JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

J. Agric. Food Chem. **2002,** *50,* 4393–4399 **4393**

Potential Influence of Sugarcane Cultivation on Estuarine Water Quality of Louisiana's Gulf Coast

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Sugarcane is cultivated on some 170000 ha of land in south central and southwestern Louisiana. This acreage drains into bayous and rivers that empty into Louisiana's coastal bays and estuaries. For a number of years the state's Department of Agriculture and Forestry and Department of Environmental Quality have collected water quality data from this sugarcane area. Study of these data shows that approximately one in five detections of atrazine is above the maximum contaminant level (MCL) for drinking water. Currently there is no U.S. atrazine standard for protection of aquatic life. February and October detections of this herbicide are probably due to sugarcane cultivation. Nitrate levels have remained below the MCL for drinking water, but nitrate and phosphorus concentrations may pose a potential for eutrophication problems. The contribution of sugarcane production to the nutrient status of Louisiana's coastal water bodies is difficult to assess because there are other sources of nutrients in the area and native soil phosphorus levels are high. Cultural practices such as subsurface drains, open drainage ditches, and postharvest residue management have potential through enhancement of soil infiltration for decreasing sugarcane's contribution to water quality problems in southern and coastal Louisiana. A new field project is being installed at the Louisiana State University Agricultural Experiment Station's Sugarcane Research Station at St. Gabriel to assess the water quality benefits of these practices with respect to sugarcane cultivation.

KEYWORDS: Nitrate; phosphorus; dissolved oxygen; herbicide; insecticide; atrazine; rainfall infiltration; estuary; bay; runoff

INTRODUCTION

In 1999 Louisiana sugarcane (*Saccharum officinarum* L.) growers were managing 171000 ha of their crop (*1*). This acreage, in south central and southwestern Louisiana, was spread over 24 parishes (**Figure 1**). These parishes encompass 6 of the 12 major drainage basins identified in the state (**Table 1**). These 6 basins account for the majority of drainage into estuarine waters of Louisiana's Gulf Coast. In this paper we assess the possible influence of sugarcane cultivation in this area of the state (south central and southwest) on water quality in coastal Louisiana.

Sugarcane is traditionally grown in a four-year crop cycle (five-year cycles are obtainable now with some of the new varieties). Planting is accomplished in late summer to early fall (August−September) by burying sections of freshly harvested stems with ~10 cm of packed soil. This portion of the crop is called seed cane and amounts to ~6% of the acreage to be harvested. Sugarcane shoots arise from adventitious growth from the nodes of the buried stems. The portion of the crop not used for seed cane is then harvested (September−January).

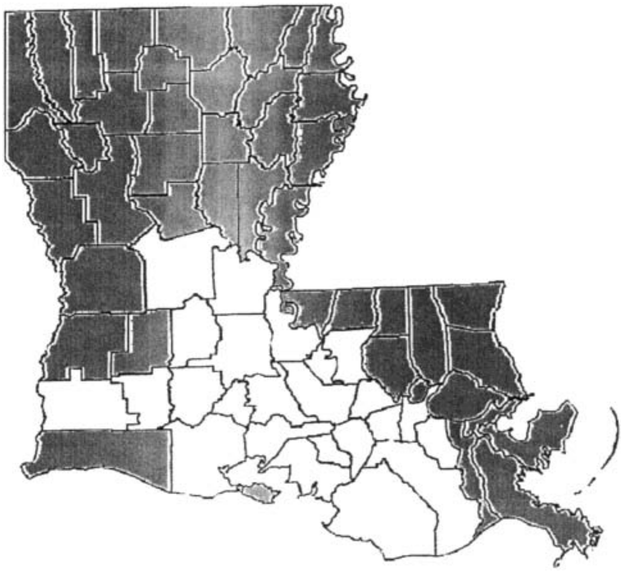

Figure 1. Sugarcane parishes (unshaded) of Louisiana.

Primary growth of the crop begins in the spring following dormancy during the cool winter months. First-year growth is referred to as plant cane, and subsequent regrowth (ratoon crops) from harvest stubble are named on the basis of the number of

10.1021/jf010051v

Table 1. Major Drainage Basins of Louisiana

basin	sugarcane production	basin	sugarcane production
Atchafalaya	yes	Pearl	no
Barataria	yes	Pontchartrain	no
Calcasieu	yes	Red	no
Mermentau	yes	Sabine	no
Mississippi	no	Terrebonne	yes
Ouachita	no	Vermilion-Teche	yes

Table 2. Sugarcane Amendments and Application Rates

amendment	application rate (kg ha^{-1})
herbicides	
atrazine	1.1–2.6
metribuzin (Sencor, Lexone)	0.9–1.6
pendimethalin (Prowl)	0.7–2.2
trifluralin (Treflan)	0.6–1.7
terbacil (Sinbar)	0.8–2.2
asulam (Asulox)	1.0–4.0
glyphosate (Roundup)	1.1–5.6
diuron (Direx)	1.2–1.3
insecticides	
λ-cyhalothrin (Karate)	0.037
esfenvalerate (Asana)	0.037
cyfluthrin (Baythroid)	0.037
tebufenozide (Confirm)	0.14
fertilizer nutrients	
nitrogen (N)	65–180
phosphorus (P_2O_5)	0–60
potassium (K_2O)	0–140

cuttings beyond plant cane (i.e., first or second stubble). Yields after the third year typically decline such that regrowth is no longer economically advantageous. After harvest of the third-year crop, that portion of the field is plowed under and allowed to lie fallow until the next fall. During this fallow period, cultivation and herbicides are commonly used for weed control.

Several herbicides are applied to sugarcane (**Table 2**). Growers rely mostly on atrazine, metribuzin, and pendimethalin. Herbicide applications are made several times each year: during planting in August−September; in the postharvest period in October−January; at regrowth in March−April; and in late May, the layby application before the crop becomes too tall for tractor use. Two major insecticides, λ-cyhalothrin and tebufenozide, are relied upon for control of the sugarcane borer (**Table 2**). In place of λ-cyhalothrin, sometimes the pyrethroids cyfluthrin and esfenvalerate are applied.

The principal fertilizer nutrients applied to sugarcane in southern Louisiana (**Table 2**) are N, P, and K, and rates vary depending on soil texture, pH, and sugarcane crop cycle (plant-cane or stubble-cane) (*2*). Nitrogen and phosphorus are the primary nutrients of interest in relation to water quality. Nitrogen is most often present in southern Louisiana soils in the nitrate form, which is highly susceptible to leaching and off-farm transport in surface runoff. Soils of southern Louisiana are generally high in native P, but the native P may not be available for plant uptake. Phosphorus is key for stimulation of sugarcane root growth and may be applied at low rates, mainly on heavy, clayey soils. Little of the native or applied P is lost in leaching or surface runoff as soluble P; however, loss of P from these agricultural soils can be significant as associated with suspended sediments, a result of soil erosion.

SURFACE WATER QUALITY IN SOUTHERN LOUISIANA

Since 1992 the Louisiana Department of Agriculture and Forestry has been measuring (grab samples) several times a year the concentrations of agricultural pesticides (mostly herbicides) in various water bodies, including bayous, lakes, and rivers. Many of these sampling sites occur in the southern part of the state where sugarcane cultivation predominates but where corn (*Zea mays* L.), grain sorghum [*Sorghum bicolor* (L.) Moench.], and soybean [*Glycine max* (L.) Merr.] are also important. During this sampling period, atrazine (applied to sugarcane, corn, and sorghum) has been the most commonly detected chemical in 19 locations examined in southern Louisiana for this paper. Cyanazine, metribuzin, metolachlor, and terbacil have been detected frequently, but not every year at each of these 19 locations. Pendimethalin and trifluralin have been reported infrequently (four times each); parathion-methyl has been detected twice and azinphos-methyl once. The above information was gleaned from unpublished data of the Louisiana Department of Agriculture and Forestry.

Data for atrazine from four sites (**Figure 2**) within the Vermilion-Teche Basin, which drains 169000 ha of south central Louisiana into Vermilion Bay, show the following patterns from bimonthly sampling by the Louisiana Department of Agriculture and Forestry: the detections fall into the months of February, May−early June, late July−August, and October; the highest concentrations tend to be in May−June. The detections in the May−June period would presumably come from spring applications to corn, sorghum, and pasture in addition to sugarcane. February detections above background would come mostly if not entirely from applications to sugarcane after harvest, and the October values greater than background would come mostly from applications to cane after planting. In the watersheds depicted in **Figure 2**, the highest atrazine concentrations occur in all cases in May−June, with ∼18 μg L^{-1} in Bayou Courtableau (**Figure 2a**) and LaSalle Coulee (**Figure 2c**) and 8 μg L^{-1} in Vermilion River (**Figure 2d**). There is a diminution in maximum concentrations of atrazine from Bayou Courtableau and LaSalle Coulee to Vermilion River, the generally observed trend in concentrations of pollutants when going from lower to higher order streams (*3*). The atrazine concentrations in Bayou Teche (**Figure 2b**) do not generally fit this trend, for they tend to be lower than those in Vermilion River. The February concentrations are near or below 1 μg L^{-1} except for those in Bayou Courtableau (5 μg L^{-1}) and Vermilion River (3 μg L^{-1}). October concentrations remain below 1 μg L^{-1} except for that in Bayou Courtableau (7 and 14 μg L^{-1}). Twenty-two percent of these detections were >3 μg L^{-1}, the maximum contaminant level (MCL) for atrazine in drinking water (*4*). The U.S. Environmental Protection Agency (EPA) has not issued a standard for protection of aquatic life, but the Canadian government has issued a standard of 2 μg L^{-1} for such protection (*5*). This guideline contains a safety factor of 10 with respect to the threshold concentration of 20 μg L^{-1} for damage to some aquatic systems (*6*). This safety factor, among other concerns, allows for the presence of multiple kinds of pesticides. In each watershed of **Figure 2**, box plots [see, for example, Helsel and Hirsch (*7*) for details about box plots] show that the medians of the concentrations are <3 μg L^{-1} (**Figure 3**).

Nitrate in selected watersheds of the Vermilion-Teche Basin (**Figure 4**) remained below 2 mg L^{-1} (except for two data points from Bayou Teche, **Figure 4b**) over an eight-year period, 1991−1998 [data from grab samples collected six times yearly by the Louisiana Department of Environmental Quality (LDEQ) and available on the Department's web site at www.deq.state.la.us/technology/tmdl/index.htm]. This value is considerably below the 10 mg L^{-1} MCL for drinking water set by the U.S. EPA (*4*). Highest concentrations fell in the June−August period. The

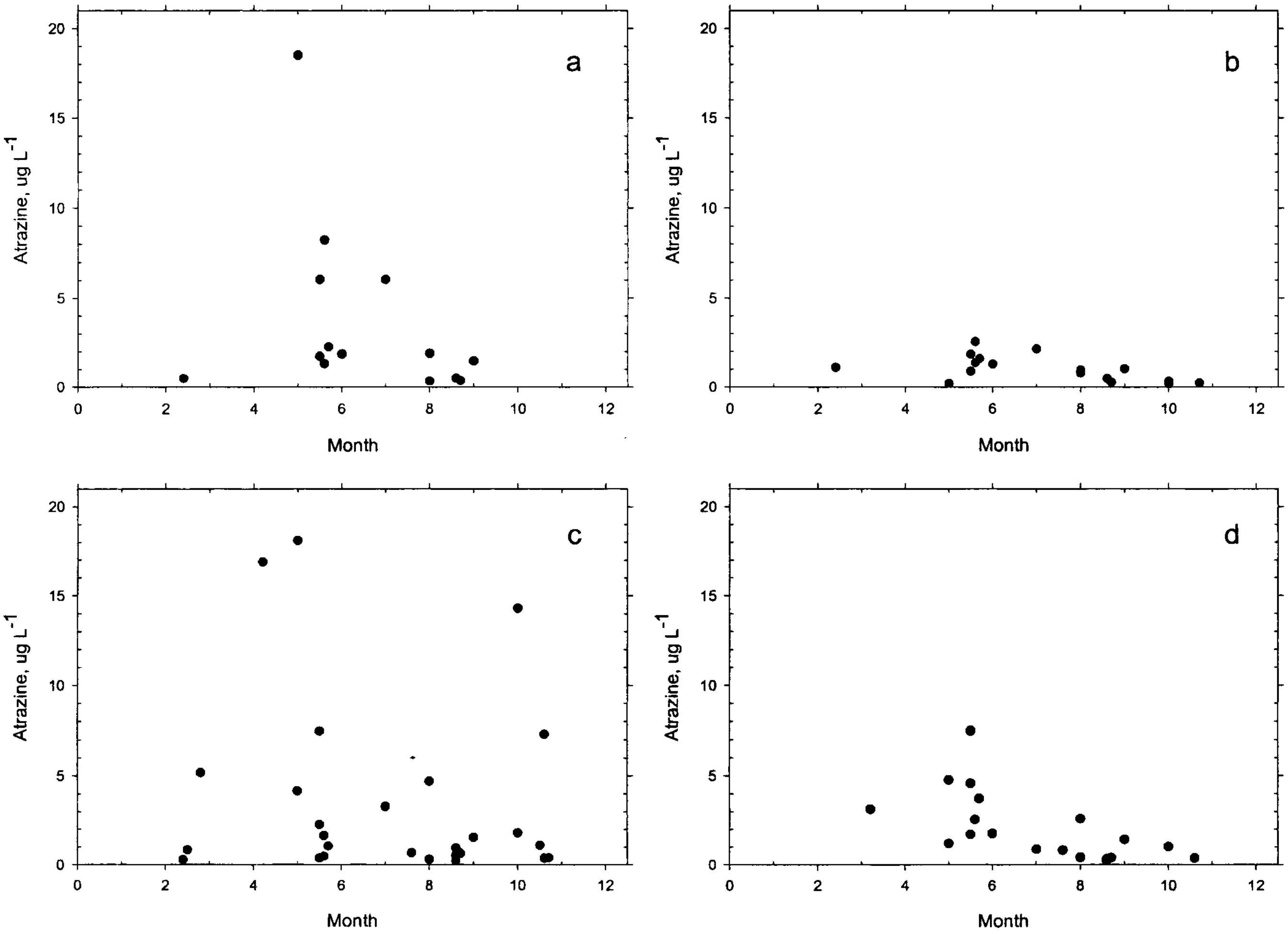

Figure 2. Atrazine in selected watersheds of the Vermilion-Teche Basin: (a) Bayou Courtableau, St. Landry Parish, 1992–1998; (b) Bayou Teche, St. Martin Parish, 1992–1999; (c) LaSalle Coulee, St. Martin Parish, 1992–1999; (d) Vermilion River, Vermilion Parish, 1992–1998.

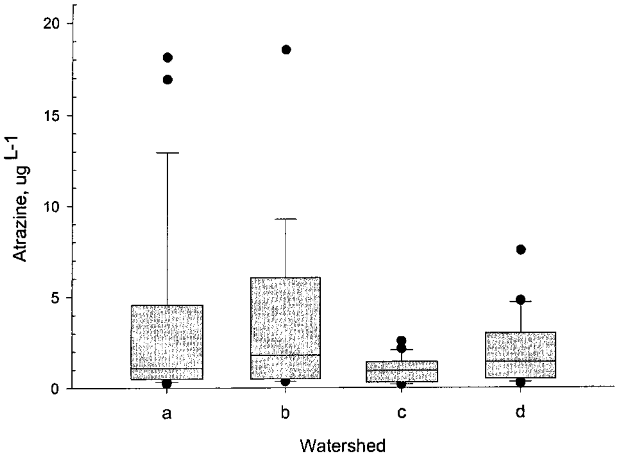

Figure 3. Box plots of atrazine in selected watersheds of the Vermilion-Teche Basin: (a) Bayou Courtableau, St. Landry Parish, 1992–1998; (b) Bayou Teche, St. Martin Parish, 1992–1999; (c) LaSalle Coulee, St. Martin Parish, 1992–1999; (d) Vermilion River, Vermilion Parish, 1992–1998. The box plots were generated by SigmaPlot 6.10. The graphs show 10th percentile (lower error bar), 25th percentile (bottom of shaded box), median (interior horizontal line), 75th percentile (upper edge of box), and 90th percentile (upper error bar). The solid circles show values below the 10th and above the 90th percentiles.

median concentration in each of the four watersheds is between 0.2 and 0.4 mg L^{-1} (**Figure 5**). A concentration of total N >0.3 mg L^{-1} may place a stream of low water velocity into a eutrophic state (*8*, *9*). Water of low velocity is prevalent in the drainage basins and estuaries of southern Louisiana. The lowest median concentration (0.22 mg L^{-1}) is exhibited by the Vermilion Bay samples. This concentration is below the estimated 0.5−1.0 mg L^{-1} range that could place the bay in a eutrophic state (*8*).

Total phosphorus (also available on LDEQ's web site) in the same selected watersheds of the Vermilion-Teche Basin (**Figure 6**) remained below 0.9 mg L^{-1} throughout the eight-year period 1991−1998. The median concentration of each watershed is greater than the total phosphorus concentration for eutrophic status (>0.02 mg L^{-1} for a slow-moving stream, >0.05 mg L^{-1} for an estuary) estimated by the U.S. Department of Agriculture (USDA) (*8*). On the other hand, to control eutrophication, the U.S. EPA (*10*) recommends a maximum concentration of 0.1 mg L^{-1} in flowing waters that do not discharge directly into lakes or impoundments (*11*). The median total phosphorus values reported for these watersheds are in excess of this recommended maximum concentration. With generally high native soil phosphorus and regular amendments for sugarcane production, sugarcane producers should consider reduction of soil erosion and sediment loss in surface runoff waters as a means of reducing P inputs to surface receiving waters in southern Louisiana. It is also important for sugarcane producers to adopt practices that maximize N and P use efficiency, thereby reducing agricultural contribution to N concentration and potential eutrophic conditions in receiving waters. Best manage-

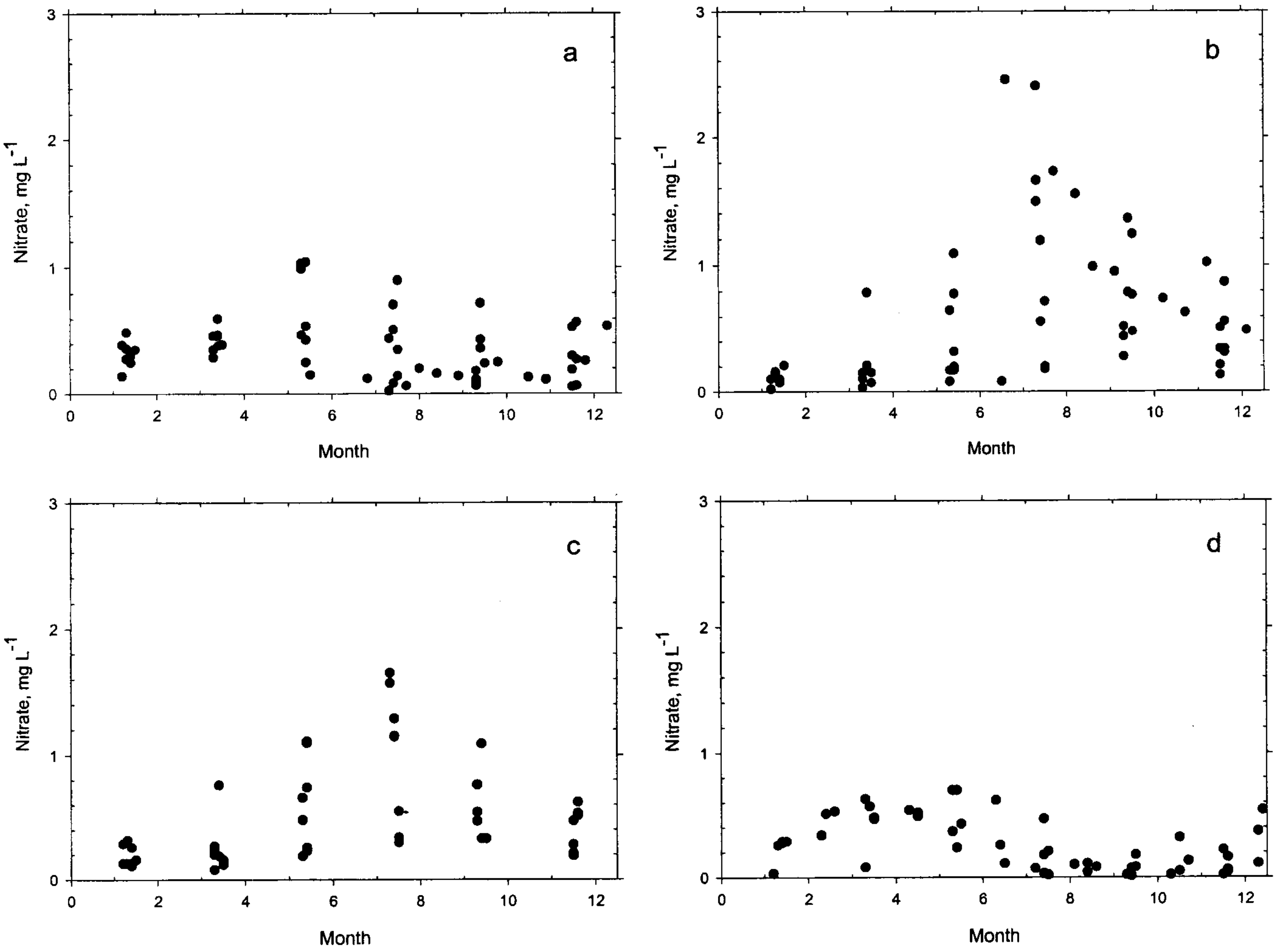

Figure 4. Nitrate in selected watersheds of the Vermilion-Teche Basin, 1991–1998: (a) Delcambre Canal, Iberia Parish; (b) Bayou Teche, St. Martin Parish; (c) Vermilion River, Lafayette Parish; (d) Vermilion Bay, St. Mary Parish.

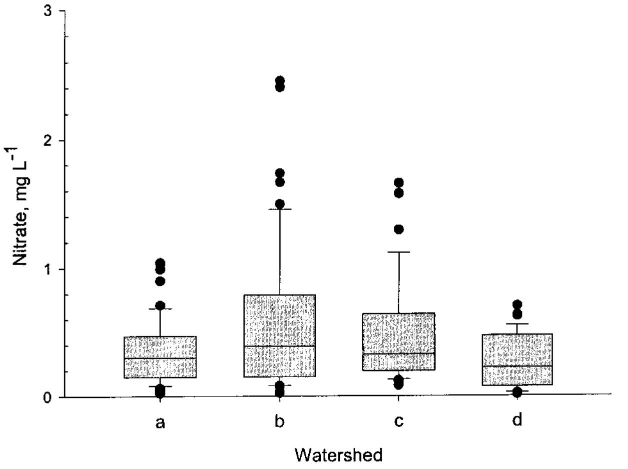

Figure 5. Box plots of nitrate in selected watersheds of the Vermilion-Teche Basin, 1991–1998: (a) Delcambre Canal, Iberia Parish; (b) Bayou Teche, St. Martin Parish; (c) Vermilion River, Lafayette Parish; (d) Vermilion Bay, St. Mary Parish.

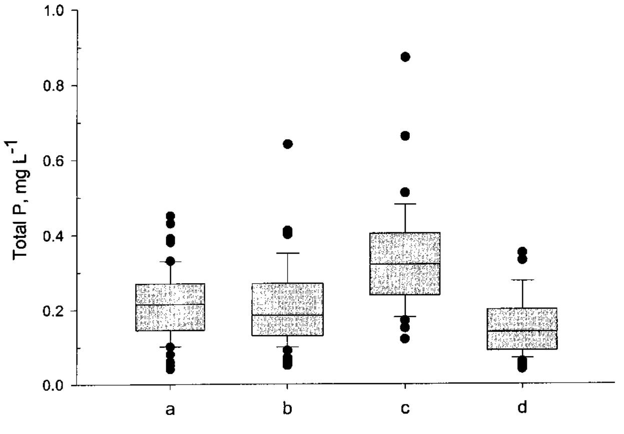

Figure 6. Total phosphorus in selected watersheds of the Vermilion-Teche Basin, 1991–1998: (a) Delcambre Canal, Iberia Parish; (b) Bayou Teche, St. Martin Parish; (c) Vermilion River, Lafayette Parish; (d) Vermilion Bay, St. Mary Parish.

ment practices (BMPs) for sugarcane production have been established to address these conservation techniques (*12*).

The Louisiana Department of Environmental Quality issued in the summer of 2000 total maximum daily loads (TMDLs) for 12 watersheds in the southern part of the state. These watersheds consisted of two rivers, nine bayous, and one lake. In all cases, these TMDLs address 5-day biochemical oxygen demand ($CBOD_5$), ammonia nitrogen (NH_3-N), and dissolved oxygen (DO). Hypoxic conditions are often defined in the range $0.1 < DO < 2$ mg/L, and anoxic conditions are considered to occur when $DO < 0.1$ mg L (*13*). Diminished dissolved oxygen results from organic enrichment stemming from excess sediment and nutrient content. For some sections, a standard of 5.0 mg L^{-1} has been proposed for the winter months (roughly Decem-

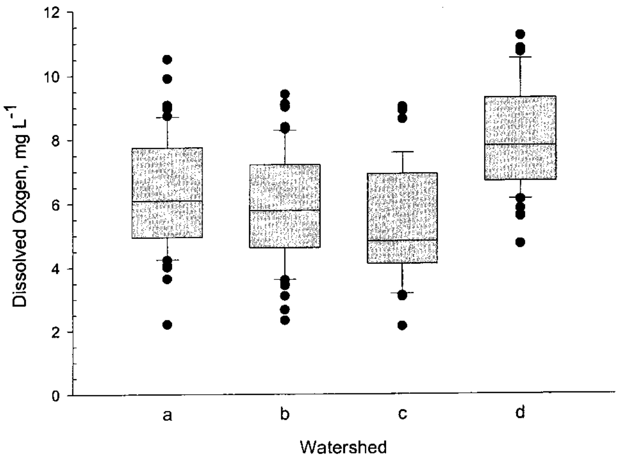

Figure 7. Dissolved oxygen in selected watersheds of the Vermilion-Teche Basin, 1991–1998: (a) Delcambre Canal, Iberia Parish; (b) Bayou Teche, St. Martin Parish; (c) Vermilion River, Lafayette Parish; (d) Vermilion Bay, St. Mary Parish.

ber−February) and 3.5 mg L^{-1} for the summer. For a number of the sections, a standard of 2.0 mg L^{-1} has been recommended for the summer months.

Dissolved oxygen in selected watersheds of the Vermilion-Teche Basin mostly remained >3.5 mg L^{-1} during the 1991−1998 sampling period (**Figure 7**). For Bayou Teche and the Vermilion River, 10% of the readings were <3.5 mg L^{-1}. If >10% of the readings from a sampling station are below the standard, that section of the watershed is considered to be impaired (not supporting designated uses) by the LDEQ. All readings below 3.5 mg L^{-1} were from the summer months. The watershed median values were >5.0 mg L^{-1}, except for the Vermilion River location, which was 4.6 mg L^{-1}. Only one reading from Vermilion Bay was <5.0 mg L^{-1} (4.7 mg L^{-1}).

In a study of impaired watersheds in the state (*14*), organic enrichment/low DO was attributed to municipal and industrial sources and to both irrigated and nonirrigated crop production. Excess nitrogen and phosphorus loads were also assigned to these nonagricultural and agricultural sources. A report of the ecological conditions of U.S. estuaries bordering the Gulf of Mexico (*13*) estimated that 35% of these water bodies were impaired. This paper also estimated that 25% of the affected estuaries in Louisiana were impaired by their nutrient content and that 20% of the impaired estuaries of the state were affected by agricultural practices.

CULTURAL PRACTICES WITH POTENTIAL WATER QUALITY BENEFITS

Conservation tillage, compared to conventional tillage, tends to increase infiltration and reduce surface runoff of water after rainfall. Consequently, runoff losses of accompanying sediment and dissolved and adsorbed pesticides and nutrients are also decreased (*15*). These relative trends are more likely to hold up over a season-long comparison; they may not be observable over short duration (*16*). For example, rainfall shortly after tillage and chemical application may produce less runoff than that from conservation-tilled land, because soil infiltration is greater immediately after tillage. Results from simulated rainfall studies have shown variable success in the reduction of runoff losses of agricultural chemicals by conservation tillage. However, natural rainfall work has tended to demonstrate decreased losses in runoff of these chemicals with conservation tillage practices compared to conventional tillage (*15*, *17*).

Table 3. Runoff Losses from Corn Cultivation As Affected by Controlled Water Table at the Ben Hur Research Station

	% reduction compared to plots without subsurface drains		
measurement	1987[a]	1992[a]	1995[a]
water volume	38	21	24
sediment	–[b]	75	59
atrazine	56	–	22
metolachlor	56	90	22
pendimethalin	–	–	53
chlorpyrifos	–	–	68

[a] Study periods: 1987, 130 days; 1992, 180 days; 1995, 33 days. [b] Data not available.

Table 4. Pesticide Concentrations in Initial Runoff Events As Affected by Controlled Water Table at the Ben Hur Research Station

	% reduction compared to plots without subsurface drains		
pesticide	1987[a]	1992[a]	1995[a]
atrazine	39	–[b]	15
metolachlor	38	86	15

[a] The first surface runoff event occurred 12 days after application (DAA) in 1987, 15 DAA in 1992, and 11 DAA in 1995. [b] Data not available.

Subsurface drains also increase infiltration at the soil surface and can thereby, like conservation tillage practices, lower runoff losses from a field after rainfall. We have conducted a number of field studies of the effectiveness of subsurface drains in reducing runoff losses of agricultural chemicals from Mississippi River alluvial soil in southern Louisiana in field plots under corn cultivation (*18*−*20*). These studies have been carried out on Commerce soil (silty clay loam and silt loam). They have demonstrated various degrees of reduction in runoff of water volume, sediment, and pesticides (**Table 3**). A significant fraction of the seasonal reductions in transport of atrazine and metolachlor in runoff was due to lower concentrations in the first runoff event from plots with subsurface drains, compared to those without such drains (**Table 4**). Reduction in the concentration of these two herbicides in the first runoff event afforded by subsurface drains has been in the range of 15−86%. The remainder in runoff loss reduction was related mostly to a decrease in runoff volume because after the first one or two events, concentrations were little affected by the presence or absence of subsurface drains. The farther away the first runoff event is from application, the less effective and needed are subsurface drains and other infiltration-enhancing cultural practices in reducing agrochemical loss in runoff. Cultural practices that increase infiltration (reduce surface runoff) do not necessarily provide lower concentrations of pesticides in the runoff: Baker et al. (*21*) reported 35−118% increases in concentrations of cyanazine and alachlor in runoff from conservation tillage plots (25% cover) compared to plots with no cover.

An important observation for atrazine and metolachlor in our work is that only ∼10% of the reduction in their runoff losses appears in the subsurface drain leachate. Presumably, the rest of the runoff decrease remains resident in the soil profile to undergo degradation reactions. One of our studies (*19*) has also shown that sediment in runoff is lessened to a greater degree than water volume and, consequently, chemicals of low water solubility, attached to sediment, are reduced in runoff to a corresponding level (**Table 3**, 1995 data).

We have limited data on the effectiveness of subsurface drains on nutrient runoff from our study plots (*22*). Subsurface drains reduced seasonal runoff losses by 25%, compared to no drains. In contrast to the herbicide results, 44% of this overall reduction reappeared in the drain effluent. Consequently, the subsurface drains led to net reduction in nitrate runoff of 14%. Conservation tillage practices have also been shown to reduce nitrate runoff by increasing leaching of this nutrient deeply into the soil profile (*23*).

We have initiated a field installation at the Louisiana State University Agricultural Experiment Station's Sugarcane Research Station at St. Gabriel, LA. These field plots will allow study of the influence of a variety of cultural practices on runoff and soil profile leachate water quality from sugarcane cultivation. Treatments will include subsurface drains and open drainage ditches as cultural practices for increasing infiltration and removing excess water. Open field ditches are more acceptable to Louisiana sugarcane growers than subsurface drains because of cost. There is evidence that vegetated ditches can effectively reduce movement of agricultural chemicals from the site of application (*24*).

In addition, allowing postharvest leaf residue to remain in the field rather than burning it will be a treatment parameter. Leaving the leaf residue in the field could enhance sequestration of soluble nitrogen within microbial biomass and reduce nitrogen transport to receiving waters in watersheds and estuaries adjacent to sugarcane production. In Louisiana, Sturgis (*25*) found that incorporation of sugarcane trash reduced nitrate concentration in the soil, a result of incorporation of excess soil nitrogen into microbial biomass. Although this could benefit receiving water quality, the practice can reduce sugarcane yield (*26*). This study will permit an assessment of these practices on the potential for lessening the possible contribution to low dissolved oxygen levels in southern Louisiana, including the coastal region, from sugarcane cultivation.

SUMMARY

If the U.S. EPA sets an atrazine standard for protection of aquatic life similar to that set by the Canadian government, some of the atrazine concentrations from the Vermilion-Teche Basin discussed in this paper will be above that standard. In this basin, atrazine has been detected in excess of the MCL for drinking water. Nitrogen and phosphorus concentrations that have been measured could potentially cause eutrophication.

Concentrations of N and P in receiving waters are not currently directly linked to sugarcane production and management. However, as regulatory instruments such as TMDLs are exercised, the direct link between nutrient contamination of receiving waters with sugarcane production will likely become established. Because off-site transport of both N and P must be addressed, a combination of improved management practices will likely be required. These conservation management practices should include reduction of surface runoff volume and reduction of soil erosion and sediment loss. Successful implementation of these practices will also require integration of improved crop residue management practices, incorporation of filter strips or water settling areas, and new sugarcane varieties that will produce profitable yields under these new conditions. Such a reduction of N and P loss to receiving waters could improve CBOD and DO levels in these waters, with respect to current and future TMDL thresholds. The current emphasis on TMDLs in Louisiana does not address pesticides, but practices such as grass filter strips, settling areas for surface runoff, and vegetation-managed drainage ditches will also reduce runoff of these chemicals.

ACKNOWLEDGMENT

We thank Butch Stegall of the Louisiana Department of Agriculture and Forestry for making available to us his department's data for atrazine. We greatly appreciate the advice of Al Hindrichs of the Louisiana Department of Environmental Quality on his department's nutrient data. Valuable comments on an early version of the manuscript were provided by Dr. Benjamin Legendre of Louisiana State University Agricultural Center, Cooperative Extension Service, Mr. Richard Coupe of the U.S. Geological Survey, Pearl, MS, and Dr. Matthew Moore, USDA-ARS, National Sedimentation Laboratory, Oxford, MS.

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Received for review January 11, 2001. Revised manuscript received July 30, 2001. Accepted October 2, 2001.

JF010051V