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# Response of Nutrients and Sediment to Hydrologic Variables in Switchgrass Intercropped Pine Forest Ecosystems on Poorly Drained Soil

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**Abstract** In the present study, we examined the relationships between (1) N, P, total organic carbon (TOC), and total suspended sediment (TSS) each and stream flow and water table elevation, individually (2) N, P, and TOC, each and TSS, and (3) stream water C/N ratios and stream flow in managed pine forests with various switchgrass treatments implemented on four watersheds in coastal North Carolina plain. The treatments included a young pine forest–natural understorey (27.5 ha), a young pine forest with switchgrass intercropped between pine rows replacing natural understorey (IC) (26.3 ha), a mature thinned pine forest (25.9 ha), and pure switchgrass (27.1 ha). Precipitation, flow, water table elevation, N, phosphate, TOC, and TSS concentrations were measured from November 2009 to June 2014 (switchgrass growth from May 2012 after site preparation (SP) that ended in April 2012). Relationships ($\alpha = 0.05$) among water quality and hydrologic variables were examined using a Spearman rank correlation coefficient and the principal component analysis (PCA). Nitrogen concentrations on IC were positively correlated with flow during SP. The export of nutrients and sediment from this drained pine plantation forest intercropped with switchgrass was affected by changes in hydrological and biochemical processes regulating the formation and transport of different water quality constituents during both site preparation and pine and switch growth periods. The PCA showed strong interaction between the hydrological and biochemical processes.

**Keywords** C/N ratio · Drainage · Principal component analysis · Spearman's correlation · Understorey vegetation · Water table

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## 1 Introduction

Understorey vegetation and silvicultural management practices can influence both hydrology and water quality, as well as their respective relationships on managed pine forests. The distribution of natural understorey vegetation is random, unlike in a managed setting, where site preparation for systematic arrangement of grass or short rotation woody crops is achieved by planting seeds or seedlings between perennial tree rows. Site preparation also involves soil disturbance, resulting in soil erosion, changes in soil surface roughness and soil properties, and incorporation of surface litter into deeper soil layers. Studies documented that site preparation for switchgrass establishment in upland loblolly pine forests in Southern USA (states of Alabama and Mississippi) increased the export of total suspended solids (TSS), total phosphorus (TP), and dissolved organic carbon (DOC) to the receiving stream (Bennett 2013; Carter 2016; Dobbs 2016). Blanco-Canqui (2010) reviewed literature on the environmental impacts of energy crops and reported that the root interaction and multi-story canopy cover in a mixture of plants with warm season grasses like switchgrass are more effective in reducing soil erosion than a monoculture. Blanco-Canqui (2010) also reported that switchgrass roots improve porosity and create macropores in the soil structure, which improve infiltration and storage, and increase saturated and unsaturated hydraulic conductivity.

The greatest changes in the hydrology and water quality of a managed forest system occur during harvesting and site preparation (Shepard 1994). Tree removal at harvest reduces evapotranspiration (ET) and increases runoff (Amatya et al. 2006; Grace III and Carter 2001), which can increase nutrient and sediment loads. The changes caused by harvest and site preparations are gradually reversed as trees and vegetation become re-established (Amatya et al. 2006; Briggs et al. 2000; McBroom et al. 2008a, 2008b; Skaggs et al. 2019). Significantly greater concentrations of ammonium nitrogen ($NH_4$-N) were observed in shallow ground water under plots established with pine and natural understorey compared with switchgrass intercropped pine and pure switchgrass plots (Cacho 2013; Cacho et al. 2018, 2019). Tree harvesting and site preparation disturb the soil and increase exposure of soil particles to the impact of raindrops, which in turn increases the potential for soil erosion. In a study conducted in the southern Piedmont of central Alabama, Grace III (2004) found that silvicultural operations affected the transport of soil particles and sites subjected to bedding (done by a special bedding harrow that forms raised beds for planting tree seedlings) stored more runoff and reduced sediment transport. Grace III (2004) also reported that precipitation intensity affected soil loss for a harvested forest in the Athens Plateau area of southwestern Arkansas. Jordan et al. (1997) identified a correlation of P with TSS and attributed this correlation to P sorption. Various studies documented water quality responses to hydrologic variables and management operations such as site preparation (e.g., harvesting, raking, bedding, and ripping), water management, and traditional pine forest regeneration. For example, Amatya et al. (1998) reported that controlled drainage, when employed as a water management practice, could reduce the export of nutrients and TSS from pine plantations through the reduction of drainage outflow. Tian et al. (2012) used long-term data from a drained pine forest (the same site used in the present study), and documented that monthly and annual nitrate flux and concentrations were significantly influenced by water table elevation and drainage outflow. Plot-scale studies conducted in eastern North Carolina revealed that a pine–switchgrass setting does not significantly affect soil N availability but does reduce nitrification rates (Cacho et al. (2018). However, sediment and nutrient response to changing hydrologic variables (drainage flow and water table elevation) during site preparation and switchgrass growth for switchgrass intercropped pine forests and pure switchgrass have not yet been explored on a watershed scale.

Gurlevik et al. (2004) conducted an experiment in a loblolly pine plantation in central North Carolina and found that with time, soil N decreases, N accumulates in plants, and the soil carbon-to-nitrogen ratio (C/N) gradually increases with the age of pine stands. The carbon-to-nitrogen ratio determines the rates of N mineralization and immobilization during soil organic carbon decomposition. For example, the N content of organic materials with C/N ratios lower than 30 is adequate for decomposing bacteria, resulting in the release of N into the soil (Palta et al. 2013). The differences in times of regeneration and distribution of above ground and below ground biomass after natural understorey control and harvesting of pine were also thought to have affected the magnitude of C/N ratios over time. Terzaghi et al. (2013) documented that the C/N of fine roots increase with age and diameter, and they attributed this to increasing lignin and complex carbon structures. Fine root C/N ratios were observed to significantly increase in spring and then return to their original values at the growing season (Terzaghi et al. 2013). Sakin et al. (2010) reported a positive correlation between C/N ratio and precipitation. Lower C/N ratios of vegetation litter have been reported to enhance foliar decomposition (Oelbermann and Gordon 2000). We hypothesized that the C/N ratio would be lower during site preparation for switchgrass establishment than for the switchgrass growth period.

Previous studies (Cacho 2013; Cacho et al. 2018, 2019; Muwamba et al. 2015, 2017) documented the detailed characterization of nitrogen (N) and phosphorus (P) during site preparation and switchgrass growth with various treatments on plot and watershed scales, respectively. The differences in understorey vegetation composition and site management practices among those treatments may affect watershed-scale relationships and interactions among hydrologic (e.g., flow and water table elevation), and water quality variables (N, P, carbon, and sediment) for young loblolly pine–switchgrass intercropped (IC), pure switchgrass (SG), and young loblolly pine–natural understorey (YP) treatments. However, these potential effects are poorly understood. The objectives of the present study were to examine the relationships and interactions between (1) water quality (nutrients and sediment) and hydrologic variables (stream flow and water table elevation); (2) total suspended sediment (TSS) and N, P, and carbon each in pine–switchgrass ecosystems; and (3) C/N ratios and stream flow in IC, SG, a traditional mature pine forest (MP), and YP, using data collected during site preparation and switchgrass growth. These research objectives were formulated to test the following hypotheses: (1) nutrients and sediment levels in drainage waters from managed forests would be altered by flow regime during site preparations or switchgrass establishment and switchgrass growth periods, respectively. In the case of each of these treatment periods, different processes potentially determined nutrient outflow and sediment transport from watersheds; (2) sediment export via drainage water from a switchgrass intercropped pine forest was expected to be either less or not significantly different from sediment export from both pine with natural understorey and pure switchgrass sites.

A paired watershed design was followed because the sites were adjacent to each other, had similar soil and drainage types, have approximately the same area, and were monitored at the same time (Amatya et al. 1998; Bren and McGuire 2012; Muwamba et al. 2015; Ssegane et al. 2013).

## 2 Materials and Methods

### 2.1 Watersheds, Experimental Design, and Silvicultural Management Operations

The watersheds were positioned from north to south in the following order in Carteret County, NC (34°49′ N, 76°40′ W): two reference watersheds (young pine–natural understorey (YP) and mature thinned pine forest (MP)) and two treatment watersheds (young pine–switchgrass (IC) and pure switchgrass (SG)) (Fig. 1). The paired watershed design was used where the watershed treatments were not replicated. The areas of the watersheds were approximately 27.5, 26.3, 25.9, and 27.1 ha for YP, IC, MP, and SG, respectively. These coastal plain watersheds have a relatively flat topography with 0.1% gradient and 3 m elevation above mean sea level (McCarthy et al. 1991). The soil on the experimental site was a Deloss fine sandy loam (fine-loamy, mixed, thermic *Typic Umbraquult*) with an acidic pH of about 4 (Beltran et al. 2010). Each watershed was drained by four parallel ditches 1.4 to 1.8 m deep and 100 m apart, draining into a roadside collector ditch. Artificial divides at mid-points between parallel ditches were used to separate the watersheds, which were surrounded by forestland, except the east side (agricultural land).

The MP watershed was thinned from 1100 to 350 trees ha$^{-1}$ between May 2008 and January 2009 at the age of 12 years. The YP watershed was clear cut between January 2009 and April 2009, sheared and bedded in June and July 2009. Pine trees were planted at a density of 1100 trees ha$^{-1}$ in January 2010 and herbicide for hardwood control was applied on YP in October 2013.

The IC watershed was clear cut between January and April 2009, sheared and bedded between June and July 2009, and then pine trees were planted at a density of 1100 trees ha$^{-1}$ in January 2010. Herbicide was applied to IC on 1 August 2011 and then switchgrass seeds were broadcasted on IC on 15 August 2011. Due to poor seed germination, switchgrass was re-seeded using a modified Land Pride Planter on 9 April 2012.

The SG watershed was 85% clear cut and harvested in October and November 2009, when conditions became too wet to continue; harvesting was resumed in April and May 2010. The SG site was then sheared and raked in April 2011 and root raked to windrows in April and May 2011. Broad leaf control took place on 1

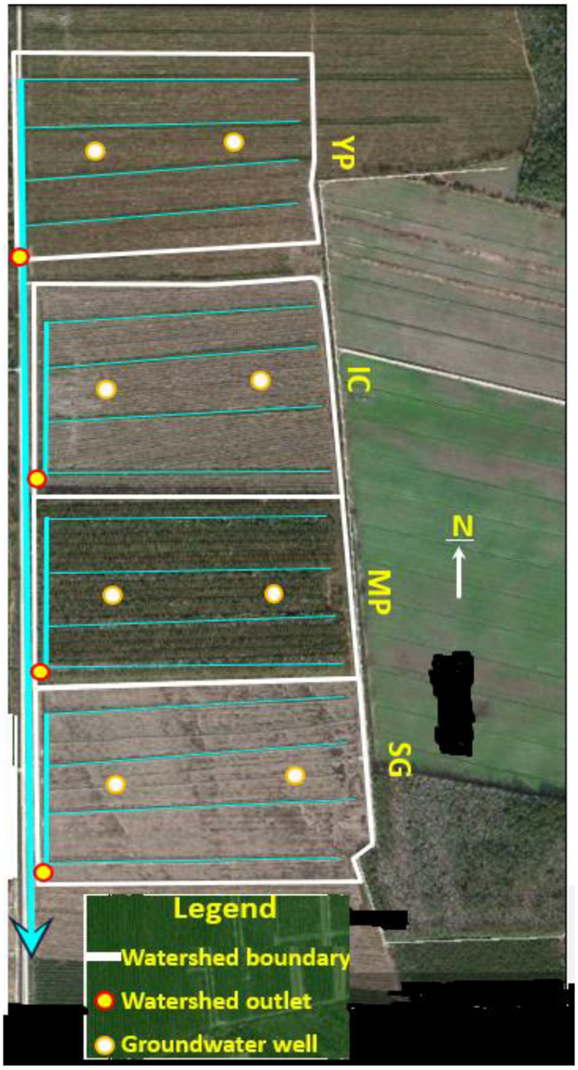


**Fig. 1** Layout of young pine–natural understorey (YP), young pine–switchgrass (IC), mature pine–natural understorey (MP), and pure switchgrass (SG) sites. The direction arrow on the left shows the direction of water flow from all the four watersheds to the roadside collector ditch

August 2011. Switchgrass seeds were broadcast on SG on 15 August 2011 using a modified Land Pride Planter and then re-seeded on 9 April 2012 due to poor seed germination of the seeds first broadcasted.

## 2.2 Measurement of Precipitation, Flow, and Water Table Elevation

Precipitation was measured with tipping-bucket precipitation gauges (HOBO) and backed up by manual gauges. Precipitation gauges were located in an open area near the roadside ditch of each watershed. Water levels (stages, measured in meters) upstream and downstream of each 120° V-notch weir were measured using automatic recorders (In-situ Level TROLL 500) installed at the outlets (destination of water from four ditches) of each watershed. A data logger (Campbell Scientific, CR200) recorded stages at 12-min intervals. The 12-min stages were then converted to flow rates using standard weir equations, accounting for weir submergence when it occasionally happened (Amatya et al. 1998). The 12-min flow rates were summed up to calculate daily flow values. The water table elevations (with respect to the mean sea level) were measured using automatic recorders (In-situ Level TROLL 500) on an hourly basis at the front (east side) and rear (west side) of each watershed and daily averages were also calculated. Daily precipitation and flow were summed for each watershed to obtain annual totals and an annual runoff coefficient was calculated as the ratio of annual flow to precipitation. Detailed hydrologic monitoring procedures are described elsewhere (Ssegane et al. 2017).

## 2.3 Measurement of Nitrogen, Phosphorus, Total Organic Carbon, and Total Suspended Sediments

An automatic sampler (SIGMA 900) was installed at each water flow measuring station to collect flow proportional-composite samples (150 mL for every 200 $m^3$ of flow) when triggered by the data logger. Samples were collected every 2 weeks, placed in ice coolers, and taken for laboratory analyses. Samples were preserved by low pH, so nitrification was inhibited during the sampling intervals. The water quality variables measured were ammonium nitrogen ($NH_4$-N), nitrate nitrogen ($NO_3$-N), total Kjeldahl nitrogen (TKN), phosphate, total organic carbon (TOC), and total suspended sediments (TSS). The laboratory analytical methods used for measuring TKN, $NO_3$-N, $NH_4$-N, and phosphate concentrations were the acid digestion method (EPA standard method—4500 Norg B, 1998), cadmium reduction (EPA standard method—4500 NO3-E, 1998), the ammonium salicylate method (EPA standard method 4500 $NH_3$G, 1998), and the ascorbic acid method (EPA standard method 4500 P-F, 1998), respectively. The gravimetric method (EPA standard method 2540, 1998), oxidation by combustion (680 to 1000 °C), and IR detection (EPA standard method 5310B, 1979) were used for TSS and TOC measurements, respectively. A Bran Luebbe Autoanalyzer II (SEAL Analytical Inc., Mequon Technology Center, 10520-C North Baehr Road, Mequon, Wisconsin 53092) was used for nitrogen analysis. The detection limits were 0.01 mg $L^{-1}$ for both $NH_4$-N and $NO_3$-N and 0.04 mg $L^{-1}$ for TKN. For phosphate and TOC, detection limits were 0.01 and 0.5 mg $L^{-1}$, respectively. The C/N ratio was calculated by dividing organic carbon by organic nitrogen. The organic nitrogen was calculated by subtracting $NH_4$-N from TKN concentrations. The C/N ratio was calculated for dates when organic carbon and organic N were measured.

## 2.4 Data Analyses

For analyses, values of water quality variables that were below detection limits were replaced with a value equal to half the equipment detection limits (Clausen and Spooner 1993). Annual exploratory statistics (mean and SD) of the water quality variables (concentrations and mass loadings) were computed using MS Excel software for 2010–2013. We aimed to identify the changes in responses of water quality from site preparation (November 2009 to April 2012) to switchgrass growth (May 2012 to June 2014) periods, in instances where a natural understorey in pine beds (YP) is replaced with switchgrass, like on the young pine–switchgrass treatment (IC), and when traditional pine forest (MP) is replaced with pure switchgrass (SG). The relationships between each of the water quality variables were explored with both water table elevation and flow individually as explanatory hydrologic variables for specified time intervals. Similar relationship analyses were carried out for each of the nutrients as response variables and total organic carbon (TOC) and total suspended sediment (TSS) individually. Nutrients attached to total suspended sediment (TSS) are transported to drainage outflow. The analyses were conducted for the two periods: site preparation (November 2009 to April 2012) and switchgrass growth (May 2012 to June 2014).

Evaluation statistics, Spearman rank correlation coefficients ($p$ value at $\alpha = 0.05$), and coefficients of determination were used to identify statistically significant relationships. A normality test performed on the water quality variables showed that the data were not normally distributed as indicated by non-zero skewness, and a kurtosis value of either less or greater than 3. Spearman rank correlation was used to evaluate these relationships because it is non-parametric and works with linear and nonlinear data, as well as continuous and discrete data (Hauke and Kossowski 2011; Gauthier 2001; Zar 1972). All statistical analyses were conducted using SAS version 9.4 (SAS Institute 2012–2013). Plots of all concentrations of water quality variables ($NO_3$-N, TKN, phosphate, TOC, and TSS) as a function of daily flow and water table elevation during site preparation and switchgrass growth periods were retrieved. The significant differences in mean C/N ratios among watersheds were also identified using one-way ANOVA with Tukey test at a significance level of 5% with consideration of equal or unequal variance. Graphs of C/N ratios and concentrations of TOC and TSS as a function of time were also plotted to show temporal trends during site preparation and switchgrass growth periods.

The relationships between hydrologic and water quality variables for all watersheds using the entire data set were also explored using principal components analysis (PCA). This analysis, which takes into consideration combined datasets, was conducted to further identify the driving processes for the changes in water quality variables. The purpose of the PCA was to detect the structure and general regularities in relationships between the examined parameters of water, to reduce the number of less responsive variables, and to describe and classify the examined variables in the separated spaces described by the new components (Bogdał et al. 2019; Fan et al. 2010; Peterson et al. 2001; Ruždjak and Ruždjak 2015; Xu et al. 2012). Such an analysis is very useful for the relationships among a large number of correlated variables. The observed variables are transformed into a new set of uncorrelated variables (Wałęga and Wachulec 2018; Wąsik et al. 2017). This way, the number of variables is reduced, and a structure and general regularities in their interactions can be determined, while the studied items are described and classified in a new space defined by new components. The analyses were carried out for the following parameters: flow, water table elevation (WTE), total Kjedahl nitrogen (TKN), nitrate nitrogen ($NO_3$-N), ammonium nitrogen ($NH_4$-N), phosphate, total suspended sediment (TSS), and total organic carbon (TOC).

In the first stage of the PCA, a correlation matrix between all variables was generated, which allowed the authors to draw preliminary conclusions as to the regularities occurring in the sample. Then, Bartlett's sphericity test was performed to assess the significance of the correlation matrix (Pekey et al. 2004), by testing the null hypothesis that the correlation matrix is a unitary matrix ($H_0$: R = I), meaning all correlation coefficients are equal to zero. When assuming a null hypothesis, there is no point in performing component analysis. In the present case, the value of Bartlett's statistics was 267.6, which corresponded to a test probability below 0.000, meaning the assumption of a null hypothesis was rejected. Thus, it was confirmed that the analyzed correlation matrix is not a unitary matrix. In the next step, the eigenvalues indicating the hierarchy of significance of the respective components explaining the overall variance were determined. Based on the recommendations given by Pekey et al. (2004), only those components whose eigenvalues exceeded 1 were selected for further analysis. For a selected number of new components (variables), component loadings, interpreted as correlation coefficients of the individual parameters, and their corresponding new components (variables) were calculated. Each new component was significantly correlated with some individual parameter (e.g., flow, WTE, TKN). As a result, the number of analyzed parameters was reduced to main variables that describe key processes affecting water quality. The PCA analyses were performed with Statistica 13 software.

## 3 Results and Discussion

### 3.1 Changes in Nutrients, Total Organic Carbon, and Total Suspended Sediment during Site Preparation and Switchgrass Growth Periods

Nitrate nitrogen ($NO_3$-N), ammonium nitrogen ($NH_4$-N), total Kjedahl nitrogen (TKN), phosphate, total organic carbon (TOC), and total suspended sediment (TSS) concentrations generally increased at the beginning of flow periods that were preceded by relatively long dry periods (March to September 2010, April to September 2011, June to September 2012, and June to August 2013) (Figs. 2, 3, 4, and 5). The concentrations subsequently decreased as flow continued (Figs. 2, 3, 4, and 5). Phosphate concentrations were relatively less variable compared with the concentrations of other water quality constituents (Figs. 2, 3, 4, and 5). Muwamba et al. (2015, 2017) reported for the same study site that the first flush effect was evident for temporal changes in N and P concentrations following dry periods. Similarly, the increase in TSS and TOC concentrations after a long dry period was attributed to first flush effects. For example, 52 and 54% of the total annual loads of TSS from the IC watershed in 2010 and 2011, respectively, occurred in the months following long dry periods (September and October 2010 and August and September 2011). Sheridan and Hubbard (1987) recorded high sediment concentrations following a long period without flow in a study that involved pine plantations.

The average TOC concentrations on the young pine–switchgrass (IC), pure switchgrass (SG), and mature pine–natural understorey (MP) watersheds, and TSS on the SG and MP were greater for site preparation (November 2009 to April 2012) than for the switchgrass growth (May 2012 to June 2014) period (Tables 1 and 2; Figs. 2, 3, 4, and 5). The average TSS concentration was lower on IC for site preparation than for the switchgrass growth period (Tables 1 and 2; Fig. 2). Total TOC loads on the IC and MP watersheds, and total TSS loads on the SG and MP watersheds were greater for site preparation than for the switchgrass growth period (Tables 1 and 2; Figs. 2, 3, and 5). Total TOC loads on the SG watershed and total TSS loads on IC were lower for site preparation than for the switchgrass growth period (Table 2; Figs. 2 and 3). Flow and water table elevation for all sites were lower during site preparation than for the switchgrass growth period (Tables 1 and 2; Figs. 2, 3, 4, and 5).

The decrease of TSS concentrations from 2010 to 2013 on reference watersheds (young pine–natural understorey (YP) and MP) was likely due to a growing natural understorey that increased canopy cover and reduced raindrop impacts on the soil surface. Sheridan and Hubbard (1987) also reported that dense canopies retained greater amounts of rainfall reducing detachment of soil particles by rainfall. Beasley et al. (1986) and Miller (1984) also attributed the reduction of sediment losses over time after clear cutting a mixed forest to rapid regrowth of natural understorey. Grace III and Carter (2001) attributed the differences in sediment among harvested sites and between harvested and control forest sites to differences in cover and surface roughness. The authors also documented the vulnerability of the surface layer to erosion by flowing water with reduced surface cover and surface roughness. Greater TSS concentrations were recorded on the SG watershed than the other watersheds in 2010 and 2011, which was likely due to absence of bedding, bare soil surface, and less surface roughness. Grace III (2004) documented that raised beds increase surface roughness and the water storage, resulting in reduced surface

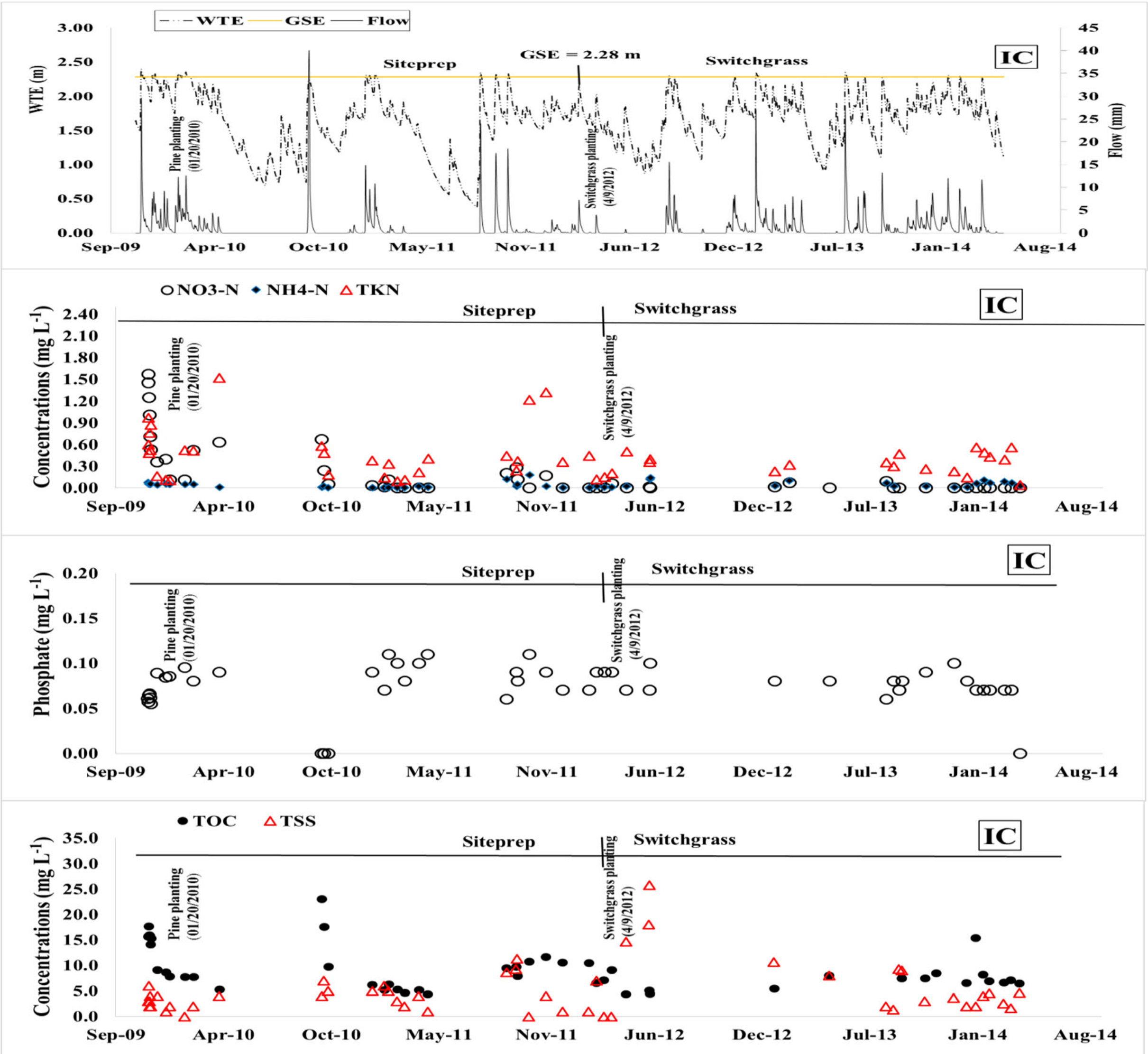


**Fig. 2** Flow, water table elevation (WTE), nitrogen ($NH_4$-N, $NO_3$-N, and TKN), phosphate, total organic carbon (TOC), and total suspended sediment (TSS) for the young pine–switchgrass site (IC). GSE is ground surface elevation

runoff and soil erosion. Detailed characterization of temporal variations in $NH_4$-N, $NO_3$-N, TKN, and phosphate concentrations and loads on different watersheds for site preparation and switchgrass growth were described by Muwamba et al. (2015) and Muwamba et al. (2017), respectively.

### 3.2 Relationships between Water Quality and Hydrologic Variables

During site preparation period, $NH_4$-N and $NO_3$-N concentrations were positively correlated ($p < 0.05$) with water table elevation (Table 3; Fig. 2) on the IC watershed. Nitrate nitrogen concentration was positively correlated ($p = 0.01$) with flow on the SG watershed during site preparation (Table 3). For the MP watershed, $NH_4$-N and $NO_3$-N concentrations were positively correlated with water table elevation (WTE) during site preparation (Table 3). The positive relationship of $NH_4$-N and $NO_3$-N on the YP, IC, and SG watersheds with flow during site preparation indicated that the rate of mineralization for harvest residues was greater than plant uptake during pine planting. Because higher WTE in the field generally causes its larger gradient toward the drainage ditch,

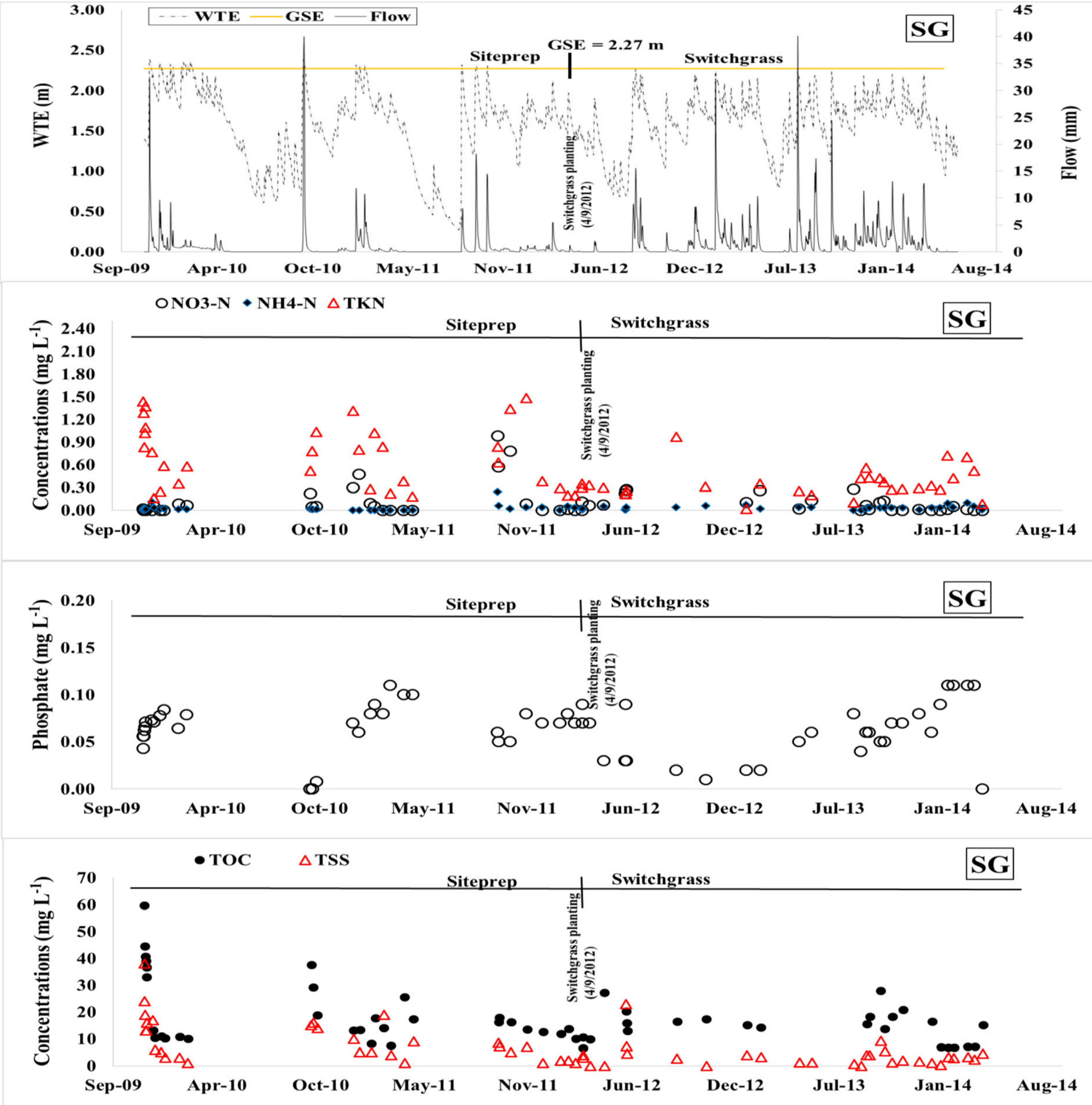


**Fig. 3** Flow, water table elevation (WTE), nitrogen ($NH_4$-N, $NO_3$-N, and TKN), phosphate, total organic carbon (TOC), and total suspended sediment (TSS) for the pure switchgrass site (SG). GSE is ground surface elevation

resulting in faster and larger subsurface drainage outflow to the ditch, positive relationships with $NH_4$-N and $NO_3$-N were also observed on YP, IC, and SG. The results for the present study during site preparation are consistent with the findings by Lynch and Corbett (1990), who documented greater decomposition rates than plant uptake rates following harvesting. Given the positive correlation between nutrients and flow, applying N fertilizers to YP, IC, and SG sites during site preparation would increase nutrient runoff. Consistent with dilution effects on phosphate concentrations for the present study, Lynch and Corbett (1990) and Li et al. (2003) reported that plant uptake increases with plant development, lowering nutrient fluxes. Water table and drainage flow were reported as governing components for nitrate and dissolved organic nitrogen fluxes in drained forests, respectively (Tian et al. (2012). Similarly, Settergren et al. (1976)

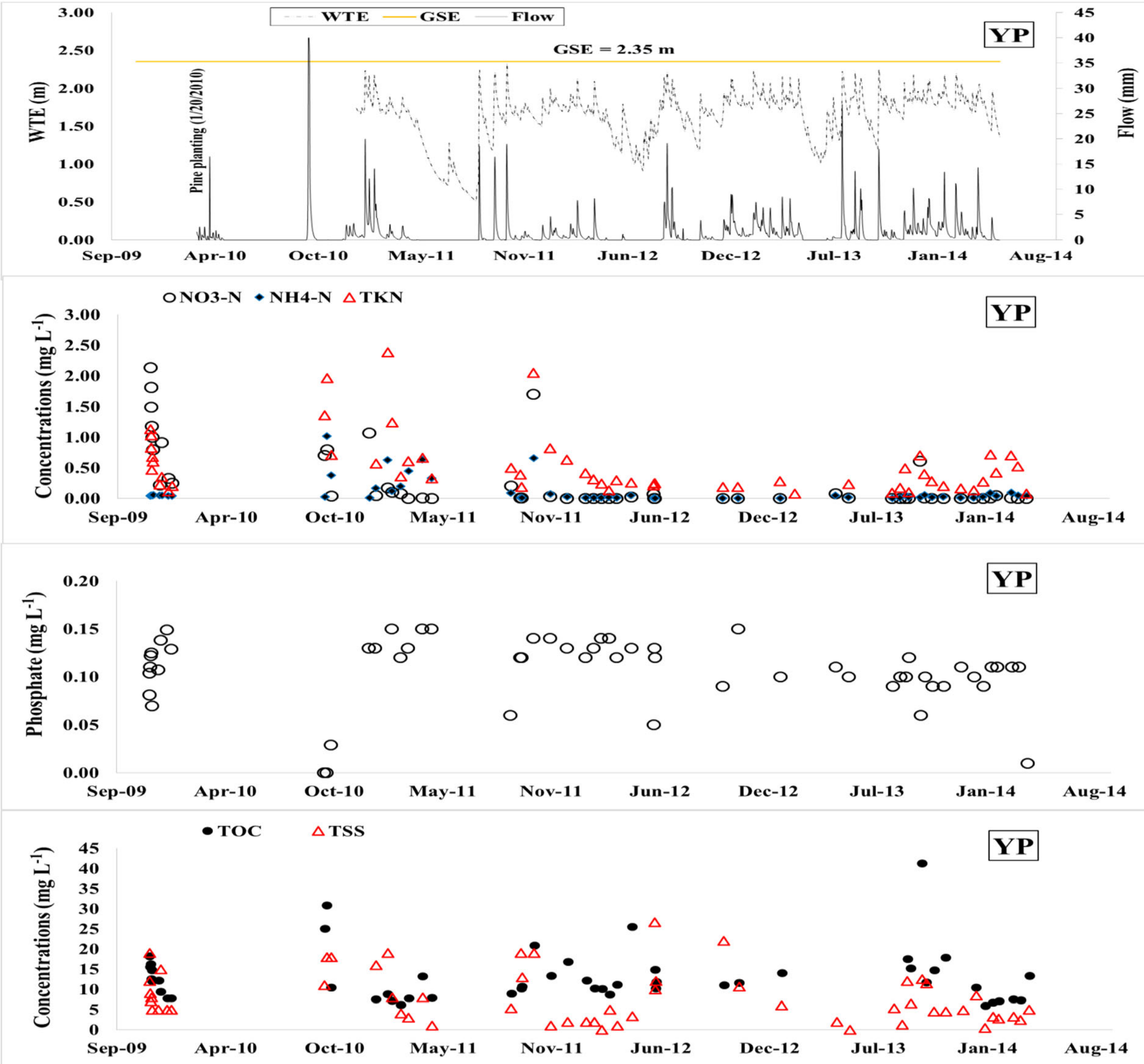


**Fig. 4** Flow, water table elevation (WTE), nitrogen ($NH_4$-N, $NO_3$-N, and TKN), phosphate, total organic carbon (TOC), and total suspended sediment (TSS) for the young pine–natural understorey site (YP). GSE is ground surface elevation

found nutrient fluxes and concentrations varying with season and stream discharge rates.

The total organic carbon (TOC) ($p = 0.02$) concentrations were positively correlated with WTE on the SG site during site preparation period (Table 3). The positive relationship was likely due to the greater TOC in the surface layer leading to surface water transport. There might have been a greater quantity and quality of degradable materials following the harvest of the IC and SG sites, leading to greater TOC during site preparation than switchgrass growth. Because water is flowing from the site, the processes in the site were being reflected in the outflow compositions. Analysis with a combined data set for all watersheds showed a relatively high dependency ($p < 0.05$) between flow and TOC. This may indicate the leaching of organic matter, which had accumulated in the soil profile, during intensive outflows from the watersheds. During outflow, WTE is relatively shallow, so there are conditions for leaching organic matter from the soil. This statement is supported by a relatively high correlation coefficient of 0.61 between flow and WTE (Table 4). Webster and McLaughlin (2010) reported that

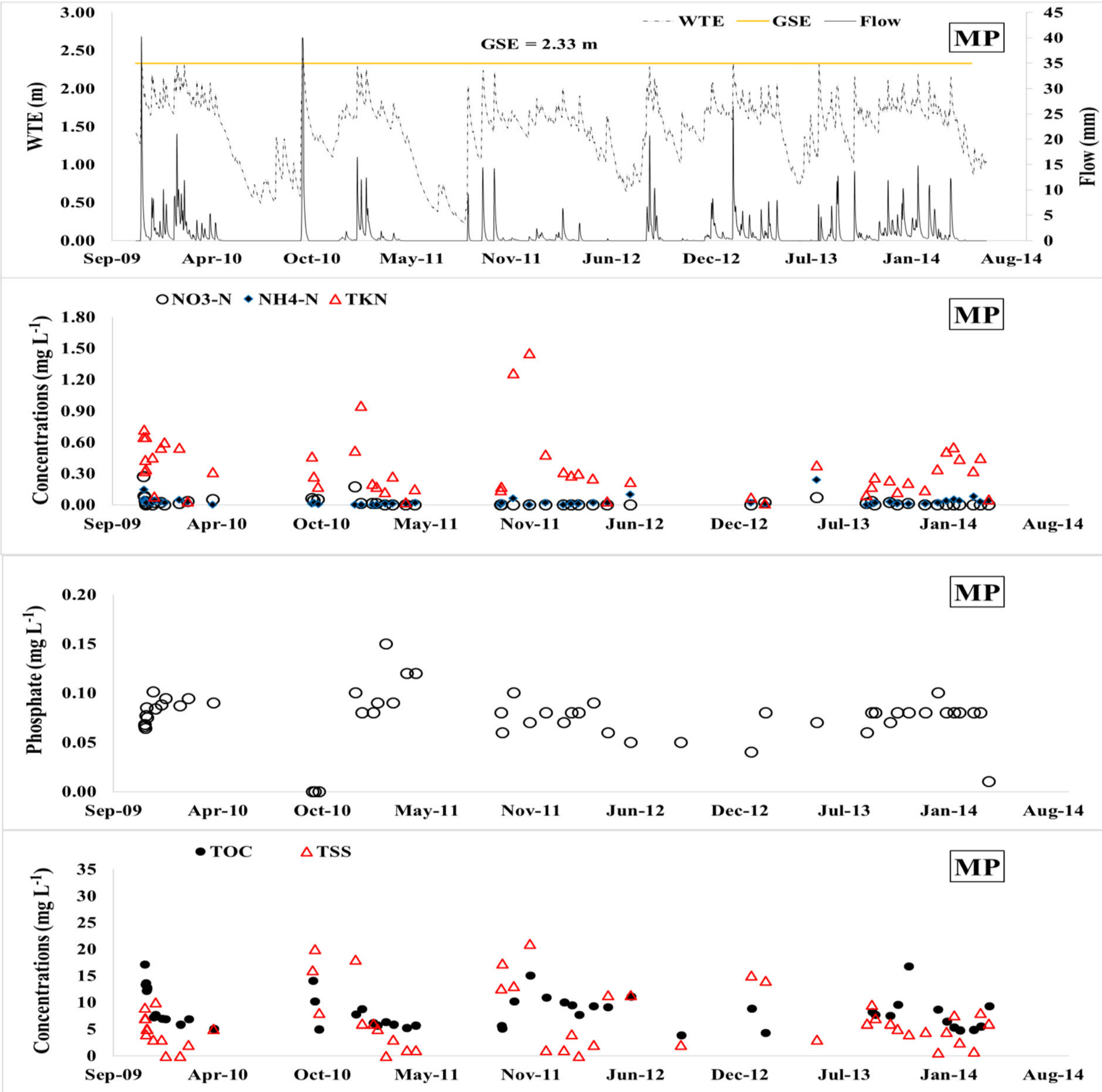


**Fig. 5** Flow, water table elevation (WTE), nitrogen ($NH_4$-N, $NO_3$-N, and TKN), phosphate, total organic carbon (TOC), and total suspended sediment (TSS) for the mature pine–natural understorey site (MP). GSE is ground surface elevation

substrate quality is a key component in the decomposition process, and that young materials are more easily degradable, which can lead to increased leaching of carbon. Accordingly, the young herbaceous plants on the YP, IC, and SG sites following harvesting might have been easily decomposable with a potential for leaching. The TSS ($p = 0.003$) concentrations were positively correlated with WTE on the SG site during site preparation (Table 3). Gradual harvesting coupled with root raking probably resulted in a positive relationship between TSS concentration and water table elevation during site preparation on the SG site.

Ammonium nitrogen concentrations were positively correlated ($p = 0.02$), and TOC ($p = 0.03$) and TSS ($p = 0.001$) concentrations were negatively correlated with WTE and flow on the YP during switchgrass growth period (Table 3). During switchgrass growth, $NO_3$-N

**Table 1** Annual rainfall, flow, and annual mean concentrations with SDs in parentheses and total loads for nitrogen, phosphorus, total organic carbon, and total suspended sediments concentrations for site preparation (2010 and 2011) and switchgrass growth years (2012 and 2013)

| Treatment/year | YP | IC | MP | SG | YP | IC | MP | SG |
|---|---|---|---|---|---|---|---|---|
| | Rain (mm) | | | | Flow (mm) | | | |
| 2010 | NA | 1484.7 | 1412.7 | 1420.3 | NA | 379.3 | 434.4 | 239.0 |
| 2011 | 1230.9 | 1219.3 | 1177.5 | 1117.3 | 381.9 | 313.8 | 263.9 | 249.8 |
| 2012 | 1466.2 | 1473.0 | 1398.4 | 1350.5 | 347.7 | 222.1 | 219.5 | 183.1 |
| 2013 | 1556.8 | 1721.9 | 1639.1 | 1653.4 | 568.6 | 513.9 | 481.4 | 781.9 |
| | TKN (mg $L^{-1}$) | | | | TKN (kg $ha^{-1}$) | | | |
| 2010 | 1.34 (0.63) | 0.63 (0.46) | 0.33 (0.19) | 0.76 (0.36) | NA | 2.92 | 1.34 | 1.43 |
| 2011 | 0.97 (0.71) | 0.46 (0.44) | 0.51 (0.52) | 0.69 (0.48) | 4.08 | 1.33 | 0.97 | 2.17 |
| 2012 | 0.25 (0.07) | 0.31 (0.15) | 0.23 (0.10) | 0.27 (0.06) | 0.83 | 0.59 | 0.27 | 1.44 |
| 2013 | 0.25 (0.19) | 0.31 (0.08) | 0.17 (0.11) | 0.30 (0.15) | 1.35 | 1.62 | 0.96 | 2.18 |
| | $NH_4$-N (mg $L^{-1}$) | | | | $NH_4$-N (kg $ha^{-1}$) | | | |
| 2010 | 0.36 (0.47) | 0.02 (0.02) | 0.02 (0.02) | 0.01 (0.01) | NA | 0.09 | 0.08 | 0.04 |
| 2011 | 0.33 (0.25) | 0.02 (0.06) | 0.01 (0.02) | 0.01(0.02) | 1.18 | 0.04 | 0.03 | 0.17 |
| 2012 | 0.01 (0.01) | 0.05 (0.06) | 0.03 (0.04) | 0.03 (0.02) | 0.03 | 0.06 | 0.04 | 0.12 |
| 2013 | 0.02 (0.02) | 0.04 (0.04) | 0.04 (0.07) | 0.03 (0.02) | 0.23 | 0.27 | 0.40 | 0.19 |
| | $NO_3$-N (mg $L^{-1}$) | | | | $NO_3$-N (kg $ha^{-1}$) | | | |
| 2010 | 0.65 (0.44) | 0.37 (0.27) | 0.06 (0.05) | 0.13 (0.11) | NA | 1.88 | 0.18 | 0.39 |
| 2011 | 0.21 (0.53) | 0.03 (0.06) | 0.003 (0.005) | 0.15 (0.26) | 1.09 | 0.43 | 0.01 | 1.03 |
| 2012 | 0.01 (0.02) | 0.01 (0.02) | 0.00 (0.00) | 0.08 (0.10) | 0.01 | 0.03 | 0.00 | 0.25 |
| 2013 | 0.06 (0.17) | 0.02 (0.04) | 0.02 (0.02) | 0.08 (0.10) | 0.25 | 0.26 | 0.14 | 0.80 |
| | $PO_4^{3}$-P (mg $L^{-1}$) | | | | $PO_4^{3}$-P (kg $ha^{-1}$) | | | |
| 2010 | 0.04 (0.06) | 0.04 (0.05) | 0.05 (0.05) | 0.04 (0.04) | NA | 0.19 | 0.22 | 0.03 |
| 2011 | 0.15 (0.03) | 0.09 (0.02) | 0.10 (0.02) | 0.08 (0.02) | 0.55 | 0.28 | 0.26 | 0.19 |
| 2012 | 0.12 (0.03) | 0.08 (0.01) | 0.07 (0.01) | 0.08 (0.02) | 0.38 | 0.18 | 0.12 | 0.08 |
| 2013 | 0.10 (0.02) | 0.08 (0.01) | 0.07 (0.01) | 0.05 (0.02) | 0.80 | 0.40 | 0.35 | 0.43 |
| | TOC (mg $L^{-1}$) | | | | TOC (kg $ha^{-1}$) | | | |
| 2010 | 22.1 (10.5) | 11.9 (6.93) | 7.83 (3.28) | 19.9 (11.2) | NA | 48.7 | 38.7 | 73.0 |
| 2011 | 11.0 (4.91) | 7.02 (2.82) | 8.00 (3.21) | 14.6 (5.14) | 40.9 | 31.7 | 20.8 | 38.6 |
| 2012 | 11.9 (2.30) | 8.40 (1.33) | 9.23 (1.57) | 11.4 (2.10) | 44.6 | 22.3 | 19.2 | 33.9 |
| 2013 | 17.2 (10.3) | 9.49 (1.87) | 9.43 (3.33) | 18.0 (4.68) | 125.9 | 40.7 | 19.4 | 114.2 |
| | TSS (mg $L^{-1}$) | | | | TSS (kg $ha^{-1}$) | | | |
| 2010 | 15.7 (4.04) | 3.67 (2.42) | 9.86 (8.09) | 9.83 (6.43) | NA | 14.0 | 39.3 | 31.0 |
| 2011 | 8.10 (7.31) | 3.10 (2.02) | 5.70 (6.62) | 13.6 (23.9) | 39.7 | 19.5 | 20.0 | 36.0 |
| 2012 | 8.59 (8.84) | 9.49 (10.2) | 4.51 (4.79) | 4.13 (6.32) | 38.4 | 18.8 | 14.1 | 7.2 |
| 2013 | 6.53 (4.56) | 5.85 (3.74) | 7.40 (4.15) | 2.92 (2.49) | 37.2 | 21.4 | 14.5 | 15.9 |

YP, IC, SG, and MP represent young pine–natural, young pine–switchgrass, switchgrass only, and mature pine–natural, respectively

*NA* no complete rain and flow data sets

concentration was negatively correlated ($p = 0.02$) and TOC ($p = 0.01$) was positively correlated with WTE on the IC site (Table 3). Phosphate concentrations were positively correlated ($p = 0.01$) and TOC was negatively correlated ($p = 0.04$) with WTE for the SG site during switchgrass growth. During switchgrass growth on the

**Table 2** Average concentrations and total loads for nitrogen, phosphorus, total organic carbon, and total suspended sediments for site preparation and switchgrass growth periods and their corresponding total flow, runoff coefficient (ROC), and average water table elevation (WTE)

| Site | Flow (mm) | ROC | WTE (m) | TKN | $NH_4$-N | $NO_3$-N | $PO_4^{3-}$ | TOC | TSS |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Site preparation (mg $L^{-1}$) | | | | | |
| IC | 693.1 | 0.26 | 1.57 | 0.48 | 0.04 | 0.50 | 0.08 | 9.98 | 3.92 |
| SG | 488.8 | 0.20 | 1.52 | 0.69 | 0.02 | 0.15 | 0.07 | 19.64 | 10.81 |
| MP | 698.3 | 0.27 | 1.39 | 0.43 | 0.02 | 0.06 | 0.09 | 8.84 | 6.73 |
| | | | | Switchgrass growth (mg $L^{-1}$) | | | | | |
| IC | 736.0 | 0.23 | 1.67 | 0.35 | 0.06 | 0.01 | 0.07 | 7.23 | 7.02 |
| SG | 965.5 | 0.34 | 1.59 | 0.33 | 0.04 | 0.08 | 0.06 | 15.29 | 3.58 |
| MP | 700.9 | 0.23 | 1.51 | 0.24 | 0.04 | 0.01 | 0.07 | 7.76 | 6.43 |
| | | | | Site preparation (kg $ha^{-1}$) | | | | | |
| IC | 693.1 | 0.26 | 1.57 | 4.99 | 0.22 | 3.20 | 0.64 | 102.4 | 38.1 |
| SG | 488.8 | 0.20 | 1.52 | 4.56 | 0.25 | 1.48 | 0.34 | 146.5 | 83.5 |
| MP | 698.3 | 0.27 | 1.39 | 3.25 | 0.20 | 0.29 | 0.66 | 80.4 | 68.0 |
| | | | | Switchgrass growth (kg $ha^{-1}$) | | | | | |
| IC | 736.0 | 0.23 | 1.67 | 3.17 | 0.46 | 0.30 | 0.74 | 78.4 | 45.4 |
| SG | 965.5 | 0.34 | 1.59 | 4.85 | 0.47 | 1.11 | 0.77 | 173.4 | 29.0 |
| MP | 700.9 | 0.23 | 1.51 | 2.10 | 0.56 | 0.14 | 0.61 | 64.8 | 52.5 |

IC, SG, and MP represent young pine–switchgrass, switchgrass only, and mature pine–natural, respectively

MP watershed, TKN ($p = 0.05$) and phosphate concentration ($p < 0.001$) were positively correlated with WTE, and TOC concentration was negatively correlated ($p = 0.002$) with flow (Table 3).

The positive relationship between TOC concentrations on the IC watershed, phosphate and TKN concentrations on the MP watershed, and phosphate concentrations on the SG watershed with flow and WTE during switchgrass growth were attributed to a pronounced first flush effect. Herbicides were also applied to the YP site for control of the natural understorey, and this might have resulted in a positive relationship of $NH_4$-N concentration with WTE. A subsequent increase in canopy cover might have led to a negative relationship between TSS concentration and WTE on the YP and SG sites during switchgrass growth. This is consistent with Grace III and Carter (2001) who documented that mature forests yield less sediment due to larger canopy cover and greater surface roughness. Comparing significant relationships among watersheds during site preparation, $NO_3$-N concentrations were positively correlated with hydrologic variables for all watersheds (Table 3; Figs. 2, 3, 4, and 5). However, TOC concentration was negatively correlated with hydrologic variables for the YP, SG, and MP watersheds during switchgrass growth (Table 3; Figs. 3, 4 and 5). Low water quality parameter concentrations due to increased uptake and dilution effects might be the reasons for the absence of hydrologic–water quality parameter correlations, and negative correlations in some years on different watersheds.

### 3.3 Sediment and Carbon Relationships with Nitrogen and Phosphorus Concentrations

Nitrate nitrogen concentration was positively correlated ($p = 0.01$) with TSS concentrations on the YP watershed during site preparation (Table 3). The $NH_4$-N concentration was negatively correlated ($p = 0.05$) and TOC concentration was positively correlated ($p = 0.03$) with TSS for the YP watershed during switchgrass growth period (Table 3). Phosphate concentrations were negatively correlated ($p < 0.001$) and $NH_4$-N was positively correlated ($p = 0.002$) with TOC for the IC watershed during site preparation. During switchgrass growth, TOC was negatively correlated with TSS on the IC watershed (Table 3). The TKN and TOC concentrations on the SG watershed were positively correlated ($p < 0.001$) with TSS concentrations (Table 3). Phosphate concentration was negatively correlated with TOC ($p = 0.02$) during site preparation for

**Table 3** Computed $p$, rho, and $R^2$ statistics for significant relationships ($\alpha = 0.05$) between water quality variables (concentrations) and hydrologic variables (water table elevation (WTE) and flow) during site preparation and switchgrass growth periods

| Site | Relationship | $p$ value | $r$ (rho) | $R^2$ | Relationship | $p$ value | $r$ (rho) | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Site preparation period | | | | Switchgrass growth | | | |
| YP | $NO_3$-N vs. TSS | 0.01 | 0.63 | 0.35 | $NH_4$-N vs. WTE | 0.02 | 0.49 | 0.41 |
| | | | | | TOC vs. WTE | 0.03 | 0.49 | 0.45 |
| | | | | | TSS vs. WTE | 0.001 | 0.60 | 0.65 |
| | | | | | $NH_4$-N vs. TSS | 0.05 | 0.40 | 0.32 |
| | | | | | TOC vs. TSS | 0.03 | 0.49 | 0.21 |
| IC | $NH_4$-N vs. WTE | 0.004 | 0.48 | 0.10 | $NO_3$-N vs. WTE | 0.02 | 0.55 | 0.31 |
| | $NO_3$-N vs. WTE | 0.001 | 0.57 | 0.46 | TOC vs. WTE | 0.01 | 0.62 | 0.47 |
| | $NH_4$-N vs. TOC | 0.002 | 0.52 | 0.26 | TOC vs. TSS | 0.02 | 0.61 | 0.54 |
| | Phosphate vs. TOC | < 0.001 | 0.66 | 0.70 | | | | |
| MP | $NH_4$-N vs. WTE | 0.002 | 0.52 | 0.45 | TKN vs. WTE | 0.05 | 0.46 | 0.44 |
| | $NO_3$-N vs. WTE | 0.005 | 0.47 | 0.22 | Phosphate vs. WTE | < 0.001 | 0.79 | 0.56 |
| | $NO_3$-N vs. TSS | 0.01 | 0.44 | 0.25 | TOC vs. flow | 0.002 | 0.71 | 0.57 |
| | Phosphate vs. TSS | 0.001 | 0.54 | 0.53 | TKN vs. TSS | 0.04 | 0.47 | 0.50 |
| | Phosphate vs. TOC | 0.02 | 0.40 | 0.32 | | | | |
| SG | $NO_3$-N vs. flow | 0.01 | 0.44 | 0.35 | Phosphate vs. WTE | 0.01 | 0.51 | 0.44 |
| | TOC vs. WTE | 0.02 | 0.40 | 0.43 | TOC vs. WTE | 0.04 | 0.45 | 0.49 |
| | TSS vs. WTE | 0.003 | 0.49 | 0.34 | $NO_3$-N vs. TSS | 0.04 | 0.43 | 0.41 |
| | TKN vs. TSS | < 0.001 | 0.63 | 0.47 | | | | |
| | TOC vs. TSS | < 0.001 | 0.66 | 0.42 | | | | |
| | Phosphate vs. TOC | 0.02 | 0.51 | 0.44 | | | | |

YP, IC, SG, and MP represent young pine–natural, young pine–switchgrass, switchgrass only, and mature pine–natural, respectively. Flow and WTE data sets for young pine-natural (YP) were not complete during site preparation

the SG watershed (Table 3). Nitrate nitrogen concentrations on the SG watershed were positively correlated ($p = 0.04$) with TSS during switchgrass growth (Table 3). Nitrate nitrogen concentration was positively correlated ($p = 0.01$) with TSS concentrations on the MP watershed during site preparation (Table 3). Phosphate concentrations were negatively correlated with TSS ($p = 0.001$) and TOC ($p = 0.02$) during site preparation for the MP watershed

**Table 4** Correlation matrix with rho statistics between analyzed parameters in pine/switchgrass ecosystems

| Parameter | $NH_4$-N (mg $L^{-1}$) | $NO_3$-N (mg $L^{-1}$) | Phosphate (mg $L^{-1}$) | TSS (mg $L^{-1}$) | TOC (mg $L^{-1}$) | Flow (mm) | WTE (m) | TKN (mg $L^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| $NH_4$-N (mg $L^{-1}$) | 1.000 | 0.379 | 0.388 | 0.088 | 0.026 | 0.007 | 0.022 | 0.469 |
| $NO_3$-N (mg $L^{-1}$) | 0.379 | 1.000 | − 0.097 | 0.067 | 0.263 | 0.297 | 0.328 | 0.512 |
| Phosphate (mg $L^{-1}$) | 0.388 | − 0.097 | 1.000 | − 0.024 | − 0.274 | − 0.305 | − 0.162 | 0.170 |
| TSS (mg $L^{-1}$) | 0.088 | 0.067 | − 0.024 | 1.000 | 0.187 | 0.123 | 0.150 | 0.266 |
| TOC (mg $L^{-1}$) | 0.026 | 0.263 | − 0.274 | 0.187 | 1.000 | 0.400 | 0.146 | 0.233 |
| Flow (mm) | 0.007 | 0.297 | − 0.305 | 0.123 | 0.400 | 1.000 | 0.611 | 0.102 |
| WTE (m) | 0.022 | 0.328 | − 0.162 | 0.150 | 0.146 | 0.611 | 1.000 | 0.150 |
| TKN (mg $L^{-1}$) | 0.469 | 0.512 | 0.170 | 0.266 | 0.233 | 0.102 | 0.150 | 1.000 |

(Table 3). During switchgrass growth, TKN concentrations were negatively correlated ($p = 0.04$) with TSS for MP watershed during switchgrass growth (Table 3).

The positive correlation between TSS, and TKN and TOC concentrations for SG reflected the binding of N to sediment during site preparation period. The TSS–$NO_3$-N positive correlation for YP and MP concentrations was attributed to similar conditions that favor transport of both TSS and $NO_3$-N. Under wet conditions, $NO_3$-N can leach via the subsurface water movement to the drainage ditches, and surface runoff and sediment loss could happen via surface water movement to the drainage ditch. The decreasing N and P concentrations over time due to increased uptake and dilution effects probably led to absence of relationships with TOC and TSS in some periods. The positive TSS–N relationships on the YP and MP sites were consistent with the findings of Xia et al. (2009) who reported that as the concentration of sediment increased, the $NH_4$-N increased because of the adsorption of $NH_4$-N to the sediment. In the present study, TKN concentrations for the MP and SG watersheds increased when TOC concentrations increased during site preparation (Table 3). This is consistent with findings by Webster and McLaughlin (2010), who reported a positive correlation between total N and carbon. The negative correlation between phosphate and TOC concentrations for the IC, MP, and SG watersheds during site preparation was likely due to sorption, which increased the partitioning of phosphate and $NH_4$-N in soil. A strong relationship between P and $NH_4$-N when the entire data for all watersheds were used for analysis shows the sorption behavior of P and $NH_4$-N in these acidic sandy loam soils. Other studies have reported similar inverse relationships between solution P and other sorbing components like iron and aluminum (Sonoda and Yeakley 2007; Richardson 1985;

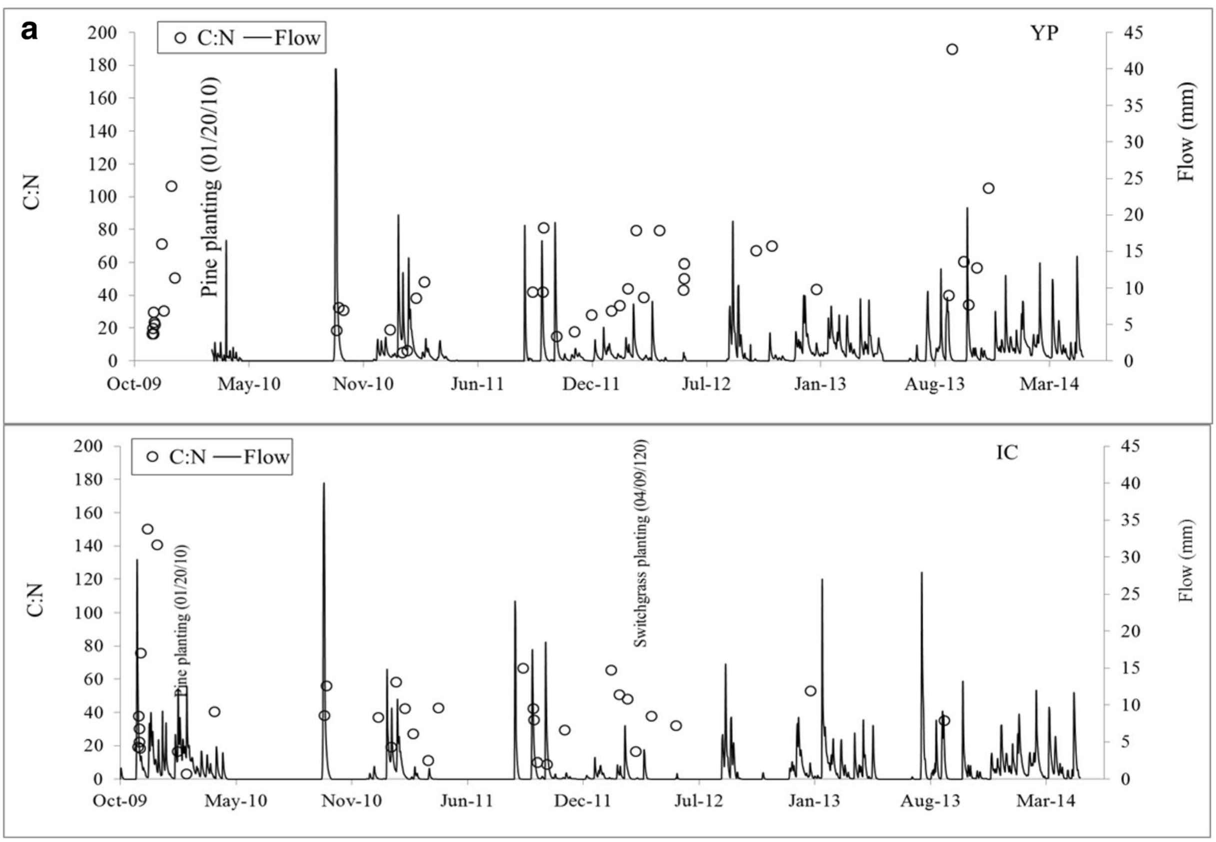


**Fig. 6** **a** Temporal variability of C/N ratios for the young pine–natural understorey (YP) and young pine–switchgrass (IC) sites for site preparation and switchgrass growth periods. **b** Temporal variability in C/N ratios for the mature pine–natural understorey (MP) and pure switchgrass (SG) sites for site preparation and switchgrass growth periods. **c** Annual mean C/N ratios for the young pine–natural understorey (YP), young pine–switchgrass (IC), mature pine–natural understorey (MP), and pure switchgrass (SG) sites. Error bars represent SDs

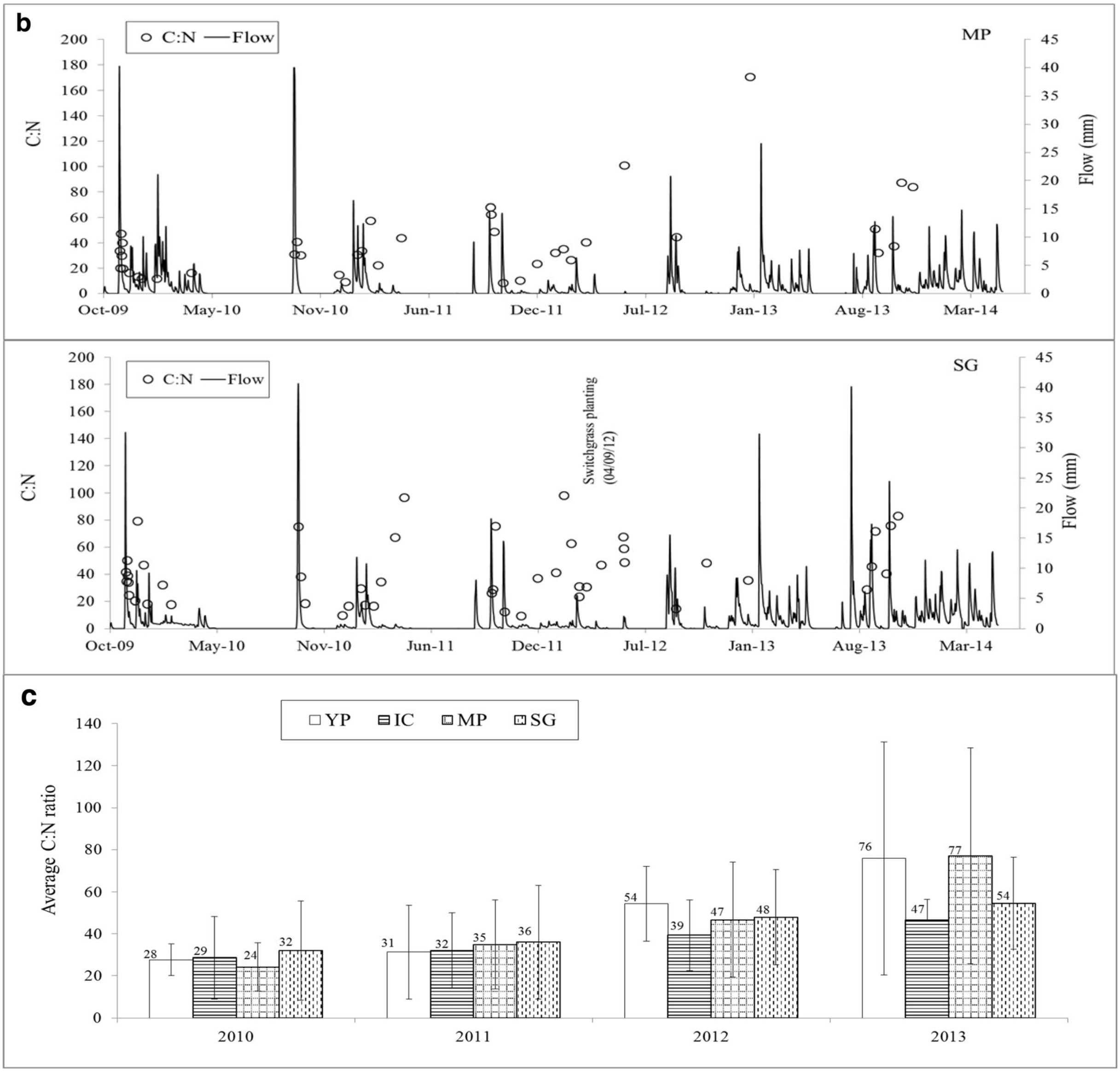


Fig. 6 (continued)

Agudelo et al. 2011). Smith et al. (1996) studied the dynamics of water quality variables for a forested watershed in the Pacific Coast of North America and identified significant relationships between sediment and particulate P, N, and organic carbon.

### 3.4 Relationships between Drainage Water C/N Ratio and Flow

The C/N ratios of drainage water outflow exhibited seasonal variations on the YP and IC watersheds from 2010 to 2013 (Fig. 6a). Ratios of C/N tended to be greater in summer than in winter. For the MP and SG watersheds, C/N ratios decreased at the end of 2009 when trees were thinned from 1100 to 350 trees ha$^{-1}$ on the MP watersheds and 85% pine tree clear-cut harvest was conducted on the SG watershed (Fig. 6b). A systematic relationship of C/N ratios with flow on all watersheds was observed during site preparation. This was likely because N concentrations were high enough to be detected by the laboratory equipment, unlike the switchgrass growth period, where N was below detection limits on most dates (Fig. 6a, b). During site preparation, C/N ratios were positively correlated with flow (Fig. 6a, b). This showed that carbon flushing from the system was greater than nitrogen and/or nitrogen was much more diluted than carbon. After 2009, C/N ratios at the MP and SG sites exhibited seasonal variations similar to those found on the YP and IC sites. For all watersheds, the annual average C/N ratios increased in magnitude from 2010 to 2013 (Fig. 6c). At the YP watershed, annual mean C/N ratios for 2012 were significantly ($p < 0.05$) greater than ratios for 2010 and 2011, and C/N ratios for 2013 were significantly ($p < 0.05$) greater than ratios for 2010, 2011, and 2012. For the IC watershed, the annual mean C/N ratios for 2013 were significantly ($p < 0.05$) greater than ratios for 2010. The annual mean C/N ratios for the MP watershed in 2013 were significantly ($p < 0.05$) greater than the ratios for 2010, 2011, and 2012, and annual mean C/N in 2012 was also significantly greater ($p < 0.05$) than for 2010. Annual mean C/N ratios for the SG watershed in 2013 and 2012 was significantly ($p < 0.05$) greater than ratios for 2010 and 2011.

The C/N ratio values were lower during site preparation than during the switchgrass growth period, and indicated a greater N availability for plant uptake and greater mineralization rates during site preparation. Differences in annual mean C/N ratios were observed between watersheds in 2012 and 2013. Annual mean C/N ratios for the YP watershed were significantly greater than for the IC watershed in 2012 and 2013 ($p < 0.05$). The annual mean C/N ratio for the YP watershed was significantly greater than for the SG watershed, and the C/N ratio for the MP watershed was significantly greater than for the IC watershed in 2013 ($p < 0.05$). The increasing annual C/N ratio trend from 2010 to 2013 was attributed to the degrading quality and quantity of mineralizable plant materials for YP, IC, and MP sites. The decline in mineralizable plant materials, along with the increasing demand for N due to increased plant development, led to an increase in C/N ratios (Blazier et al. 2012; Gurlevik et al. 2004; He et al. 2012; Li et al. 2003). These conditions occurred on the watersheds in the years after harvest (YP and IC sites) and thinning (MP site). Seasonal variations in C/N ratios similar to those observed on our watersheds (lower values during Fall and Spring and highest values in Summer) were observed in the waters draining to Kansas River (Whiles and Dodds 2002). Wu et al. (2008) and Tian et al. (2016) also explained that seasonal variations in temperature and precipitation lead to fluctuations in soil carbon storage and above ground production, and that these patterns may also be reflected in seasonal C/N ratio fluctuations and mineralization rates.

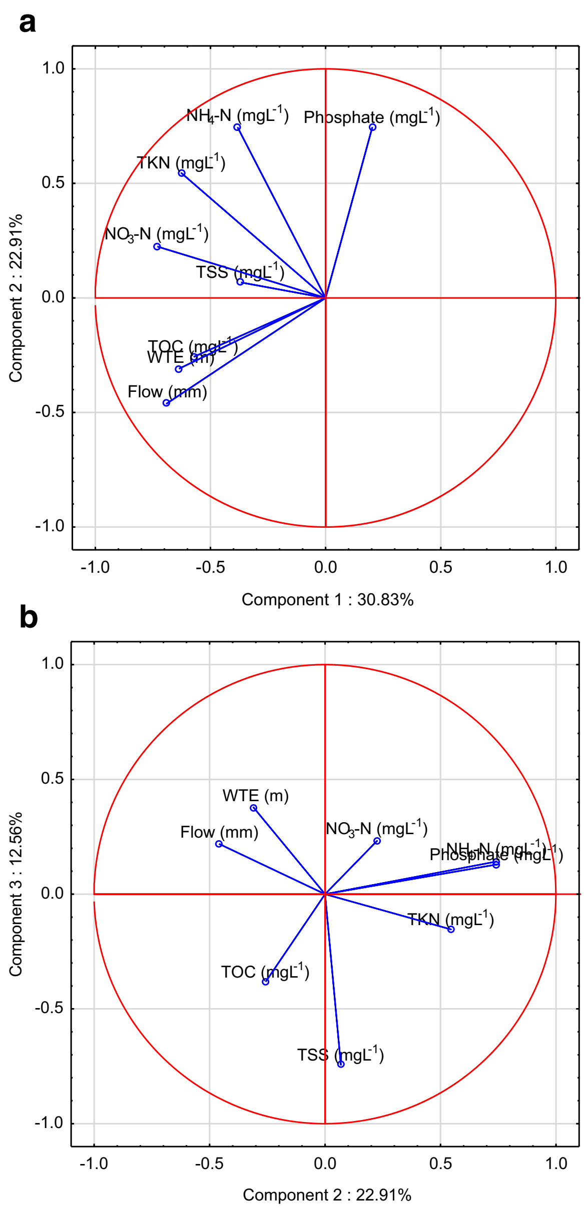


**Fig. 7** Configuration of points representing component variations between **a** components 1 and 2, **b** components 2 and 3

### 3.5 Global Interactions between Flow, Nutrient Compounds, and Sediment Transport in Pine–Switchgrass Ecosystems

The correlation matrix of parameters for all watersheds (Table 4) showed that TKN is most strongly correlated with $NH_4$-N and $NO_3$-N, with correlation coefficients equal 0.47 and 0.51, respectively. This result was expected since TKN is a sum of organic nitrogen and $NH_4$-N. Similarly, the positive correlation between $NO_3$-N and TKN and $NH_4$-N each is explained by the increase in the nitrification rate as more ammonium is available for nitrifying bacteria. A relatively high dependency of 0.40 was observed between flow and TOC. This forested ecosystem has relatively high soil organic matter, fresh organic material from tree harvest and thinning, and disturbed top soil from site preparation processes. Under these conditions, organic carbon would be available in abundance in the soil profile both in soluble and insoluble forms. Subsequently, the transport of TOC from the soil profile to the downstream surface water becomes limited by the hydrological processes. Therefore, it is expected to find a strong correlation between drainage outflow and TOC export from the site. During outflow events, WTE was relatively shallow, indicating good conditions for leaching organic matter from the soil.

Based on the PCA, the authors showed that the processes related to the pattern of the outflow water quality from the analyzed catchments are determined by three main components explaining 66.3% of the variance, with components 1, 2, and 3 explaining 30.8, 22.9, and 12.6% of the variance, respectively. Other components were considered less important. Based on high values of $NO_3$-N and TKN (Fig. 7), it was concluded that component 1 was primarily associated with the transformation of nitrogen compounds. Thus, the formation and transport of these forms of nitrogen are affected by both the hydrological processes and conditions regulating the outflow of water (flow and WTE) and the biogeochemical processes influencing soil carbon and nitrogen dynamics (e.g., OC decomposition and associated N mineralization/immobilization, nitrification). The content of organic matter would influence on the formation of these nitrogen forms with biogeochemical processes influencing carbon and nitrogen

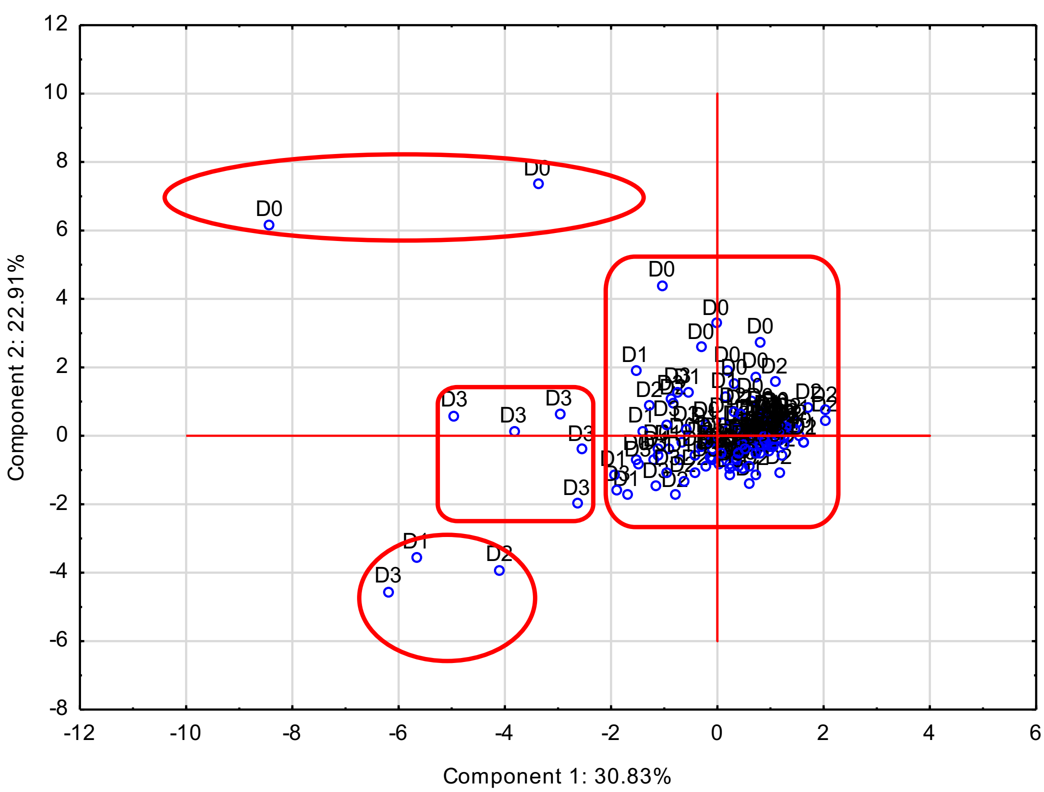


**Fig. 8** Throw cases on the plane of components 1 and 2. The watersheds young pine-natural understorey, young pine-switchgrass, mature pine-natural understorey, and pure switchgrass are represented by D0, D1, D2, and D3, respectively

dynamics. This component can, therefore, be associated with the nitrogen leaching from the soil. In the case of component 2, the main roles were played by $NH_4$-N and phosphate. A strong positive relationship between these two parameters may be responsible for sorption processes P and $NH_4$-N in these acidic sandy loam soils. Component 3 was primarily responsible for transporting TSS. In the final step of the analysis, on the three main components, individual observations were dropped.

Figure 8 presents a projection of individual observations on the plane of components 1 and 2, which significantly affect the processes occurring in the catchment areas. As can be seen from Fig. 8, four clusters can be distinguished. The first contains two cases observed in the young pine with switchgrass catchment characterized by significant positive values for component 2 and negative for component 1. In the samples representing this cluster, high TKN, phosphates, and $NH_4$-N values were observed. Positive values for component 2 and negative values for component 1 indicated that a decreased sorption of compounds in the soil influences how much those compounds leach during runoff. The next cluster contained only samples taken in the pure switchgrass catchment. In this case, negative values for component 1 corresponded to close to 0 values for component 2. Thus, in pure switchgrass site, sorption of nutrients did not play a significant role in the leaching of nutrients. Perhaps this was due to the fact that during event outflow, the WTE was relatively deep (over 2 m), which resulted in very low $NH_4$-N values and rising $NO_3$-N in water. The WTE level favored the greater presence of oxygen in the soil and, therefore, stimulated the nitrification process. The next cluster contained three elements from the intercropped pine forest, mature pine with natural understorey, and pure switchgrass catchments. High but negative values for components 1 and 2 were caused by very high daily flow values, at 40 mm in the outflow from all three aforementioned catchments. Such a large outflow could affect the leaching of nutrients, increasing their levels, and at the same time limit the sorption of compounds in the soil. The largest concentration was observed for relatively small values for component 1, while the considerable variability was observed for component 2. The phenomenon was found

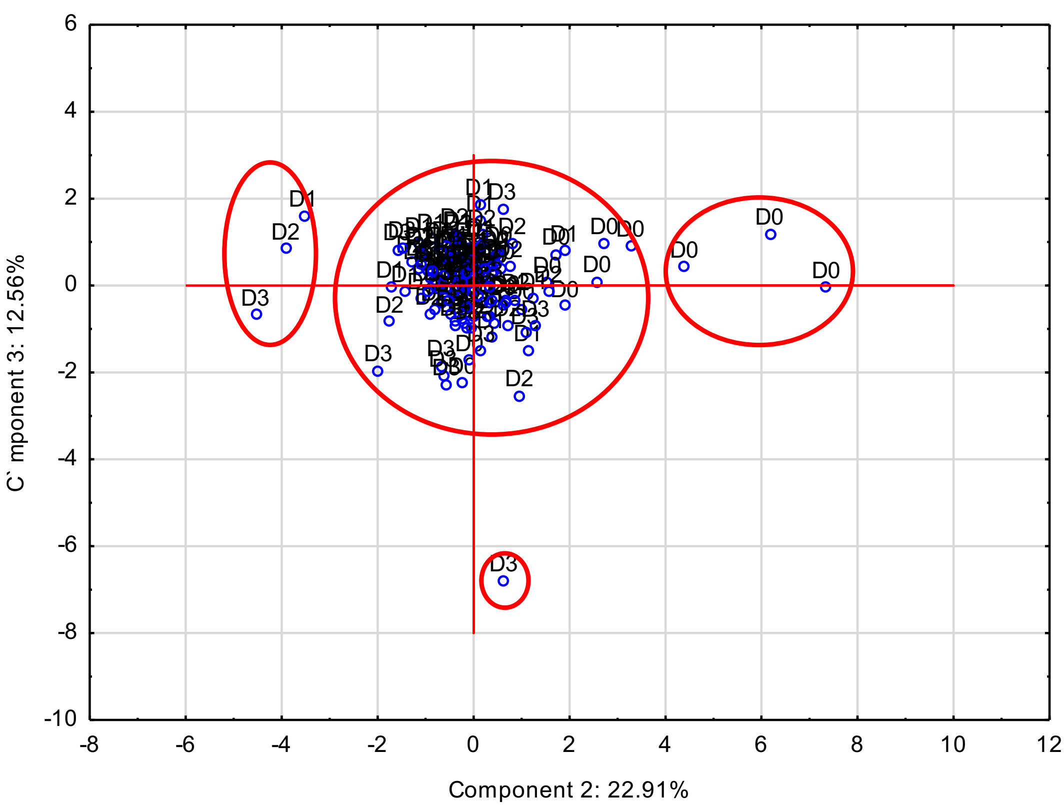


**Fig. 9** Throw cases on the plane of components 2 and 3. The watersheds young pine-natural understorey, young pine-switchgrass, mature pine-natural understorey, and pure switchgrass are represented by D0, D1, D2, and D3, respectively

in outflows from all catchments. The significant variability of observations for component 2 and relatively less significant variability for component 1 indicated the important role of sorption of nutrients in their export from all catchments. In the case of components 2 and 3 (Fig. 9), the plots generally distinguished four aggregated clusters. However, one of the clusters resulted in only one element. The plot also shows a high variability of component 2 with relatively stable values of component 3. Based on this result, it can be concluded that the sorption process, represented as component 2, does not substantially influence any change in component 3—TSS. A fourth cluster consisting of one SG element was considered as an outlier.

## 4 Conclusion

Significant relationships were observed among some of the nutrient constituents with flow and water table elevation, individually, as explanatory variables for site preparation and switchgrass growth periods. Nitrogen exhibited positive relationships with either flow or water table elevation during site preparation and negative relationships during switchgrass growth on the pine–switchgrass and pure switchgrass watersheds. Concentrations of N increased with flow and water table elevation for 2 years during site preparation. Sorption of P and ammonium nitrogen in these acidic sandy loam soils was reflected in the inverse relationships between these nutrients and total organic carbon concentrations. Annual mean C/N ratios increased from 2010 to 2013 on all watersheds, possibly due to the decreasing quality and quantity of mineralizable materials as vegetation was established on the watersheds. The increasing C/N ratio trend for all watersheds from 2010 to 2013 was associated with increased nutrient uptake in pine and switchgrass with establishment and growth. In the case of this pine–switchgrass ecosystem, processes influencing the quality of drainage outflow were determined by three main components: (1) the transformation of nitrogen compounds, (2) the sorption process affecting the transport of $NH_4$-N and phosphate, and (3) transport of total suspended sediment. Also, the export of nutrients and sediment from this drained pine plantation forest intercropped with switchgrass was affected by changes in hydrological and biochemical processes in response to the varying types of site preparation and pine and switchgrass growth. The different processes were responsible for the export of nutrient outflow and sediment transport in different watersheds. Switchgrass establishment by intercropping it in pine stand sites reduced N leaching and for that matter export in the outflow as shown by negative nutrients–hydrologic relationships, indicating a promising water quality improvement.

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