Modeling Effectiveness of Broiler Litter Application Method and Timing for Reducing Phosphorus and Nitrogen losses in Big Creek Watershed, Alabama

by

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Abstract

Agriculture plays an important role in the economy of Alabama (AL) and the United States (US). In AL, broiler litter is commonly used to fertilize pastures. However, repeated application of broiler litter to same pasture fields year after year results in build-up of nutrients in soils. Excessive loss of nutrients to surface waters via agricultural runoff results in toxic algal blooms, reduces dissolved oxygen levels, and causes fish kills. The linkages among the best management practices implemented at the field-level and downstream water quality improvement at the watershed level are complex, because the processes that link management practices and watershed-level water quality span a range of scales. However, it is important to understand the effect of nutrient management strategies on watershed-level water quality because most of the water quality management occurs at the watershed scale. Specific objectives of this study were: (a) quantify the effect of broiler litter application method (surface vs. subsurface application) on P and N losses in surface runoff, and (b) determine the effect of timing of broiler litter application (with respect to the occurrence of a storm event) on P and N losses in surface runoff. The research was conducted in the Big Creek watershed (8024 ha) located in Mobile County, AL. The Soil and Water Assessment Tool (SWAT) model was used to evaluate the effectiveness of best management practices to reduce P and N losses on a long-term basis at the hydrologic response unit (HRU), subwatershed and watershed level. The results show that SWAT successfully simulated streamflow and N and P losses at the watershed outlet. Subsurface application of broiler litter helped to reduce N and P losses in surface runoff compared to surface application of broiler litter. Losses of P and N were greater in winter followed by spring, summer, and fall. Application of broiler litter with respect to the occurrence of a storm event did not affect P and N losses in surface runoff. Overall, results of this study suggest that subsurface application of broiler litter helps to reduce nutrient losses in surface runoff on a long-term basis at the watershed level.

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

The Alabama (AL) poultry and allied industries provide about 80,000 jobs and preserve hundreds of rural economies (ACES, 2007). Poultry production in AL results in the generation of more than 1.25 million tons of broiler litter annually (Aksoy et al., 2008). Broiler litter is usually applied to pastures near the production facilities due to the expense and logistics of transporting broiler litter (Moore Jr et al., 1995). The application of broiler litter to pastures in proximity to the production facilities results in repeated (year after year) application of broiler litter to the same agricultural fields and causes build-up of nutrients (e.g., phosphorus (P), nitrogen (N)) in soils. Loss of nutrients from agricultural landscapes to surface waters causes eutrophication of waterbodies that support aquatic, recreational, and drinking water uses.

Best management practices can help reduce nutrient losses in surface runoff. Method of application of broiler litter to pastures (Harmel et al., 2009; Pote et al., 2011; Sistani et al., 2008; Torbert and Watts, 2014) and timing of broiler litter application with respect to the occurrence of a storm event (Smith et al., 2007) affects N and P losses in surface runoff. Surface application of broiler litter (broadcasting broiler litter on the soil surface) is a common method of fertilizing pastures. Additionally, broiler litter can be applied beneath the soil surface. This method of application is typically referred to as subsurface application of broiler litter. Recent studies have shown that subsurface application of broiler litter helps to reduce nutrient losses in surface runoff relative to the surface application of broiler litter (Lamba et al., 2013; Otinga et al., 2013; Randall and Hoeft, 1988; Rehim et al., 2012; Webb et al., 2010). Similarly, the timing of application of broiler litter with respect to the occurrence of a storm event affects nutrient losses in surface runoff. For example, Sistani et al. (2009) showed that increasing the time between broiler litter application and the first runoff producing storm event reduced nutrient losses in surface runoff from tall fescue pasture. Most previous researchers used plot and field-based experiments to quantify the effect of broiler litter application method and timing on nutrient losses. However, limited research has been done to understand the effect of these management practices on nutrient losses at the watershed level on a long-term basis.

1.2 GOAL AND RESEARCH OBJECTIVES

The overall goal of this study was to advance our knowledge of nutrient transport processes at the watershed scale. The study site for this research was Big Creek watershed (82 km^2) located in Mobile County, AL. Specific research objectives of this study were:

1) Quantify the effect of broiler litter application method on P and N losses in surface runoff.
2) Determine the effect of timing of broiler litter application (w.r.t. occurrence of a storm event) on P and N losses in surface runoff.

1.3 ORGANIZATION OF THE THESIS

This study focusses on the above-mentioned two objectives. Each objective is explained in an individual chapter and each chapter is written as a separate manuscript.

The focus of chapter 2 is to quantify the effect of broiler litter application method on P and N losses in surface runoff.

In Chapter 3, N and P losses in surface runoff were compared when broiler litter is applied 1 day, 3 day, 5 day and 7 day before a storm event. Additionally, long-term N and P losses in surface runoff were compared when broiler litter was applied in winter, spring, summer, and fall.

Chapter 4 contains the summary and suggestions for future work.

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CHAPTER 2

QUANTIFICATION OF PHOSPHORUS AND NITROGEN LOSSES AS A FUNCTION OF BROILER LITTER APPLICATION METHOD

2.1 INTRODUCTION:

Increased levels of nutrients in surface waters results in water quality impairment. For example, excessive delivery of nitrogen (N) and phosphorus (P) to surface waters results in growth of toxic algae and eutrophication (Carpenter et al., 1998). In USA, about 10% (~113,000 miles) of the assessed streams and rivers are impaired because of excessive levels of nutrients (USEPA, 2014). Similarly, in Alabama (AL) approximately 7% (~777 miles) of stream impairment in assessed streams is due to excessive concentration of nutrients (USEPA, 2014). Agricultural runoff has been recognized as one of the major sources of nutrients in surface waters (States et al., 2009). Loss of nutrients via agricultural runoff to surface waters is significant in areas of intensive animal production.

In AL, approximately 1.08 billion (12.4 % of U.S. production) meat birds are produced yearly, ranking it third behind Georgia and Arkansas (USDA, 2016). Annually, about 1.8 million tons of broiler litter is generated in AL (Kang et al., 2008). With the increasing production of broiler litter in AL, disposal of broiler litter is becoming a priority concern (Torbert and Watts, 2014). Being an inexpensive option as compared to commercial fertilizers, broiler litter is commonly used to fertilize pastures (Lamba et al., 2013). Because of the expense and logistics of transporting broiler litter, it is typically surface-applied (broadcasted) to pasture fields in proximity to the production facilities. Broiler litter application to same pasture fields (in proximity to the production facilities) year after year, contributes to increase in soil nutrient (specifically, P) levels. For example, Ranatunga et al. (2013) reported that in the Sand Mountain region of north AL, Mehlich-3 P levels are greater than

200 mg kg^{-1}, which are significantly greater than the agronomic optimum level of 50 mg kg^{-1}. The high concentration of P in soils increases P (dissolved or particulate forms) losses in surface runoff (Edem and Udo-inyang, 2017; Lamba et al., 2012). Losses of P in dissolved form are dominant in surface runoff generated from grasses, forests and uncultivated soils since soil erosion from these land uses is minimal (Elrashidi, 2010).

Implementation of best management practices (BMPs) can help to reduce loss of N and P in surface runoff from agricultural landscapes (Arabi et al., 2006). To study the effectiveness of BMPs at a watershed level, long-term monitoring data is required. However, collection of long-term flow and water quality data is time consuming, labor intensive and expensive. Therefore, typically, long-term data required to quantify the effectiveness of BMPs is not available (Arabi et al., 2006). Watershed-level models are commonly used to understand complex watershed level hydrological, sediment and nutrient transport processes, and assess the effectiveness of BMPs (Artita et al., 2013; Mirhosseini et al., 2016). Several watershed-level models (e.g., Agricultural Policy/Environmental eXtender (APEX), Soil and Water Assessment Tool (SWAT), MIKE SHE, MIKE SWMM) have been successfully used by researchers to understand hydrological processes at the watershed level. From the above-mentioned models, SWAT is a prominent model, which has been used extensively to simulate the effectiveness of BMPs in controlling nutrient losses in agricultural watersheds (Artita et al., 2013; Dechmi and Skhiri, 2013; Lee et al., 2010; Liu et al., 2014; Panagopoulos et al., 2011). For example, Lee et al. (2010) used SWAT model to quantify the effectiveness of vegetative filter strips, riparian buffer system, fertilizer application rate on total P and N losses . Similarly, Panagopoulos et al. (2011) showed effect of BMPs, such as, contour farming with zero tillage, filter strips, and reduction of animal numbers in pastureland on sediment, P and N losses.

Nutrient management guidelines or tools (e.g., P Index) can help producers and conservation personnel to limit nutrient losses from fields (Kleinman et al., 2017). Effective nutrient management requires consideration of four independent factors, collectively referred to as “4R” factors: a) Right placement, b) Right time, c) Right rate, and d) Right form (Collick et al., 2016). Method of application of broiler litter to pastures can affect P and N loss in surface runoff (Blackshaw et al., 2002; Booth Laura B., 2002; Kleinman and Sharpley, 2003; Lamba et al., 2012; Pote et al., 2011; Randall and Hoeft, 1988; Roberts, 2007). For example, subsurface application of broiler litter can help to reduce P loss in surface runoff by limiting the contact between surface runoff and P in broiler litter. Similarly, N loss through ammonia (NH_3) volatilization will be less from fields with subsurface-applied broiler litter compared to fields in which broiler litter is broadcasted/surface-applied (Pote et al., 2011). Therefore, as a result of increased availability of nutrients to crops, subsurface application of manure (e.g., cattle dung and farm yard manure) has shown to increase crop yield compared to surface application of manure (Gana, 2011; Otinga et al., 2013; Rehim et al., 2012). Several studies have been conducted to assess the effectiveness of subsurface application of broiler litter to reduce N and P losses in surface runoff. However, most of the previous studies have quantified the effectiveness of subsurface application of broiler litter for individual storm events at a plot or field scale (Glæsner et al., 2011; Kanwar et al., 1985; Lamba et al., 2012; Pote et al., 2011; Torbert and Watts, 2014). To our knowledge, no studies have been conducted to assess the effectiveness of subsurface application of broiler litter to reduce nutrient losses in surface runoff on a long-term basis at the watershed level. Therefore, objectives of this study were to: (a) use SWAT model to quantify the effectiveness of subsurface application of broiler litter on P and N losses, and (b) determine the effect of soil type and slope on N and P losses as a function of broiler litter application method. The overall goal of this study was to advance our knowledge of nutrient transport processes at the watershed level.

2.2 METHODOLOGY:

2.2.1 Study Area:

The study area for this research was 82 km^2 and is known as Big Creek watershed, located in Mobile County, AL (Figure 2.1). This watershed drains to the Converse Lake, which is the major source of drinking water for Mobile, AL. The mean annual (1990-2015) precipitation in the watershed is about 1678 mm. The dominant land uses in this watershed include 38% forest, 4% agricultural, 31% rangelands, 11% wetlands, 12% pasture (NLCD, 2006) on coastal plain soils. It should be noted that the land use within this watershed has not changed significantly (<10%) over the last two decades, therefore use of NLCD, 2006 to run the model on the long-term basis will not affect water quantity and quality results. The two major reasons for selecting this watershed for our study were: (a) this watershed consists of the coastal plain soils, which are the dominant type of soils in Southeast AL, one of the major regions of broiler litter industry in AL and (b) availability of measured streamflow, P and N data at the watershed outlet required for model calibration and validation.

2.2.2 SWAT Model Description:

SWAT is a watershed scale model developed by the United States Department of Agriculture - Agricultural Research Service (USDA-ARS). It is a continuous time model that operates on a daily time-step. The SWAT model is capable of simulating hydrological and nutrient transport processes and dynamics at a watershed level as a function of different management operations and practices. Major components of this model include hydrology, weather, erosion, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Santhi et al., 2006). In SWAT, a watershed is divided into subwatersheds, which are further subdivided into Hydrological Response Units (HRUs). The HRUs are lumped non-spatial areas with the same land use, slope and soil type within a subwatershed (Mirhosseini et al., 2016). For the HRU definition step, threshold levels for soil class, land use percentage and slope were set to 0%, so that all land uses, soil type and slope are represented within the watershed. For this study, the entire watershed was divided into 13 different subwatersheds and consisted of 1808 HRUs. In this study, we used SWAT 2016 revision 664 version. Surface runoff in SWAT can be calculated by using SCS curve number method or Green Ampt infiltration equation (Neitsch et al., 2002). SCS curve number method was used in this study. The methods available in SWAT to calculate potential evapotranspiration include Hargreaves method, Priestley Taylor, and Penman-Monteith (Neitsch et al., 2002). The Penman-Monteith method was used for this study. Modified Universal Soil Loss equation (MUSLE) was used to determine erosion and sediment yield for each HRU (Neitsch et al., 2002). Eroded sediment that enters the channel in SWAT was simulated by using deposition and degradation technique (Neitsch et al., 2011). In addition to simulating sediment processes within a watershed, SWAT simulates fate and transport of P and N. Phosphorus and N pools and processes which are modeled by SWAT are described in detail in the SWAT theoretical documentation (Neitsch et al., 2011). Briefly, SWAT partitions soil N into five different N pools. Two of the pools are inorganic (ammonium-N [NH_4-N] and nitrate-N [NO_3-N]) and three pools are organic (active, stable and fresh) (Figure 2.4(a)). Transformation of N in different pools is modeled using mineralization, decomposition, immobilization, nitrification, denitrification and ammonium volatilization processes (Chaubey et al., 2006). Plant use of N is estimated using supply and demand approach (Santhi et al., 2006). Unlike N, soil P in SWAT is divided into six pools (three mineral and three organic) (Figure 2.4(b)). Crop residue and biomass contribute to fresh organic P pool, and humus substances contribute to active and stable organic pool. Soil inorganic pool includes active, solution and stable pools (Chaubey et al., 2006). The portion of P from solution inorganic P is taken up by plants and is in rapid equilibrium with the active pool. Active P pool is in rapid equilibrium with the solution pool and in slow equilibrium with the stable pool. Stable inorganic pool is relatively unavailable for plant uptake (Neitsch et al., 2002). Plant use of P is estimated using the supply and demand approach similar to N (Santhi et al., 2006).

2.2.3 Input data:

The input data required to setup a SWAT model includes digital elevation model (DEM), soil properties, land use information, management data (e.g., crop rotations, manure/fertilizer application rate), and weather (Mirhosseini et al., 2016). A 10-m DEM was used to delineate the watershed. National land cover dataset (2006) was used to provide land cover information (Fry et al., 2011) and properties of soils in watershed were derived using Soil Survey Geographical dataset (SSURGO) (USDA-NRCS, 1995). The only weather station available in proximity to the watershed was located around 19 miles away from watershed outlet and it was used to obtain daily temperature (maximum and minimum temperature) and precipitation data. SWAT built-in weather generator was used for the relative humidity, solar radiation and wind speed data because this data was not available from the weather station. Management practices and operations significantly affect the hydrological and nutrient processes within a watershed. Therefore, it is important to incorporate management practices information in the SWAT model. Management practices were selected from BMPs database developed by Butler and Srivastava (2007). This management database has been used in previous studies conducted in AL (Mirhosseini et al., 2016; Srivastava et al., 2010). For cropland areas, Peanut - Cotton rotation was used and Bermuda grass for pastures. The management information for the peanut-cotton rotation is included in Table 2.1. Bermuda grass was planted in the beginning of March and then harvested in July every year (Ahring et al., 1974; Shaver et al., 2006) for the period of 25 years. In the final year of SWAT model run, Bermuda grass was harvested and killed for all HRUs under pasture land use.

2.2.4 Calibration and Validation:

To perform model calibration, sensitive parameters were identified from the scientific literature. SWAT model calibration and validation was performed at a monthly time-step for streamflow (surface runoff and baseflow), total P and total N. To minimize uncertain conditions (e.g., ground water level, soil moisture content) in the SWAT model from the start of the calibration period, we used a warm-up period of six years (Jan. 1985- Dec. 1990). The model calibration and validation was performed separately for surface runoff and baseflow (Mirhosseini et al., 2016; Srivastava et al., 2010). Web-based Hydrograph Analysis Tool (WHAT) was used to separate total streamflow into surface runoff and baseflow (Lim et al., 2005). Surface runoff and baseflow calibration and validation periods were Jan. 1991- Dec. 2003 and Jan. 2004- Dec. 2015, respectively. The observed streamflow data required for model calibration and validation was obtained from the United States Geological Survey (USGS) gage (02479945) at the watershed outlet. Compared to streamflow data, observed data for P and N at the watershed outlet was limited. The P and N loading data at the watershed outlet were obtained from the USGS water resources investigation report (Journey and Gill, 2001). The P and N calibration was performed from Jan. 1991- Dec. 1995 and validation was performed from Jan. 1996- July 1998. The parameters used for surface runoff, baseflow, P and N calibration are listed in Table 2.2.

Model performance was assessed by using qualitative and quantitative methods. Qualitative method involved plotting observed and simulated surface runoff, baseflow, streamflow, total P and N loading at a monthly time-step. In quantitative methods, a wide variety of statistical techniques can be used to evaluate model performance. Coffey et al. (2004) and Moriasi et al. (2012) described over a dozen statistical tests/parameters (e.g., root mean square error, coefficient of determination (R^2), percent bias (PBIAS), Nash-Sutcliffe efficiency (NSE), cross correlation, non-parametric tests and t-test) that can be used to quantify model performance. In literature, NSE, PBIAS and R^2 proposed by Moriasi et al. (2007) are most commonly used (Mirhosseini et al., 2016; Niraula et al., 2013; Rahman et al., 2013; Strauch et al., 2012). Therefore, we used NSE, PBIAS and R^2 to evaluate model performance. NSE, PBIAS and R^2 were computed using equations 1, 2 and 3, respectively:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Oi - Pi)^2}{\sum_{i=1}^{n}(Oi - \overline{O})^2} \qquad (1)$$

$$PBIAS = \frac{\sum_{i=1}^{n}(Oi - Pi) * 100}{\sum_{i=1}^{n} Oi} \qquad (2)$$

$$R^2 = \frac{\sum_{i=1}^{n}(Oi - \overline{O})(Pi - \overline{P})}{\sqrt{\sum_{i=1}^{n}(Oi - \overline{O})^2}\sqrt{\sum_{i=1}^{n}(Pi - \overline{P})^2}} \qquad (3)$$

where O_i is the i^{th} observation for the constituent being evaluated; P_i is the i^{th} simulated value for the constituent being evaluated; $\overline{O}$ is the mean of observed data for the constituent being evaluated; $\overline{P}$ is the mean of simulated data for the constituent being evaluated and n is the total number of observations.

2.2.5 Method of application of broiler litter:

Nutrients (N and P) losses in surface runoff were compared from pastures as a function of surface and subsurface application of broiler litter. Fertilizer operations in SWAT allows the user to specify the fraction of fertilizer applied to the top 10 mm of soil (Neitsch et al., 2002). For surface application of broiler litter, fraction of fertilizer applied to the top 10 mm of soil was one (i.e., all the broiler litter was applied to the first 10 mm of soil). Unlike surface application of broiler litter, all the broiler litter was applied to the first soil layer (below 10 mm of soil)) for the subsurface application of broiler litter. Based on the typical application rate of broiler litter in the southeastern US, an application rate of 13400 kg ha^{-1} was used for both surface and subsurface application of broiler litter (Torbert and Watts, 2014). Based on the application rate of 13400 kg ha^{-1}, amount of total P and N applied to the pastures per year was 188 kg ha^{-1} and 670 kg ha^{-1}, respectively. The nutrient losses were compared on a long-term basis (1991-2015) at the HRU, subwatershed and watershed level as a function of broiler litter application methods. To compare nutrient losses between surface and subsurface broiler litter application methods we used Mann-Whitney test and significance level of $\alpha = 0.05$ for all hypothesis testing.

2.2.6 Land use change scenario:

Land use under pastures in the study watershed was approximately 12%. To accurately quantify if litter application method can help to reduce nutrient losses at the watershed level, we performed a land use change scenario. For this scenario, all the rangelands (31%) within this watershed were converted to pastures. Conversion of rangelands to pastures increased the percentage of area under pastures to 43% in this watershed. The increase in land use under pastures helped to reduce the effect of unmanaged land uses on nutrient losses at the watershed level and therefore accurately assess if the litter application method can improve watershed level water quality.

2.3 RESULTS AND DISCUSSIONS:

2.3.1 SWAT model calibration and validation:

The graphs showing time series of observed and simulated surface runoff, baseflow and streamflow are shown in Figure 2.5. The SWAT model performed satisfactorily to simulate surface runoff, baseflow, and streamflow. The differences in average monthly simulated and observed values of surface runoff, baseflow and streamflow were less than 10% (Table 2.3). The NSE, PBIAS and R^2 values for surface runoff, baseflow and streamflow for the calibration and validation periods are included in Table 2.4. Based on the criteria’s specified by Moriasi et al. (2007), SWAT satisfactorily simulated streamflow. The observed vs. simulated total P and N loads at a monthly time-step are shown in Figure 2.6. The total P and N loads predicted by the model followed the trends of observed total P and N loadings and the model performed very well (based on PBIAS values) (Moriasi et al., 2007) in simulating total P and N loads (Table 2.4). The average monthly (Jan 1991- Sept 1998) observed and simulated P loading at the watershed outlet was 139 kg and 105 kg, respectively. Similarly, at the watershed outlet the observed and simulated average monthly N loadings were 3446 kg and 3298 kg, respectively. Overall, SWAT model adequately simulated the trends in observed monthly surface runoff, baseflow, total streamflow, total P, and total N. The model simulated results were comparable to the previous studies conducted in this watershed (Mirhosseini et al., 2016; Srivastava et al., 2010).

2.3.2 Effect of broiler litter application method on P and N losses:

At the HRU level, nutrient losses were significantly less ($\alpha = 0.05$) in surface runoff when broiler litter was subsurface applied compared to surface application of broiler litter. Subsurface-application of broiler litter to pastures reduced average annual soluble P losses in surface runoff at the HRU level by 71.5% compared to surface application of broiler litter (Figure 2.7). Average annual total P losses were reduced by 71.7% in surface runoff at the HRU level when broiler litter was subsurface-applied in comparison with the surface application of broiler litter to pastures (Figure 2.8). Since soluble P was the dominant part (around 72%) of total P in surface runoff from pastures (erosion rates from pastures are less), trends in reduction of soluble P and total P as a result of subsurface application of broiler litter were similar. Similarly, Lamba et al. (2013) reported that soluble P is the dominant form of total P in surface runoff from pastures. Compared to surface application of broiler litter, subsurface application of broiler litter reduced average annual total N losses in surface runoff at the HRU level by 33% (Figure 2.10). Similar trends were observed for NO_3 losses in surface runoff between two broiler litter application methods (Figure 2.9). Unlike N, P is less mobile and bounds to soil particles (Heathwaite et al., 2000), which likely resulted in greater reduction in P losses relative to N losses when broiler litter was subsurface-applied instead of broadcasting broiler litter on the soil surface.

Sharpley (1985) reported that the surface runoff interacts with top few cms of soil. In SWAT, top 10 mm of soil profile interacts with the surface runoff. In subsurface application of broiler litter method, broiler litter was applied to the first soil layer (below the top 10 mm of soil profile). Therefore, P and N losses for the subsurface application of broiler litter method were less compared to surface application of broiler litter due to lack of direct contact between surface runoff and broiler litter. Whereas, in surface application of broiler litter, surface runoff was in direct contact with the broiler litter applied to the soil (broiler litter integrated within the top 10 mm of soil profile), which resulted in greater losses of P and N in this method of litter application relative to subsurface application of broiler litter. Several field-based studies (Glæsner et al., 2011 and Lamba et al., 2012) have reported that P and N losses are less in surface runoff when broiler litter is applied beneath the soil surface relative to surface application of broiler litter. For example, Pote et al. (2011) reported around 90% reduction in total P and N losses in surface runoff with subsurface band application of broiler litter compared to surface application of broiler litter. Similar results were reported by Glæsner et al. (2011) and Lamba et al. (2012). The results of this study showed that SWAT model satisfactorily predicted the effect of subsurface application of broiler litter on P and N losses in surface runoff. Overall, subsurface application of broiler litter helped to reduce nutrient losses in surface runoff on a long-term basis.

2.3.3 Effect of soil type and slope on P and N losses:

A combination of different factors can influence P and N losses in surface runoff from pastures. For example, amount of surface runoff generated from an HRU, soil type and slope can affect P and N losses in surface runoff. The amount of surface runoff generated from an HRU was affected by the soil hydrological soil group (HSG) and slope (Table 2.5). The results show that the HSG D HRUs (mainly clayey soils) and HRUs at a slope greater than 10% generated greater amount of surface runoff compared to HSG A or B soils on less steep (<10%) slopes. The P and N losses in surface runoff were greater from the HSG D soils and soils at a slope >10%. The HSG D soils have potential to generate high surface runoff due to low infiltration rates compared to the HSG A and B soils

(Edwards and Daniel, 1993; Fang et al., 2015). Soluble P losses increased as the amount of surface runoff generated from an HRU increased ($R^2 = 0.722$). Similar trends were observed between total P losses and amount of surface runoff generated from an HRU ($R^2 = 0.723$). The trends between surface runoff vs. soluble P losses and surface runoff vs. total P losses were similar because soluble P was the dominant component (~72%) of total P in surface runoff from pastures. Since erosion rates from pastures are low, particulate P losses are minimal from pastures. Similarly, soluble P and P losses from HRUs with slope >10% were greater compared to HRUs with slope 0-5% and 5-10% (Figure 2.12). The percentage reduction in soluble and total P losses per unit area as a result of subsurface application of broiler litter among HRUs on different HSG soils and slope classes was similar (Figure 2.11 and 2.12). The effect of HSG and slope was similar on N losses in surface runoff as a function of broiler litter application method (Figure 2.13-2.14). Overall, results show that subsurface application of broiler litter helped to reduce P and N losses significantly ($\alpha = 0.05$) in surface runoff regardless of soil type and slope. The HRUs with HSG D and on slope >10% can help to reduce P and N losses significantly as a result of subsurface application of broiler litter.

2.3.4 Nutrient losses at the subwatershed and watershed level:

The reduction in N and P losses because of subsurface application of broiler litter varied as a function of spatial scale (e.g. HRU, subwatershed and watershed level). The effectiveness of subsurface application of broiler liter in reducing nutrient losses diminished with the increase in the spatial scale. For example, the reductions in average annual total N and total P losses in surface runoff as a result of subsurface application of broiler litter at the subwatershed level ranged from 3% to 16% and 2% to 12%, respectively. Similarly, average annual soluble P and soluble N ranged from 3% to 16% and 1% to 10%, respectively. Whereas, subsurface application of broiler litter to pastures reduced average annual total N and total P losses in surface runoff at the HRU level by 33% and 77%, respectively. Land use percentage under pastures within subwatersheds ranged from 12% to 43 %. Since only a small fraction of area was under pastures within each subwatershed, effect of subsurface application of broiler litter on nutrient losses at the subwatershed level was less compared to HRU level. It should be noted that in addition to land use within a subwatershed, additional characteristics (e.g., soil type, slope, size,) can affect N and P losses within a subwatershed. For example, amount of surface runoff generated within a subwatershed affected P and N losses at the subwatershed level. Subwatersheds generating high amount of surface runoff per unit area contributed greater amount of P and N to a stream (R^2= 0.99). At the watershed level, subsurface application of broiler litter reduced P and N losses by 3% and 2%, respectively. The effect of subsurface application of broiler litter on P and N losses at the watershed level was minimal because only 12% of the total watershed area was under pastures, whereas around 80% of the total watershed area was under unmanaged land uses (e.g., forests, rangelands). The P and N losses from the unmanaged land uses were minimal and likely masked the reduction in P and N at the watershed outlet as a result of subsurface application of broiler litter. For example, at the HRU level average annual P and N losses in surface runoff from rangelands were 0.117 and 0.238 kg ha^{-1}, respectively. Similarly, for forested areas, average annual P and N losses in surface runoff were 0.037 and 0.085 kg ha^{-1}, respectively. Therefore, dilution of P enriched surface runoff from pastures with P depleted surface runoff from unmanaged areas masked the downstream improvement in water quality at the watershed outlet. Additionally, baseflow is the dominant component (57%) of the total streamflow in the study watershed, which further masked the improvement in water quality at the watershed outlet.

As mentioned earlier, rangelands were converted into pasture land use to assess the effectiveness of subsurface application of broiler litter at the watershed level. The percentage of total watershed area under pastures was 43% after converting rangelands to pastures. After the land use conversion of rangelands to pastures, subsurface application of broiler litter helped to reduce average annual (1991-2015) total P and N losses at the watershed level by 39% and 20%, respectively, compared to surface application of broiler litter (Table 2.6). Therefore, results of this study show that subsurface application of broiler litter can help to reduce P and N losses at the watershed level in agricultural watersheds.

2.4 CONCLUSIONS:

This study used the SWAT model to test the effectiveness of subsurface application of broiler litter in reducing P and N losses from pastures. The results of this study show that at the HRU level subsurface application of broiler litter helped to reduce average annual total P and N losses in surface runoff by 71% and 33%, respectively, compared to surface application of broiler litter. The reduction in P and N losses at the HRU level was greater compared to subwatershed and watershed level. Soluble P was the dominant fraction of total P losses in surface runoff from pastures. The subsurface application of broiler litter on clayey soils at steep slopes can help to reduce P and N losses in surface runoff substantially. The land use change scenario (conversion of rangelands to pastures) showed that subsurface application of broiler litter can help to improve watershed level water quality in agricultural watersheds.

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Plant type	**Operation Date**	**Operation type**	**Operation attributes**
Peanut	15-May	Planting	
	21-Oct	Harvesting	
Cotton	25-Mar	Tillage	Generic Conservation tillage
	15-Apr	Planting	
	15-Apr	Fertilization	50 kg ha^{-1} Nitrogen
		Fertilization	45 kg ha^{-1} Phosphorus
	1-Jun	Fertilization	50 kg ha^{-1} Nitrogen
	1-Oct	Harvesting	

Table 2.1: Management operations for cropland HRUs.

Parameter description	Parameter	Default Values	Final Values	HRUs for which parameter is changed
Curve number	CN	Varies	15% decrease	All HRU’s
Available water capacity of soil layer (mm H_2O/mm soil)	SOL_AWC	Varies	15% increase	All HRU’s
Saturated hydraulic conductivity (mm/hr)	SOL_K	Varies	10% decrease	All HRU’s
Biological mixing efficiency	BIOMIX	0.2	0.01	All HRU’s
Baseflow alpha factor (days)	ALPHA_BF	0.048	0.50	All HRU’s
Groundwater “revap” coefficient	GW_REVAP	0.02	0.2	All HRU’s
Deep aquifer percolation factor	RCHRG_DP	0.05	0.25	All HRU’s
Groundwater delay time (days)	GW_DELAY	31	100	All HRU’s
USLE equation support practice factor	USLE_P	1	15% decrease	All HRU’s
Exponent parameter for calculating sediment reentrained in channel sediment routing	SPEXP	1	1.5	All HRU’s
Peak rate adjustment factor for sediment routing in the main channel	PRF	1	0.5	All HRU’s
Peak rate adjustment factor for sediment routing in sub watershed	ADJ_PKR	1	0.5	All HRU’s
Manning's "n" value for overland flow	OV_N	0.1	0.4	FORESTED
Initial soluble P concentration in soil layer (mg/kg)	SOL_LABP	5	3	All HRU’s
Initial organic P concentration in soil	SOL_ORGP	0	0.01	All HRU’s

layer (mg/kg)				
Organic N in the baseflow (mg/l)	LAT_ORGN	0	2	All HRU’s
Initial organic N concentration in the soil layer (mg/kg)	SOL_ORGN	0	0.01	All HRU’s

Table 2.2: Parameters used for calibration of surface runoff, baseflow, P and N.

Variable	Average annual total value (m^3 s^{-1})
Observed Streamflow	1.67
Simulated Streamflow	1.81
Estimated Surface runoff	0.62
Simulated Surface runoff	0.74
Estimated Baseflow	1.05
Simulated Baseflow	1.05

Table 2.3: Average annual observed and simulated streamflow, surface runoff and baseflow for the time-period of Jan. 1991- Dec. 2015.

	Streamflow		**Surface runoff**		**Baseflow**		**Total P**		**Total N**	
	Calibration	*Validation*	*Calibration*	*Validation*	*Calibration*	*Validation*	*Calibration*	*Validation*	*Calibration*	*Validation*
NSE	0.593	0.651	0.527	0.557	0.557	0.574	0.215	0.125	0.624	0.605
R^2	0.604	0.689	0.682	0.563	0.627	0.611	0.565	0.125	0.728	0.776
PBIAS	-6.034	3.477	6.277	-7.724	1.174	-4.847	20.5	24.05	10.15	-3.96

Table 2.4: NSE, R^2 and PBIAS values for the calibration and validation time periods.

Soil/Slope	**Surface Runoff (mm)**
A	50 ± 0.29
B	254 ± 0.31
D	598 ± 0.36
0-5%	136 ± 0.35
5-10%	167 ± 0.35
>10%	174 ± 0.48

Table 2.5: Average annual (1991-2015) surface runoff values (mm) ± standard error for pasture HRUs as a function of HSG and slope classes.

	Before land use change (%)				After land use change (%)			
Spatial Scale	Soluble P	Total P	Nitrate	Total N	Soluble P	Total P	Nitrate	Total N
HRU level	69	71	31	33	65	65	69	33
Subwatershed level	11	12	8	8	46	48	22	25
Watershed level	2.5	3	2	2	35	39	17	20

Table 2.6: Percentage reduction in average annual (1991-2015) P and N losses before and after land use change scenario at the HRU, subwatershed and watershed level.

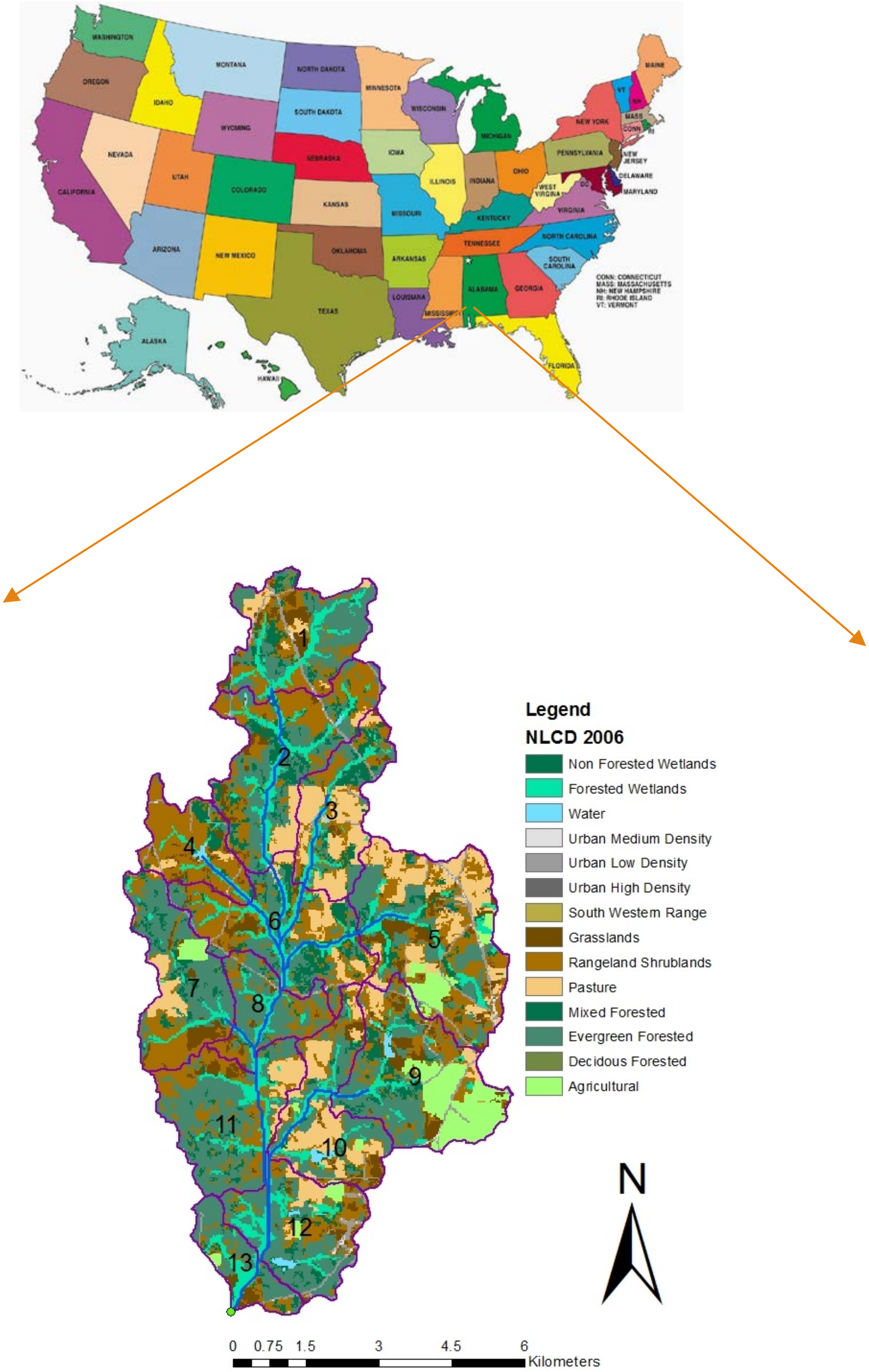


Figure 2.1: Land use distribution in the Big Creek watershed, Alabama.

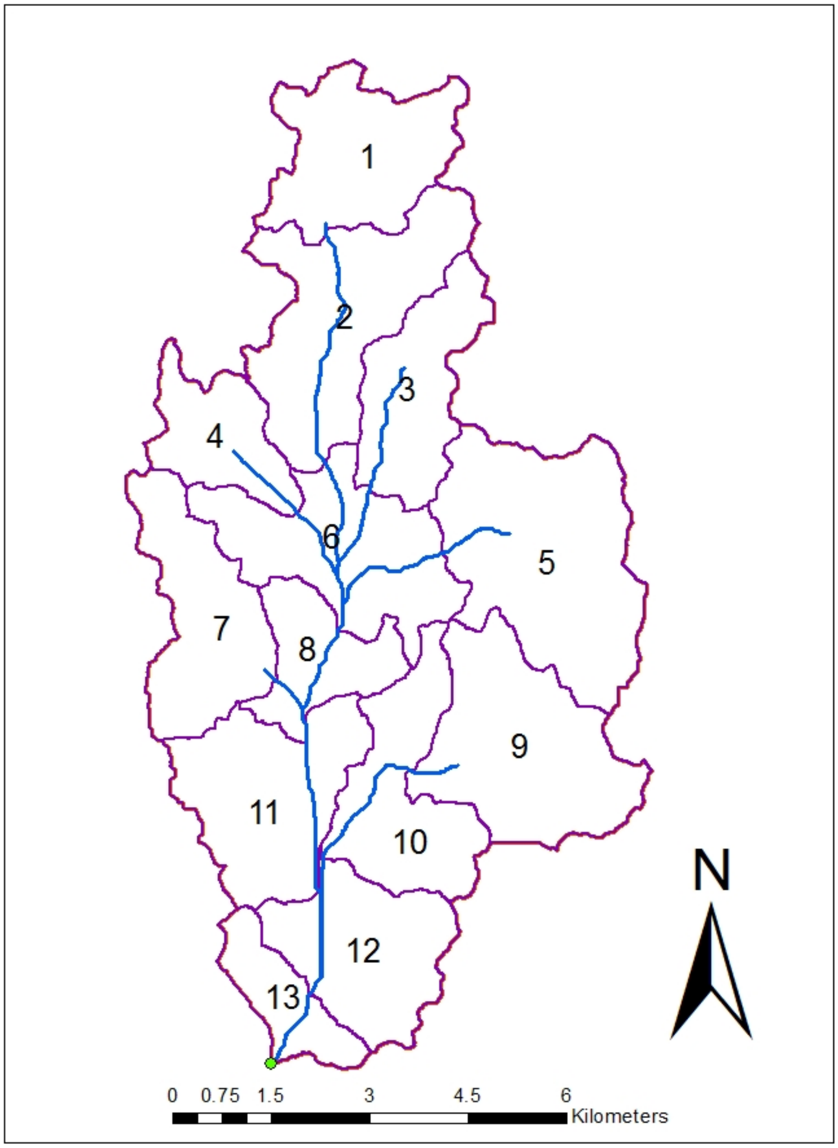


Figure 2.2: Subwatersheds boundaries delineated in the Big Creek watershed, AL.

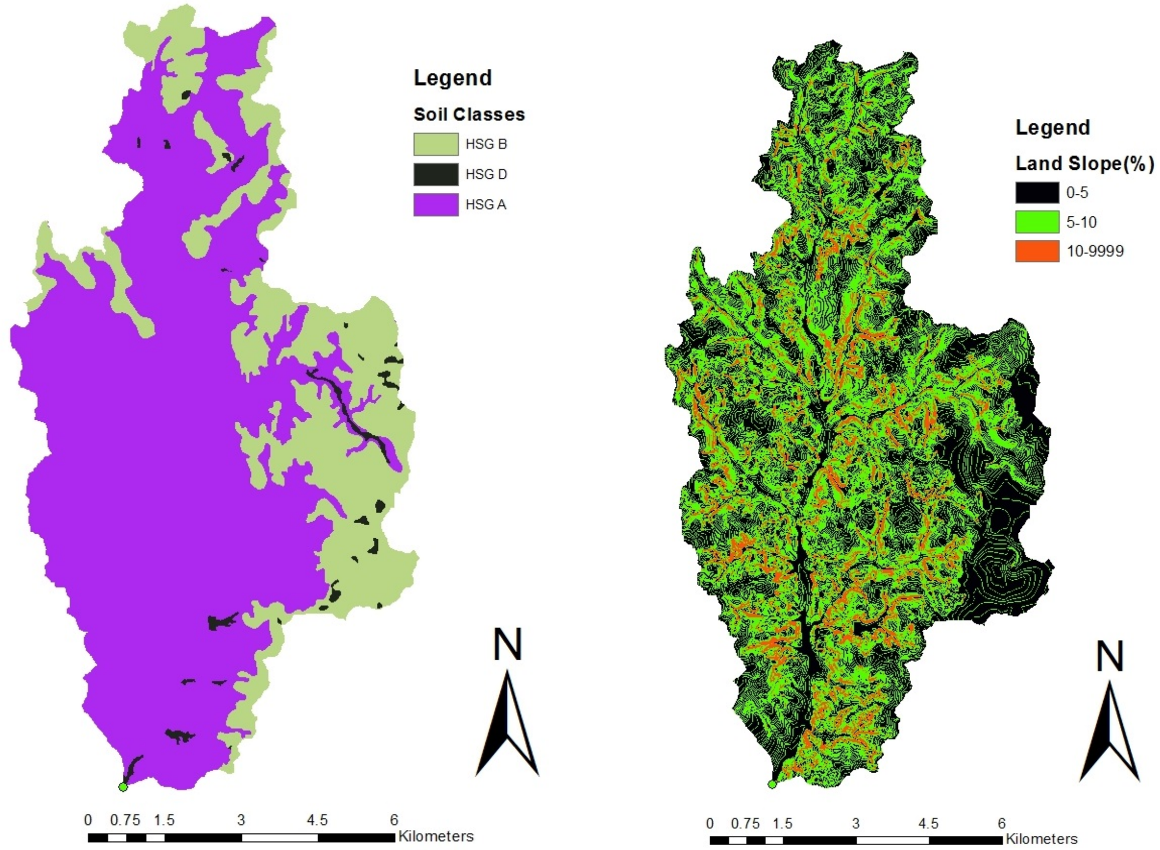


Figure 2.3: Map showing HSG and slope classes in Big Creek watershed, AL.

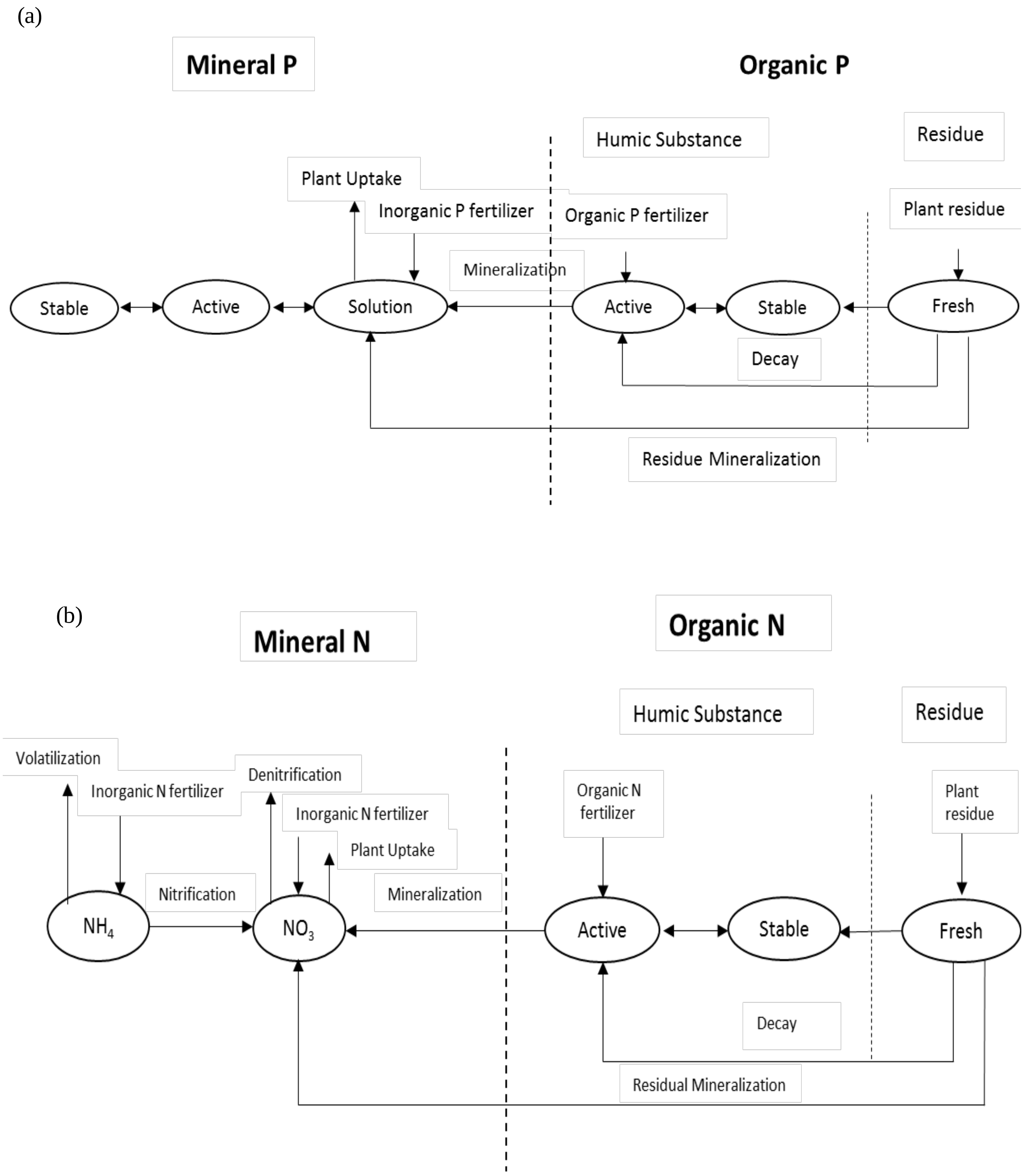
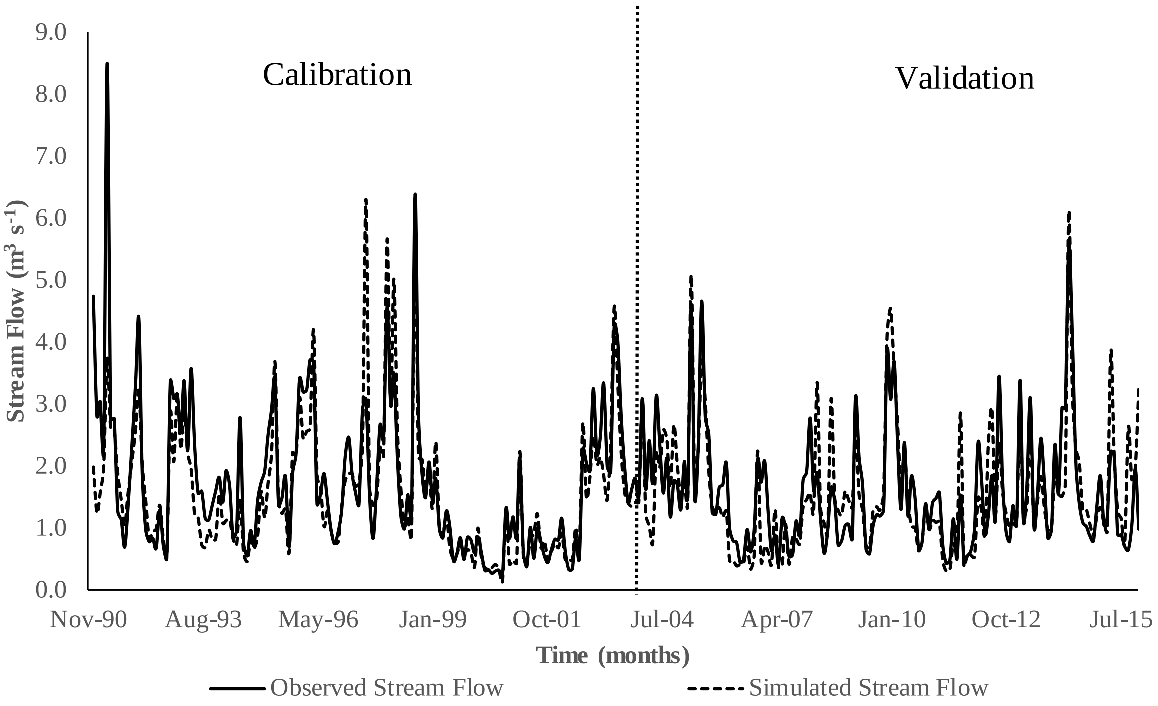
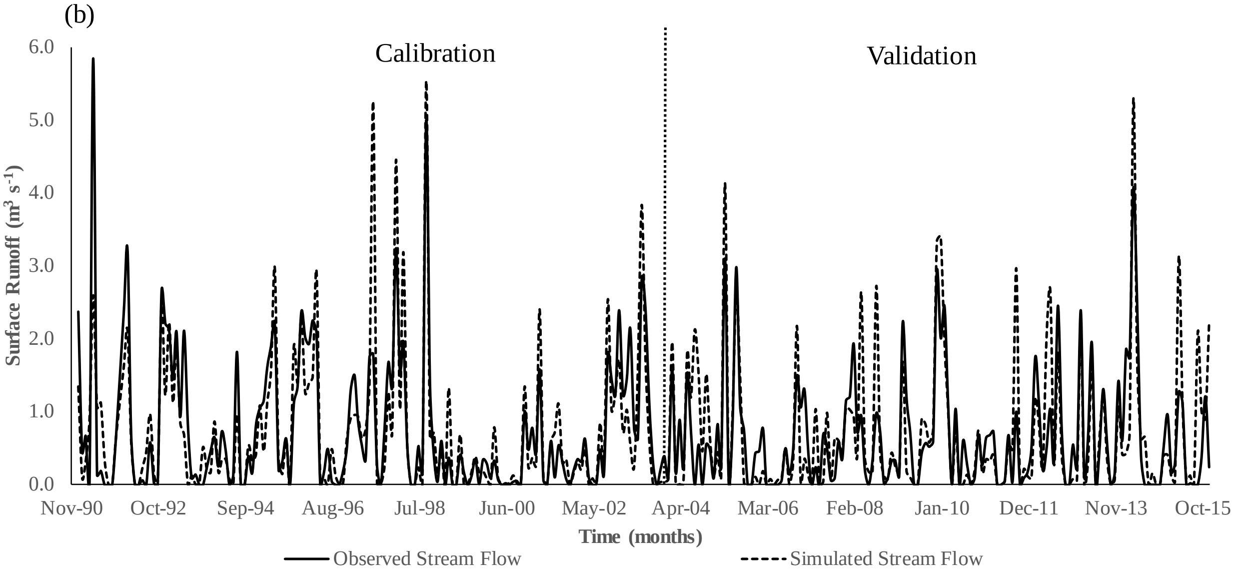


Figure 2.4: SWAT soil nutrient pools: (a) P and (b) N (adapted from Neitsch et al., 2011).

(a)


9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Stream Flow (m³ s⁻¹)
Calibration
Validation
Nov-90
Aug-93
May-96
Jan-99
Oct-01
Jul-04
Apr-07
Jan-10
Oct-12
Jul-15
Time (months)
Observed Stream Flow
Simulated Stream Flow

(b)


6.0
5.0
4.0
3.0
2.0
1.0
0.0
Surface Runoff (m³ s⁻¹)
Calibration
Validation
Nov-90
Oct-92
Sep-94
Aug-96
Jul-98
Jun-00
May-02
Apr-04
Mar-06
Feb-08
Jan-10
Dec-11
Nov-13
Oct-15
Time (months)
Observed Stream Flow
Simulated Stream Flow

(c)

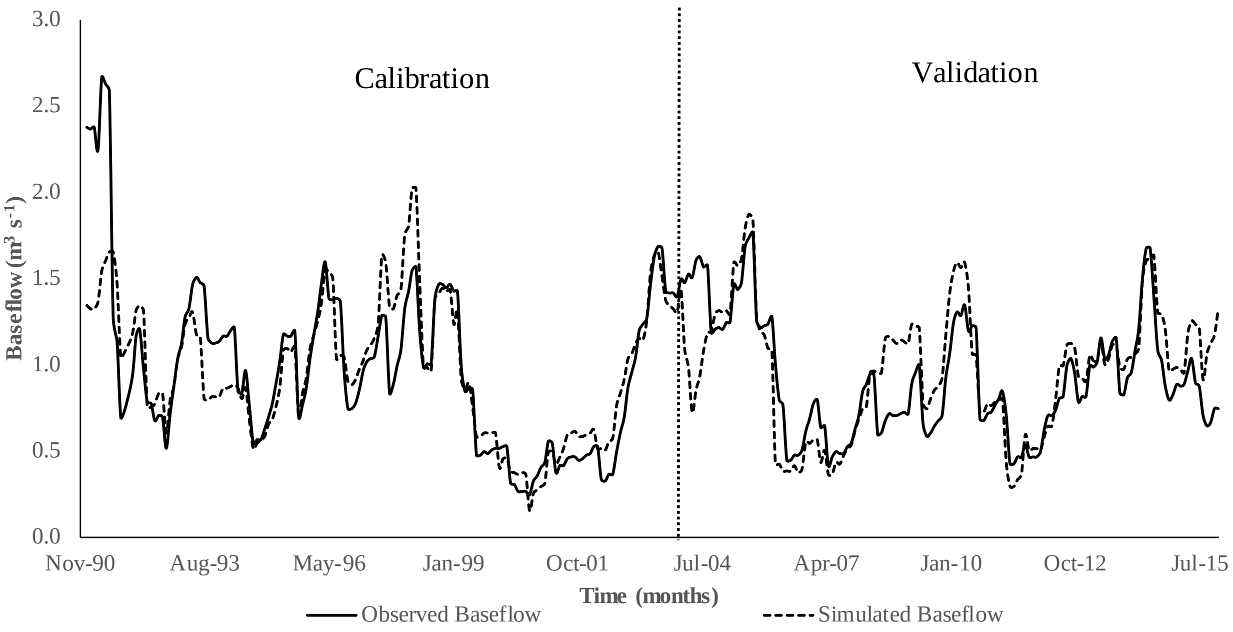


Figure 2.5: Observed vs. simulated: (a) streamflow ($m^3 s^{-1}$), (b) surface runoff ($m^3 s^{-1}$) and (c) baseflow ($m^3 s^{-1}$).

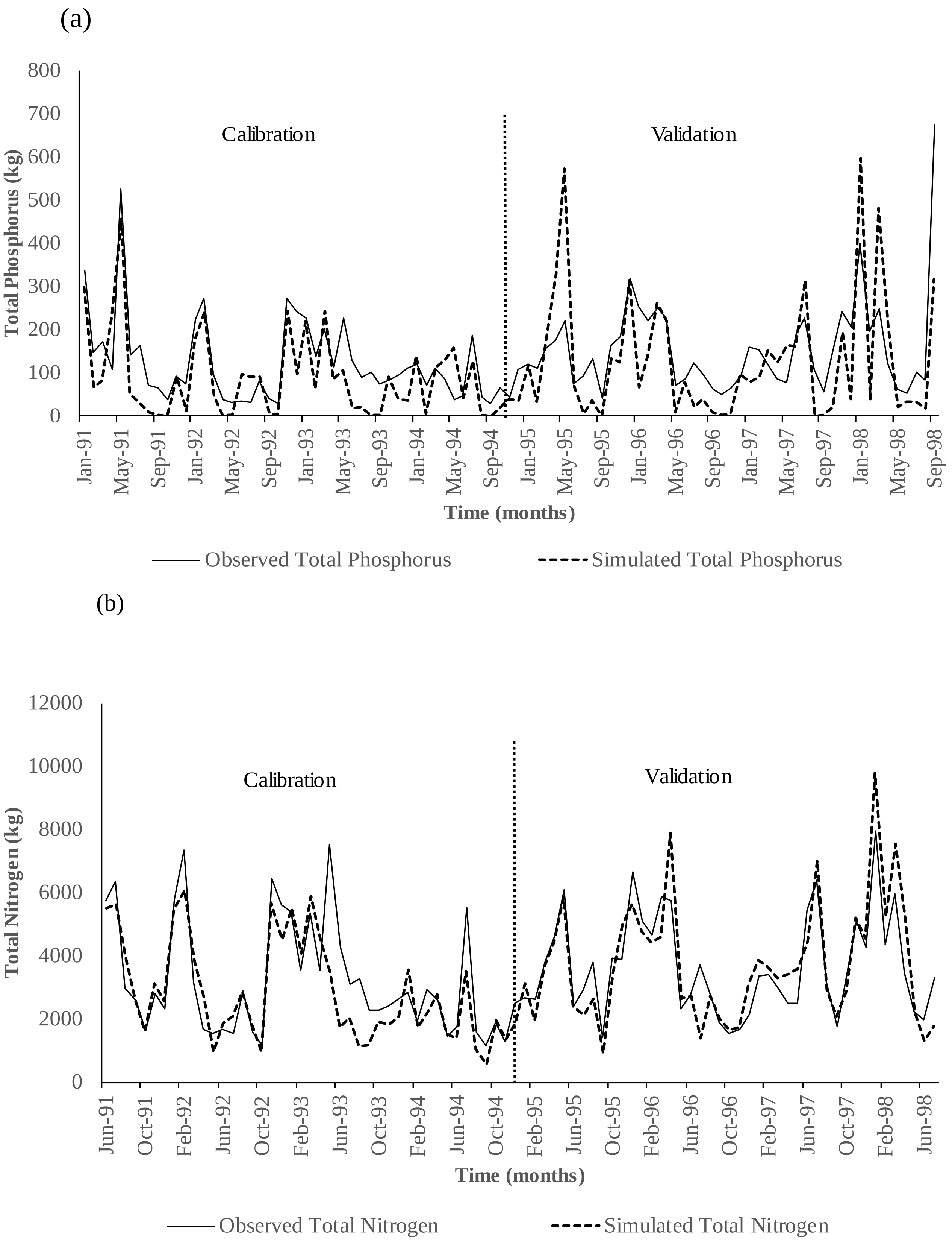


Figure 2.6: Observed vs. simulated monthly: (a) P and (b) N loading at the watershed outlet.

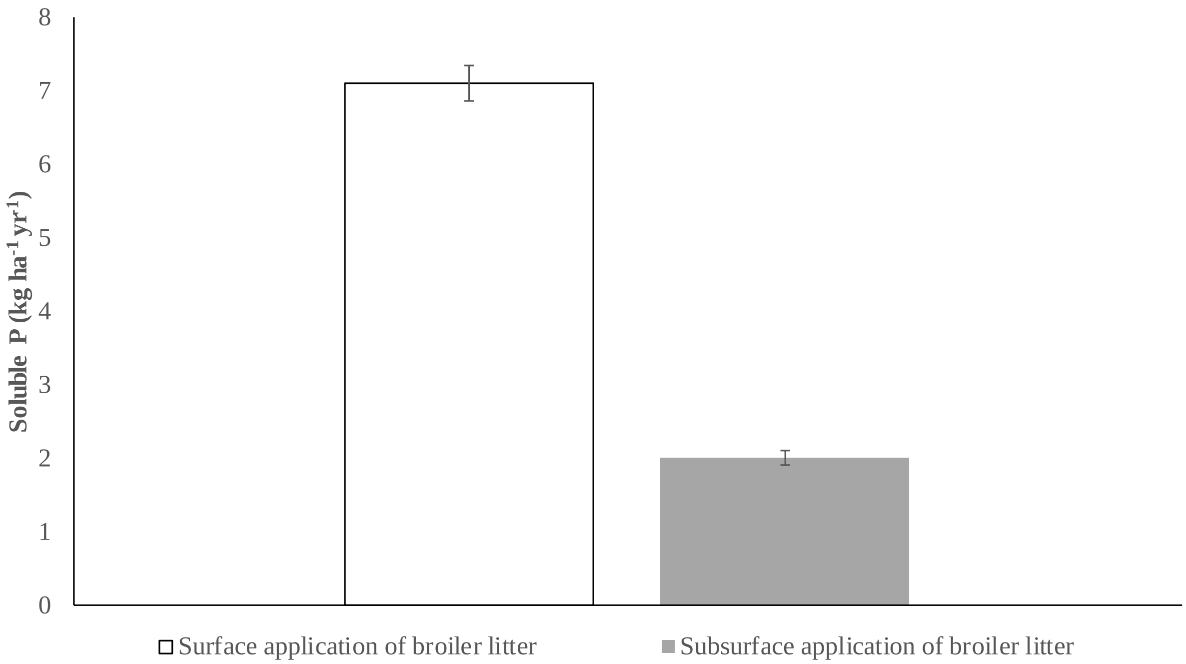


Figure 2.7: Average annual (1991-2015) soluble P losses from pasture HRUs as a function of surface and subsurface application of broiler litter. The soluble P losses were significantly different ($\alpha = 0.05$) between two litter application methods. Each half bar represents one standard error.

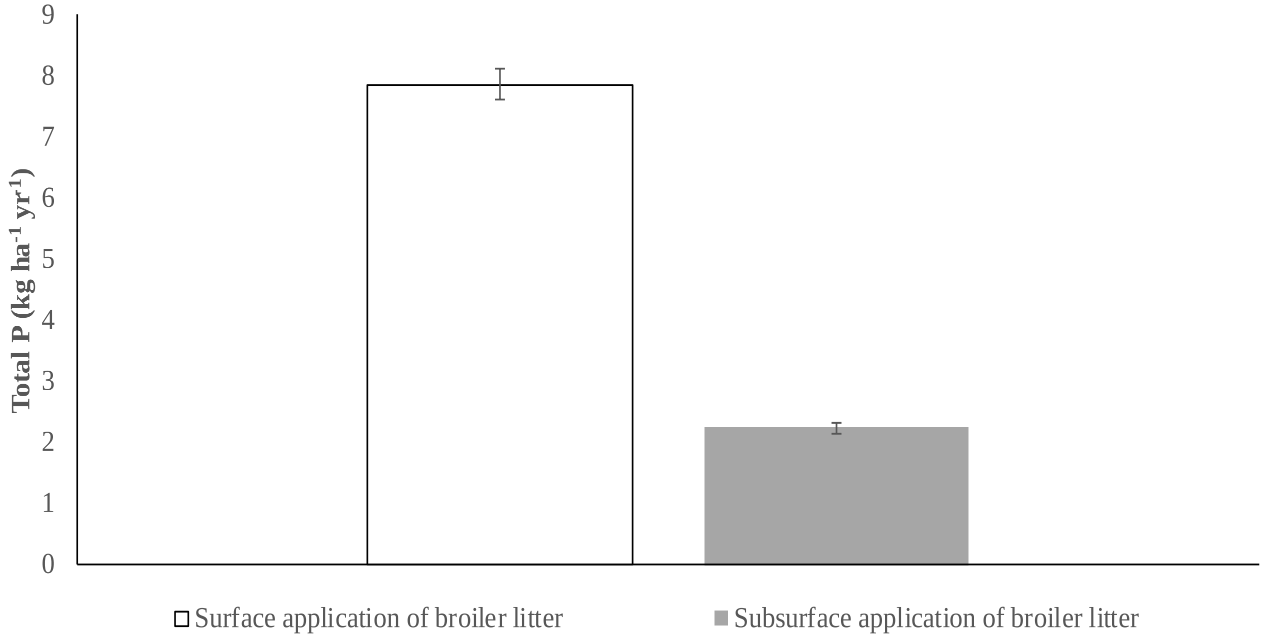


Figure 2.8: Average annual (1991-2015) total P losses from pasture HRUs as a function of surface and subsurface application of broiler litter. The total P losses were significantly different (α = 0.05) between two broiler litter application methods. Each half bar represents one standard error.

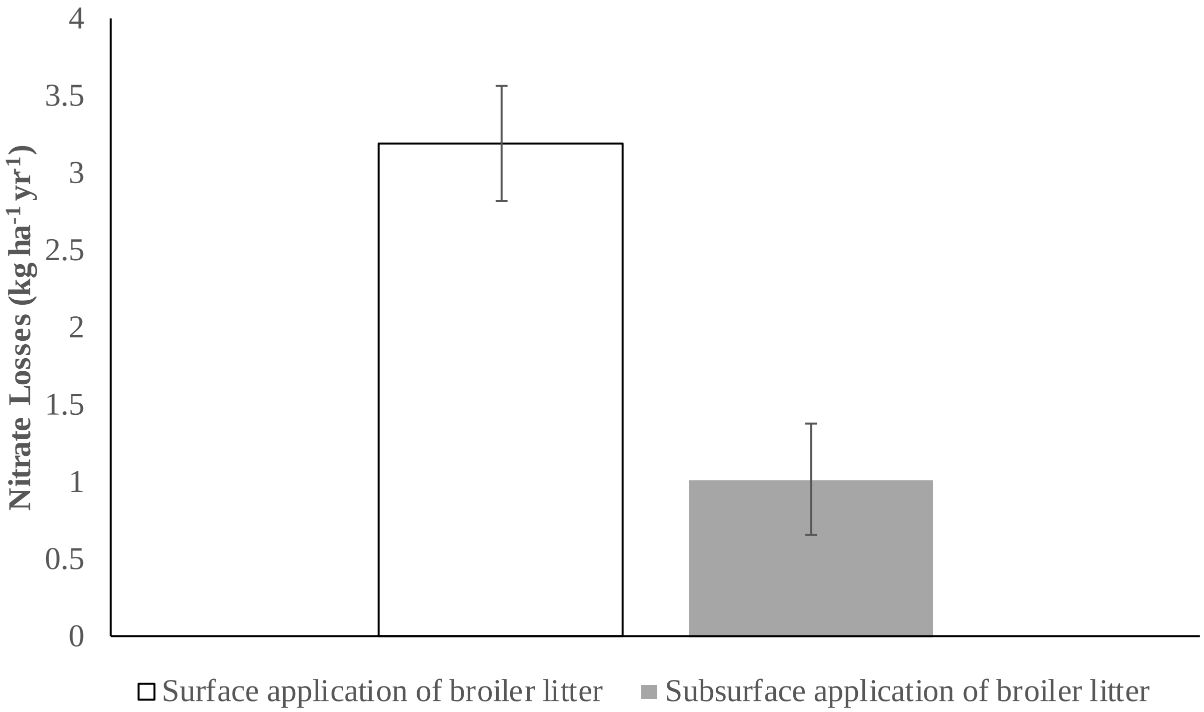


Figure 2.9: Average annual (1991-2015) nitrate losses from pasture HRUs as a function of surface and subsurface application of broiler litter. The nitrate losses were significantly different ($\alpha = 0.05$) between two broiler litter application methods. Each half bar represents one standard error.

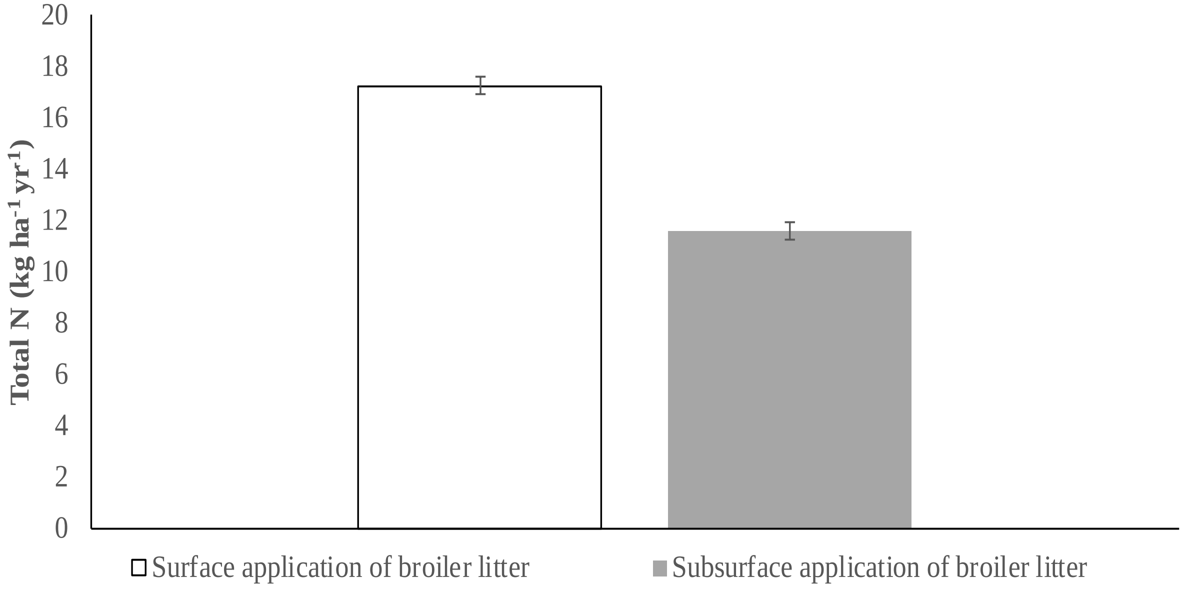


Figure 2.10: Average annual (1991-2015) total N losses from pasture HRUs as a function of surface and subsurface application of broiler litter. The total N losses were significantly ($\alpha = 0.05$) different between two broiler litter application methods. Each half bar represents one standard error.

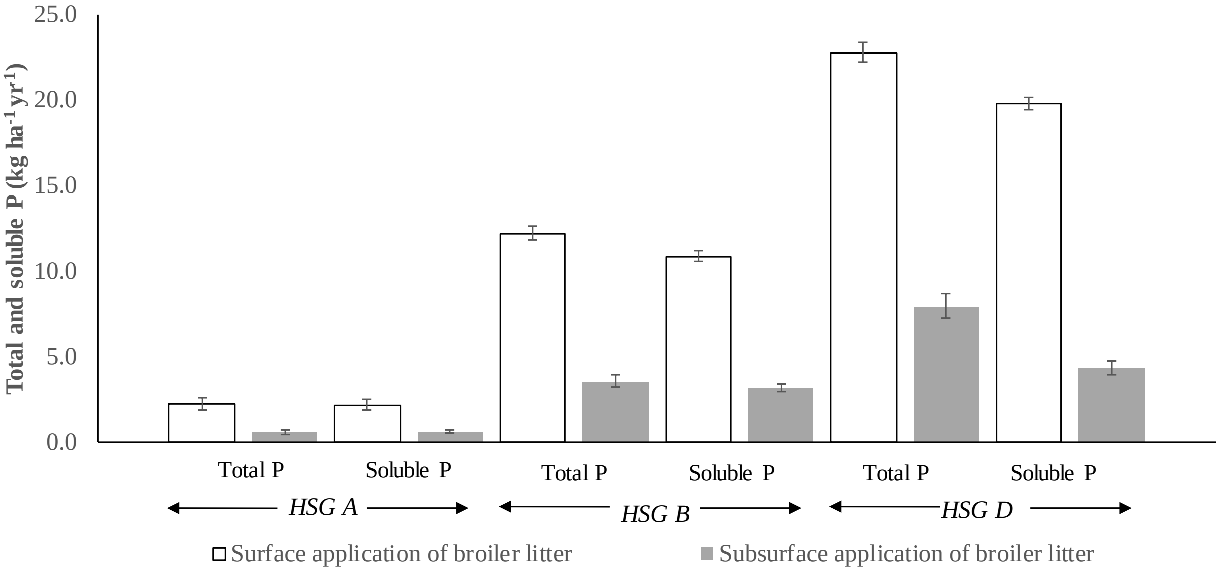


Figure 2.11: Average annual (1991-2015) total and soluble P losses in surface runoff from pasture HRUs. Within each HSG, total and soluble P losses were significantly different ($\alpha = 0.05$) between two litter application methods. Each half bar represents one standard error.

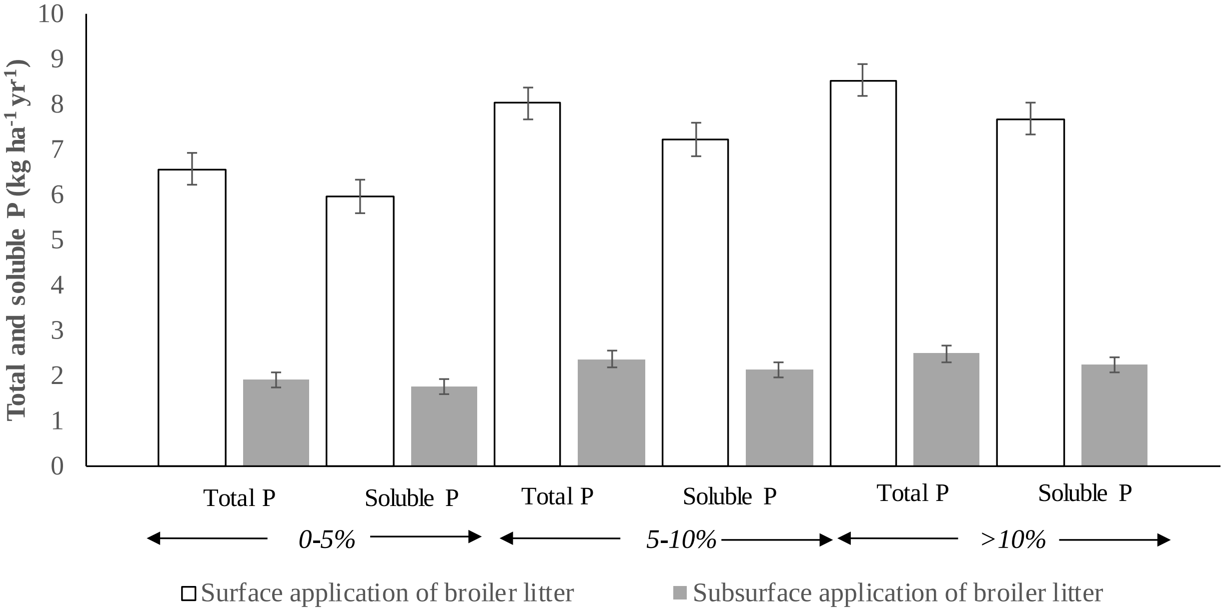


Figure 2.12: Average annual (1991-2015) total and soluble P losses in surface runoff from pastures at the HRU level. Within each slope class, total and soluble P losses were significantly different ($\alpha = 0.05$) between two litter application methods. Each half bar represents one standard error.

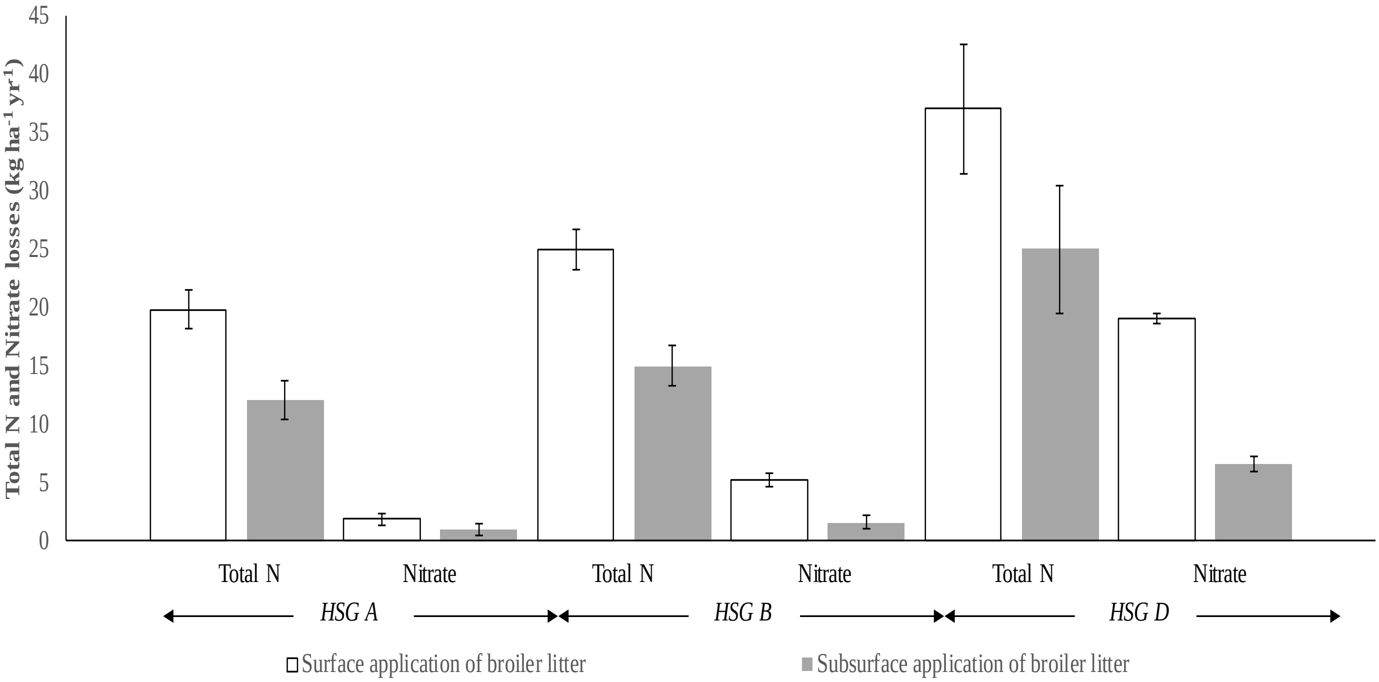


Figure 2.13: Average annual (1991-2015) total N and nitrate losses in surface runoff from pastures at the HRU level. Within each HSG, total N and nitrate losses were significantly different ($\alpha = 0.05$) between two litter application methods. Each half bar represents one standard error.

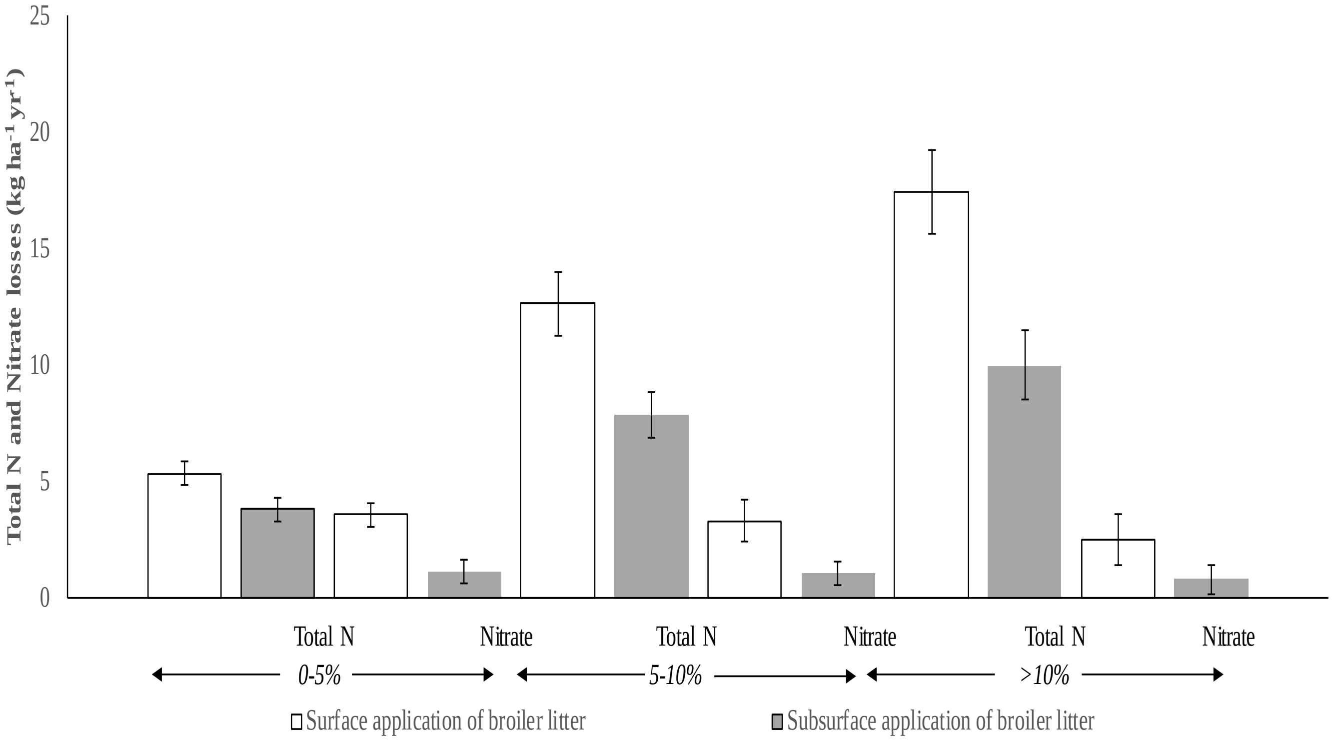


Figure 2.14: Average annual (1991-2015) total N and nitrate losses in surface runoff. Within each slope class, total N and nitrate losses were significantly different ($\alpha = 0.05$) between two litter application methods. Each half bar represents one standard error.

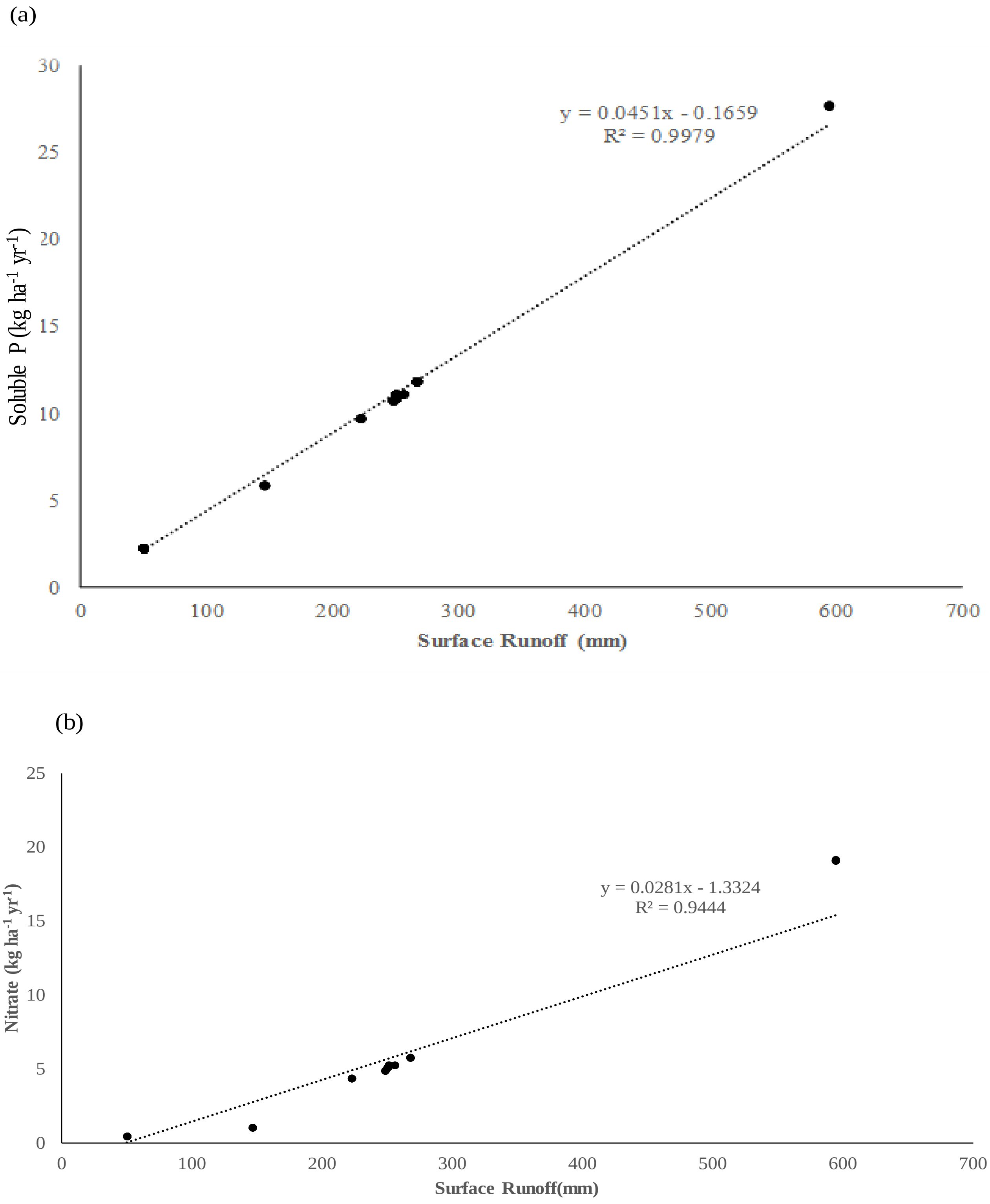


Figure 2.15: Relationship between average annual (1991-2015) (a) surface runoff vs. soluble P and (b) surface runoff vs. nitrate losses at the HRU level for pasture land use.

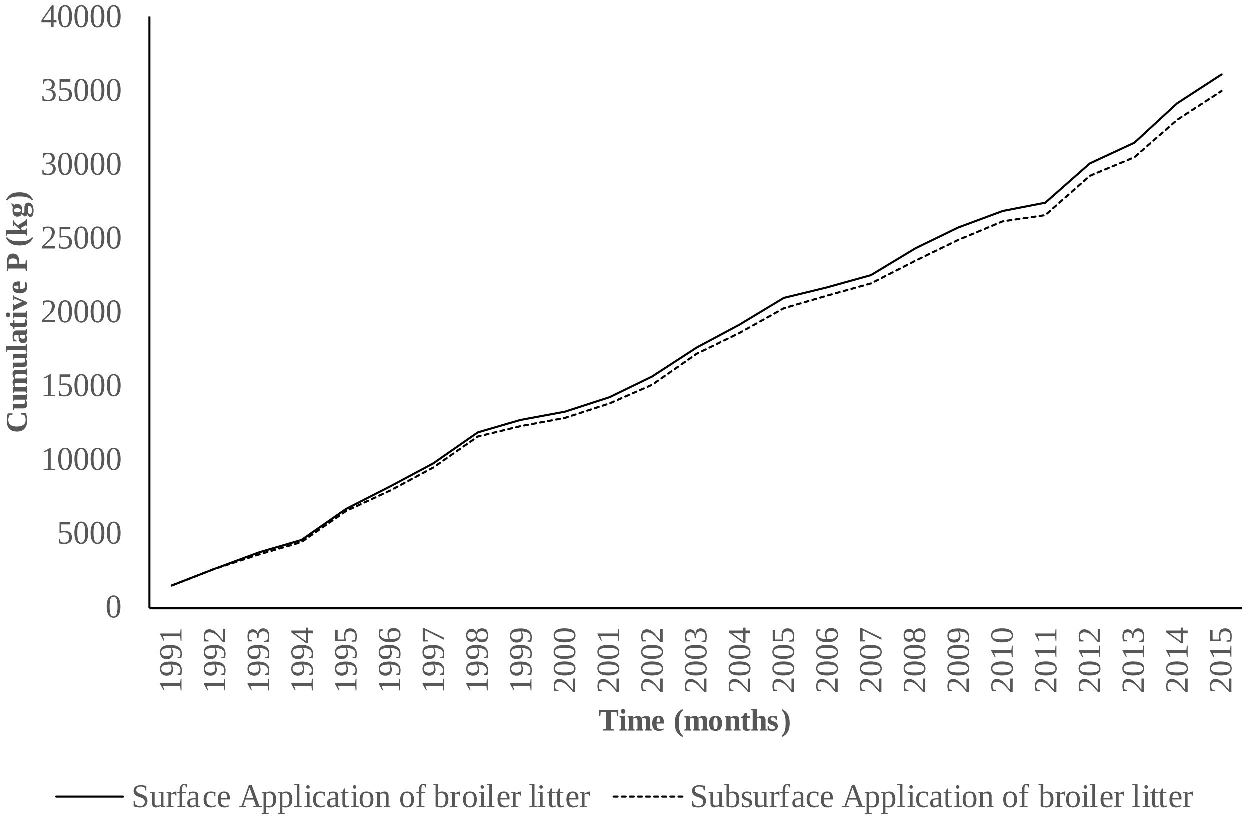


Figure 2.16: Cumulative P losses at the watershed level for the default land use (NLCD, 2006).

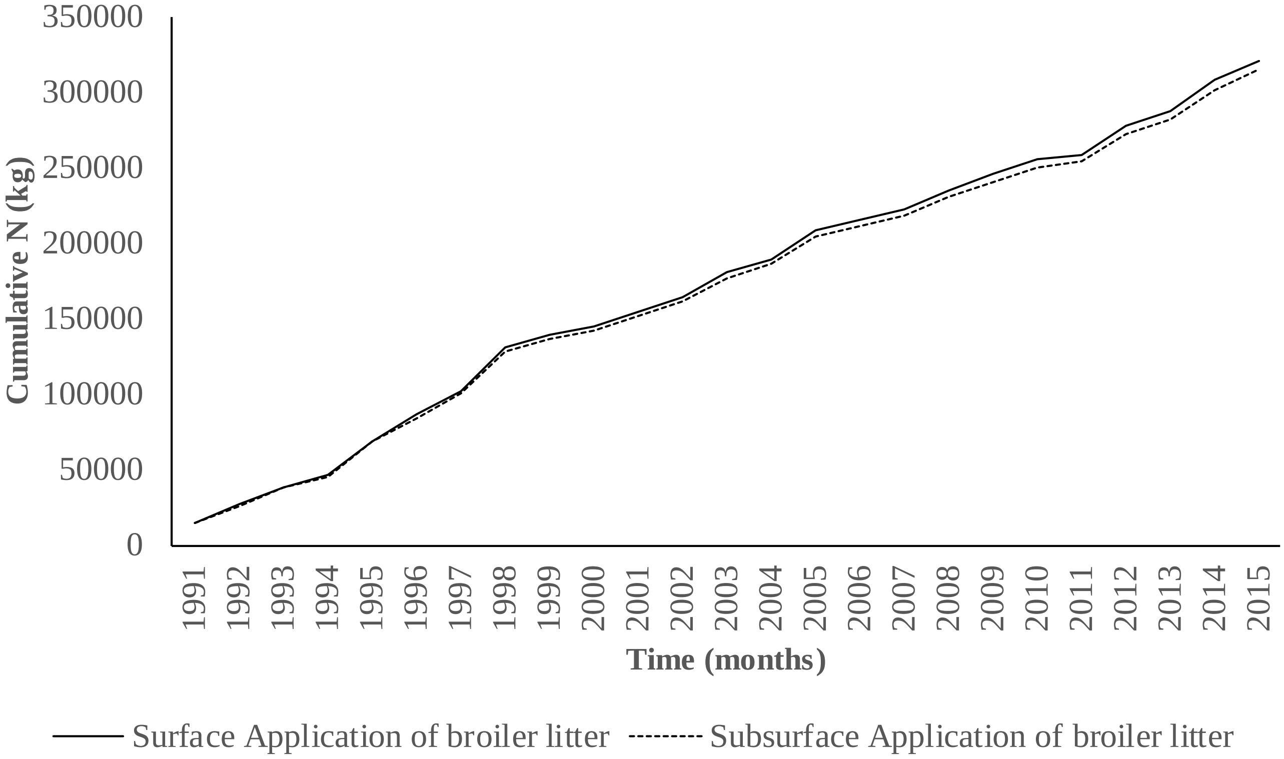


Figure 2.17: Cumulative N losses at the watershed level for the default land use (NLCD, 2006).

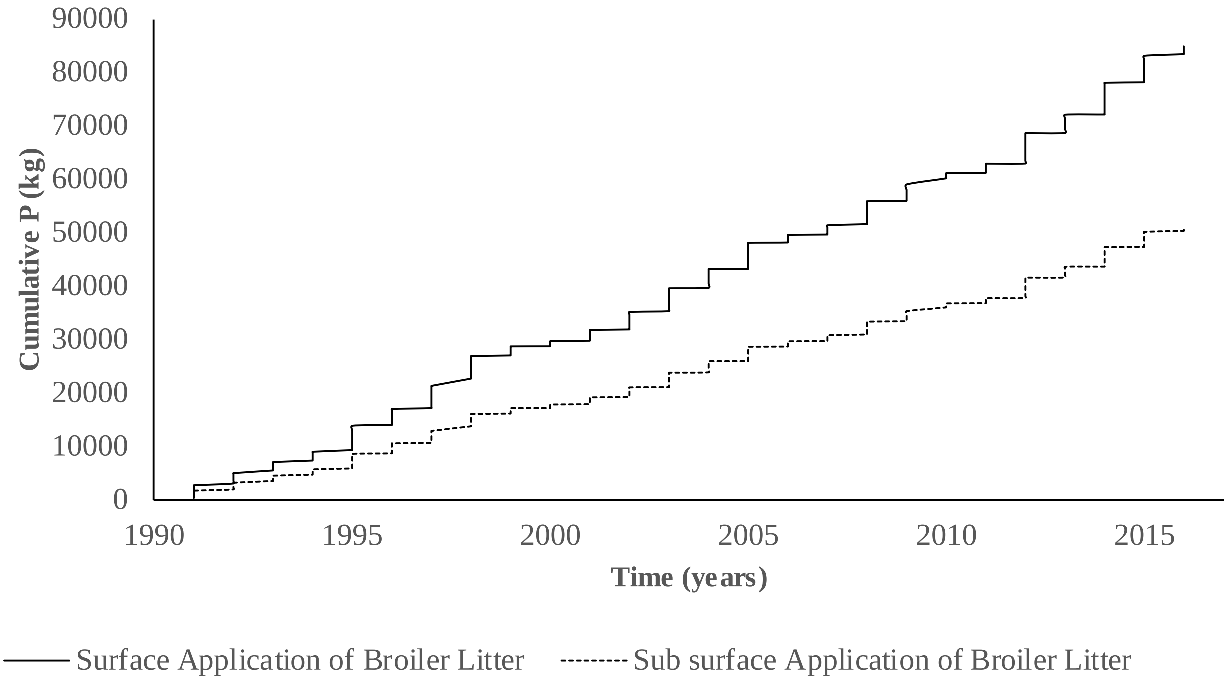


Figure 2.18: Cumulative P losses at the watershed level when rangelands were converted to pastures.

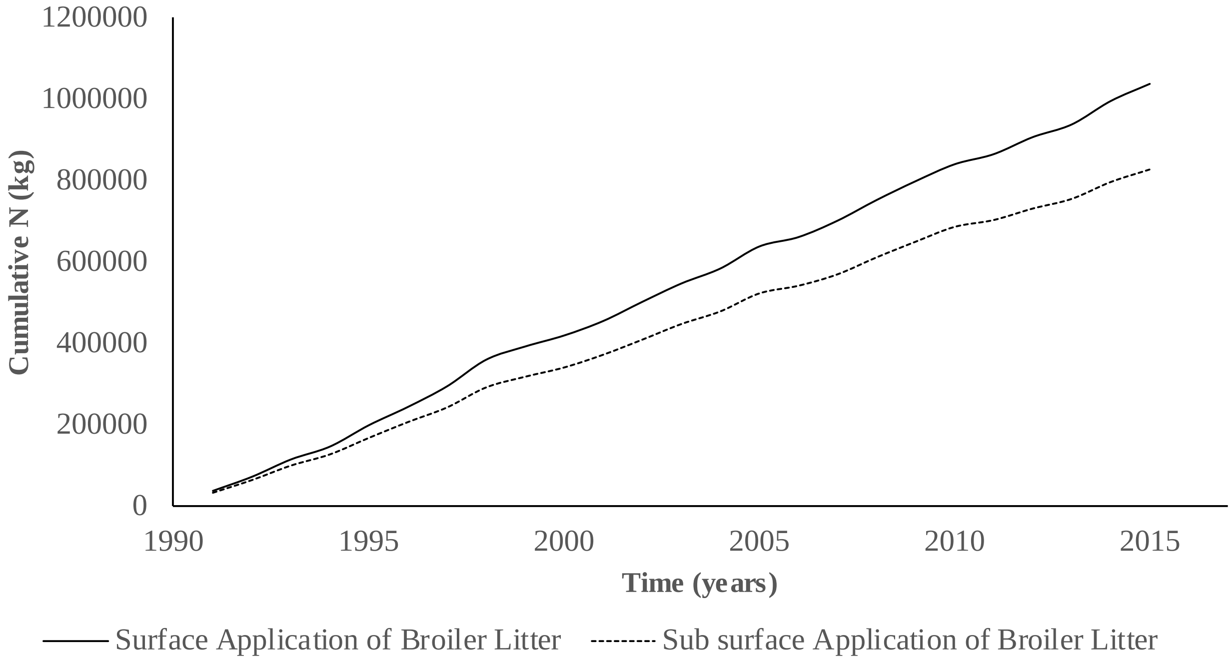


Figure 2.19: Cumulative N losses at the watershed level when rangelands were converted to pastures.

CHAPTER 3

EFFECT OF BROILER LITTER APPLICATION TIMING ON NUTRIENT LOSSES

3.1 INTRODUCTION:

Excessive levels of nutrients (e.g. phosphorus (P), nitrogen (N)) in surface water results in water quality impairment. Approximately, 11% (35,120 miles) of the total assessed streams in U.S. are impaired due to excessive levels of nutrients (USEPA, 2016). Similarly, in Alabama (AL) high levels of nutrients are cause of water quality impairment for approximately 10% (512 miles) of the total assessed streams (USEPA, 2016). Runoff generated from agricultural areas is one of the major sources of these nutrients in surface waters (States et al., 2009). Nutrient losses in agricultural runoff further exacerbate in areas used for intensive animal production due to high concentration of nutrients in soils receiving repeated application of animal manure.

Alabama is ranked among the top three states in U.S. for the production of meat birds (USDA, 2016). In AL, annually about 1.08 billion (12.4% of U.S. production) meat birds are produced (USDA, 2016) and greater than 1.25 million Mg of broiler litter is generated (Aksoy et al., 2008). Broiler litter is a rich source of nutrients required for crop production. More than 85% of the broiler litter produced in AL is applied on pastures all year - round (Sistani et al., 2008). Because of the cost associated with the transportation of broiler litter away from the production facilities, it is mainly applied on pastures in proximity to these facilities.

Repeated application of broiler litter to pastures fields located close to the production facilities results in build-up of nutrients (specifically, P) in soils. Additionally, broiler litter is typically applied to pastures based on the N requirement of a crop, which results in supplying P to soils at a rate greater than the crop P removal rate (Pote et al., 2011). For example, crops often requires a P/N ratio of 1:8 and P/N ratio in broiler litter is greater than 2:8. Furthermore, with the loss of N via volatilization from broiler litter, the P/N ratio exceeds 3:8. Therefore, repeated application of broiler litter based on the N requirement of crop results in increased concentration of P in soils. The high levels of P in soils results in excessive loss of P in surface runoff from agricultural landscapes (Sharpley et al., 2000). Loss of nutrients (N and P) in agricultural runoff can occur in dissolved or particulate form (Edem and Udo-inyang, 2017). However, erosion rates from pastures are typically not significant. Therefore, dissolved forms of nutrients are the dominant component of nutrients in surface runoff generated from pastures.

Best management practices (BMPs) can help to reduce nutrient delivery to streams and contribute to water quality improvement (Zhen et al., 2004). Typically, long-term measured flow and water quality data for the pre- and post- BMP implementation time periods is not available (Arabi et al., 2006) due to the cost associated with the maintenance of instrument, sample analysis and labor. Therefore, watershed-scale models are commonly used to quantify the effectiveness of BMPs on a long-term basis at the watershed level. The Soil and Water Assessment Tool is a well-established watershed model that has been used in various previous studies to simulate hydrological, sediment and nutrient transport processes and assess the effectiveness of BMPs to improve water quality (Artita et al., 2013; Dechmi and Skhiri, 2013; Lee et al., 2010; Liu et al., 2014; Panagopoulos et al., 2011).

Four independent nutrient management factors, referred to as the 4R factors: a) Right placement, b) Right time, c) Right rate, d) Right form (Collick et al., 2016) can help to increase the crop production and improve downstream water quality. Timing of manure application with respect to the occurrence of a rainfall event can significantly affect nutrient losses in surface runoff (Vadas et al., 2011). Various studies have investigated the effect of timing of manure application on loss of nutrients in surface runoff at a plot and field -scale (Hanrahan et al., 2009; Nyambati et al., 2006; Schroeder et al., 2004; Vadas et al., 2011). For example, Hanrahan et al. (2009) showed that total and dissolved P concentrations reduces when time between dairy manure application and rainfall (from 2-9 days) increases. Similarly, Nyambati et al. (2006) reported reduction in P and N concentration in surface runoff when time-period between rainfall and manure application increased from 0-9 days on sandy loam soils established with Bermuda grass. Increase in time between manure application and rainfall event helps to reduce nutrient losses (particularly dissolved form) because nutrients in manure have opportunity to bound to soil particles (Vadas et al., 2011).

Various studies have been conducted at the plot and field -level to assess the effect of timing of broiler litter application with respect to occurrence of a storm event on P and N losses (Hanrahan et al., 2009; Nyambati et al., 2006; Schroeder et al., 2004; Vadas et al., 2011). However, limited work has been done quantify P and N losses in surface runoff as a function of occurrence of a storm event following a broiler litter application at the watershed level. Therefore, objective of this study was to quantify P and N losses on a long-term basis in surface runoff when broiler litter was applied 1 day, 3 day, 5 day and 7 day before a storm event on a long-term basis using SWAT model. Additionally, effect of application of broiler litter in different seasons (spring, summer, fall, and winter) on nutrient losses in surface runoff was quantified.

3.2 METHODOLOGY:

3.2.1 Study Area:

The study was conducted in the Big Creek watershed (82 km^2), located in Mobile County, AL (Figure 3.1). Approximately 37% of the land cover in the watershed is forest, 4% is agricultural, 31% is rangelands, 11% is wetlands, 12% is hay (NLCD, 2006) on coastal plain soils. This watershed has a U. S. Geological Survey (USGS 02479945) streamflow gage at the outlet of the watershed. The mean annual (1990-2015) precipitation in the watershed is about 1676 mm. Major reasons for selecting the Big Creek watershed for this study were: (a) the observed data (streamflow, P and N loading) required for model calibration and validation was available for this watershed and (b) coastal plain soils are the dominant soils in this watershed, which are also found in the southeast AL (one of the dominant poultry litter industry area in AL is located in the southeast AL).

3.2.2 SWAT Model Description:

The Soil and Water Assessment Tool (SWAT) model is a continuous time watershed scale model developed by United States Department of Agriculture- Agricultural Research Service (USDA-ARS) to quantify the impact of land management practices in large and complex watersheds (Mirhosseini et al., 2016). SWAT is a process based model and is capable of simulating hydrological and nutrient transport processes and dynamics (Arnold et al., 2012). In SWAT, a watershed is divided into subwatersheds, which are further divided into hydrological response units (HRUs) (Cao et al., 2006). All the areas which have same land use, soil type and slope within a subwatershed are combined together as HRUs. To calculate surface runoff, SCS (Soil Conservation Service) curve number method was used (USDA-SCS, 1972). SWAT model can compute potential evapotranspiration using Hargreaves method, Priestley Taylor method or Penman/Monteith method (Neitsch et al., 2002). The Penman/Monteith method was used to compute potential evapotranspiration in this study. Modified Universal Soil Loss equation (MUSLE) was used for estimating erosion losses (Neitsch et al., 2002). Deposition and degradation techniques are used in SWAT to simulate sediment transport in channels. SWAT simulates N and P transport processes and dynamics within a watershed. Soil N in SWAT is partitioned into five N pools, two of them being inorganic (including ammonium-N [NH_4-N] and nitrate-N [NO_3-N]) and three being organic (active, stable and fresh). Different processes (e.g., mineralization, decomposition, immobilization, nitrification, denitrification and ammonium volatilization) are modeled by SWAT to simulate movement of N in different pools (Chaubey et al., 2006). Unlike N, soil P is divided into six pools in SWAT, with three mineral and three organic P pools. Crop residue and biomass contribute to fresh organic P pool, and humus substances contribute to active and stable organic pool. Soil inorganic pool includes active, solution and stable pools

(Chaubey et al., 2006). At equilibrium, stable P is four times the size of active P (Sen et al., 2012). Plant use of P is estimated using the supply and demand approach similar to N (Santhi et al., 2006). In this study, we used SWAT 2016 revision 664 version.

3.2.3 Input data:

A 10 m DEM resolution was used to delineate subwatershed and watershed boundaries. A weather station located around 19 miles away from watershed outlet was used for the daily temperature and precipitation data. It should be noted that this was the only weather station available within proximity of the watershed. SWAT in-built weather generator was used to generate relative humidity, solar radiation and wind speed data. The National Land Cover Database (NLCD, 2006) for the land use and Soil Survey Geographical Database (SSURGO) for soils was used for this study (USDA- NRCS 1995). Management practices were selected from the BMP database developed by Butler and Srivastava (2007). This management database has been used in previous studies conducted in AL (Mirhosseini et al., 2016; Srivastava et al., 2010). Peanut–Cotton rotation was used for cropland areas and Bermuda grass for pastures. The management information (e.g., harvest date, fertilizer application date and rate) for Peanut-Cotton rotation is included in table 3.1. Bermuda grass was planted in March and harvested in July for all areas under pasture land use.

3.2.4 Calibration and Validation:

In this study, model calibration and validation was performed at a monthly time-step. Time-period used for streamflow (surface runoff + baseflow) calibration and validation was Jan. 1991- Dec. 2003 and Jan. 2004- Dec. 2015, respectively. Compared to streamflow, observed P and N data was limited. Phosphorus and N calibration and validation time periods were Jun. 1991- Sep. 1998. The parameters used for surface runoff, baseflow, P and N calibration are listed in table 3.2.

To assess model performance in simulating surface runoff, baseflow, N and P ,we used Nash-Sutcliffe Efficiency (NSE), Coefficient of Determination (R^2) and Percent Bias (PBIAS) (Moriasi et al., 2007). NSE, PBIAS and R^2 were computed using equation 1, 2 and 3, respectively:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - O)^2} \qquad (1)$$

$$PBIAS = \frac{\sum_{i=1}^{n}(O_i - P_i) * 100}{\sum_{i=1}^{n} O_i} \qquad (2)$$

$$R^2 = \frac{\sum_{i=1}^{n}(O_i - O)(P_i - P)}{\sqrt{\sum_{i=1}^{n}(O_i - O)^2}\sqrt{\sum_{i=1}^{n}(P_i - P)^2}} \qquad (3)$$

where O_i is the i^{th} observation for the constituent being evaluated; P_i is the i^{th} simulated value for the constituent being evaluated; O is the mean of observed data for the constituent being evaluated; P is the mean of simulated data for the constituent being evaluated and n is the total number of observations. Qualitatively, model performance was evaluating by plotting observed vs. simulated surface runoff, baseflow, streamflow, N loading, and P loading at a monthly time step.

3.2.5 Timing of Manure Application:

To quantify the effect of timing of broiler litter application with respect to the occurrence of a storm event on N and P losses in surface runoff, broiler litter was surface applied to pastures 1 day, 3 day, 5 day and 7 day before a storm event in different seasons (fall, spring, summer and fall) for 25 years. It should be noted that to simulate these scenarios broiler litter was applied once a year. The dates and total rainfall amount of the storm events selected for this scenario are included in table 3.5. The storm events with maximum amount of rainfall were selected within a given season (to simulate worst-case scenario in terms of nutrient loss). Broiler litter was applied at the rate of 13400 kg ha^{-1} in this study (application rate commonly used by the producers in the southeast US) (Torbert and Watts, 2014).

To compare nutrient losses among different seasons we used Mann-Whitney test and significance level of $\alpha = 0.05$ for all hypothesis testing.

3.3 RESULTS AND DISCUSSIONS:

3.3.1 Model Calibration and Validation:

Plots of measured and simulated surface runoff, baseflow and total streamflow at a monthly time step are shown in figure 3.3. Overall SWAT satisfactorily predicted flows (total, surface and baseflow) at a monthly time-step. The NSE, R^2 and PBIAS values for observed vs. simulated surface runoff, baseflow and streamflow are included in table 3.3. Based on the criteria's specified by Moriasi et al. (2007), model satisfactorily simulated surface runoff, baseflow and streamflow. Similarly, SWAT satisfactorily captured temporal trends of P and N loading at the watershed outlet (Figure 3.3). The NSE, R^2 and PBIAS values for observed vs. simulated N and P loading were acceptable (Moriasi et al., 2007). Overall, SWAT model successfully simulated streamflow (surface runoff + baseflow), N and P loading for this watershed.

3.3.2 Effect of broiler litter application timing w.r.t. occurrence of a storm event on nutrient losses:

Average annual N and P losses in surface runoff at the HRU level were similar irrespective of timing of broiler litter application with respect to the occurrence of a storm event (Table 3.6). The results were similar even if instead of broiler litter, dairy manure or commercial fertilizer was used. The results simulated by SWAT model were contrary to field and lab -based studies (Schroeder et al., 2004; Smith et al., 2007), which reported that as the time between manure application and runoff generating storm event increases, nutrient losses in surface runoff decreases because nutrients in manure bound to the soil particles. Similarly, Collick et al. (2016) reported that standard P routines available in SWAT (used in our study) simulated similar P losses when dairy manure was applied 1d, 5d and 10d before a storm event. In the standard P routines available in SWAT model, when manure is surface applied to the soil, SWAT model adds manure into the top 10 mm of soil, instead of adding a discrete layer of manure on the top of the soil surface. After adding manure to the top 10 mm of soil, SWAT uses the soil nutrient cycling routines to simulate fate and transport of P (Collick et al., 2016). Collick et al. (2016) modified the standard P routines using the P loss equations developed by Vadas et al. (2012, 2007) and showed that new P routines predicted P losses accurately. Similarly, Sen et al. (2012) reported that since SWAT incorporates P from manure directly into the top 10 mm of soil, P losses simulated by SWAT on the long-term basis might not be accurate. The incorporation of new P routines to simulate nutrient losses was not within the scope of the current study. Overall, results show that the standard P routines available in SWAT model did not simulate the effect of broiler litter application timing with respect to occurrence of the storm event on nutrient losses.

3.3.3 Effect of broiler litter application in different seasons on nutrient losses:

Depending upon the season (fall, spring, summer and winter) in which broiler litter was applied to pastures, average annual N and P losses in surface runoff varied. The soluble and total P average annual losses ranged from 6.7 to 7.2 kg ha^{-1} and 6.7 to 7.9 kg ha^{-1}, respectively (Figure 3.4(a)). Similarly, average annual nitrate and total N losses in surface runoff varied from 1.4 to 2.2 kg ha^{-1} and 14.5 to 16.8 kg ha^{-1}, respectively (Figure 3.4(b)). The soluble P, total P and nitrate losses were significantly different ($\alpha = 0.05$) among all seasons. The losses of soluble P and total P were significantly greater ($\alpha = 0.05$) in winter compared to other seasons. Similarly, total N losses were significantly greater ($\alpha = 0.05$) in winter compared to other seasons. However, no significant difference ($\alpha = 0.05$) was found in total N losses between spring and summer & fall and summer. The amount of surface runoff generated in winter months was greater compared to the amount of surface runoff generated in months of spring, summer and fall season (Table 3.7). It should be noted that the amount of rainfall was greater in summer followed by spring, winter and fall (Table 3.8). The results of this study indicate that application of broiler litter during the winter months increases the loss of nutrients via surface runoff. In addition to the amount of surface runoff generated in winter months, the uptake of nutrients by Bermuda grass in winter months also affected P and N losses in surface runoff. For example, in winter uptake of total P and N by Bermuda grass was 61 and 191 kg ha^{-1}, respectively. Whereas, in spring uptake of total P and N was 92 and 342 kg ha^{-1}, respectively. Therefore, results show that application of broiler litter during the months when nutrient requirement of a crop is high, and amount of surface runoff generated is not substantial can help to reduce nutrient losses in surface runoff on a long-term basis.

3.4 CONCLUSIONS:

The focus of this study was to assess the effect of timing of broiler litter application with respect to occurrence of a storm event on nutrient losses. Additionally, effect of broiler litter application in different seasons on nutrient losses in surface runoff was evaluated. The application of broiler litter with respect to the occurrence of a storm event did not influence P and N losses in surface runoff. Therefore, nutrient routines available in SWAT model did not simulated the effect of timing of broiler litter with respect to occurrence of a storm event accurately. The results of this study show that application of broiler litter in different seasons affected P and N losses in surface runoff. The application of broiler litter in winter increases the loss of P and N in surface runoff on a long-term basis. Whereas, application of broiler litter in fall can help to reduce P and N losses in surface runoff.

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Plant type	Operation Date	Operation type	Operation attributes
Peanut	15-May	Planting	
	21-Oct	Harvesting	
Cotton	25-Mar	Tillage	Generic Conservation tillage
	15-Apr	Planting	
	15-Apr	Fertilization	50 kg ha^{-1} Nitrogen
		Fertilization	45 kg ha^{-1} Phosphorus
	1-Jun	Fertilization	50 kg ha^{-1} Nitrogen
	1-Oct	Harvesting	

Table 3.1: Management operations for cropland HRU's.

Parameter description	Parameter	Default Values	Final Values	HRUs for which parameter is changed
Curve number	CN	Varies	15% decrease	All HRU’s
Available water capacity of soil layer (mm H_2O/mm soil)	SOL_AWC	Varies	15% increase	All HRU’s
Saturated hydraulic conductivity (mm/hr)	SOL_K	Varies	10% decrease	All HRU’s
Biological mixing efficiency	BIOMIX	0.2	0.01	All HRU’s
Baseflow alpha factor (days)	ALPHA_BF	0.048	0.50	All HRU’s
Groundwater “revap” coefficient	GW_REVAP	0.02	0.2	All HRU’s
Deep aquifer percolation factor	RCHRG_DP	0.05	0.25	All HRU’s
Groundwater delay time (days)	GW_DELAY	31	100	All HRU’s
USLE equation support practice factor	USLE_P	1	15% decrease	All HRU’s
Exponent parameter for calculating sediment reentrained in channel sediment routing	SPEXP	1	1.5	All HRU’s
Peak rate adjustment factor for sediment routing in the main channel	PRF	1	0.5	All HRU’s
Peak rate adjustment factor for sediment routing in sub watershed	ADJ_PKR	1	0.5	All HRU’s
Manning's "n" value for overland flow	OV_N	0.1	0.4	FORESTED
Initial soluble P concentration in soil layer (mg/kg)	SOL_LABP	5	3	All HRU’s

Initial organic P concentration in soil layer (mg/kg)	SOL_ORGP	0	0.01	All HRU’s
Organic N in the baseflow (mg/l)	LAT_ORGN	0	2	All HRU’s
Initial organic N concentration in the soil layer (mg/kg)	SOL_ORGN	0	0.01	All HRU’s

Table 3.2: Parameters used for surface runoff, baseflow, P and N calibration.

	Streamflow (Jan 91-Dec 03)	**Surface runoff** (Jan 91-Dec 03)	**Baseflow** (Jan 91-Dec 03)	**Total Phosphorus** (Jan 91- Dec 94)	**Total Nitrogen** (June 91- Dec 95)
NSE	0.593	0.527	0.557	0.215	0.624
R^2	0.604	0.682	0.627	0.565	0.728
PBIAS	-6.034	6.277	1.174	20.5	10.15

Table 3.3: NSE, R^2 and PBIAS for the calibration time-period.

	Streamflow (Jan 04-Dec 15)	**Surface Runoff** (Jan 04-Dec 15)	**Baseflow** (Jan 04-Dec 15)	**Total Phosphorus** (Jan 95- Sep 98)	**Total Nitrogen** (June 96- Aug 98)
NSE	0.651	0.557	0.574	0.125	0.605
R^2	0.689	0.563	0.611	0.125	0.776
PBIAS	3.477	-7.724	-4.847	24.05	-3.96

Table 3.4: NSE, R^2 and PBIAS for the validation time-period.

Year	Date and storm event (mm) in spring (Mar. 1- May 31)	Date and storm event (mm) in summer (June 1- Aug 31)	Date and storm event (mm) in fall (Sep. 1- Nov. 30)	Date and storm event (mm) in winter (Dec. 1- Feb. 28)
1991	08 Apr-55.6	17 Jun-16.5	18 Nov-23.6	13 Feb-9.4
1992	24 May-8.6	30 Jun-2.8	01 Nov-29.7	08 Jan-31.2
1993	12 Mar-51.8	14 Jun-8.6	29 Oct-113	13 Dec-31.2
1994	09 Mar-31	21 Aug-15.2	01 Oct-72.9	27 Jan-64
1995	11 Apr-80.3	26 Jun-37.6	03 Oct-81.5	17 Dec-76.2
1996	14 Apr-120.7	08 Jul-37.3	15 Sep-23.1	19 Feb-35.6
1997	13 Mar-85.9	20 Aug-8.1	29 Nov-70.6	23 Dec-30.7
1998	28 Apr-73.4	21 Jun-10.4	10 Nov-54.4	15 Feb-29.7
1999	25 Mar-10.2	19 Aug-41.4	20 Nov-59.7	22 Jan-17.3
2000	24 Apr-27.9	31 Jul-33.3	06 Nov-45.2	13 Feb-15.7
2001	12 Mar-72.4	27 Aug-19.1	06 Oct-25.4	15 Jan-28.7
2002	28 May-53.1	24 Jul-48.8	22 Sep-40.9	20 Feb-32.5
2003	18 May-160	17 Jul-21.3	18 Nov-23.9	23 Dec-17.3
2004	31 May-12.2	20 Aug-37.6	15 Sep-87.9	23 Feb-43.4
2005	15 May-56.4	29 Jul-33	22 Sep-8.6	08 Jan-18.3
2006	21 Apr-15.7	15 Jul-48.8	06 Nov-85.3	25 Feb-52.8
2007	01 Apr-109.2	18 Jun-23.1	25 Nov-72.1	15 Dec-20.6
2008	19 Mar-16.3	10 Jun-30.7	07 Oct-43.2	10 Dec-59.2
2009	14 Mar-37.1	28 Jul-26.2	09 Nov-67.3	11 Feb-18.3
2010	15 May-50.5	29 Jun-37.1	24 Oct-24.1	11 Dec-14.2
2011	26 May-8.1	11 Jul-51.6	19 Sep-48.3	18 Jan-29.7
2012	02 May-172.7	28 Aug-105.4	27 Nov-29	17 Jan-19.8
2013	11 Apr-35.1	03 Jul-11.2	24 Sep-34.8	22 Dec-87.6
2014	28 May-78	28 Aug-26.2	13 Nov-31.5	21 Feb-34.8
2015	12 Apr-184.9	24 Jun-36.8	26 Oct-122.2	15 Jan-18.3

Table 3.5: Storm events selected to simulate effect of litter application with respect to the occurrence of a storm event on nutrient losses.

	P losses (kg ha^{-1} yr^{-1})				N losses (kg ha^{-1}yr^{-1})			
	Fall	Spring	Summer	Winter	Fall	Spring	Summer	Winter
1 day	7.47± 0.85	7.55± 0.85	7.49± 0.85	7.57± 0.85	15.45±1.96	15.55±1.96	15.45±1.96	15.60±1.96
3 day	7.48±0.85	7.55±0.85	7.48±0.85	7.55±0.85	15.43±1.95	15.53±1.95	15.40±1.95	15.60±1.95
5 day	7.47±0.85	7.54±0.85	7.48±0.85	7.55±0.85	15.43±1.96	15.53±1.96	15.38±1.96	15.59±1.96
7 day	7.46±0.85	7.54±0.85	7.46±0.85	7.53±0.85	15.43±1.96	15.52±1.96	15.34±1.96	15.57±1.96

Table 3.6: Average annual (1991-2015) P and N losses ± standard error for different seasons when broiler litter was applied 1d, 3d, 5d and 7d before a storm event.

Months	**Surface Runoff (mm)**	**Seasons**
1	27.89 ± 0.17	Winter
2	33.51 ± 0.27	Winter
3	20.1 ± 0.17	Spring
4	24.36 ± 0.21	Spring
5	22.12 ± 0.17	Spring
6	23.19 ± 0.19	Summer
7	14.97 ± 0.12	Summer
8	19.05 ± 0.15	Summer
9	26.76 ± 0.27	Fall
10	11.59 ± 0.10	Fall
11	20.61 ± 0.15	Fall
12	22.45 ± 0.17	Winter

Table 3.7 Average annual surface runoff ± standard error for different months.

Seasons	**Average annual rainfall (mm)**
Fall (Sept 1 to Nov 30)	310.37
Spring (Mar 1 to May 31)	348.47
Summer (Jun 1 to Aug 31)	464.76
Winter (Dec 1 to Feb 28)	331.98

Table 3.8: Average annual (1991-2015) rainfall values for different seasons.

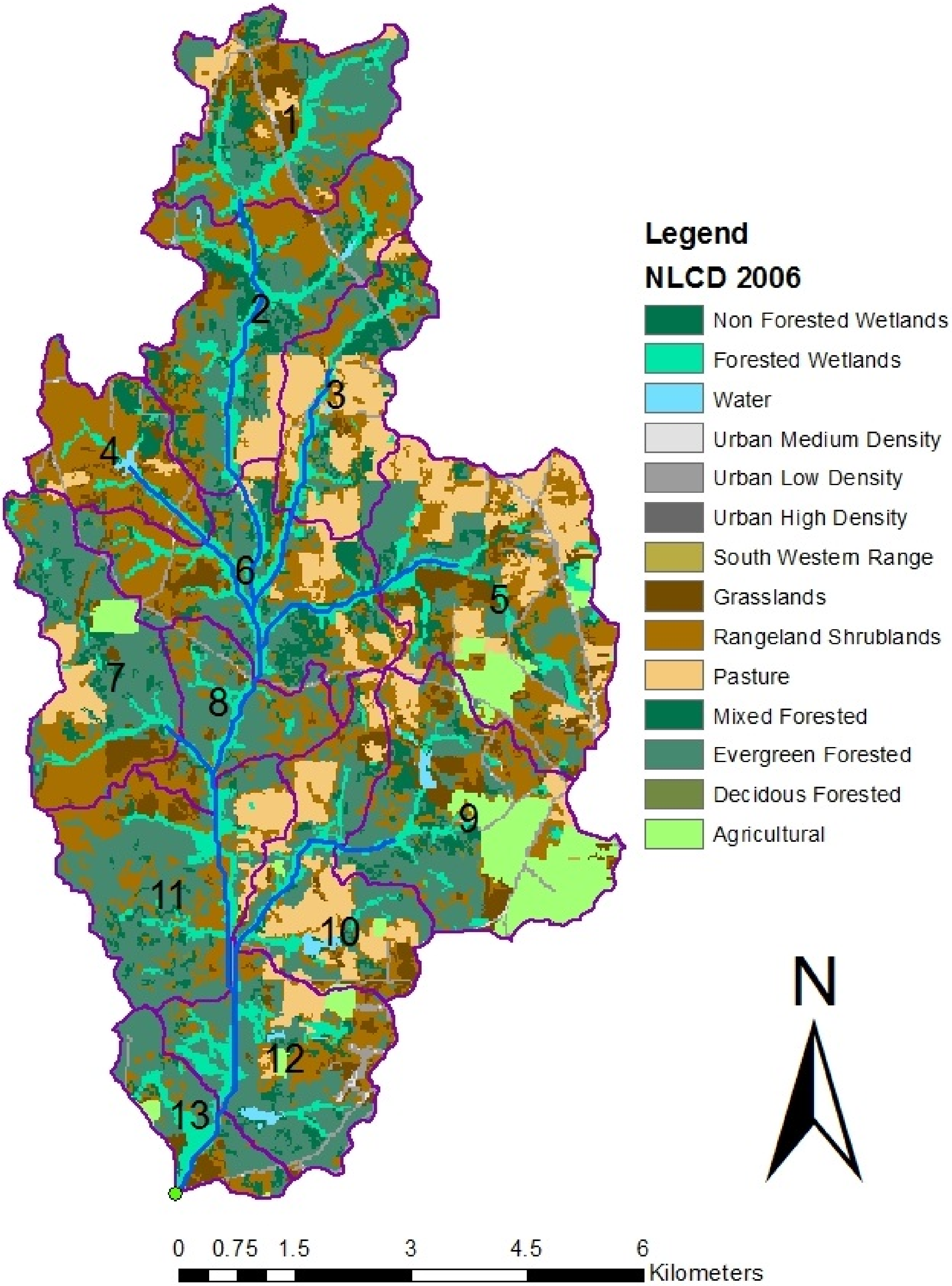


Figure. 3.1: Land use distribution in the Big Creek watershed, AL.

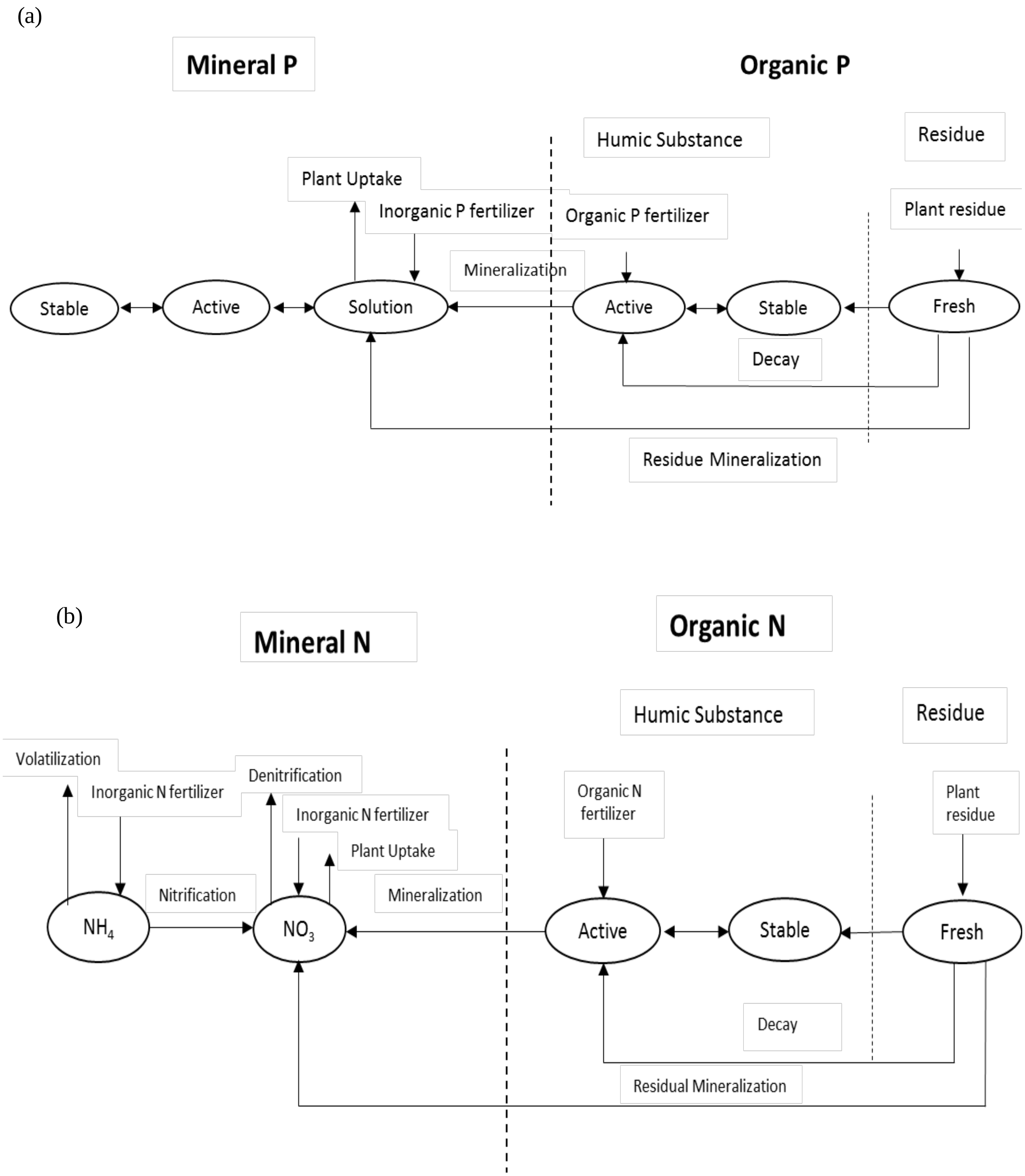
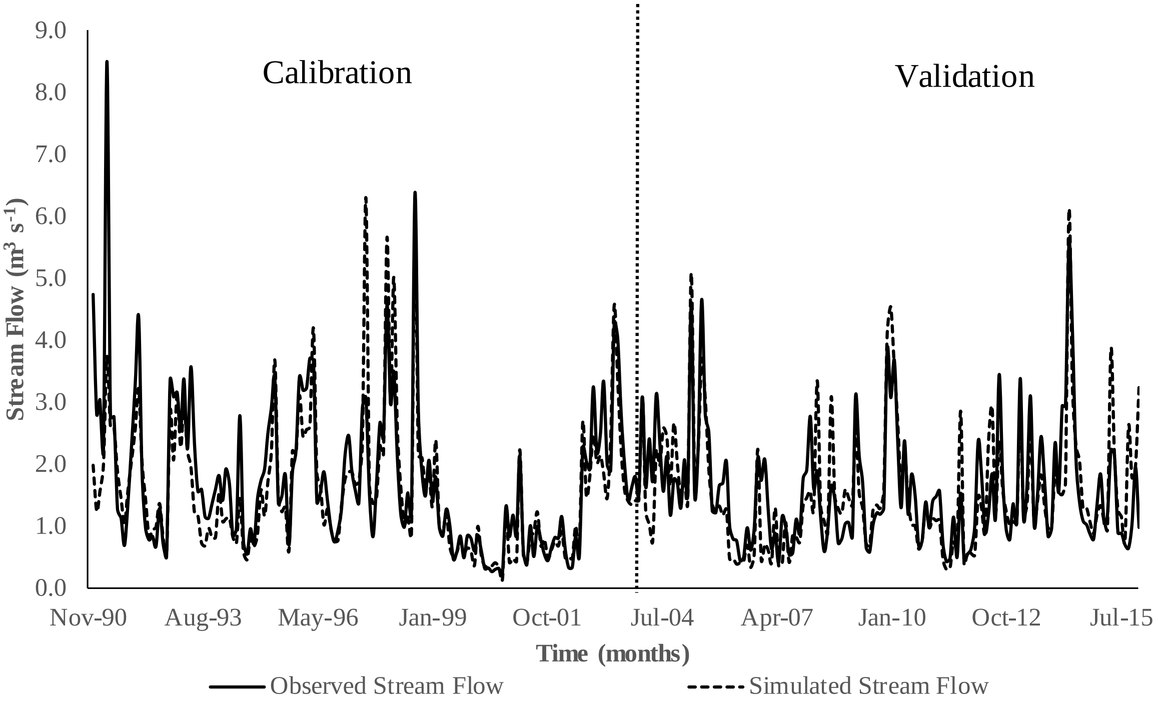
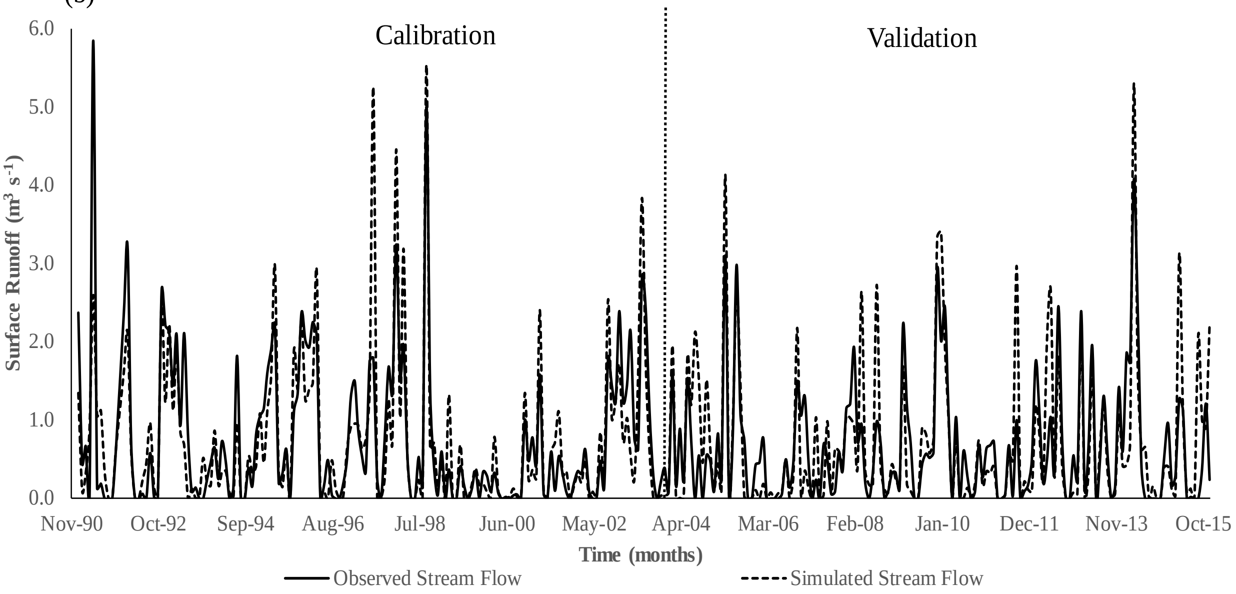


Figure 3.2: SWAT soil nutrient pools: (a) P and (b) N (adapted from Neitsch et al., 2011).

(a)


Calibration
Validation
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Stream Flow (m³ s⁻¹)
Nov-90
Aug-93
May-96
Jan-99
Oct-01
Jul-04
Apr-07
Jan-10
Oct-12
Jul-15
Time (months)
Observed Stream Flow
Simulated Stream Flow

(b)


Calibration
Validation
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Surface Runoff (m³ s⁻¹)
Nov-90
Oct-92
Sep-94
Aug-96
Jul-98
Jun-00
May-02
Apr-04
Mar-06
Feb-08
Jan-10
Dec-11
Nov-13
Oct-15
Time (months)
Observed Stream Flow
Simulated Stream Flow

(c)

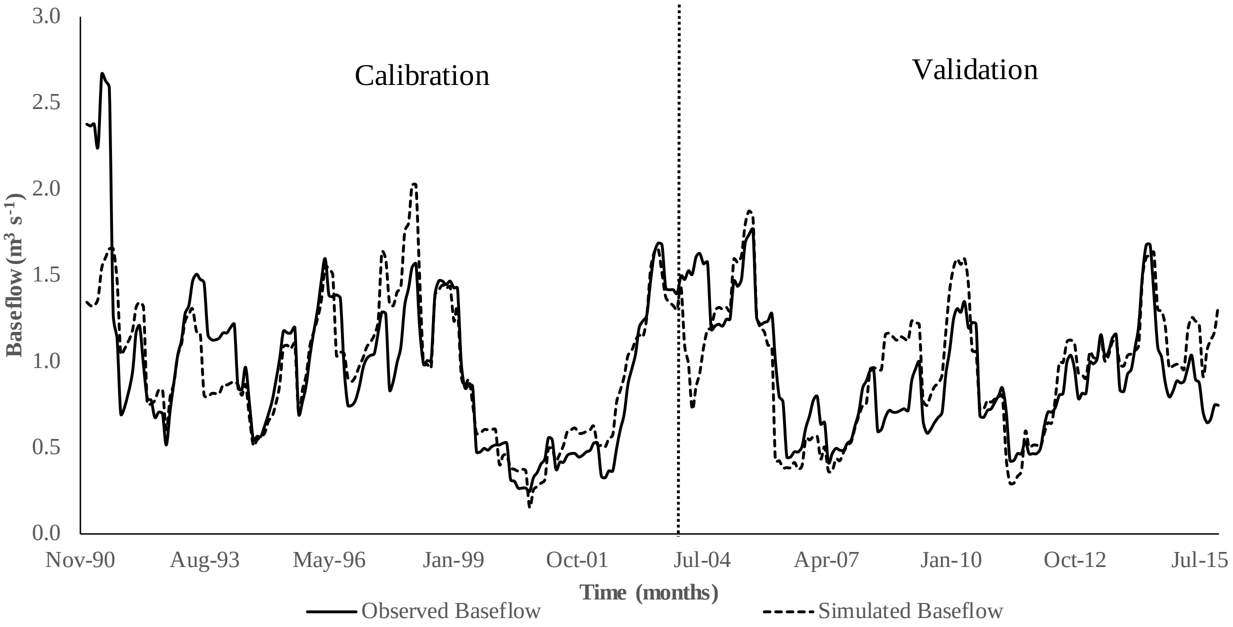


Figure 3.3: Observed vs. simulated: (a) streamflow (m^3 s^{-1}), (b) surface runoff (m^3 s^{-1}) and (c) baseflow (m^3 s^{-1}).

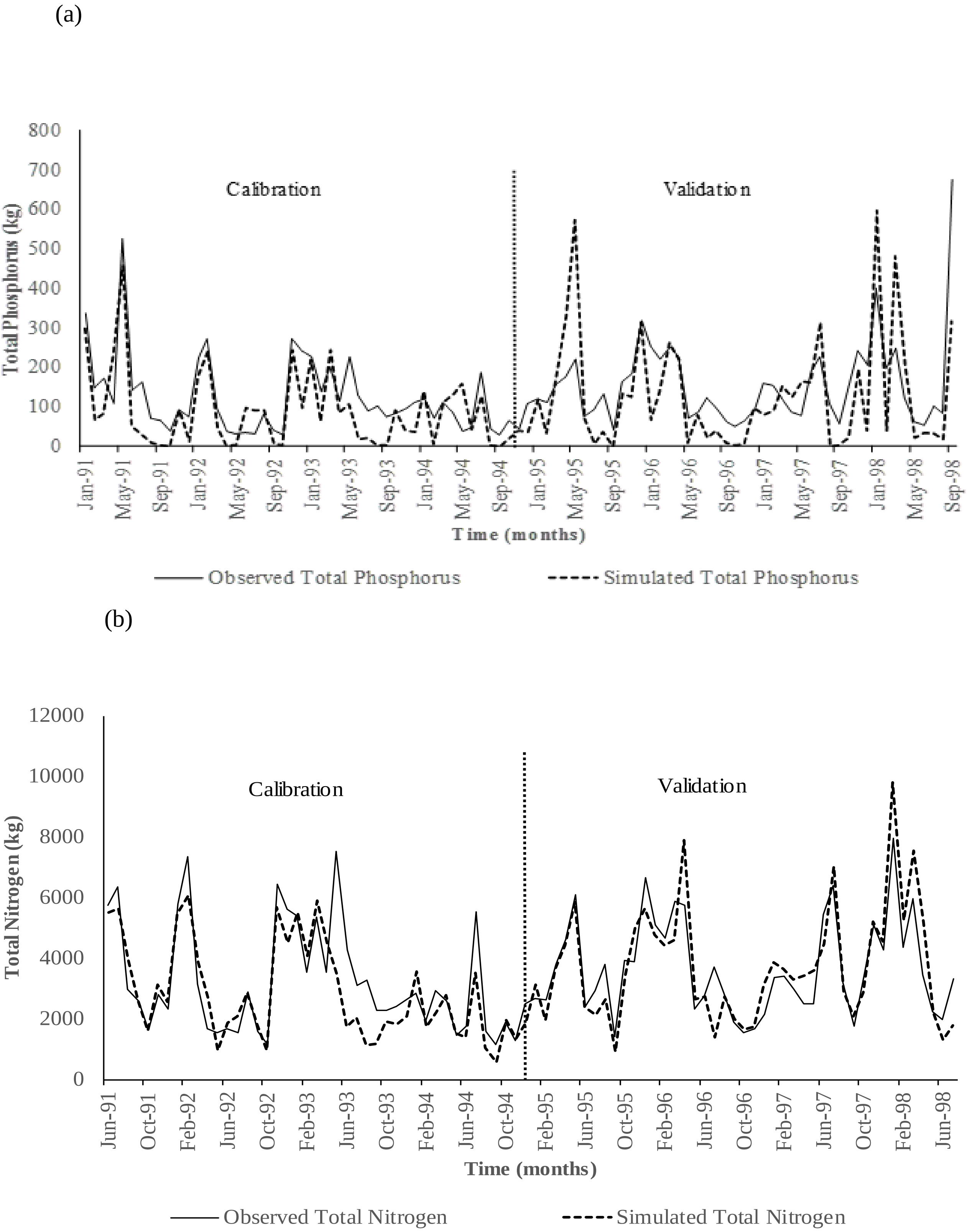


Figure 3.4: Observed vs. simulated: (a) total P (kg) and (b) total N (kg).

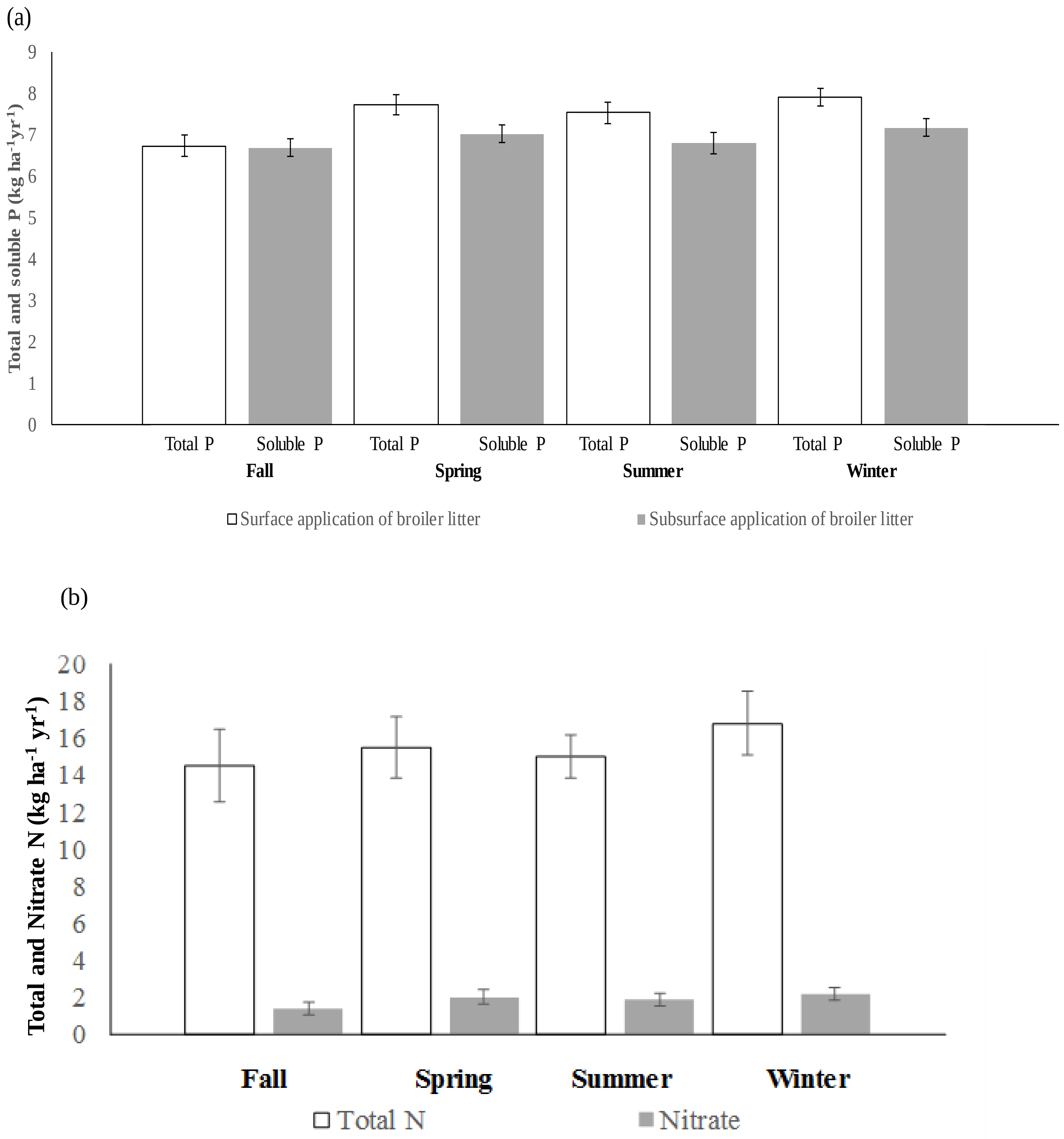


Figure 3.5: Average annual (1991-2015) losses of nutrients in fall, spring, summer, and winter: (a) P and (b) N. Each half bar represents one standard error.

CHAPTER 4

SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY AND CONCLUSIONS

This study used the SWAT model to determine the effect of broiler litter application method and timing on N and P losses from pastures in surface runoff. The major conclusions from this study were: (a) subsurface application of broiler litter helped to reduce N and P losses in surface runoff from pastures, (b) timing of application of broiler litter to pastures with respect to the occurrence of a storm event did not affect N and P losses in surface runoff and (c) P and N losses in surface runoff were greater in winter compared to spring, summer and fall.

Losses of N and P in surface runoff varied as a function of soil type and slope. The soils with the high clay content on steep slopes showed greater N and P losses in surface runoff compared to soils with less clay content (e.g., sandy loam) on flat slopes. Typically, as the surface runoff generated from the pasture HRUs increased, so did the N and P losses. The land use change scenario (conversion of rangelands to pastures) showed that subsurface application of broiler litter can help to reduce P and N losses at the subwatershed and watershed level. The application of broiler litter with respect to the occurrence of the storm event, did not affect N and P losses in surface runoff. This was likely because of the limitations associated with the standard nutrient routines available in SWAT model. Overall, subsurface application of nutrients can help to reduce nutrient losses in surface runoff on a long-term basis.

4.2 RECOMMENDATIONS FOR FUTURE WORK

Future studies should focus on assessing N and P losses in surface runoff as a function of subsurface application of different types of manures (e.g., dairy, hogs). Depending upon inorganic and organic content of N and P in a manure, N and P losses can vary in surface runoff as a function of manure type. Effect of timing of broiler litter with respect to the occurrence of a storm event did not influence N and P losses in surface runoff. Therefore, standard N and P routines available in SWAT should be further tested to evaluate the sensitivity of N and P losses in surface runoff with respect to the occurrence of a storm event.