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Herbicide Retention and Runoff Losses as Affected by Sugarcane Mulch Residue

H. Magdi Selim[1], Brian J. Naquin[2], Richard L. Bengtson[3], Hongxia Zhu[2], James L. Griffin[1] and Liuzong Zhou[2]

Introduction

The effect of surface crop residue on interception, subsequent wash-off and movement of herbicide in the soil profile is the primary focus associated with conservation measures in today's agriculture. Various forms of soil conservation are recommended in an effort to reduce soil losses and runoff of applied agricultural chemicals. Several conservation production systems are characterized by the presence of mulch residue left on the soil surface to protect it from water and soil erosion. In fact, several studies on best management practices have shown distinct advantages of minimum or no-till systems (Dao, 1991; 1995, Banks and Robinson, 1982).

Since 1995, the sugarcane industry in Louisiana has gradually adopted a new harvesting system that involves the use of a combine harvester that cuts the cane stalks into billets, which are directly loaded into wagons for transport to the mill. Extractor fans in the combine harvester separate leaf-material from billets, and the plant residue is deposited on the soil surface. It has been reported that mulch produced from the leaf material and plant residue can promote diseases and lower sugar yields in subsequent ratoon crops (Richard, 1999). Recently, Richard and Johnson (2003) reported reduction in sugar yields as much as 14 percent when the mulch residue was not removed. Removal of the mulch from the sugarcane rows by burning before harvest or burning the residue after harvest are measures to reduce the impact of the residue on crop emergence in the spring and, ultimately, sugar yield.

We are not aware of published research that correlates the effectiveness of plant residue remaining on the soil surface, following sugarcane harvest, on the retention of applied herbicides, leaching losses in the runoff and their downward movement in soil profile. We know of no research that addresses the adsorption-desorption kinetics of herbicides or their fate during the growing season as influenced by the sugarcane residue remaining on the soil surface after harvest. Such information is a prerequisite in quantifying the role of the sugarcane residue in minimizing the leaching losses of applied agricultural chemicals.

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The purpose of this study was to evaluate the effectiveness of sugarcane residue (mulch cover) in reducing non-point source contamination of applied chemicals from sugarcane fields. For this purpose, two main treatments were investigated: (1) a no-till treatment where mulch following harvest of sugarcane by a combine harvester was left on the soil surface and (2) a burn treatment where sugarcane leaves were removed by burning before harvest with a combine harvester. The effect of mulch residue on herbicide retention was quantified following spring and layby applications. The amounts of extractable atrazine, metribuzin and pendimethalin from the mulch residue and the surface soil layer were quantified during the 1999 and 2000 growing seasons. A second objective was to quantify the retention of atrazine and metribuzin by the sugarcane mulch and to characterize their kinetic behavior in soil. To achieve this objective, laboratory studies of the retention kinetics of metribuzin and atrazine by the mulch residue as well as the soil were carried out. Changes in herbicide retention characteristics as a function of the age of the mulch, that is, as the residue decays in the field, were also investigated. In addition, mechanisms for herbicide retention by the mulch residue as a function of lignin content on a mass basis of the residue were quantified.

METHODS

FIELD INVESTIGATION

In the spring of 1999, several treatments were implemented on LCP85-384 grown on a Commerce silt loam soil (fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquept) located south of Baton Rouge, La. The field, which is on a private farm, was identified for the purpose of evaluating best management practices, including mulch management, where the effect of mulch on herbicide movement in surface water and weed control was quantified. The sugarcane crop was harvested in December 1998 using a combine harvester. The mulch residue was not removed or burned. Instead, the mulch was maintained on the soil surface for weed control during the winter.

In our study, chemicals were applied according to Louisiana Cooperative Extension Service (LCES) recommendations for weed control for sugarcane (Anonymous 2002), which usually requires two herbicide applications, one in the spring as sugarcane is emerging from the winter dormant period and another before the crop canopy closes. Sugarcane producers in Louisiana refer to the latter application as the “layby” treatment; it usually follows the last cultivation in May or June. We made a spring herbicide application March 26, 1999, when a mixture of atrazine and pendimethalin was applied at the rate of 1.12 and 1.1 kg of active ingredient per hectare, respectively. In another treatment, metribuzin (rather than atrazine) was applied as a spring herbicide (at a rate of 1.1 kg ha^{-1}) on the same day to test the environmental impact of an alternative herbicide. Our soil management treatments consisted of "no-till," where the mulch residue was not removed, and "no-mulch," where the mulch was maintained in-furrow only. That is, the mulch was raked off the row tops and incorporated within the wheel furrows during the cultivation or off-barring operation. Herbicide application at layby was made June 7, 1999, with a mixture of atrazine, 2,4-D and pendimethalin applied (broadcast) at the rate of 2.5, 1.1 and 2.2 kg ha^{-1}, respectively. The amounts applied as reported here were based on the active ingredient (a.i.) for each herbicide. All treatments received the layby herbicide application.

For all treatments investigated, two plots (or replications) were implemented. Each plot consisted of three center rows 25 meters long and outlined with two border rows. In Louisiana, sugarcane is commonly planted in rows 1.8 meters (6 feet) apart. To monitor the rate of disappearance of applied herbicides, composite samples of mulch residue and surface soil (25-mm depth) were taken along the center row for each plot during the entire growing season. Runoff water samples were collected routinely following rainfall that caused sufficient runoff to occur. In-row low impact flow event (LIFE) samplers designed by USDA-ARS (Tifton, Ga.) were installed in-row for runoff sample collection (Sheridan et al., 1996). The LIFE sampler was designed to meet the need for an unattended surface flow for riparian-buffer study areas and provided an excellent way to collect surface water samples.

In late September 1999, because of high wind and excessive rainfall, sugarcane stalks were extensively lodged, and continued sampling was not possible. Burning of cane leaves from the entire field was necessary before harvest. As a result, our mulch treatments were destroyed, and mulch residue was no longer available for subsequent growing seasons. Therefore, an alternative nearby site (5 miles south of the existing plots) was selected at the LSU AgCenter St. Gabriel Research Station because a combine harvester was used. This site was also on a Commerce soil and consisted of six 0.22-ha plots (two replications and three treatments). Each plot consisted of nine rows 150 meters long with 1.8-meter spacing, with levees surrounding each treatment. At the lowest corner of each plot, a sump made of corrugated iron was dug (1.50 meters in diameter, 1.80 meters deep) to collect runoff water. Sump pumps were installed in each sump, equipped with flow meters and ISCO (Lincoln, Neb.) samplers. Sugarcane (var. CP70-321) was planted in September 1996, and all sugarcane plots were combine-harvested December 7, 1999. Four plots were harvested, and the mulch was not removed. The other two plots were burned with the sugarcane standing before harvest. Two plots received metribuzin at a rate of (a.i.) 1.0 kg ha^{-1} where all other plots received atrazine at a rate of (a.i) 1.1 kg ha^{-1} as spring herbicide application (April 7, 2000). Layby application consisting of broadcast atrazine at (a.i) 2.2 kg ha^{-1} was made June 5 for all plots. Composite samples of mulch residue and surface soil (25-mm depth) also were collected along the center row for each plot in a similar manner as described above.

HERBICIDE EXTRACTION

All mulch residue, soil and runoff water samples were stored at 4 degrees C until laboratory analysis for pesticide concentrations. In the laboratory, extraction of pesticides from soil and mulch residue was as follows. Extractions from field (moist) soil (15 g soil and 30 mL solution) were performed by using 0.01 *M* NaCl methanol and water solution (4:1 v/v), shaking for 24 hours, centrifuging, decanting and removing water with anhydrous sodium sulfate. The extracts were subsequently evaporated and transferred in hexane to 2.0-mL vials (Granovsky et al., 1996). Extractions from mulch-residue samples were similar to those from soil samples except that 1 g of mulch residue with 30 mL of 0.01 *M* NaCl methanol and water solutions was used. Runoff water samples (250 mL) were extracted using dichloromethane in a separatory funnel. The remaining steps were similar to those for soil extractions.

Extracts from mulch residue, soil samples and runoff water were analyzed using gas chromatography. The instrument used was a Hewlett-Packard (Palo Alto, CA) 5890 Series II gas chromatograph with a split/splitless inlet, temperature programmed oven and nitrogen–phosphorus and electron capture detectors. The column used was a Hewlett-Packard PAS-1701 capillary column (25 m in length, 0.32-mm i.d., 0.25-µm film thickness). Operating parameters were: inlet temperature at 250 degrees C; column temperature at 80 degrees C for 1 minute, then 30 degrees C per minute to 190 degrees C, then 3.6 degrees C per minute to 260 degrees C; detector temperature at 300 degrees C. Flow of ultra-high purity (UHP) helium through the column was 2 mL min^{-1} and makeup gas (5 percent methane, balance argon) flow rate was 36 mL min^{-1}. Concentration in solution was back-calculated to a standard solution with known herbicide concentrations. Limits of detection were approximately 0.40 mg L^{-1} for atrazine, 0.02 mg L^{-1} for metribuzin and 0.01 mg L^{-1} for pendimethalin. The retention times for atrazine, metribuzin and pendimethalin were 6.139 ± 0.015, 7.014 ± 0.016 and 7.807 ± 0.027 minutes, respectively.

DECAY OF MULCH

To assess the effect of the presence of a surface mulch residue on the retention of herbicides, the rate of decay of the sugarcane residue was quantified. For the 1999-2000 growing season, the decay of mulch residue for CP70-321 was monitored after harvest. The 1999-2000 growing season was the third stubble (CP70-321), and the plots were fallow the following season. Since it was decided to monitor the rate of mulch decay in three successive growing seasons (plant cane, and first and second stubbles) during 2000 to 2003, a nearby field at the St. Gabriel Research Station was selected. The sugarcane variety was LCP85-384, which is widely grown in Louisiana and was grown on Sharkey clay soil (very-fine, montmorillonitic nonacid, thermic, vertic Haplaquept), on which sugarcane is widely grown in south Louisiana.

The sugarcane residue was collected randomly within each plot, by measuring multiple 1 m^2 areas and collecting all surface mulch within each area. The residue was dried at 55 degrees C for 24 hours and weighed. A portion of dry residue was cut into 1-cm sections for herbicide retention studies in the laboratory. Another portion of the residue was ground to a powder and mixed for homogeneity as required for fiber analysis.

Fiber Analysis

The residue from the 2001-2002 sampling dates was analyzed for neutral detergent fiber (NDF) and acid detergent fiber (ADF) at the Southeast Research Station. NDF is the fraction of the plant that contains hemicellulose, cellulose and lignin. ADF is the sub-fraction of NDF consisting of mainly lignin and cellulose. The NDF and ADF values are used as indicators of lignin, cellulose and hemicellulose content of sugarcane residue on a mass basis. Neutral detergent fiber and acid detergent fiber were analyzed using the methods described by Goering and Van Soest (1970), which were modified by excluding decalin. Additionally, 2.0 mL of a 2 percent (w/v) α-amylase solution and 0.5 g sodium sulfite was added at the beginning of the NDF procedure (Van Soest and Robertson, 1980).

Soil Retention of Herbicides

A sample was taken from the Ap horizon of the Commerce soil to quantify herbicide retention by the soil. The soil properties were: organic matter content of 1.31 percent, pH of 5.93, cation exchange capacity of 16.5 meq/100g soil, sand = 30 percent, silt = 54 percent and clay = 16 percent. Batch experiments were carried out in the laboratory to determine the adsorption for atrazine and metribuzin by the soil. Radioactive metribuzin (^{14}C-UL ring labeled) was used as a tracer to monitor the extent of retention. The labeled material was diluted to 0.43 X 10^5 Bq L^{-1} and used as the input solution. Six initial metribuzin concentrations C_o's (1.39, 5.40, 10.29, 30.29, 80.23 and 100.2 mg L^{-1}) were prepared in 0.005 M $CaCl_2$ solution and spiked with ^{14}C-ring labeled metribuzin. In a similar fashion, six initial atrazine concentrations C_o's (1.80, 2.5, 5.4, 10.3, 20.2, and 30.0 mg L^{-1}) were prepared in 0.005 M $CaCl_2$ solution and spiked with ^{14}C-ring labeled atrazine. Adsorption was initiated by mixing, in triplicates, 10 g of air dry soil with 30 mL of the various atrazine or metribuzin solutions in a 40-mL Teflon centrifuge tube. The mixtures were shaken 15 minutes every hour and centrifuged at 500 x g for 10 minutes after each specific reaction time before sampling. A 0.5-mL aliquot was sampled from the supernatant at reaction times of 2, 6, 12, 24, 48, 96, 192 and 384 hours (16 days). The mixtures were subsequently returned to the shaker after each sampling. The collected samples were analyzed using liquid scintillation counting (LSC). The amount of pesticide retained by the soil at each reaction time was calculated from the difference in concentrations of the supernatant and that of the initial solution.

Residue Retention of Herbicides

To assess herbicide retention of the sugarcane mulch residue remaining on the soil surface over time after harvest, adsorption by the mulch residue was carried out in the laboratory using the batch equilibration technique described. The mulch samples used were taken at different times following sugarcane harvest of the 2000-2001 and 2001-2002 growing seasons. Adsorption was initiated by mixing 1g of dried and cut sugarcane mulch residue with 30 mL of the various herbicide concentration solutions in a 40-mL Teflon centrifuge tube. Six ^{14}C-atrazine/metribuzin spike samples having initial concentrations ranging from 2.98 to 29.8 mg L^{-1} for atrazine and from 2 to 98 mg L^{-1} for metribuzin in 0.005 M $CaCl_2$ were used. The mixtures were shaken for each specific reaction time and subsequently centrifuged in a similar manner to the batch method used for the Commerce soil. A 0.5-mL aliquot was sampled from the supernatant at reaction times of 1, 2, 7, 14, and 21 days. Similarly, the collected samples were analyzed using liquid scintillation (LSC).

Results and Discussion

Field Decay of Mulch Residue

In Figure 1, we present the amount of mulch residue (on dry matter basis) versus time following sugarcane harvest. This mulch data represent 4 different growing seasons form 1999 through 2003. For CP70-321, the amount of mulch on the soil surface decreased from 3.58±0.95 tons/acre on December 17, 1999, to 0.740±0.143 on August 18, 2000. For LCP85-384, the mulch decreased from 1.70±0.308 to 0.64±0.239 tons/acre within a four-month period for the 2000 season. In 2001, the amount of mulch decreased from 2.58±0.642 to 0.870±0.247 tons/acre in five months. Such differences may be attributed to differences in the variety and yields, soil type, combine setting during harvest and other harvest conditions.

A rate of residue decay was derived based on simple linear regression where the (negative) slope represents the mass of mulch degradation per acre over time. For CP70-321 grown on Commerce silt loam, the estimated rate of decay was 20±3.2 lbs/acre/day. Whereas for variety LCP85-384 grown on Sharkey clay, the rates of degradations were of 18.2±3.8, 14.9±3.8, 11.7±7.8 lb/acre/day for the three growing seasons (plant cane, first and second stubble), respectively. Regression analysis suggests a linear model provided a good description of the decay of the mulch for all growing seasons. Moreover, the respective slopes of the regression lines were not significantly different. We also carried out nonlinear regression to estimate the rate of decay based on first-order decay. We found out that the half lives for the mulch decay ranged from 126 to 171 days.

Retention of Herbicides by Soil

Selected adsorption isotherms for metribuzin and atrazine by the Commerce soil are shown in Figs. 2 and 3, respectively. Here, we present adsorption isotherms for a wide range of retention times (2 hours to 16 days) to illustrate the extent of time-dependent retention for metribuzin and atrazine. Such relationships are used to quantify the affinity of herbicide sorption by an individual soil and are often described by either a Freundlich or linear equilibrium model. We described adsorption results based on the Freundlich approach (Selim 2003):

$$S = K_f C^N$$

where S is the amount sorbed (mg kg^{-1} soil), C is concentration in the liquid phase (mg L^{-1}), K_f is partitioning coefficient (mL g^{-1}) and N is a dimensionless parameter commonly less than unity. For cases where $N = 1$ we have the linear model (Selim 2003):

$$S = K_d C$$

where the parameter K_d (mL g^{-1}) is the solute distribution coefficient which is widely reported in the literature. Estimates for these parameters were obtained using nonlinear regression procedures (SAS Institute 1999). Best-fit K_d values for metribuzin ranged from 1.12 to 1.25 mL g^{-1} for 2 hours and 16 days of retention time, respectively (see Table 1). Respective values for the Freundlich coefficient K_f also exhibited limited kinetics with the nonlinear parameter N close to unity (0.892 to 0.975). Based on such small K_d values, metribuzin is best regarded as a weakly sorbed herbicide. Ma and Selim (1996) showed a lack of kinetic retention and an extremely small value (K_d=0.23 mL g^{-1}) for a Cecil (kaolinitic) soil and K_d of 0.74 mL g^{-1} for a Sharkey (montmorillonitic) clay soil. Savage (1976) reported K_d values for metribuzin in 16 soils from the lower alluvial flood plain of the Mississippi River. The reported K_d values are within a similar range, indicating low retention of metribuzin and thus high potential mobility in soils. It was also shown that metribuzin retention was well correlated with clay and organic matter contents (Savage, 1976; Harper, 1988). Johnson and Pepperman (1995) reported K_d values of 0.24-0.6 mL g^{-1} for four alluvial surface soils from central Louisiana with lower K_d values (0.09-0.47) for the subsurface soil layers. In a leaching experiment, Peter and Weber (1985) found that metribuzin was considerably more mobile in soil than atrazine. Other studies have shown the susceptibility of metribuzin to leaching in soils (Starr and Glotfelty, 1990).

For atrazine, adsorption by Commerce soil exhibited time-dependent retention behavior as indicated by the adsorption isotherms shown in Fig. 3. The K_d values for atrazine increased from 1.84 to 2.35 mL g^{-1} after 2 hours and 16 days of reaction time, respectively (see Table 1). The dependence K_d versus retention time clearly indicate higher retention as well as stronger kinetic retention for atrazine by this Commerce soil compared to metribuzin. Estimated values for K_f exhibited similar kinetic retention with that for K_d as indicated by the results shown in Table 1. Here K_f increased from 2.54 to 3.81 mL g^{-1} for 2 hours and 16 days of retention, respectively. The estimated nonlinear parameter N was significantly different from unity and ranged from 0.821 to 0.888. No consistent trend of N values versus time was observed. Ma et al. (1993) reported an N value of 0.877 for a Sharkey clay after 24 h adsorption; however, Ma et al. (1993) reported higher K_f values and kinetic behavior of atrazine for a Sharkey clay soil compared to our Commerce loam soil. Higher herbicide retention by Sharkey soil was expected because of its higher clay content than Commerce loam soil. Clay and organic matter fractions are responsible for most herbicide retention in soils (see Wauchope et al., 1992).

Sorption of Herbicides by Mulch Residue

A family of adsorption isotherms for atrazine and metribuzin by the mulch residue are shown in Fig. 4. Such relationships clearly illustrate herbicide affinity by the mulch residue. These adsorption isotherms were well described using the linear retention model, for all reaction times. Best-fit values for the distribution coefficient (K_d) for atrazine and metribuzin were obtained. For atrazine, the K_d values increased as the reaction time increased from 15.9 to 20.08 mL g^{-1} after 1 day and 21 days, respectively (see Table 2). This is indicative of the time-dependent behavior of atrazine adsorption by the mulch residue. For metribuzin, the K_d values increased from 11.2 to 14.72 mL g^{-1} after 1 day and 21 days, respectively. These increases illustrate the kinetic behavior of metribuzin as well as atrazine adsorption by the sugarcane mulch residue. Clearly, the adsorption of both atrazine and metribuzin by the mulch residue was initially rapid and exhibited slower retention after 1day of reaction time (Fig. 5). Therefore it is not recommended to rely on K_d values based on 24-hour adsorption as an estimate for the affinity of sorption of atrazine and metribuzin as commonly reported in the literature (see Wauchope et al., 1992).

The atrazine and metribuzin K_d values for the mulch residue discussed above were an order of magnitude higher than that found for the Commerce soil. This was expected since organic matter is the principal soil component affecting the adsorption of many herbicides in the soil environment (Boyd et al. 1990). Specifically, for Commerce soil K_d values for atrazine ranged from 2.095 to 2.352 mL g^{-1} after 1 day and 16 days of reaction time, respectively. The corresponding values for metribuzin were 1.18 to 1.52 mL g^{-1} after 1 day and 16 days of reaction time, respectively. As illustrated in Fig. 5, these K_d values for Commerce soil clearly exhibited limited kinetic behavior for both atrazine and metribuzin when compared to the mulch residue.

Effect of Mulch Decay

The family of isotherms shown in Fig. 4 was obtained from a mulch sample collected January 3, 2001 (26 days after harvest). To determine the effect of the decaying mulch residue on the behavior of atrazine and metribuzin retention, we carried out sorption experiments for mulch samples collected at different dates. Specifically, we obtained a set of isotherms for samples collected on January 3, February 7, March 23 and April 27, 2001 (see Table 3). A family of isotherms from mulch samples collected on April 27, 2001, some 140 days after harvest, is shown in Fig. 6. For both herbicides, the linear model clearly described the various isotherms for the different retention times. Such retention behavior as illustrated in Fig. 6 is consistent with the family of isotherms from the January 3, 2001, mulch samples of Fig. 4. Moreover, the affinity of metribuzin to the mulch residue was not different for samples for the two sampling dates. In fact, for the April 27, 2001 mulch sample, the K_d values for metribuzin were 12.45 and 14.67 mL g^{-1}, for 1 and 21 days, retention, respectively. Such values were not significantly different from the January 3 sample.

The retention capability of the mulch residue versus time of decay in the field following harvest is further depicted in Fig. 7. Here we quantified the atrazine and metribuzin retention to find out the changes of adsorption characteristics caused by weather-induced changes in the field following harvest. Specifically, the K_d values were measured using 24-hour batch adsorption and for individual mulch samples for two growing seasons (2000-2001 and 2001-2002). The retention was strikingly similar over the two growing seasons and did not change significantly with age of residue or the time of decay in the field over the two growing seasons (see Tables 3 and 4). This is significant and implies that only one K_d value is needed to quantify herbicide retention behavior and that such value is nearly time invariant for the mulch regardless of its age. Such a conclusion is valid for both herbicides. Our results are consistent with earlier data reported by Zhu (2002) on atrazine K_d for sugarcane mulch residue sampled April 16, 1999, from the plantation field site (see METHODS). The range of K_d reported was 16.4 and 23.4 for 1 day and 21 days of retention time, respectively.

The K_d results reported above are consistent with those of Dao (1991) for metribuzin adsorption on chopped wheat straw versus time following harvest. The only exception is that a lower retention value was reported from samples obtained immediately after harvest followed by little, if any, increase in retention over the succeeding five months.

Neutral Detergent Fiber during Decay

Simple regression analysis on K_d versus percent acid detergent fiber for metribuzin and atrazine were carried out to ascertain whether a significant *linear* relation exists. Extremely low r^2 was realized for both metribuzin and atrazine, as clearly exhibited in Fig. 8. Based on t-test, the corresponding p-values for metribuzin and atrazine were 0.1174 to 0.4335, respectively. Therefore, the respective slopes of the regression lines were not significantly different from 0 and thus conclude that K_d is invariant with the age of the residue, and a single value for K_d for metribuzin or atrazine can be used in the predictions of field results.

Following harvest, the amount of residue in the field decreased by an average of 1.34 tons/acre over five months. The percentage of ADF in the mulch increased slightly as time in the field increased. The content of the residue has larger amounts of lignin with a higher adsorption capacity with time. Therefore the residue has the ability, on a mass basis, to adsorb increasing amounts of herbicides with time in the field; however, such an increase is at best modest (see Table 5). This is consistent with metribuzin and lignin relationships described by Dao (1991). Dao (1991) argues that the increase in the percentage of lignin of intact wheat straw is caused by the decay of cellulose. Moreover, he assumed that lignin accounted for most of the sorption sites for metribuzin by the residue. In two separate batch studies, a purified cellulose fraction did not show significant retention of metribuzin or atrazine (Dao, 1991), and Abdelhafid et al. (2000). Increased sorption capacity of decaying straw was thus associated with a decline in cellulose concentration or, conversely, the lignin enrichment of the straw (Dao, 1991).

Dissipation of Herbicides

Atrazine: Results from the 1999 growing season for extractable atrazine versus time are shown in Figs. 9 and 10. Here we present atrazine concentrations for surface soil (25-mm depth) and mulch residue from the no-mulch and mulch (no-till) treatments, respectively. The atrazine concentration in the surface soil exhibited a gradual decrease with time following both the pre-emergence and post-emergence applications. These results also exhibit extensive scattering that is often observed for extractable herbicides from soils of field experiments. Atrazine results clearly show that the presence of mulch residue on the soil surface substantially reduced the amount of atrazine received and subsequently retained by the soil surface layer. In fact, in the absence of mulch residue, extractable atrazine as high as 2.4 mg kg^{-1} was measured compared to only 1.2 mg kg^{-1} for the no-till treatment. Such differences in extractable atrazine from the surface soil were highest following pre-emergence application and gradually decreased over time because of continued degradation of the mulch residue.

Results of extractable atrazine from the sugarcane mulch residue during the 1999 growing season from the no-till plots are shown in Fig. 10. Clearly the range of extractable atrazine concentrations was much higher in the mulch residue than for the surface soil (see Figs. 9 and 10). A major portion of atrazine was intercepted by the sugarcane mulch residue during application. In the meantime, a significant amount of this initially intercepted atrazine reached the soil surface. Based on the extractable amounts measured, some 22% of the applied atrazine was retained by the mulch residue one week after application. Larger amounts of retention by the mulch residue were expected immediately following application, however. Sampling was not initiated until one week after pre-emergence application, during which time cumulative precipitation of 23 mm occurred. Thus a significant amount of this initially intercepted atrazine reached the surface soil by the second week after application. Higher amounts of extractable atrazine were observed following post-emergence application (day 73) in comparison to the pre-emergence application. These higher values were expected because our sampling was initiated one day after the layby application of June 7, 1999 (see Fig. 10). Here some 40% of applied atrazine was retained by the mulch residue.

Ghadiri et al. (1984) reported 30% and 31% of applied atrazine intercepted by flat and standing wheat stubble, respectively, immediately following application. In our study, we did not account for standing sugarcane stubble. Ghadiri et al. (1984) also reported that three weeks after application, only 11% and 3% of applied atrazine was retained by the flat and standing wheat stubble, respectively, while atrazine on surface soil increased more than twofold. Cumulative precipitation during their three-week period was 50 mm. Similar to Ghadiri et al. (1984), atrazine retained by the sugarcane mulch residue in our study decreased sharply after each atrazine application as shown in Fig. 10. For example, atrazine mulch concentration decreased from 50 to 10 mg kg^{-1} within 10 days after layby application, during which time 84 mm of cumulative precipitation was received.

The large values of atrazine retained by the mulch residue over time illustrate its high retention compared to that for the soil. We are not aware of earlier studies where herbicide retention by sugarcane mulch was measured. Nevertheless, Shelton et al. (1995) reported a laboratory measured sorption capacity for dried and ground cornstalk of 860 mg kg^{-1}. Our maximum extractable atrazine from sugarcane mulch did not exceed 80 mg kg^{-1}. To illustrate the strong sorption of atrazine by mulch residue, Abdelhafid et al. (2000) measured high K_d values for wheat straw compared to soil (15.01 versus 0.77 mL g^{-1}, respectively). Their results were based on 24-hour equilibration.

For the 2000 growing season, results of extractable atrazine from the surface soil and mulch residue versus time are given in Fig. 11. These results illustrate the extensive scattering of the measured values from our field experiments. In addition, measured concentrations following each atrazine application were much lower than those observed in 1999. For the surface soil, except for times immediately following applications, comparable concentration range for atrazine was observed (up 2.0 mg kg^{-1}); however, this was not the case for the mulch residue where the concentrations were consistently lower and did not exceed 20 mg kg^{-1} compared to more than 50 mg kg^{-1} in 1999. The reason for such lower concentrations is not clear and cannot be contributed to precipitation because, during April and May 2000, the amounts of precipitation received were 25 and 4 mm, respectively. Overall year 2000 received 71% of normal precipitation and was the third driest year on record. Reasons for the extensive variability are perhaps caused by wind drift during application, interception by the crop at layby or soil heterogeneity, among others.

Because of the extensive scattering of extractable herbicide concentrations from surface soil following application, our efforts to quantify the rate of decay or disappearance were limited. Nonlinear regression analysis is often used to provide estimates for rates of disappearance of applied atrazine for the two growing seasons (see solid curves in Figs. 9-11). The assumption of first order or exponential decay was used here. Specifically, SAS procedure PROC NLIN was used. ANOVA table of the regression analysis (not shown) suggests a first-order approach provided a good description of atrazine dissipation in surface soil as well as mulch residue based on our model. Moreover, for the 1999 growing season, an overall dissipation rate λ of 0.0277 and 0.0218 day^{-1} were estimated for the surface soil and mulch residue, respectively (see Tables 6 and 7). These values correspond to half-lives ($t_{1/2}$) of 25.0 and 31.8 days, respectively. For year 2000, estimates for half-lives were 29 days and 38.3 days, for the surface soil and mulch residue, respectively. Such results indicate that the rate of dissipation is consistent among the two growing seasons. Moreover, the rate of dissipation of atrazine retained by the mulch was slightly higher than that for the surface soil. Although Ghadiri et al. (1984) did not estimate λ retained by flat and standing wheat stubble, based on their results we estimate half-lives of 5-7 days and 12-15 days, respectively. Such values are somewhat smaller than our half-life values. We are not aware of atrazine dissipation half-lives values for sugarcane mulch residue in the literature.

Our atrazine results of Figs. 9 to 11 provide the data necessary to quantify the influence of mulch residue on the rate of disappearance of atrazine retained in the surface soil. Based on first-order dissipation, estimate for the half-life from the no-mulch plots was 25.0 days (see Table 7). In contrast, for the no-till treatment estimate for half-life was 52.9 days. Therefore, the rate of disappearance for atrazine in the surface soil was considerably higher in the absence of the mulch residue compared to that for the no-till plots. Higher microbial degradation and hydrolysis are responsible for the higher rate of atrazine disappearance in the absence of residue on the soil surface. Moreover, values of half-lives for the surface soil based on other studies are consistent with estimated rate coefficient from our study. For example, Southwick et al. (1992) estimated atrazine half-lives in a Sharkey soil of 24 days and 102 days in 1989 and 1990 growing seasons, respectively. They postulate that such differences may be caused by the influence of soil temperature as well as moisture content of the soil. In a later study, Southwick et al. (1995) reported half-lives for atrazine of 14.4 days and 21 days for winter of 1991 and summer of 1992, respectively.

Pendimethalin: This herbicide was applied in combination with atrazine at pre-emergence as well as at layby. Pendimethalin is effective for most annual grasses and some broadleaf weeds. According to Wauchope et al. (1992), pendimethalin, commonly known as Prowl, has an average half-life of 90 days with a low water solubility of 0.275 mg L^{-1}. Solubility for atrazine and metribuzin in water are 33 and 1200 mg L^{-1}, respectively. Wauchope et al. (1992) also reported an average retention coefficient (K_{oc}) for pendimethalin as 5000 mL g^{-1} , whereas a value for atrazine was given as 100 mL g^{-1}. Such high retention capacity is well manifested by the extremely high concentrations of extractable pendimethalin retained by the surface soil layer and mulch residue as illustrated in Figs. 12-13. These results are for the no-mulch and the no-till treatments during the 1999 growing season.

Since pendimethalin was tank mixed with atrazine, it is not surprising that patterns of pendimethalin concentrations versus time in surface soil and mulch residue closely resemble those for atrazine. As illustrated in Fig. 12, much higher pendimethalin was retained in the surface soil where the residue was not removed when compared to the no-till plots. Such a finding was not surprising and is consistent with that observed for atrazine. In fact, the presence of mulch residue resulted in as much as a 50% reduction of pendimethalin concentration in the surface soil. In addition, as illustrated in Fig. 13, measured pendimethalin retained by the mulch residue versus time following were within the same concentration range as that for atrazine (see Fig. 11). Since the rate of application was slightly less than atrazine, the amount of pendimethalin intercepted by the mulch residue was also slightly higher than for atrazine. In fact, one day following layby application, the range of concentration in mulch residue was 15-50 and 20-65 mg kg^{-1} for pendimethalin and atrazine, respectively. Stahnke et al. (1991) and Schleicher et al. (1995) reported higher pendimethalin concentration retained by thatch than underlying soil for Kentucky blue grass and perennial ryegrass turf, respectively. Schleicher et al. (1995) measured a pendimethalin concentration range of 50-100 and 50-200 mg kg^{-1} within the first week following applications for the verdure and thatch, respectively. In contrast, in the underlying mat, maximum pendimethalin concentrations ranged between 5-6 mg kg^{-1}. For the 5-cm surface soil layer, pendimethalin ranged between 0.03-0.05 mg kg^{-1} and decreased to less than 0.01 mg kg^{-1} some 60 days after application. Such results are highly consistent with results from the present study and clearly illustrate the high affinity of pendimethalin in the soil.

Nonlinear regression was used to provide estimates for the rates of disappearance of applied pendimethalin during 1999 (see solid curves in Figs. 12 and 13) in a similar fashion to atrazine. Based on model estimates, an overall pendimethalin dissipation rate coefficient λ of 0.0175 and 0.0186 d^{-1} was estimated for the surface soil from the no-till and no-mulch plots, respectively (see Table 6). These values correspond to half-lives ($t_{1/2}$) of 39.6 and 37.3 days, respectively. Similarity in the rate of dissipation, regardless of the presence of mulch, is perhaps indicative of the strong affinity of pendimethalin by the soil as reported in Wauchope et al. (1992). Estimate for rate of dissipation of pendimethalin retained by the mulch residue was 0.0354 day^{-1} , which corresponds to $t_{1/2}$ of 19.6 days (see Table 7). This is a higher rate than that for the surface soil and is perhaps caused by increased volatilization and/or photo-degradation. Schleicher et al. (1995) reported an estimated time of 23 days to account for 50% of detectable residue (DT_{50}) of pendimethalin in the entire sampling zone including verdure, thatch, mat and surface soil layers. Based on their results of concentration versus time, we estimate an approximate dissipation rate or $t_{1/2}$ of 12-15 days for pendimethalin retained by the thatch layer. Our estimated half-life of 19.6 days for the sugarcane mulch is somewhat longer and is possibly caused by lower rate of photo-degradation and volatilization. In another study, Zimdahl et al. (1994) reported half-lives for pendimethalin for two surface soils in the range of 5 to 36 days, which is consistent with that estimated in our study.

Metribuzin: Contrary to atrazine and pendimethalin, metribuzin was applied as an alternative herbicide only once in the spring (pre-emergence) during 1999 as well as 2000. As shown in Fig. 14, considerable soil extractable amounts of metribuzin were measured from surface soil regardless of the presence of mulch residue. Measured amounts ranged from 3.0-4.0 mg kg^{-1} initially and continued to decrease over time, reaching 0.3-0.4 mg kg^{-1} some 60 days after application. Moreover, metribuzin results showed consistently lower extractable amounts retained by the surface soil in the presence of mulch residue compared to the treatment where the mulch was removed from the top of the sugarcane rows. Such differences were caused by the interception of applied metribuzin by the mulch residue and are consistent with earlier results of Sorenson et al. (1991). In their experiment, metribuzin dissipation was measured following pre-emergence and split application on no-till soybeans in rotation with corn or wheat. Moreover, our metribuzin concentrations in the surface soil continued to decrease and reached levels below 0.1 mg kg^{-1} some 100 days after application, regardless of whether or not the sugarcane mulch residue was removed from the top of the rows (see Fig. 14).

Results of extractable metribuzin from mulch residue and surface soil during the 2000 growing season are shown in Fig. 15. Although a similar dissipation trend was observed, the metribuzin concentrations in surface soil for year 2000 (Fig. 15) were considerably lower than those measured for 1999 (Fig. 14). Nevertheless, our field results from year 2000 are consistent with others. For example, Sorenson et al. (1991) measured metribuzin concentration from surface soil in the range of 0.2 – 0.6 mg kg^{-1} for no-till wheat/soybean rotation and 0.04 – 0.1 mg kg^{-1} for wheat/soybean rotation. In their experiment, extremely low concentrations were found (<0.05 mg kg^{-1}) some 50 days following either single or split metribuzin application. In contrast, during the 2000 growing season, concentrations exceeding 0.1 mg kg^{-1} some 100 days following application were measured. For the mulch residue, Fig. 15 indicates that metribuzin concentrations ranged from 12-14 mg kg^{-1} initially and decreased to values approximately 1 mg kg^{-1} within 10 weeks. Metribuzin results also indicate an order of magnitude higher concentration in the mulch residue over that retained by the surface soil. This finding is consistent with earlier results for atrazine as well as pendimethalin.

Estimates for the rates of metribuzin disappearance during 1999 and 2000 are given in Tables 6 and 7. In addition, predictions based on first order decay are shown by the solid curves shown in Figs. 14 and 15. Based on estimates, an overall metribuzin dissipation rate λ of 0.0441 and 0.0553 day^{-1} were estimated for the surface soil in the presence and absence of mulch residue, respectively (see Table 7). These values correspond to half-lives ($t_{1/2}$) of 15.7 and 12.5 days, respectively. Such values indicate a slightly higher rate of metribuzin dissipation of surface soil when the mulch residue was removed. Our results are in agreement with Banks and Robinson (1982), who reported that the presence of wheat straw mulch affects the soil reception of applied metribuzin but not subsequent degradation in the soil. From our 2000 results, a half-life of 15.6 days was estimated for the surface soil. Such $t_{1/2}$ value is similar to those estimated from 1999 growing season and in the range of half-lives based on other studies. Southwick et al. (1995) reported a half-life of 22.3 days for metribuzin in a Sharkey soil. Based on reported data for several soils, Wauchope et al. (1992) reported half-life values of 40 days. Our estimated $t_{1/2}$ for metribuzin retained by the mulch residue was 24 days, which is significantly larger than that for surface soil.

Runoff Losses

Year 2000 was the third driest year on record in south Louisiana. As a result, no runoff was collected during the 2000 growing season. Thus only runoff results from the 1999 growing season are presented. As can be seen in Figs. 16 and 17, most runoff events occurred after the layby application. For atrazine, concentrations in the runoff from the no-till and no-mulch treatments are shown in Fig. 16. The difference between the two treatments was that in the no-mulch treatment, the mulch was removed from the row tops and the rows were off-barred before band applications of herbicides. As illustrated in Fig. 16, the lowest average concentration of atrazine in the runoff was consistently measured in the no-till treatment. Maximum concentration did not exceed 80 μg L^{-1} for the no-till, whereas it reached some160 μg L^{-1} when the mulch was removed. This illustrates the influence of mulch in reducing runoff losses of applied herbicides.

Pendimethalin runoff results indicate a much lower concentration in comparison to that for atrazine. Results from our pendimethalin concentration in the runoff as illustrated in Fig. 17 reached a maximum of only 3-4 μg L^{-1} for the no-till treatment compared to a range of 11-12 μg L^{-1} when the mulch was removed. Within three months following layby application, pendimethalin concentrations reached 1-2 μg L^{-1}. Overall, pendimethalin concentrations were at least one order of magnitude lower than that for atrazine. Two reasons may be responsible for such behavior: namely low solubility and high retention or affinity to the soil as well as the mulch residue. Such high retention is well manifested by the extremely high concentrations of extractable pendimethalin observed in the mulch residue as well as the soil surface layer as illustrated in Figs. 12 and 13.

Metribuzin was detected only at extremely low concentrations in the runoff and at no time did it exceed 10 μg L^{-1} , regardless of whether the mulch residue was removed from the sugarcane rows (Fig not shown). Selim et al. (2000) published data showing concentrations of 200-300 μg L^{-1} metribuzin in runoff waters 6 days after spring application in 1994 and 1995. In this study, runoff was not encountered until some 47 days (May 12, 1999). Following such long duration, low runoff concentrations are expected because of decreased amounts of metribuzin concentrations retained by the surface soil as well as mulch residue.

Several studies measured high initial concentrations of herbicides in runoff waters from soils under various management practices (Southwick et al., 1992; Isensee and Sadeghi, 1999). For example, Isensee and Sadeghi (1993) quantified concentrations and runoff amounts of atrazine, alachlor and cyanzine herbicides from no-till (NT) and conventional tillage (CT) 0.25-0.50-ha plots. All herbicides were tank mixed and applied (broadcast) uniformly across the plots one day after planting. They found that atrazine concentrations were 2 to 10 μg L^{-1} higher in runoff water from the NT compared to the CT plots. The highest atrazine concentrations occurred 3 days after applications and ranged from 2061-2733 μg L^{-1} for NT and 773-989 μg L^{-1} for CT. Such concentrations are considerably higher than that measured in our experiment. Isensee and Sadeghi (1993) also reported that the values decreased to 36 μg L^{-1} for NT and 3-4 μg L^{-1} for CT some 34 days after applications. Our runoff results shown in Fig. 9 are consistent with those reported for broadcast applications by Isensee and Sadeghi (1993).

Summary and Conclusions

In this study we evaluated the effectiveness of sugarcane residue (mulch cover) in reducing nonpoint-source contamination of applied herbicides from sugarcane fields. For this purpose, two main treatments were investigated: no-till (100% mulch) and no-mulch treatments. The effect of mulch residue on herbicide retention was quantified following spring as well as layby applications. Major findings include:

1. The amounts of extractable atrazine, metribuzin and pendimethalin from the mulch residue and the surface soil layer were quantified during the 1999 and 2000 growing seasons, and the mulch residue intercepted significant amounts of applied herbicides. Extractable concentrations were at least one order of magnitude higher for the mulch residue compared with that retained by the soil. Such observations were consistent with measured retention parameters for metribuzin and atrazine by the mulch residue and surface soil.

2. The effect of the decaying residue on the retention of herbicides was investigated. We found that retention capability of the residue for either metribuzin or atrazine did not change significantly with the age of the decaying residue over two growing seasons. Consequently only one single retention parameter or K_d is necessary to describe herbicide retention, regardless of when the application is made.

3. Nonlinear regression was used to provide estimates of the rates of decay or disappearance of the herbicides retained by the surface soil as well as the mulch residue following spring as well as layby applications. We found that one rate of herbicide decay was applicable for the entire growing season.

4. The presence of mulch residue resulted in consistently lower rates of disappearance of atrazine and pendimethalin in the surface soil.

5. The presence of mulch residue on the sugarcane rows was highly beneficial in minimizing runoff losses of the herbicides applied. A minimum of 50% reduction in runoff effluent concentrations for atrazine and pendimethalin was realized when the mulch residue was not removed.

Although these findings show the potential benefits of the sugarcane residue on reducing herbicide loss from fields, such benefits should be weighed against the negative impact that the residue can have on sugarcane emergence and growth in the spring and on yields. Research is under way at the Louisiana Agricultural Experiment Station (LAES) that addresses long-term effects of sugarcane residue on the total production system.

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Tables 1-7

Table 1. Estimated Linear and Freundlich model parameters (with 95% confidence interval) for atrazine and metribuzin adsorption by Commerce soil at different reaction times.

Reaction Time	Linear Model	Freundlich Model	
	K_d	K_f	N
(h)	(mL g^{-1})	(mL g^{-1})	
	Atrazine		
2	1.84 ± 0.04	2.54 ± 0.07	0.88 ± 0.01
6	1.97 ± 0.05	2.84 ± 0.17	0.87 ± 0.02
12	2.07 ± 0.04	2.81 ± 0.04	0.89 ± 0.01
24	2.09 ± 0.04	2.88 ± 0.01	0.88 ± 0.01
48	2.05 ± 0.05	2.97 ± 0.14	0.87 ± 0.01
96	2.33 ± 0.07	3.46 ± 0.23	0.85 ± 0.02
192	2.25 ± 0.08	3.56 ± 0.26	0.83 ± 0.02
384	2.35 ± 0.09	3.81 ± 0.24	0.82 ± 0.02
	Metribuzin		
2	1.12 ± 0.49	1.245 ± 0.18	0.98 ± 0.03
6	1.16 ± 0.81	1.445 ± 0.18	0.95 ± 0.03
12	1.18 ± 0.42	1.325 ± 0.16	0.97 ± 0.02
24	1.18 ± 0.05	1.533 ± 0.19	0.94 ± 0.02
48	1.20 ± 0.06	1.901 ± 0.28	0.89 ± 0.03
96	1.28 ± 0.07	1.872 ± 0.11	0.91 ± 0.01
192	1.18 ± 0.07	1.667 ± 0.05	0.92 ± 0.01
384	1.25 ± 0.09	1.543 ± 0.16	0.95 ± 0.02

Table 2. Estimated linear and Freundlich model parameters (with 95% confidence interval) for atrazine and metribuzin adsorption versus reaction time by the sugarcane mulch residue. The residue was sampled on March 23, 2001.

Reaction Time	Linear Model	Freundlich Model	
	K_d	K_f	N
(days)	(mL g^{-1})	(mL g^{-1})	
	Atrazine		
1	15.90 ± 0.22	19.36 ± 1.82	0.92 ± 0.03
2	16.50 ± 0.16	20.01 ± 3.10	0.92 ± 0.02
7	17.65 ± 0.37	23.32 ± 3.10	0.89 ± 0.04
14	19.46 ± 0.25	25.29 ± 1.62	0.90 ± 0.02
21	20.08 ± 0.26	26.55 ± 1.57	0.89 ± 0.01
	Metribuzin		
1	11.20 ± 0.20	13.72 ± 2.46	0.94 ± 0.04
2	11.56 ± 0.22	17.20 ± 2.78	0.90 ± 0.04
7	12.91 ± 0.20	16.94 ± 2.39	0.93 ± 0.03
14	13.47 ± 0.18	17.85 ± 2.08	0.92 ± 0.02
21	14.72 ± 0.19	17.66 ± 2.20	0.95 ± 0.03

Table 3. Estimated linear and Freundlich model parameters (with 95% confidence interval) for atrazine and metribuzin adsorption by the sugarcane mulch residue (var. LCP85-384). The residue was sampled at several dates following sugarcane harvest of December 8, 2000.

Sampling Date	Age of Residue (days)	Linear Model K_d *(mL g⁻¹)*	Freundlich Model K_f *(mL g⁻¹)*	N
		Atrazine		
03-Jan-01	26	14.99 ± 0.15	18.27 ± 1.11	0.92 ± 0.02
07-Feb-01	61	16.52 ± 0.13	19.48 ± 0.87	0.93 ± 0.01
23-Mar-01	105	15.90 ± 0.22	19.36 ± 1.82	0.92 ± 0.03
27-Apr-01	140	18.09 ± 0.13	20.70 ± 0.97	0.94 ± 0.01
		Metribuzin		
03-Jan-01	26	10.00 ± 0.15	13.05 ± 0.80	0.96 ± 0.01
07-Feb-01	61	11.29 ± 0.49	10.11 ± 4.93	1.02 ± 0.12
23-Mar-01	105	11.20 ± 0.20	13.72 ± 2.46	0.94 ± 0.04
27-Apr-01	140	10.36 ± 0.10	13.31 ± 1.18	0.93 ± 0.02

Table 4. Estimated linear and Freundlich model parameters (with 95% confidence interval) for atrazine and metribuzin adsorption by the sugarcane mulch residue (var. LCP85-384). The residue was sampled at several dates following sugarcane harvest of October 22, 2001.

Sampling Date	Age of Residue (days)	Linear Model K_d *(mL g⁻¹)*	Freundlich Model K_f *(mL g⁻¹)*	N
		Atrazine		
30-Oct-01	12	16.21 ± 0.36	22.62 ± 3.10	0.87 ± 0.05
26-Nov-01	39	14.92± 0.39	18.28 ± 3.51	0.92 ± 0.07
20-Dec-01	63	16.72 ± 0.27	20.67 ± 2.26	0.92 ± 0.04
22-Feb-02	127	15.65 ± 0.16	18.46 ± 1.32	0.93 ± 0.02
20-Mar-02	153	17.18 ± 0.31	22.69 ± 2.63	0.89 ± 0.04
23-May-02	217	15.93 ± 0.18	18.24 ± 1.54	0.94 ± 0.03
		Metribuzin		
30-Oct-01	12	9.23 ± 0.32	10.90 ± 4.02	0.95 ±0.09
26-Nov-01	39	9.47 ± 0.20	8.49 ± 2.12	1.02 ± 0.06
20-Dec-01	63	10.47 ± 0.22	8.76 ± 2.09	1.04 ± 0.05
22-Feb-02	127	11.11 ± 0.04	10.57 ± 0.42	1.01 ± 0.00
20-Mar-02	153	10.07 ± 0.06	11.56 ± 0.67	0.96 ± 0.01
23-May-02	217	10.97 ± 0.06	12.10 ± 0.73	0.97 ± 0.01

Table 5. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) analysis for sugarcane (LCP85-384) mulch residue for different sampling dates.

Date Sampled	Age of Residue (day)	Average %* ADF**	NDF***
30-Oct-01	12	47.41	70.89
26-Nov-01	39	47.85	72.47
20-Dec-01	63	50.47	73.59
22-Feb-02	127	51.69	75.47
20-Mar-02	153	52.92	76.77
23-May-02	217	53.97	76.15

*ADF and NDF are percentages of total dry mass of residue.
**Acid Detergent Fiber (ADF) includes lignin and cellulose.
***Neutral Detergent Fiber (NDF) includes lignin, cellulose and hemicellulose.

Table 6. Estimated half-life ($t_{1/2}$), dissipation rate coefficient (λ)* and its standard error based on first-order disappearance for atrazine, pendimethalin and metribuzin in surface soil.

Herbicide	Treatment	Half Life $t_{1/2}$ (day)	Dissipation` Rate Coefficient λ (day^{-1})	Standard error (day^{-1})
Atrazine (1999)	No-till	52.9	0.0131	0.00462
Atrazine (1999)	No mulch – banded	25.0	0.0277	0.00499
Atrazine (2000)	Mulch & off-barred	29	0.0239	0.00960
Atrazine (2000)	No mulch & off-barred	15.7	0.0441	0.0118
Pendimethalin(1999)	No-till	39.6	0.0175	0.00663
Pendimethalin(1999)	No mulch & banded	37.3	0.0186	0.00414
Metribuzin (1999)	Mulch & off-barred	15.7	0.0441	0.00614
Metribuzin (1999)	No mulch & off-barred	12.5	0.0553	0.00792
Metribuzin (2000)	Mulch & off-barred	15.6	0.0445	0.00733

* First-order decay equation used is $S = S_o \exp(-\lambda t)$, where S is herbicide concentration at time t (days), S_o is herbicide concentration at t = 0, and l is the dissipation rate coefficient.

Table 7. Estimated half-life ($t_{1/2}$), dissipation rate coefficient (λ) and its standard error based on first-order disappearance for atrazine, pendimethalin and metribuzin in sugarcane mulch residue.

Herbicide	Treatment	Half Life $t_{1/2}$ (day)	Dissipation Rate Coefficient λ (day^{-1})	Standard error (day^{-1})
Atrazine (1999)	No-till	31.8	0.0218	0.00616
Atrazine (2000)	Mulch & off-barred	38.3	0.0181	0.00427
Pendimethalin(1999)	No-till	19.6	0.0354	0.00771
Metribuzin (2000)	Mulch & off-barred	24.0	0.0288	0.00664

Figures 1-17

Fig. 1. Field decay of sugarcane residue following harvest of CP70-321 and LCP85-384.

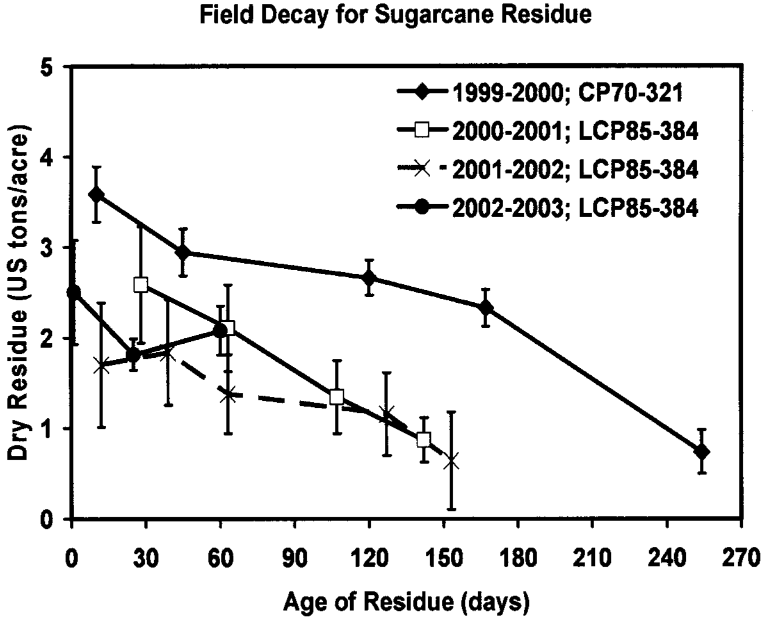


Fig.2. Adsorption isotherms for metribuzin by Commerce soil for 2 hours, 1 day and 16 days reaction time.

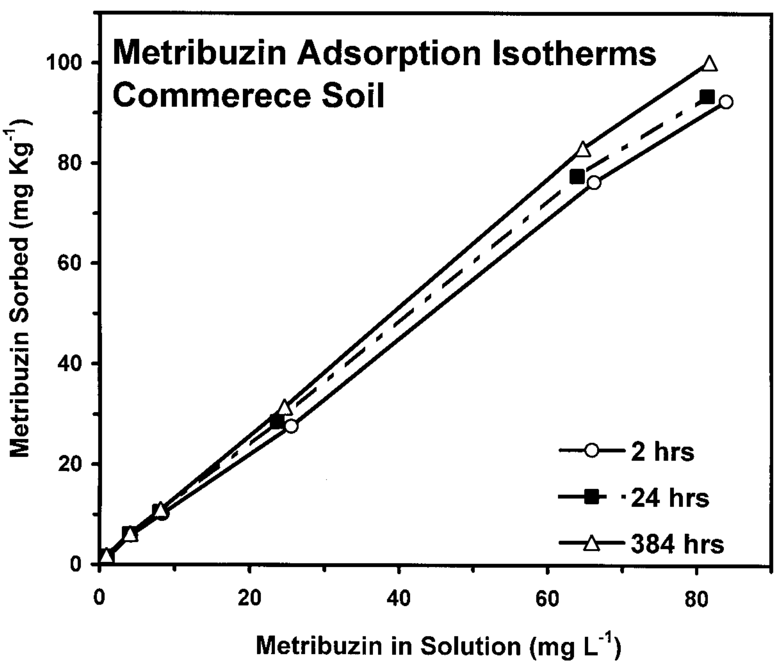


Fig.3. Adsorption isotherms for atrazine by Commerce soil for 2 hours, 1 day and 16 days reaction time. Solid curves are predictions using a linear model.

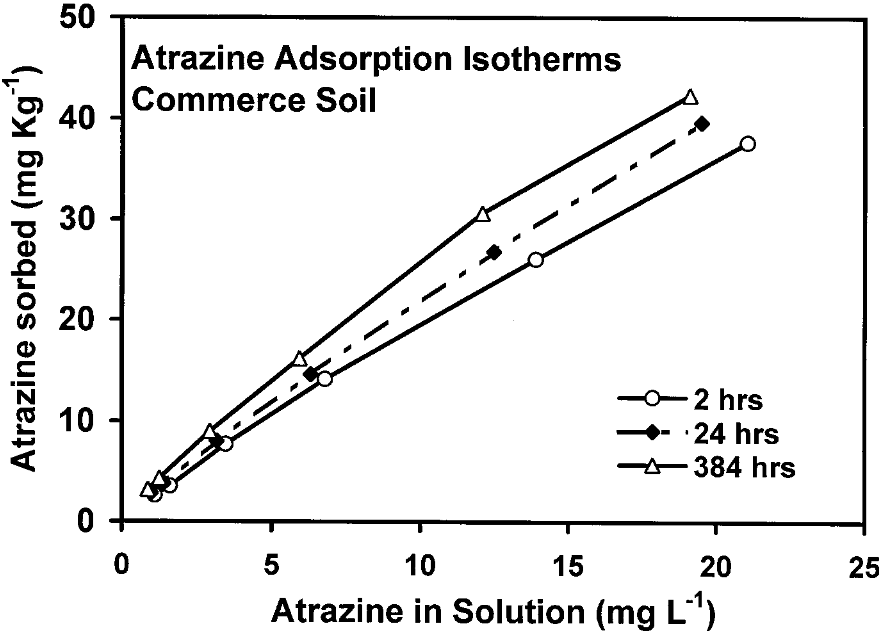
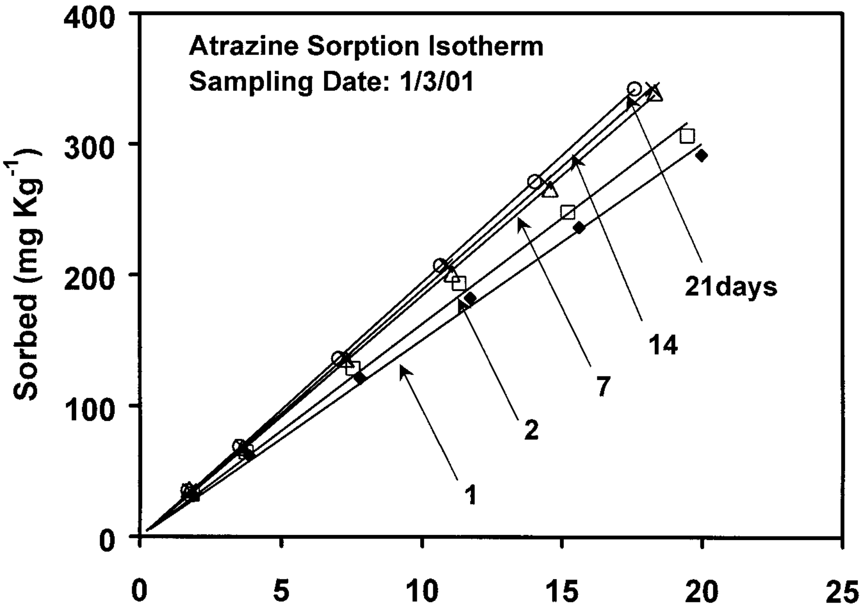


Fig. 4. Adsorption isotherms for atrazine (top) and metribuzin (bottom) for sugarcane mulch residue at different reaction times. The residue was sampled on January 3, 2001.



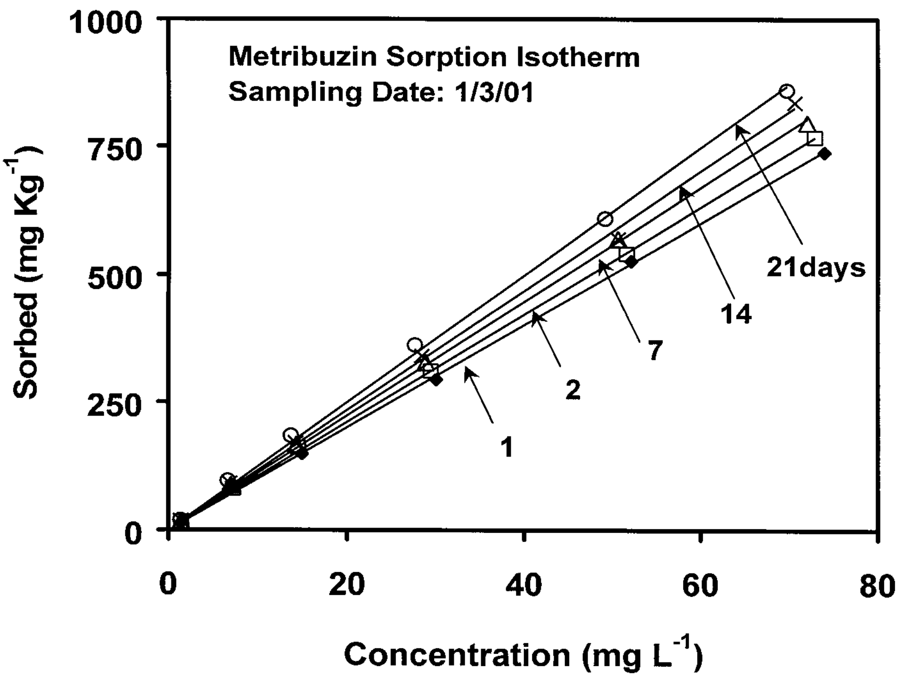


Fig. 5. Measured atrazine and metribuzin distribution coefficient (K_d) versus reaction time for sugarcane mulch residue and Commerce soil. Error bars represent one standard deviation.

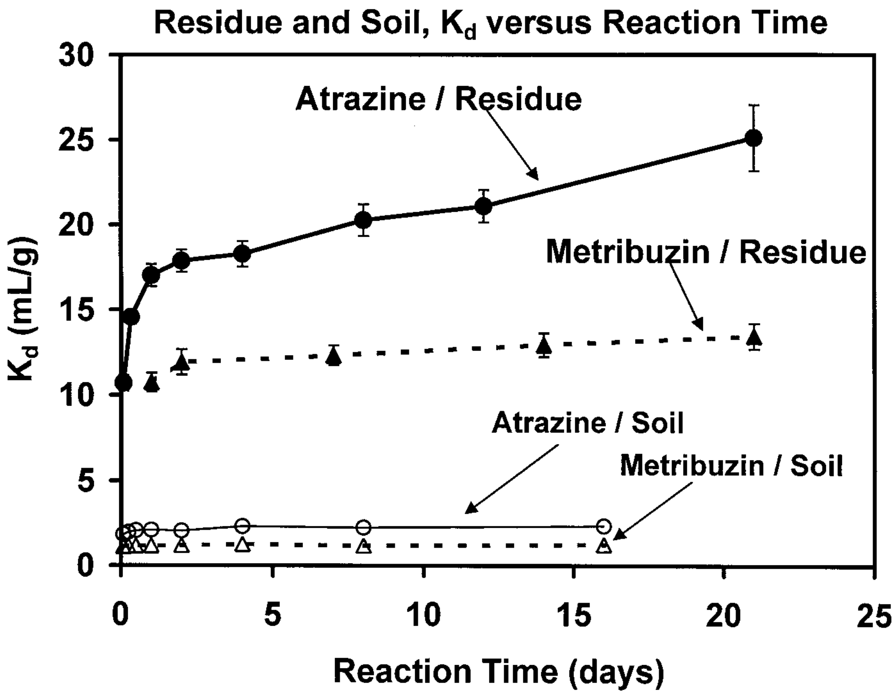


Fig. 6. Adsorption isotherms for atrazine (top) and metribuzin (bottom) for sugarcane mulch residue at different reaction times. The residue was sampled on April 27, 2001.

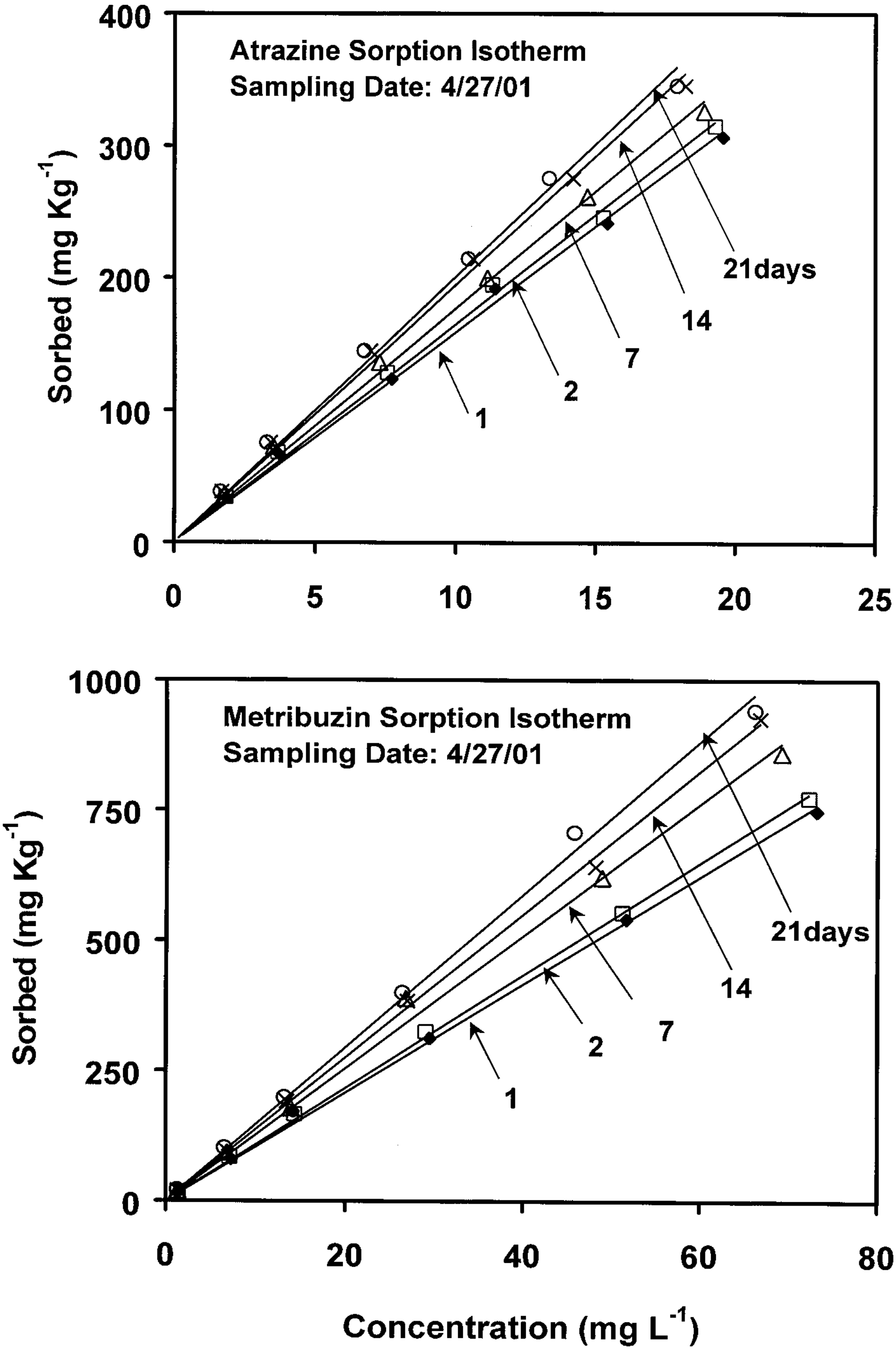


Fig. 7. Distribution coefficient (K_d) for atrazine and metribuzin by the sugarcane residue versus age of the mulch during for 2000-2001 and 2001-2002.

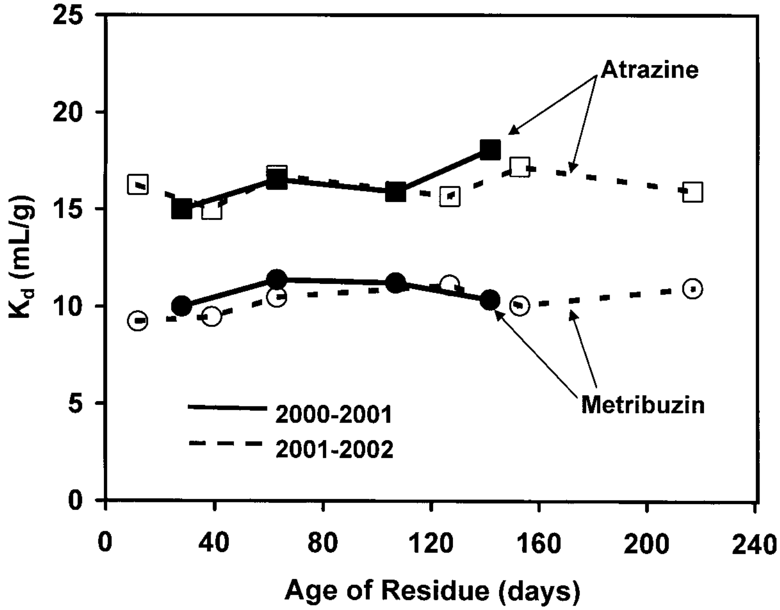


Fig. 8. Relationship between atrazine and metribuzin K_d for sugarcane mulch residue and acid detergent fiber content at different sampling dates.

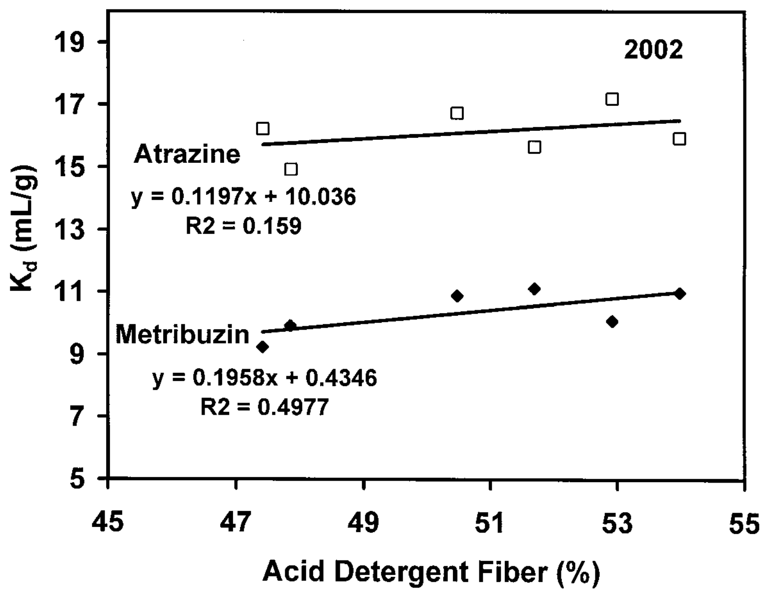


Fig. 9. Measured and simulated atrazine concentration versus time in the top 25 mm of Commerce soil for the no-mulch treatment (top figure) and the no-till (mulch not removed) treatment (bottom figure). Two atrazine applications were made in 1999: spring application on Day 0 (March 26) and layby (preemergence) on Day 73 (June 7). Simulations are based on best fit using the first-order decay model.

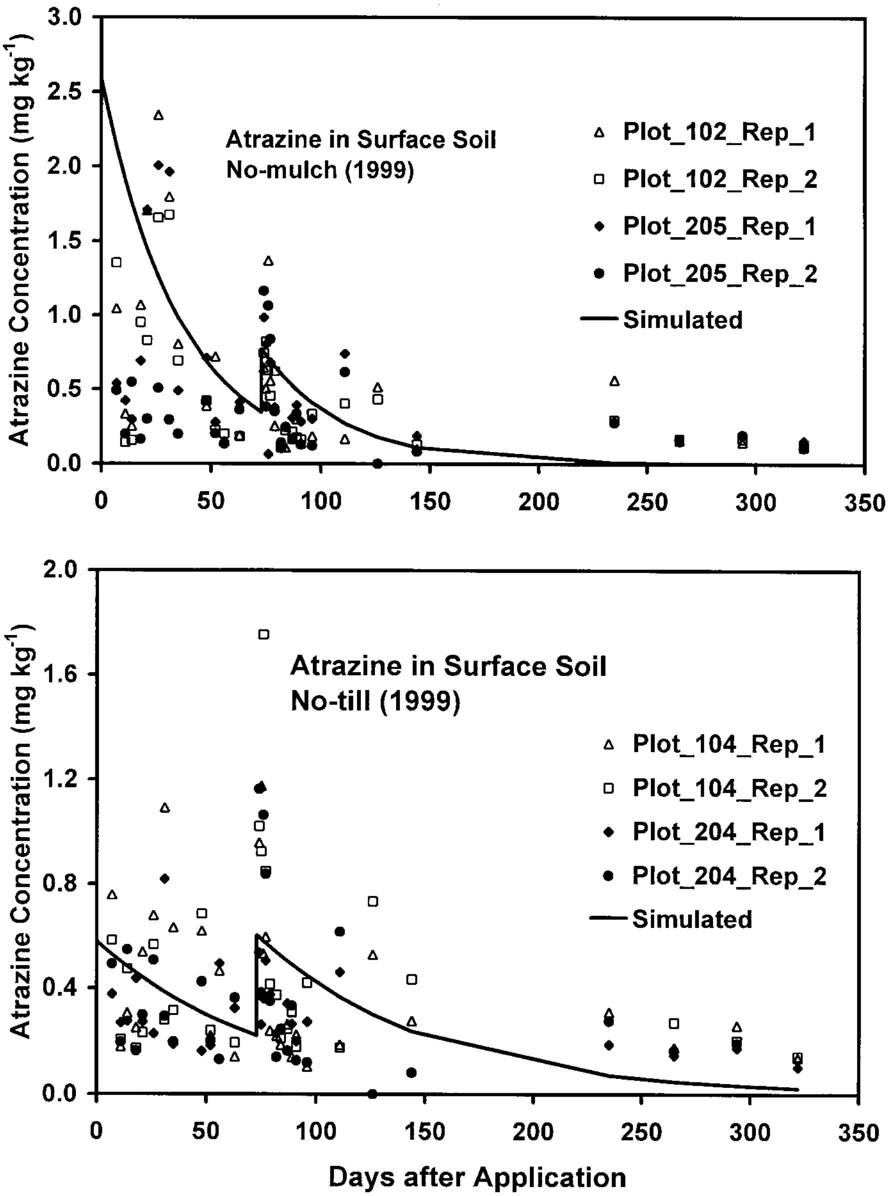


Fig. 10. Measured and predicted atrazine retained by sugarcane mulch versus time from the no-till treatment. Two applications were made during 1999: spring application on Day 0 (March 26) and layby (preemergence) on Day 73 (June 7). Simulations are based on best fit using the first-order decay model.

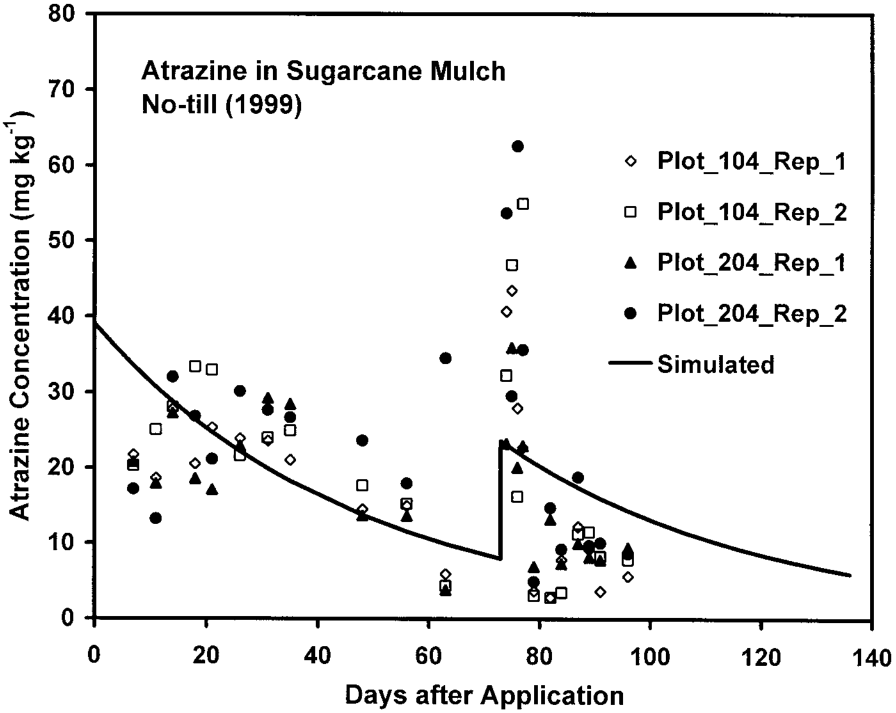


Fig. 11. Measured and predicted extractable atrazine concentration versus time from the top 25 mm of surface soil (top figure) and the mulch residue (bottom figure). Two applications were made during 2000: spring and layby applications on Day 0 and Day 59 (April 7 and June 5, respectively). Simulations are based on best fit using the first-order decay model.

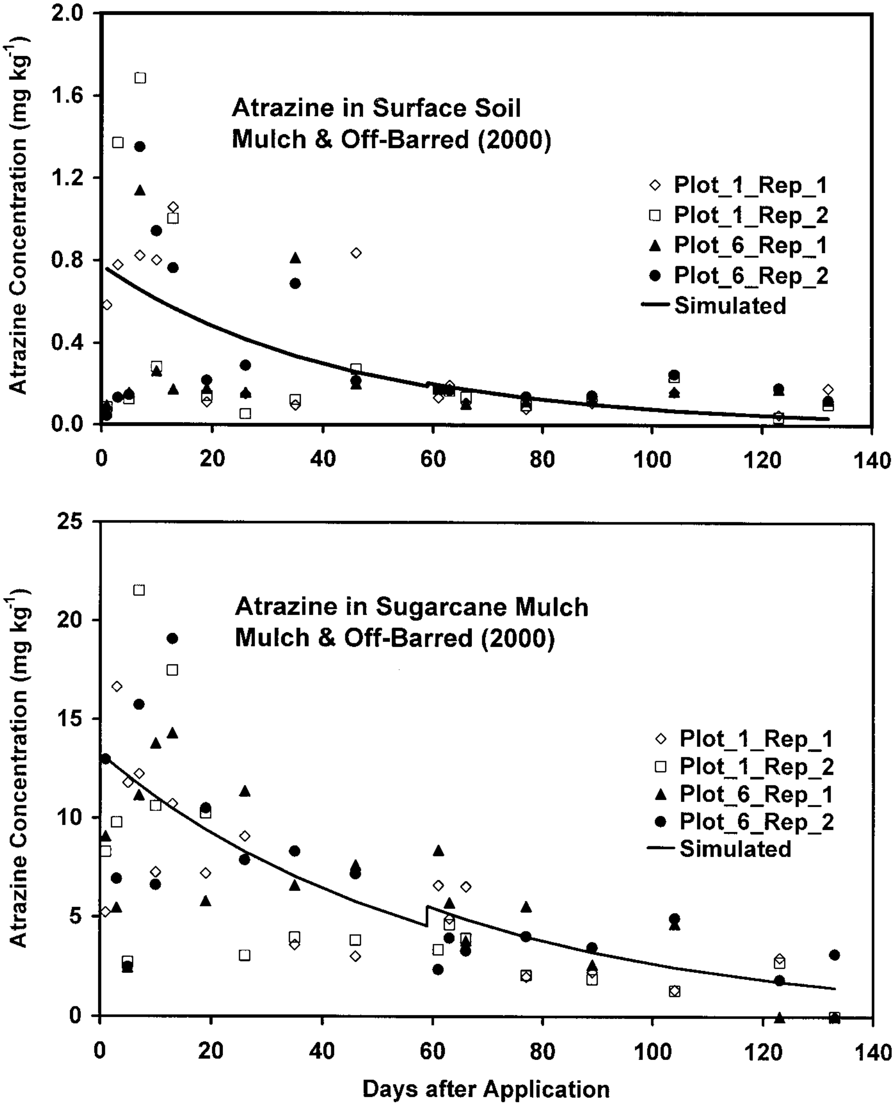


Fig. 12. Measured and predicted pendimethalin concentration versus time in the top 25 mm of surface soil for the no-mulch (top figure) and no-till (bottom figure) treatments. Two applications were made during 1999: spring application on Day 0 (March 26) and layby (preemergence) on Day 73 (June 7). Simulations are based on best fit using the first-order decay model.

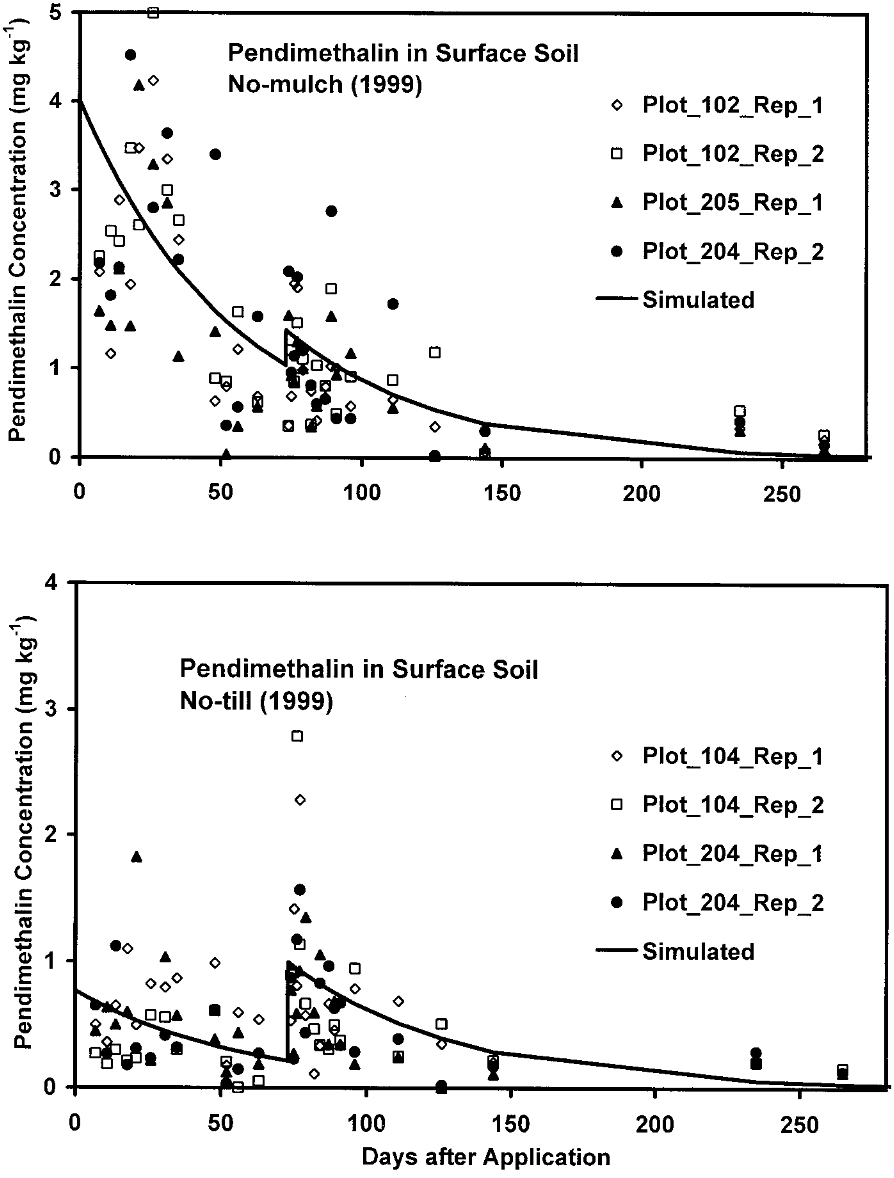


Fig. 13. Measured and predicted pendimethalin retained by sugarcane mulch versus time from the no-till treatment. Two applications were made during 1999: spring application on Day 0 (March 26) and layby (preemergence) on Day 73 (June 7).

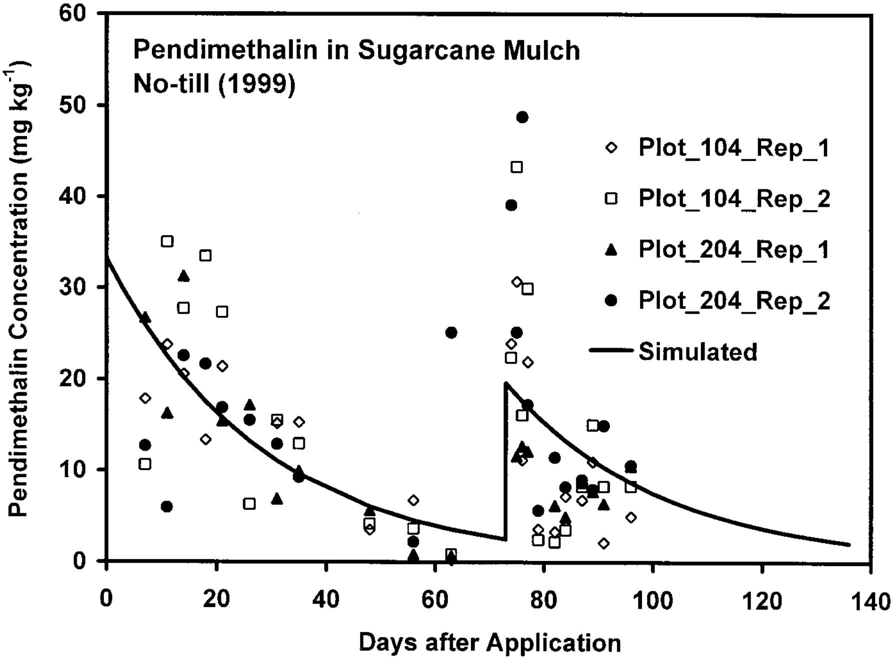


Fig. 14. Metribuzin concentration versus time in the top 25 mm of surface soil from the mulch and off-barred treatment (top figure) and the no-mulch treatment (bottom figure) during the 1999 growing season.

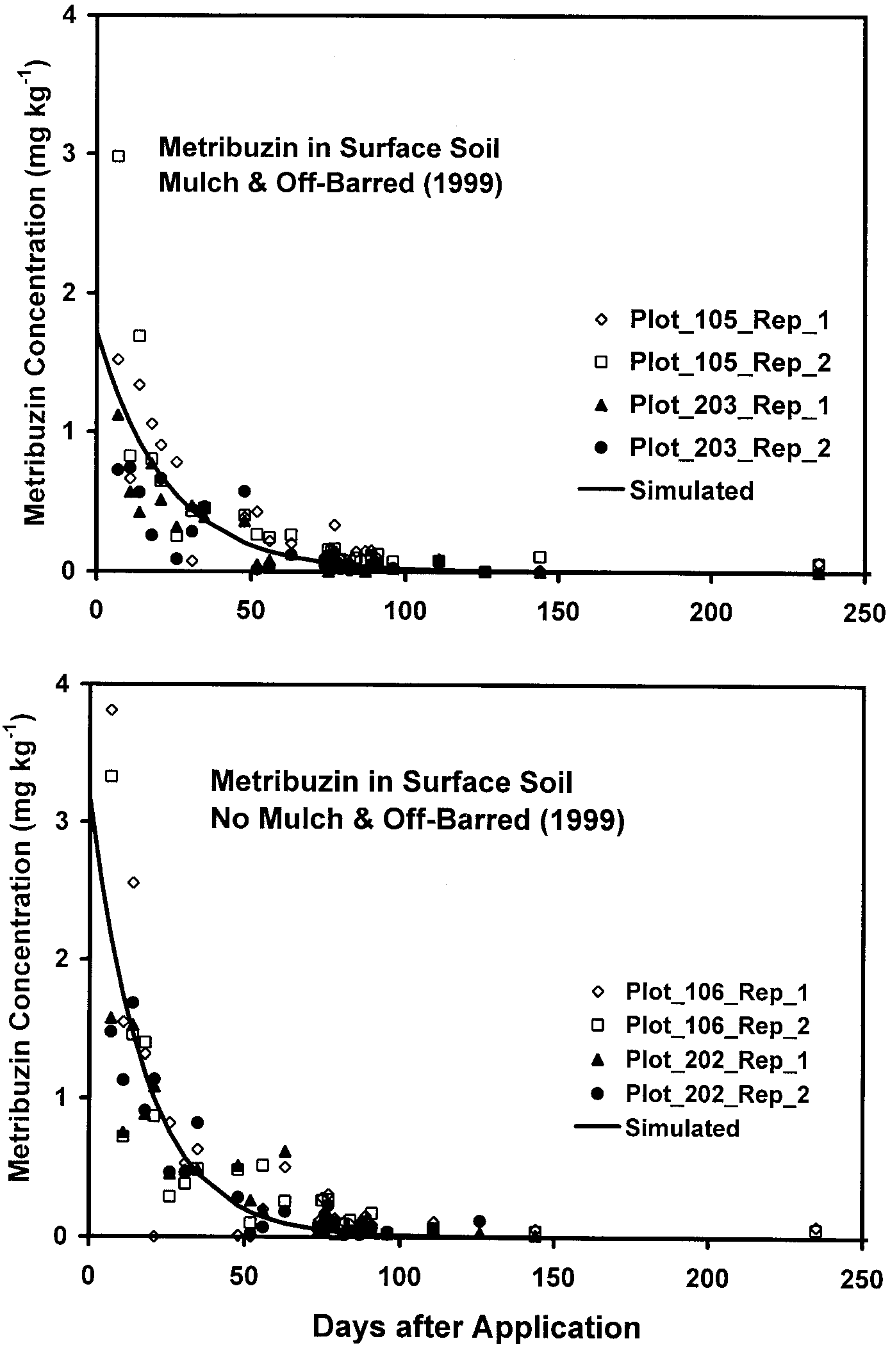


Fig. 15. Extractable metribuzin concentration versus time from the mulch residue (top figure) and the 25-mm surface soil (bottom figure) in the no-mulch and off-barred plot treatment during 2000.

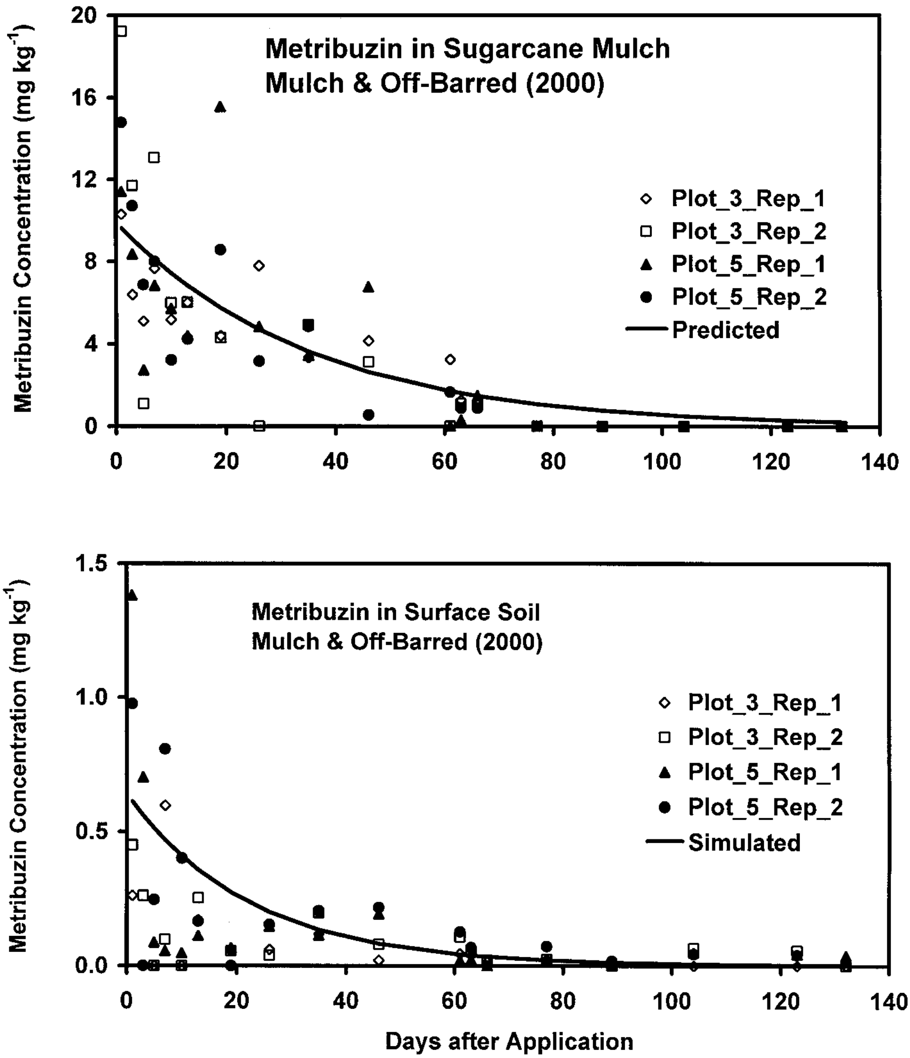


Fig. 16. Rainfall distribution and atrazine concentration in runoff water during 1999.

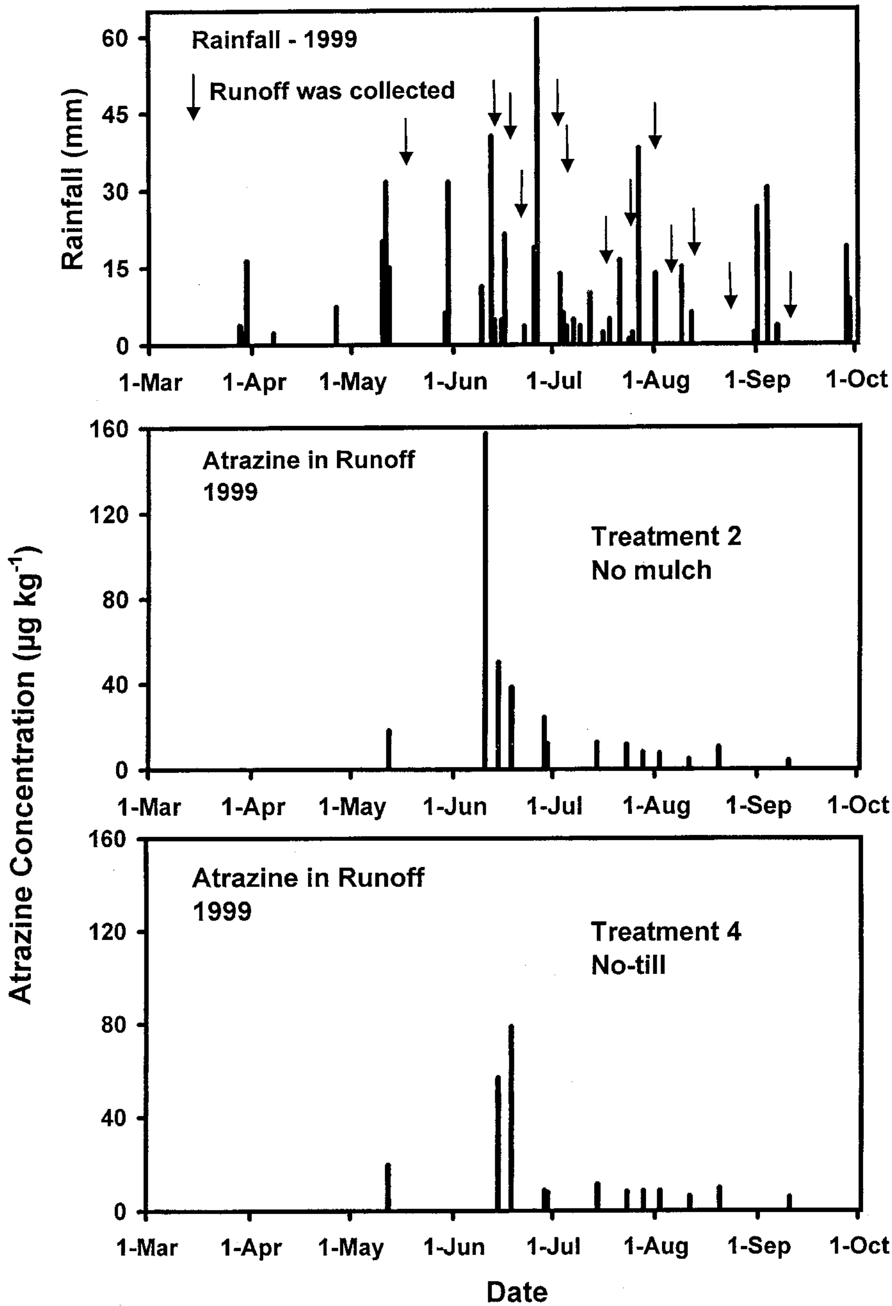
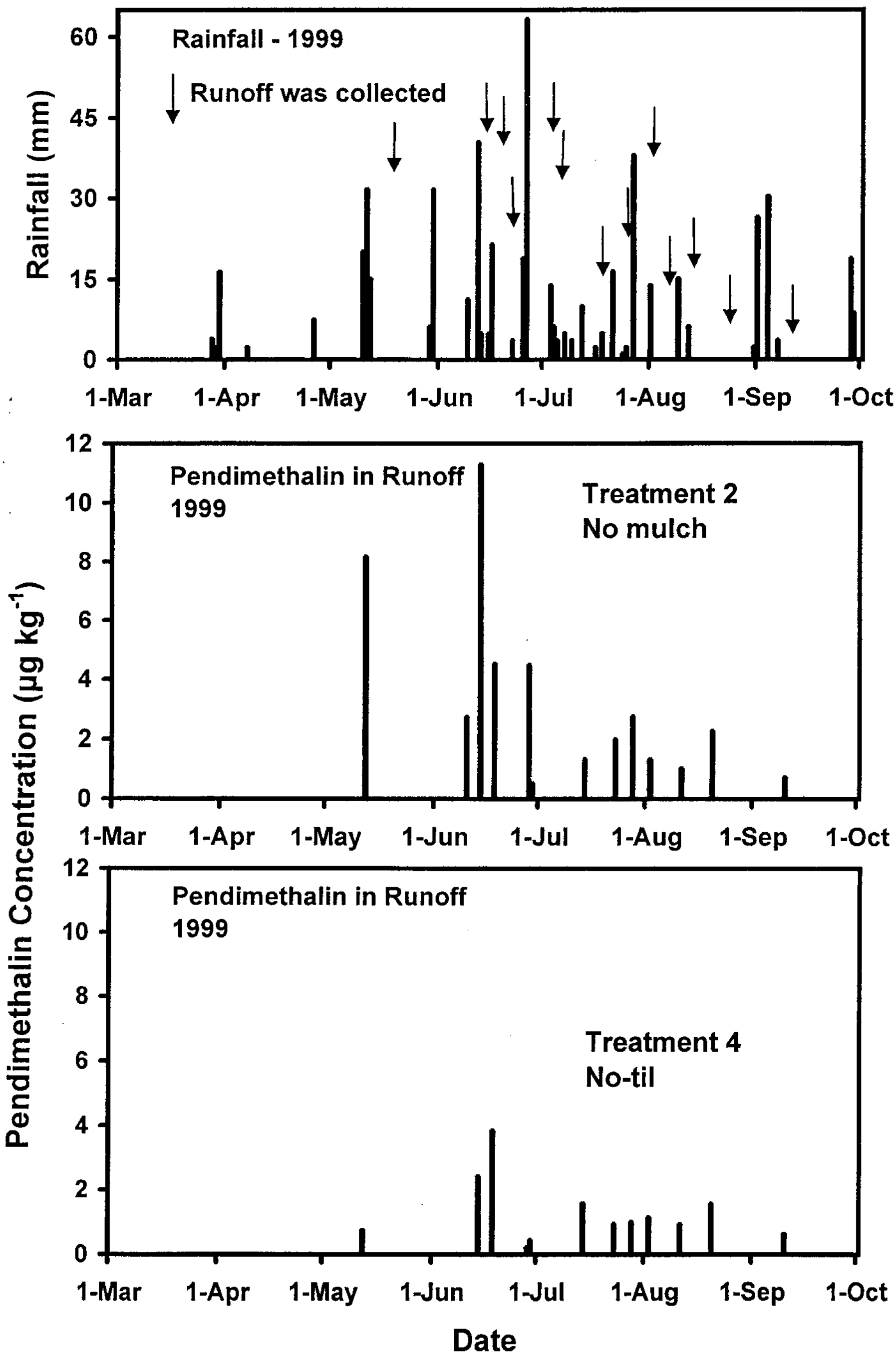


Fig. 17. Pendimethalin concentration in runoff water during 1999.



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Herbicide Retention and Runoff Losses as Affected by Sugarcane Mulch Residue

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