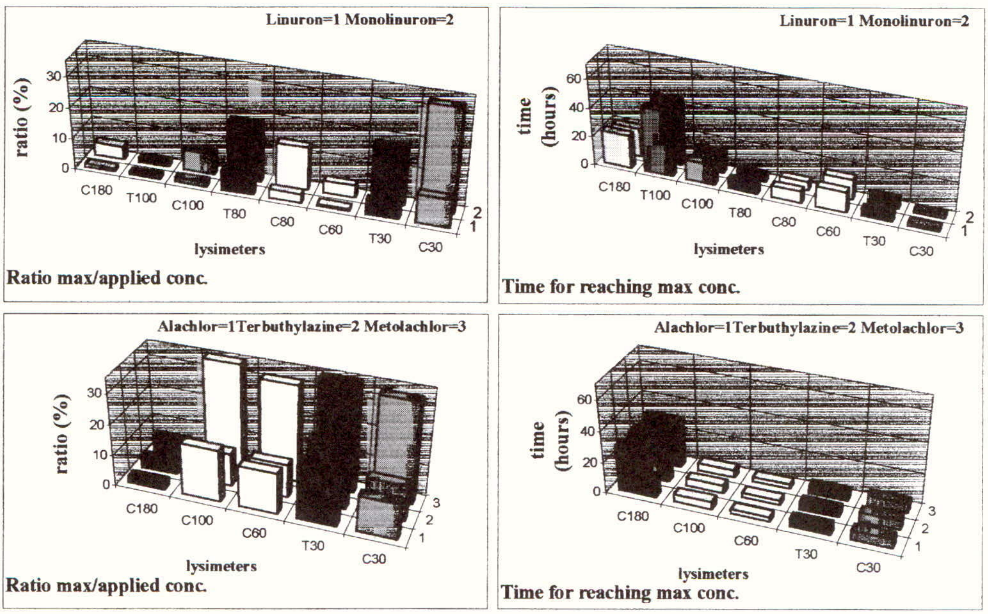

Figure 4. Time necessary for reaching the maximum concentration and ratio of maximum value to applied concentrations of herbicides in the third campaign.

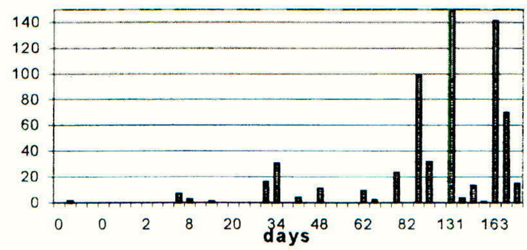

Figure 5. Natural rainfall (mm/day) in the third experiment

The natural precipitation trend of the third experiment is showed in Figure 5. The first consistent rainfalls were recorded after 24 days of dry time period and therefore the herbicide transport was initially driven only through the water applied during herbicide soil treatment. The herbicide application modalities (the 600 L solution used for the plot treatment) too seemed therefore to influence the herbicide leaching from top soil horizon.

CONCLUSIONS

The constant hydraulic water head applied in the first experiment and the natural precipitation simulation of the third experiment promoted rapid downward transport and leaching. Amongst the herbicides tested, metolachlor and monolinuron showed the greatest mobility from agricultural topsoil to groundwater.

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