

Agricultural Runoff, Coastal Engineering and Flooding



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Short Communication A

SEASONAL PATTERNS OF NITROGEN AND PHOSPHORUS LOSSES IN AGRICULTURAL DRAINAGE DITCHES IN NORTHERN MISSISSIPPI

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ABSTRACT

Non point source pollutants such as nitrogen and phosphorus are transported via agricultural drainage ditches to receiving waters and result in eutrophication and downstream ecosystem degradation. Seasonal precipitation patterns, and land use contribute to variable concentrations of nitrogen and phosphorus loss from the landscape. This study investigated the differences in total inorganic-phosphate (TIP) and dissolved inorganic-nitrogen (DIN) concentrations in drainage ditches as a function of hydrology (stormflow vs. baseflow), land use (farmed vs. CRP vs. control) and season (growing vs. dormant). TIP and DIN ditch concentrations typically decreased from farms > CRP > control over both seasons. DIN concentrations were highest in baseflows during the growing season; however, mean DIN concentrations in baseflow were not significantly higher in the growing season than in the dormant season. Mean TIP concentrations and particulate phosphorus ratios increased in the dormant season with increased precipitation volumes and storm events. TIP concentrations were highest in growing season stormflows following fertilizer applications. A change in land use from agriculture to CRP decreases associated TIP and DIN in runoff and baseflow concentrations but residual phosphorus is still present in stormflows 10 yrs post the discontinuation of farming activity. This research highlights the episodic nature of nutrient contamination

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driven by land use, anthropogenic fertilization, and the temporal variability of storm events.

INTRODUCTION

Nutrients and sediments from agriculture are major contributors to non-point sources of pollution and the impairment of U.S. waters (Carpenter et al. 1998). Contaminated discharge in the Mississippi River Basin is transported via drainage ditches to receiving waters such as streams and rivers, and eventually impacts coastal ecosystems such as the Gulf of Mexico (Rabalais et al. 1996, Turner and Rabalais 2003). Surface drainage ditches act as a primary conduit for surface and subsurface flows from the agricultural landscape, and thus are a major source of agricultural non-point source (NPS) pollutants (Nguyen and Sukias 2002). Agricultural discharge into drainage ditches is episodic, and thus information is needed on the variability of nutrient input as a result of hydrology, fertilization and land use to evaluate the temporal contribution of nutrient pollutants receiving waters.

Nitrogen (N) and phosphorus (P) are major contributors of nutrient NPS pollution from farms. However, N and P are each variable in respect to hydrological transport pathways. Typically, soil cation exchange capacity tends to increase ammonium concentrations in silt, loam, and clay soils. Depending on the intensity of subsurface drainage, management practices and connectivity of macropore flow, negatively charged nitrate NO_3^- may be transported to tile drains and receiving waters through prominent pathways of subsurface-flow (Owens et al. 1992, Angle et al. 1993, Skaggs et al. 1994). Leaching of NO_3^- most likely occurs post fertilizer application, when it is in excess in the root zone of the crops. Furthermore, NO_3^- is subject to leaching through late fall (October), and winter (November-February) when crop uptake of N is minimal or the farms lie fallow (Angle et al. 1993).

The loss of P in surface runoff occurs in inorganic, organic, dissolved and particulate forms (Sharpley et al. 1994). For the majority, P adsorbs to the fine particulate fraction in soil profiles, and is transported via bedload or suspended-sediment in surface runoff and erosion to receiving waters. However, some studies have shown P to move with subsurface drainage (Skaggs et al. 1994, Sims et al. 1998), where P flows occurs from downward movement of P by leaching or preferential flow through macropores.

Change in land use out of agriculture has an effect on anthropogenic sources of nutrients. The Natural Resources Conservation Services' (NRCS) Conservation Reserve Program (CRP) puts farm lands adjacent to receiving water out of crop production to create a buffer between the agricultural landscape and aquatic systems. The lack of agriculture results in a lack of anthropogenic fertilizer application, which potentially decreases nutrient concentrations within drainage ditches, and subsequently downstream aquatic ecosystems.

Seasonal influences on rainfall amounts, intensity, and frequency will have an effect on nutrient concentrations especially in relation to timing of fertilizer application and the time lag between application and rainfall patterns. Farm management practices are also seasonally influenced. In the growing season planting and crop growth occurs, while over the dormant season crops are harvested and the farms lie fallow. This study investigated the differences in TIP and DIN concentrations in drainage ditches as a function of hydrology (stormflow vs. baseflow), land use (farm vs. CRP vs. control) and season (growing vs. dormant).

MATERIALS AND METHODS

Study Sites

Primary intercept drainage ditches were sampled for 2 yrs within three different land use categories (farm vs. CRP vs. control) to compare the seasonal losses of nitrogen and phosphorus in baseflow and stormflow (Figure 1).

The farm ditches sampled drained no-till cotton farmed in a summer row-crop, winter fallow sequence. The two farms had a single surface drainage ditch, each draining approximately 13 ha. The farms were underlined with Chenneby silt loam soils (Morris 1981), high water tables and had no subsurface tile drains. Farm drainage ditches were on average 440 m (± 26) long, and consisted of eight sampling locations positioned equidistant (± 50 m) along the drainage ditches.

The CRP ditch drained an area of farmland previously farmed in conventional tilled cotton and rotational soybean, but was converted 10 y ago into CRP. The CRP site had a similar surface geology and had no subsurface tile drains. The CRP ditch was situated in close proximity to the farm ditches so that weather and storm event patterns were consistent between ditches. Within the same county and watershed, the control ditch drained a watershed with negligible anthropogenic influences.

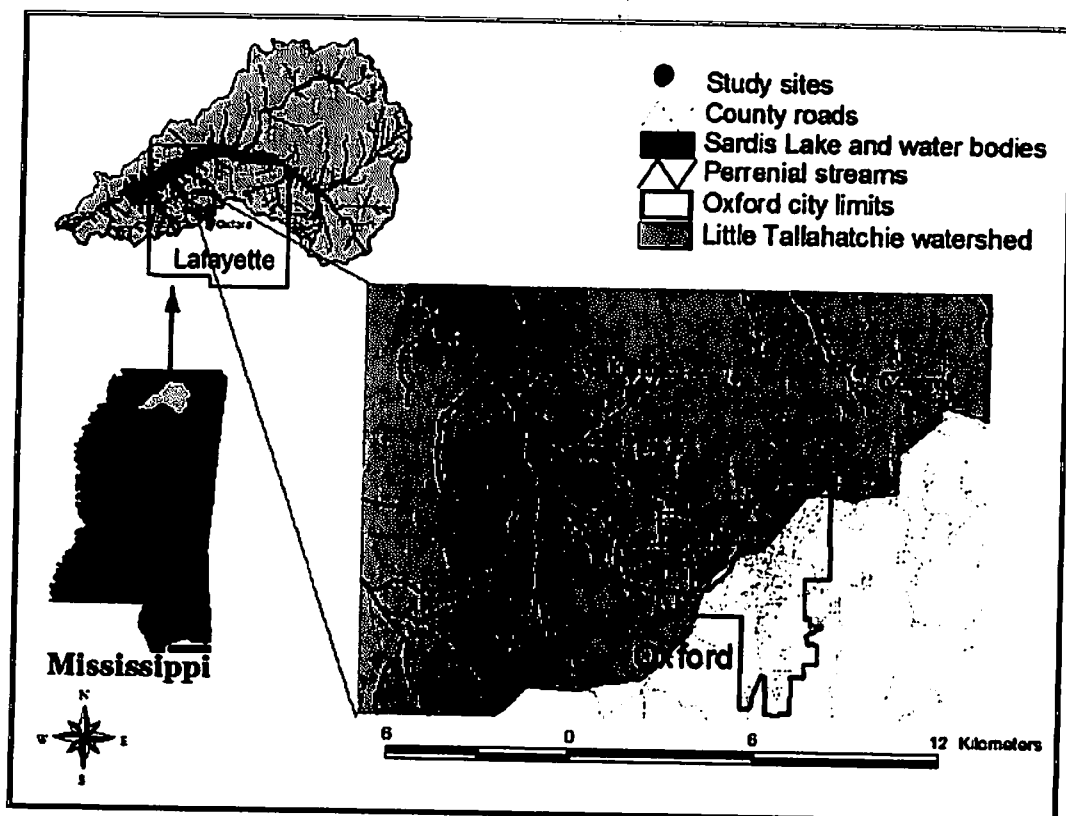


Figure 1. Study locations within the Little Tallahatchie watershed, northern Mississippi. GIS layers and data courtesy MARIS (www.maris.state.ms.us).

The control ditch flowed continuously throughout the year out of a non-agricultural watershed (± 200 ha) and had a similar soil type to both farm and CRP ditches (Chenneby silt loam) (Morris 1981). CRP and control ditches were on average 600 m (± 95) long, and consisted of seven sampling locations positioned equidistant (± 90 m) along the drainage ditch.

Farms were annually fertilized with ammonium nitrate (NH_4NO_3) and phosphate (PO_4^{3-}) using a split fertilizer application. The first application occurred pre-planting in May of 112 kg ha⁻¹ NH_4NO_3 and 56 kg ha⁻¹ PO_4^{3-} . Subsequently, a second application of 56 kg ha⁻¹ NH_4NO_3 was applied early July when the cotton was six nodes in height. Seasons were defined as growing (April – September) and dormant (October – March). April – September was used to adequately represent spring-bloomers such as *Juncus effusus* (March-May) and late summer blooms, e.g. *Sagittaria* sp. and goldenrods (*Solidago* and *Euthamia* spp.). The dormant season was classed as the remaining months from October – March.

Sampling of Baseflow Versus Stormflow Events

Surface flows typically as a result of a storm event are defined as stormflows. In contrast, baseflow is typically independent of a rainfall event, and is more than likely subsurface flows that may have been transformed by exposure through the soil profile (Haygarth et al. 2000). Sampling was divided into baseflow and stormflow samples. Grab baseflow samples were taken monthly at each sampling location to determine seasonal and annual differences in nutrient concentrations.

Stormflow samples were representative water samples generated by a specific storm event that elevated water levels within the ditch. Storm events were defined as rainfall events that generated sufficient surface runoff to elevate water volumes, and velocities within the drainage ditches. The storm water sample was obtained using a 400ml sampling container attached to a stake in the middle of the ditch, suspended 2 - 3cm above the baseflow water level. Storm samples were retrieved within 48 hours (usually 24 hrs) to negate the influence of evaporation on nutrient concentrations. The storm sample was a representative water and sediment sample of that specific storm event, which was more than likely a conservative measure as it was a mixed sample from the rising or first flush event, peak and falling limbs of the storm hydrograph. Refer to Kröger et al. (2007a, 2008) for hydrological and nutrient load data. All water samples were transported back to the lab in an ice chest, and kept at 4°C until chemical analysis took place. A total of 26 storm events over 2 y generated sufficient surface runoff to raise water levels in the respective ditches. Rainfall was recorded for the farms and CRP sites at the USDA-National Sedimentation Laboratory, Oxford MS, located 3 km from both CRP and farm sites. Control rainfall data was provided by the UMFS weather station on site of the control ditch.

Chemical Analyses for Nitrogen and Phosphorus

Unfiltered samples were analyzed for total inorganic phosphorus (TIP) using the ammonia persulfate digestion procedure with a colorimetric molybdate reaction read at 880 nm on a spectrophotometer (Murphy and Riley 1962). The TIP analysis procedure converts organic dissolved and particulate forms to inorganic P during digestion. Samples filtered through a 0.45µm cellulose membrane were analyzed for dissolved inorganic phosphorus (DIP), ammonia (NH_3), nitrate (NO_3^-) and nitrite (NO_2^-). Subtracting DIP from TIP produced the particulate phosphorus (PP) fraction. Dissolved inorganic phosphorus was determined

using the same colorimetric method as TIP, only after the sample was filtered. Nitrate and NO_2^- were analyzed using a Dionex Ion Chromatograph fitted with an anion conductivity detector (detection limit $>0.05\text{mg l}^{-1}$). Ammonia was determined by a standard phenate method (APHA 1998). Dissolved inorganic nitrogen (DIN) was the summation of NH_3 , NO_3^- and NO_2^- .

Statistical Analyses

A one-way ANOVA was used to compare the means of nutrient concentrations between sites (land use) and season, and subsequently between base- and stormflow. All data were log transformed to meet the assumptions set forth by ANOVA. When sites (farm vs. CRP + control) were grouped together, or compared between base and storm flows they were compared using 2-sample, two tail, unequal variance student t-tests. All averages reported are \pm standard error at an alpha of 0.05. Sample location data were averaged for a ditch to provide a single estimate on nutrient concentrations, rather than violating the assumptions of independence by examining each sampling location independently within a single ditch.

RESULTS

Seasonal Rainfall Patterns

Variations in precipitation amounts and intensity of storm events occurred between growing and dormant seasons for 2004 and 2005 (Table 1). In both 2004 and 2005, approximately 50% of the rainfall occurred in short, intense rainfall events (stormflows) that generated significant amounts of overland surface runoff and elevated water levels within all ditches. In 2004, there was a greater overall stormflow within the dormant season, with more than double as much precipitation ($p < 0.0001$) falling over the 2004 dormant season than the growing season. In 2005 there were no significant differences ($p = 0.95$) in stormflow amounts, precipitation amounts ($p = 0.87$) and average storm size between the growing and dormant seasons (Table 1). Storm events were significantly larger ($p < 0.0001$) over the 2004 dormant season than the 2005 dormant season ($81.9 \pm 27 \text{ mm storm event}^{-1}$) (Table 1). There were no significant differences ($p = 0.082$) in total rainfall volumes between 2004 and 2005; however, the distribution of rainfall between growing and dormant seasons was quite marked.

Total Inorganic Phosphorus: Seasonal Vs. Flow Conditions Vs. Land Use

Figures 2 and 3 specify the differences in baseflow and stormflow TIP species respectively between farm, CRP and unfarmed drainage ditches in different seasons. Farm ditches consistently had significantly higher concentrations of all TIP species for base- and stormflows throughout both growing ($F_{\text{Base } 3, 254} = 18.05, p < 0.0001$; $F_{\text{Storm } 3, 218} = 53.09, p < 0.0001$) and dormant seasons ($F_{\text{Base } 3, 239} = 42.48, p < 0.0001$; $F_{\text{Storm } 3, 357} = 63.09, p < 0.0001$) than control and CRP ditches.

Table 1. Differences in rainfall patterns (number of storm events) and precipitation amounts over the growing and dormant seasons between 2004 and 2005.

Year		Season	Σ (mm)	Mean (Σ) (mm/storm event)	n	S.E.
2004-05	Storm Events	Growing	221	36.84	6	8.17
		Dormant	573	81.9	7	27.49
	Precipitation	Growing	543.313	3.0184	180	0.68
		Dormant	1005.586	5.55	179	1.12
2005-06	Storm Events	Growing	369.67	52.81	7	4.33
		Dormant	322.07	53.67	6	4.75
	Precipitation	Growing	658.15	3.61	183	0.86
		Dormant	676.67	3.80	178	0.72

n represents the total number of storm or precipitation events for a particular season. Precipitation includes all rainfall events that did not produce significant runoff to elevate water levels within the ditch

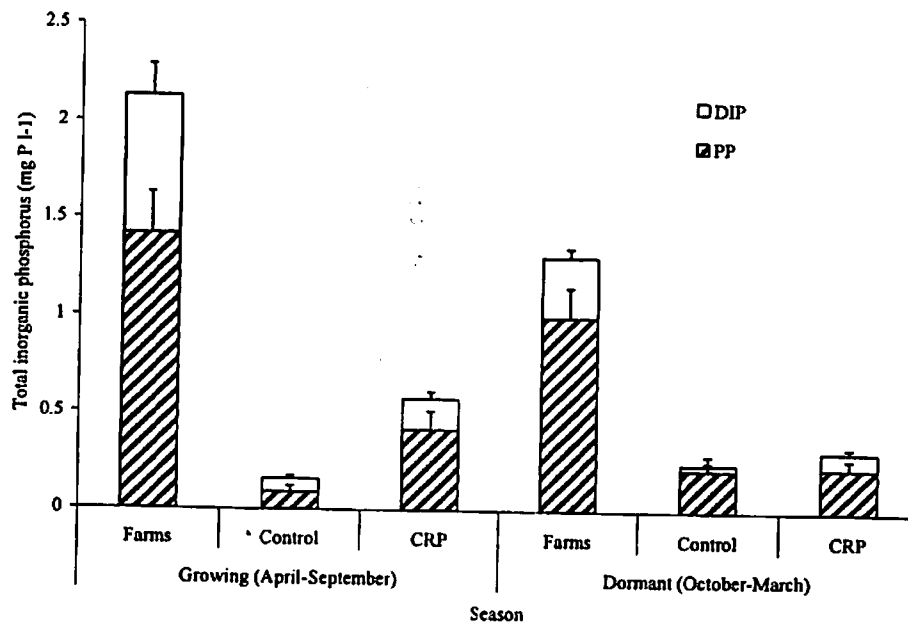


Figure 2. Mean (\pm S.E.) seasonal TIP (DIP+PP) concentrations within surface drainage ditches for monthly baseflow conditions from June 2004 – May 2006.

Even though there were no significant differences between base- and stormflow DIP concentrations between growing and dormant seasons for either farm ($p = 0.1144$) or control ditches ($p = 0.3841$), the larger proportion of DIP over the growing season in farm ditches suggests an anthropogenic fertilizer application (Figure 2 and 3).

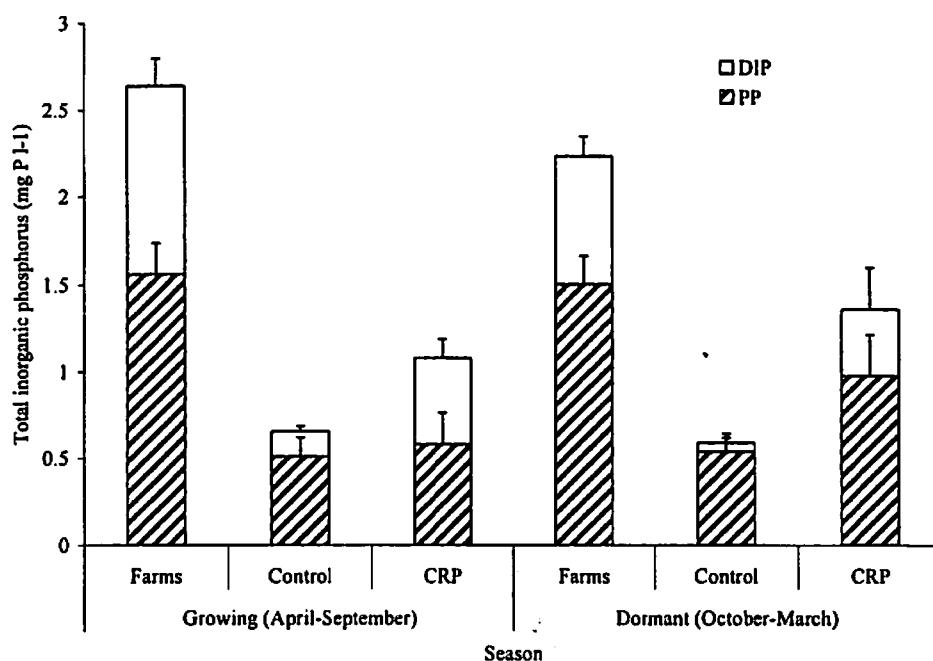


Figure 3. Mean (\pm S.E.) seasonal TIP (DIP+PP) concentrations within surface drainage ditches for stormflow conditions from June 2004 – May 2006

The relative proportion of PP contributed to TIP in base- and stormflows increases from the growing season to the dormant season for both farms (67 – 77%) and controls (65 – 85%) most likely as a result of increased water volumes and sediment loads. The CRP ditch always had significantly higher baseflow TIP, PP and DIP concentrations ($p \leq 0.0001$) than the control ditch for base- and stormflows.

Stormflow (Figure 3) TIP concentrations for farm, CRP and control ditches were significantly higher for growing ($t_{\text{farm}}=5.629$, $t_{\text{CRP}}=3.826$, $t_{\text{UMFS}}=4.712$; $p < 0.001$) and dormant seasons ($t_{\text{farm}}=6.072$, $t_{\text{CRP}}=5.232$, $t_{\text{UMFS}}=4.571$; $p < 0.001$) than baseflow concentrations. Furthermore, the CRP ditch again, had significantly higher concentrations ($p < 0.001$) concentrations of DIP and PP when compared to the control ditch. The control ditch had no significant differences in TIP concentrations between growing and dormant seasons ($p = 0.167$). The growing season ratio of DIP: PP for farm baseflow was 0.48. The growing season ratio of DIP:PP for farm stormflow within the growing season was 0.69, suggesting a larger DIP contribution in stormflow than in baseflow.

Dissolved Inorganic Nitrogen: Seasonal Vs. Flow Conditions Vs. Land Use

Figures 4 and 5 specify the differences in baseflow and stormflow DIN species respectively between farm, CRP and control drainage ditches in different seasons. Farm ditches consistently have significantly higher concentrations of all DIN species when compared to the CRP and control ditches ($F_{\text{Base3, 281}}=18.05$; $p < 0.001$).

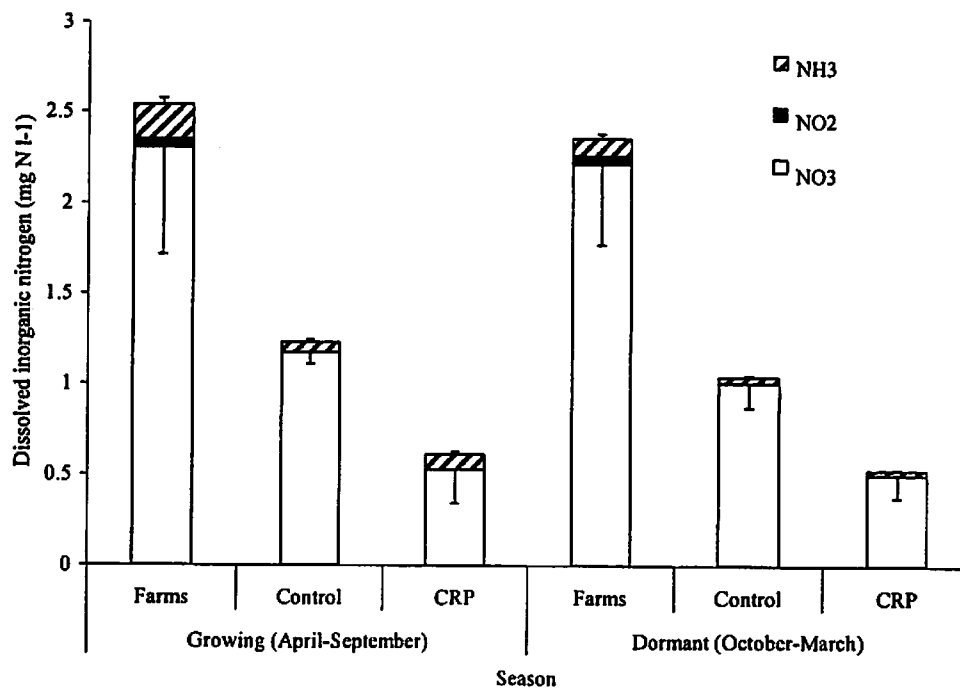


Figure 4. Mean (\pm S.E) seasonal DIN ($\text{NO}_3 + \text{NO}_2 + \text{NH}_3$) concentrations within surface drainage ditches for monthly baseflow conditions from June 2004 to May 2006

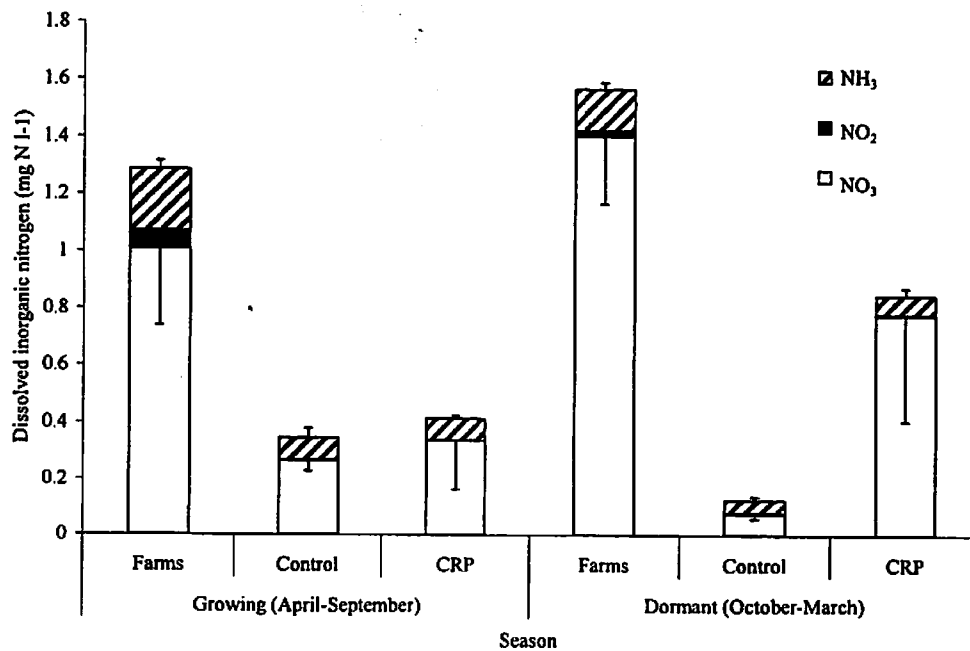


Figure 5. Mean (\pm S.E) seasonal DIN ($\text{NO}_3 + \text{NO}_2 + \text{NH}_3$) concentrations within surface drainage ditches for stormflow conditions from June 2004 to May 2006

There were no significant differences between seasons for CRP and control ditches for NH_3 and NO_2^- . Nitrite contributed close to zero to the overall DIN concentrations for control and CRP ditches, and contributed less than 5% to DIN for farm ditches, where as NO_3^- was always at least 90% of DIN for both farm, CRP and control ditches. There were no significant differences ($p = 0.359$) in farm DIN baseflow concentrations between the growing and dormant seasons.

Stormflow (Figure 5) conditions had significantly lower concentrations of DIN, particularly NO_3^- for farms, UMFS and CRP ditches for both the growing ($F_{\text{Storm } 3, 218} = 2.38, p = 0.07$) and dormant seasons ($F_{\text{Storm } 3, 313} = 5.94, p = 0.006$) as compared to baseflow conditions. Dormant season farm stormflow DIN and NO_3^- concentrations were higher than the growing season, but were not significant ($p = 0.18$). Ammonia ($p = 0.001$) and NO_2^- ($p = 0.041$) farm concentrations were significantly more concentrated in the growing season than the dormant season (Figure 5).

DISCUSSION

Nutrient movement from the agricultural landscape into drainage ditches was a factor of variable precipitation events, surface runoff contributions and surrounding watershed land use. The contribution of applied fertilizers on the farms resulted in maximum concentrations of farm NO_3^- , DIN, DIP and TIP occurring in the growing season post fertilization in both baseflow and stormflow conditions in both years of study as a result of runoff and leaching. The exception occurred for DIN and NO_3^- for farm dormant season stormflows. A lack of NO_3^- leaching and growing season rainfall during 2004, coupled with large storm events over the dormant season would more than likely increase NO_3^- concentrations. Angle et al (1993) suggested that N fertilizer accumulation, and lack of leaching would result in higher concentrations of N being transported through late fall into winter. Furthermore it was hypothesized that the senescence of nutrient enriched above ground ditch vegetation could have resulted in an increase in DIN over the dormant season (Kröger et al. 2007b).

Lower concentrations of DIN in the dormant season baseflows suggest a decrease in N source with time after fertilizer application as a result of subsurface leaching and overland surface runoff (Owens et al. 1992). Significantly higher concentrations of DIN in baseflow over stormflow suggest a predominance of NO_3^- leaching through subsurface flows. Many studies support that baseflow will have higher concentrations of NO_3^- and other mobile constituents, than a stormflow that has generated overland surface runoff (Jackson et al. 1973, Timmons et al. 1977, Bauder and Schneider 1979, Owens et al. 1992). However, the conversion of land from agriculture into CRP, or the lack of agriculture has shown significantly lower, if not negligible DIN concentrations in surface drainage ditches. Thus removing sensitive land from agricultural production reduces DIN fertilizer applications which play a major role in the contribution toward NPS pollution of downstream ecosystems and ultimately coastal environments.

Higher concentrations of TIP (DIP and PP) in stormflows suggest that phosphorus, in the mid-South, is predominantly transported via overland surface pathways. A decrease in TIP concentrations with time highlights the effect of an anthropogenic fertilizer event on P concentrations in farm ditches and suggests temporal leaching post application. However,

conversely, TIP concentrations increase with time from the growing to dormant season for the CRP and control ditches. The likelihood of increased precipitation in the dormant season, resulting in increased overland runoff suggests an increased sediment load, and higher stormflow TIP and PP concentrations than baseflow. CRP ditches had higher P concentrations in base- and storm flows when compared against the control or reference site within the watershed. Prior to CRP conversion the landscape had been actively farmed and fertilized in accordance with standard practices for cotton and soybean. Long term P fertilizer additions have the effect of concentration and accumulation in the soil, thus providing a potentially long term source of P leachate via stormflows (Haygarth and Jarvis 1999).

Understanding nutrient concentrations within the drainage ditch under variable land uses allows farm effluent loads to be determined (Kröger et al. 2007a, Kröger et al. 2008). It is important to remember that agricultural drainage ditches are wetland ecosystems that potentially play a mitigating role on influent nutrient loads further downstream. Determining the role of agricultural drainage ditches in their capacity to reduce nutrient loads is vital to understanding the effluent concentrations and loads reaching receiving waters.

CONCLUSION

Nutrient contamination from agricultural landscapes is characteristically episodic and driven by fertilization events, management practices, and hydrological variability of storm events. The order of TIP and DIN concentrations in base- and stormflows were farms > CRP > control, where the addition of annual fertilizers on farms elevated DIN and TIP concentrations with respect to CRP and control ditches. Nitrogen and P concentrations in base- and stormflows for all land uses were driven by the characteristics of storm events between the seasons influencing sub-surface and surface runoff.

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