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Response of Soil and Water Quality to Winter Manure Application from Small Agricultural Watersheds in South Dakota

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RESPONSE OF SOIL AND WATER QUALITY TO WINTER MANURE APPLICATION FROM SMALL AGRICULTURAL WATERSHEDS IN SOUTH DAKOTA

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

RESPONSE OF SOIL AND WATER QUALITY TO WINTER MANURE APPLICATION FROM SMALL AGRICULTURAL WATERSHEDS IN SOUTH DAKOTA

SHIKHA SINGH

2016

The extreme winter conditions prevailing in the state of South Dakota make it difficult for the livestock producers to manage the manure generated at the farm. The South Dakota Department of Environmental and Natural Resources does not recommend manure application in the state during the winter months when the ground is frozen. Thus, producers are left with the options such as storing the manure over a longer period until summer or spreading on snow or frozen ground. Storing manure for longer duration leads to increased risks of concentrated spills into the streams. Thus, it is important to develop management strategies for manure to reduce negative impacts to the environment. The present study was conducted to test the hypothesis that manure spread near the outlets of the watersheds would lead to an increased loss of nutrients as compared to the manure spread away from the watershed outlets. A paired watershed study was established near Colman, South Dakota, in which two watersheds were used as treatment watersheds while one was used as control. The watersheds were named as north (NW), south (SW) and east (CW) watersheds; north and south were treatment watersheds while east was the control. The North watershed received manure application on 50% area close to its outlet while south watershed received manure 50% of its area away from its outlet. At the East watershed and the areas in the north and south watershed that did not receive any manure, inorganic fertilizer was applied to meet the nutrient needs for the crop growth. Surface runoff was measured from the three watersheds, and runoff samples were collected from 2013 to 2015 to assess the impacts of manure application on water quantity and quality. Soil samples were also extracted from the three watersheds to measure the physical and chemical properties as impacted by the manure treatment. In addition, soil erosion was estimated using the Revised Universal Soil Loss Equation 2 (RUSLE2) model. Results from this study showed that soil quality, organic matter and water infiltration improved in the landscape positions that received the manure application. Manure improved the infiltration capacity of the soil and also improved the nutrient status of the soil. Runoff data did not show any particular trend among the three watersheds, rather, it varied according to the precipitation pattern and the topography of the watershed. The runoff depth was not statistically significant across the three watersheds. The north watershed showed the highest loss of nutrients into the streams while the south watershed showed the lowest. The east watershed also showed high nutrient losses which may be due to high solubility of the inorganic fertilizers. Soil erosion results showed that topography (LS factor in RUSLE) played the most important role in determining the soil erosion. Our soil erosion estimation results were coherent with the results obtained for the total suspended solids. Thus, it can be concluded that manure treatment in the south watershed showed best results in terms of reduced water quality impairment and soil erosion as nutrient concentrations in the surface runoff samples were significantly higher from the NW as compared to the other watersheds. Results from this study would provide an insight to the producers about managing

manure during winter months. In addition, monitoring water quantity and quality for longer duration is strongly encouraged to assess the impacts of manure on soils and water.

CHAPTER 1

INTRODUCTION

Manure, an organic substance obtained from animal waste, is a rich source of plant nutrients (Gruhn et al., 2016; Wijnja, 2016). Nutrient contents in manure vary based on the animal species (Sommer and Hutchings, 2001). For example, cattle manure contains 76% dry matter, 34% organic matter, 1.9% nitrogen, 0.6% phosphorus, and 1.4% potassium (Cruz, 1997; Sommer and Hutchings, 2001). Appropriate and recurring manure application can increase soil organic matter (SOM) content, which in turn increases plant nutrient availability, promotes plant growth, and facilitates nutrient cycling (Abawi and Widmer, 2000). Manure contributes to soil fertility (Lupwayi et al., 2014) and when properly managed in the fields, manure contributes to economical gain through increased crop productivity, and environmental benefits through improved soil resilience to variations in climate, cropping system, and management (Kongoli and Bland, 2002). However, application of manure at inappropriate landscape position, time and amount can impair the quality of receiving water bodies. During high intensity precipitation events, surface runoff may lead to manure washing off into nearby water bodies. Manure and nutrients originating from manure entering surface waters from agricultural fields may result in nutrient enrichment, eutrophication, and pathogen enrichment, rendering the water unsafe for recreational activities or drinking purposes and create hypoxic conditions for the aquatic ecosystem (Haack et al., 2015). Thus, to minimize the risk of movement of manure into surface waters, several states in the United

States have established minimum setback distances between the point of manure application and waterways (Haack et al., 2015).

The concept of maintaining a setback distance could be of help in all the seasons, especially during winter months when the soil is frozen and covered with snow. Solid manure can be applied to these frozen soils only if the slope is less than 4% (USDA, 2012), however, this varies from state to state. A setback distance of 91 meters for water conveyance systems, and 305 meters for lakes, rivers and perennial streams is recommended (USDA, 2012). Some states such as South Dakota do not recommend manure spreading on frozen soils (South Dakota, DENR, 2008; USDA, 2012) because of extreme winter conditions. In these situations, proper guidelines about manure application and management practices in managing agricultural waste during winter to minimize the risk of water quality degradation, are strongly needed. Spreading manure on soils during extreme winter conditions in the Upper Midwestern states have advantages and disadvantages. The advantages include that lower soil compaction occurs while driving heavy machinery on the frozen soil for manure application, less manure storage space is required and the risk of concentrated spills into streams is reduced, while the major disadvantage is that manure can be washed off into nearby streams during snowmelt events. Manure application on frozen soils can also lead to ammonia volatilization as frozen soils do not foster infiltration and typically does not allow for mechanical incorporation into the soil (Hayashi et al., 2003); thereby, reducing nutrient content in the soil profile.

Not applying manure during the winter period and storing it may lead to risks of concentrated spills into streams and rivers. In addition, it may be difficult for farmers to store manure during winter months in the upper Midwest states, with a large number of cattle operations. In South Dakota, there are substantial animal farms that raise beef cattle, hogs, lambs, sheep for wool production, therefore, a huge amount of agricultural waste is generated from these farms. Managing agricultural waste on these farms during winter months may be challenging. A range of various factors that include type and application method of manure, soil type, slope, ground cover and precipitation impact runoff from the agricultural fields that receive manure application (Gilley and Risse, 2000; Tomer et al., 2016). Long-term application of manure improves soil properties and water infiltration, and tends to reduce runoff and soil loss (Ahmed et al., 2013; O'Flynn et al., 2013). The benefits of manure application may not be fully realized until several years after application, and long-term experiments under field conditions are required to determine the impacts of manure application on runoff (Gilley and Risse, 2000). It has been reported that monitoring of runoff that occurs from natural precipitation events from a long-term field scale plots is potentially an efficient way to identify the effect of manure on runoff water quantity (Gilley and Risse, 2000). Runoff water carries nutrients, fertilizers, chemicals, pesticides, and various harmful bacteria which may impair the water quality. These pollutants, carried by runoff water, are known as non-point source (NPS) pollutants. Agricultural fields are the major contributor of NPS pollution to streams and rivers in North America (Berka et al., 2001; Kellogg et al., 1994; USEPA, 1996). Intensive agricultural practices release considerable amounts of NPS pollutants such as nitrogen and phosphorus into the streams (Monaghan et al., 2005). Therefore, best management practices need to be implemented to control the NPS pollutants from the agricultural fields that are receiving excessive amount of manure.

Understanding the relationships between runoff quantity and quality, and the type, timing, rates, and methods of manure application can help in developing best manure management practices to improve water quality. Assessing ways for appropriate winter manure spreading can have positive impacts on soil and water quality. The present study was based on the hypothesis that application of manure at the higher landscape (upslope) position will lead to less water quality problems compared to manure application at the lower landscape (downslope) position.

Objectives

The objective of this study was to evaluate the impacts of different field manure application on runoff quantity and quality. The study has the following three objectives:

Objective 1*:* To evaluate the response of soil nutrients and selected properties (soil pH, electrical conductivity, soil organic carbon, available phosphorus, soil total nitrogen, water retention, bulk density, water infiltration rate) to winter manure application.

Objective 2*:* To evaluate the response of water quality to winter manure application during winter months.

Objective 3: To estimate the soil erosion using RUSLE (Revised Universal Soil Loss Equation) model and simulate the impacts of various management practices on soil erosion.

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CHAPTER 2

LITERATURE REVIEW

2.1. Inorganic fertilizers and concerns

The application of high amount of inorganic fertilizers to enhance the crop yield was one of the several alternative management systems those have been used by producers for long time across the world. The fertilizer use in the world has been predicted to increase above 200 million tons in 2018 which is 25% higher than that was recorded in 2008 (FAO, 2015). An increased amount of fertilizer application negatively impacts environmental quality such as increases greenhouse gas (GHG) emissions (Yue et al., 2016), impairs water quality of streams (Khan et al., 2013), and reduces soil quality (Sun et al., 2012). Application of inorganic fertilizers also have detrimental effect on groundwater quality as nitrates are soluble and enter the groundwater easily and lead to eutrophication (Chislock et al., 2013; van Wijnen et al., 2015). The inorganic fertilizers also led to the death of marine vertebrates, fishes, and degrade the quality of water which can cause methaemoglobinaemia in humans, and various others diseases (Camargo and Alonso, 2006). Therefore, alternative management practices in using the inorganic fertilizers are strongly needed for improving the soils and environmental quality. According to Hildebrand (1990), a change in the system of agriculture is required in a way so that the practices conform to the environment instead of dominating and degrading them. Therefore, reduction in chemical fertilizer application, and use of manure in croplands was proposed by various researchers across the globe to improve the farm profitability without impacting the environmental concerns (Evanylo et al., 2008;

Liu et al., 2010). However, there are various benefits and concerns involved with the application and management of livestock manure, and some of those will be discussed in this review.

2.2. Manure

In the late 20th century, farmers mainly focused on one or two crops (Kirschenmann, 2002), which was neither economically profitable for the producers nor for the environment. Since many decades, farmers have used agricultural practices which interfered with the normal functioning of environment to obtain the maximum profitability from the farms (Hildebrand, 1990). Manure application enhances the crop productivity, however, excessive manure application may lead to leaching of nitrates, phosphates and other pollutants into the soil, which in turn can impair the groundwater (Choudhary et al., 1996). Figure 2.1 shows the benefits and concerns associated with manure. In the Upper Midwest in the USA, there are extreme winter conditions with frozen soils and snow cover, and this region has a very large number of livestock production facilities, thus, it becomes very difficult for the producers to store the farm wastes for a longer period of time as the waste generated in this region is very high (Hatfield, 2014). Storing the manure can have detrimental impacts on the environment because of increased risk of concentrated spills in the streams and higher GHG emissions (Gao et al., 2014). A proper implementation of best manure management can help in improving soils and water quality (Karmakar et al., 2007). Any best management practice (BMP) selected for manure management should help in maintaining or improving the environmental quality (Karmakar et al., 2007). A few examples of BMPs include winter manure application using BMPs when spreading the manure on snow covered/frozen grounds.

The application of manure during winters may potentially lead to water impairment as surface runoff water can carry the nutrients into the streams and also leach down, leading to groundwater impairment. The application of livestock manure in croplands, and its management is a major concern in the Northern Great Plains (NGP) of USA where the temperature is below freezing point for around 3 to 4 months of the year.

2.2.1. Types of manure

Commonly there are three types of manure that include farmyard manure, green manure and vermicompost manure (Solapure et al., 2015). In this review, we will only be focusing about the farmyard manure from the livestock. There are two forms of farmyard manure; solid and liquid, that can be applied to the soil. The solid manure is applied on the soil surface and are typically incorporated into the soil using disc ploughing or similar implement. This process helps in reduction of ammonia emissions into the atmosphere (Webb et al., 2010). However, in colder regions where the soil is frozen and often covered with snow, incorporation of the surface applied manure is not possible as it is difficult for the equipment to enter the soil surface. This practice of leaving the manure on the snow covered soil leads to reduction in the nitrogen content of the manure, as ammonia is lost from the manure due to its volatile nature. It is reported that incorporation of manure within an hour of application can reduce the ammonia loss by 85 – 90% (Lupis et al., 2012). The depth of incorporation should be within about 5 to 10 cm so as to conserve the nitrogen in the soil profile (Lupis et al., 2012).

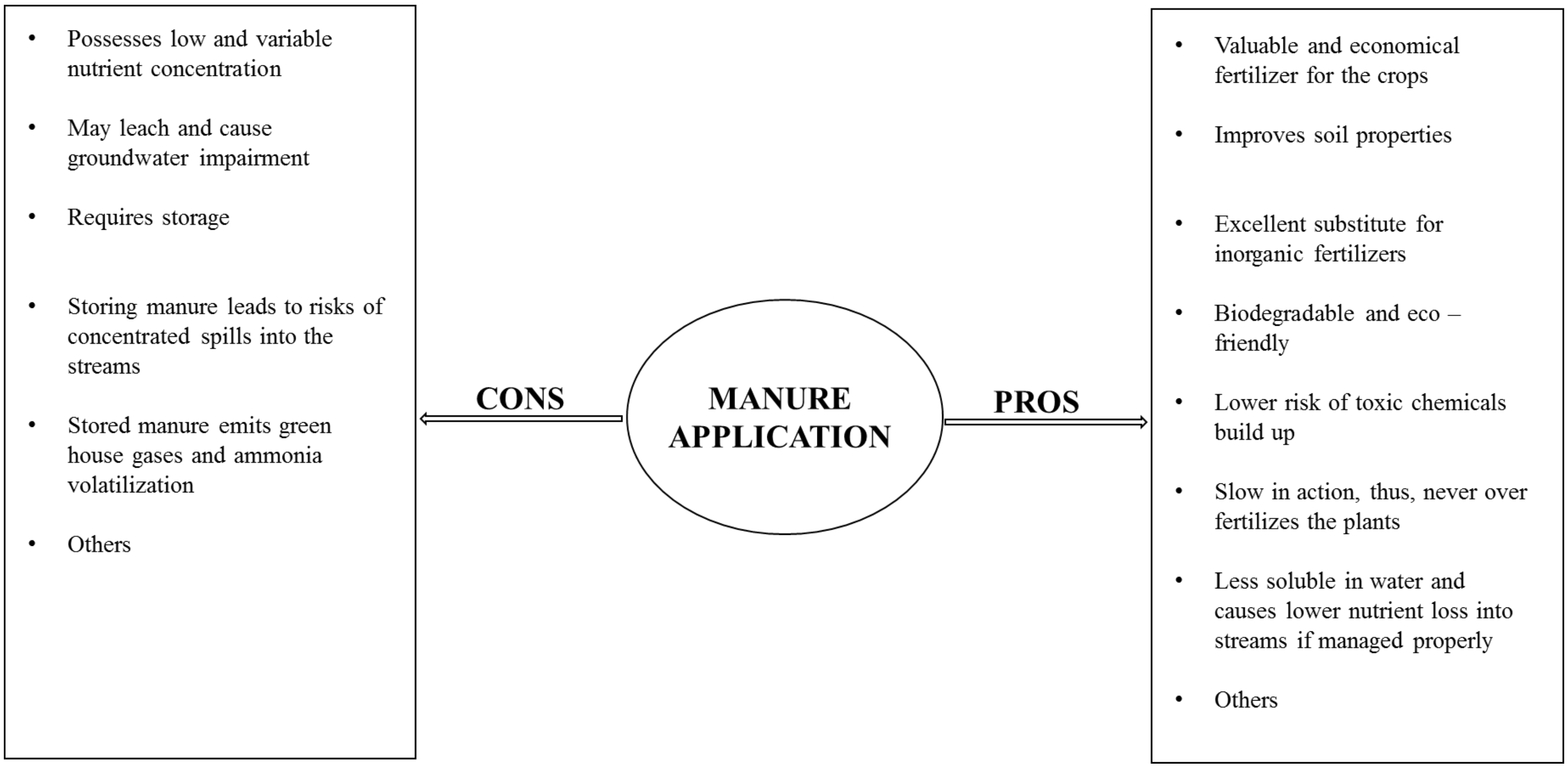

Figure 2.1. The pros and cons of manure application

Liquid manure contains almost 98% water and less dry matter (Lupis et al., 2012). According to the South Dakota Department of Environment and Natural Resources (SD DENR), it is not recommended to spread liquid manure on the fields until unless it is incorporated or knifed in. A study was conducted by Komiskey et al. (2011) in Wisconsin to assess the impacts of solid and liquid manures on nutrient loss and runoff. They concluded that the runoff volumes were independent of the type of manure being applied, and nutrient losses from runoff were depended on the time of manure application. The nutrient loss was higher when the manure application was followed by heavy runoff event. Thus, the study concluded that runoff and nutrient losses were independent of the type of manure being applied, however, these were more related to climate and time of manure application.

2.2.1. Climatic factors influencing manure management

Climate plays a vital role in manure management and subsequent impacts on runoff and water quality. A study conducted by Kannan et al. (2015) reported that warm climate (higher temperature) and changes in the precipitation events affect the water availability. Another study conducted by Sterk et al. (2016) aimed to quantify the impacts of climate change on pathogen runoff, and concluded that a change in the climatic factors (air temperature, precipitation, wind and sea level) had little overall impact on the runoff water impairment. Similarly, Vadas et al. (2015) conducted a study to assess the impacts of application of manure in different seasons on phosphorus losses in runoff. They reported that phosphorus losses were reduced in the runoff when the manure was applied between March and October. However, during winter applications, they observed an increase from 2.8 to 4.2 times in phosphorus loss in runoff water. Further, these researchers also concluded that sites those are prone to high runoff losses are susceptible to lose as much as 7 times phosphorus than the sites prone to less runoff losses. Thus, it can be concluded that temperature and precipitation have an important role to play in the runoff and water quality of streams.

2.2.2. Rate and time of manure spread

Rate of manure application depends on the nutrient requirement of the crops and the soil nutrient status. Runoff and nutrient losses are strongly affected by the rate of manure application. A study conducted by Ahmed et al. (2013) reported that higher rates of manure application in winter and spring season led to a significant increase in the residual N and P in the soil. They further concluded that though the residual N and P increased, the runoff and the nutrient losses in runoff was substantially low during spring and summer as compared to that during fall and winter. Another study by Komiskey et al. (2011) reported that varying rates of manure application in the watersheds did not impact runoff because the application of manure followed by a runoff event within a week. Thus, these studies showed that the time of application of manure during winters is as important as the rate of application, due to its direct impact on the runoff quantity and quality. Another important thing that needs to be considered while applying manure during winter is that manure should be applied during the time of no thawing to reduce the risk of pollutants entering the stream.

2.3. Manure storage and application in croplands of Northern Great Plains (NGP)

2.3.1. Manure storage and application in winter

Manure is often stored during periods of inaccessibility (during crop growing season or during the winter months). When manure is stored in tanks, it forms a sludge layer on the bottom (Zhang and Day, 1996). Therefore, it is important to stir the manure so as to maintain consistent nutrient content (Park et al., 2006). Stored manure is a potential source of greenhouse gas (GHG) emissions and ammonia gas. According to Park et al. (2006), the methane flux during winter was over predicted partially due to the fact that ammonia was trapped by the ice in the manure, and subsequently released during the spring thaw. However, methane flux can still be observed during winter months due to the presence of psychrophilic bacteria which can survive below 10°C (Lettinga et al., 2001). Manure storage in concrete tanks is a good option to reduce runoff nutrient loss especially in areas where there is a high risk of manure being washed off as runoff (Johnson, 2009). More often, areas where livestock farming is less, manure can be stored in concrete bins so that water impairment can be reduced. Manure storage in NGP region can be difficult because of larger number of livestock farms as compared to other states in the United States of America (Hatfield, 2014). Thus, in this region, it would be difficult to store manure as manure accumulation would really be high and it would cost the producers more to build several storage tanks. Stored manure led to various kinds of pathogens (Placha et al., 2001). In addition to that, it will also be difficult from environmental point of view, as if the tank leaks or is dismantled due to any reason, it may lead to the risk of concentrated spill in the stream, which will be much more difficult to handle and control. Solid manure usually spread on the soil surface followed by incorporation by ploughing (Lupis et al., 2012). During winter months, incorporation of manure is difficult as the soil is frozen which reduces the nitrogen content of the manure as ammonia gets volatilized. However, there are different techniques employed for spreading the liquid manure to the soil. One of them is broadcasting the liquid manure, which is not considered economically as well as environmentally safe as it increases the air borne nitrogen loss (due to ammonia volatilization) and the nutrient loss in the runoff water (Lupis et al., 2012). Another technique is deep injection, which is considered appropriate for reducing the airborne losses of nitrogen and conserving the nutrient in the soil profile. Few other techniques include sub-canopy banding using a sleighfoot, incorporation using an aerator, surface banding using a dribble bar (Chen et al., 2001). All these practices may or may not work in states like South Dakota due to periodical very low temperatures during the whole year. Researchers have always criticized the winter manure application in the past, even though it had been a normal practice (Pepin, 2013). Spreading manure in winter is considered inappropriate mainly because of two reasons: economics and environment (Pepin, 2013). From environmental point of view, it is not good as it increases the concentration of nitrogen and phosphorus in the water which led to eutrophication, while from economical point of view, it is uneconomical as it reduces the nutrient content of the manure because the incorporation of manure during winters is difficult as the soil is frozen and ammonia lost as it is volatile (Pepin, 2013). Regarding winter application of manure, few things should be considered to reduce the nonpoint source pollution in these areas. Manure should spread in areas that have soil texture which is least likely to produce runoff and have high infiltration capacity (Mamedov et al., 2001), long term no-till management or fall till management help in increasing the soil infiltration rate (DeLaune and Sij, 2012). Thus, implementing these practices could help in reducing the runoff, thereby, improving the water quality.

2.4. Response of soils and water quality to livestock manure application

2.4.1. Soil organic carbon

Soil organic carbon (SOC) is as the main food source for microbes in the soil, and also an important parameter of soil quality. Soils with higher SOC have the ability to retain nutrients and improve soils quality. Manure, obtained from the livestock, is an important source of organic carbon. A number of studies have shown that the application of manure in soils helps in increasing the SOC (Liang et al., 2012; Maillard and Angers, 2014; Manna et al., 2005; Mikha et al., 2015). Haynes and Naidu (1998) reported that addition of manure to soils increases the available carbon which ultimately enhances soil microbial biomass and their enzyme activity. Such an increased microbial activity helps in improving various soil properties such as aggregation, porosity, infiltration and various chemical properties (Celik et al., 2004; Eghball et al., 2004; Liu et al., 2010). Another long-term (15 years) study conducted by Liang et al. (2012) in Northern Great Plains of China under a corn-wheat cropping system showed that SOC and total nitrogen were significantly higher for the 0-30 cm depth in the manured plots as compared to that of managed with control (unfertilized) and inorganic fertilizers. Several other studies documented similar conclusions that addition of manure in the soil increases the SOC and helps the microbial population bloom in the soil which increases the fertility and the productivity of soil. However, if the application rate of manure is exceeded the optimum limit (depending upon crop requirement), it may lead to dispersion which includes ions accumulation such as potassium, ammonium and sodium in the soil and production of hydrophobic substance by decomposers (Haynes and Naidu, 1998).

2.4.2. Water infiltration

In general, manure has been known for improving the soil aggregate stability and increasing the infiltration rate of the soil. Hatfield (2014) reported that manure application increases the food source for the soil biological systems which subsequently improve the soil aggregate stability and furthermore, improve the water infiltration of the soils and reduce the soil erosion. Several studies conducted in the past have reported that manure application in soil can improve carbon status, increase aggregate stability and improve the water infiltration rates (Gong et al., 2011).

2.4.3. Soil nutrients (nitrogen and phosphorus)

Manure application has an important role to play in maintaining the soil nutrient status. A study conducted by Allen et al. (2006) reported that for Midwestern soils, manure increased soil phosphorus which led to an increase in the runoff phosphorus concentrations. Dinnes et al. (2002) reported that application of animal manure in the soils of the Midwestern states, leads to an increase in the physical, chemical and biological environment leading to improving the nutrient status of the soil. Daniel et al. (1998) reported that manure application and its periodic inversion helped to redistribute the soil phosphorus and increase its availability in the soil. Novak et al. (2014) also suggested that application of organic amendments in the soil helped in increasing the soil nutrient content considerably. Another study conducted in Iowa by Ahmed et al. (2013) reported that application of manure during spring resulted in significantly higher residual nitrogen and phosphorus accumulation in the soil, which increased the corn yields. They also reported that though spring manure application led to a higher nutrient content in the soil, the risk of surface runoff losses from the spring application also gets reduced compared to fall and winter application. Therefore, it can be concluded that manure helps in building up the nutrient status of the soil and increases the fertility.

2.4.4. Surface runoff

Manure application helps in improving soil aggregation and infiltration capacity, and decreasing the runoff water quantity. Table 2.1 shows the various manure and fertilizer treatment effects on surface runoff and water quality. Several studies conducted in the past have reported that the application of manure improves the soil infiltration capacity, thereby, reducing the surface runoff. Chinkuyu et al. (2002) studied the manure application on runoff from a Nicollet loamy soil under a corn-soybean system and observed greater runoff in fertilizer treated soil than that of manure treated soil. They further concluded that manure increases the infiltration capacity of soil and hence reduces the runoff. A similar study was conducted by Kongoli and Bland (2002) and reported that the manure application slowed down the snow melt in proportion to the manure application, as manure acts as an insulating layer and delays snow melt. This resulted in greater infiltration of water which reduces the runoff. Evanylo et al. (2008) studied impacts of different treatments such as poultry litter, compost and poultry litter with yard waste application on snowmelt under a Fauquier silty clay loam (Ultic Hapludalfs) soil in Virginia. They concluded that the compost and poultry litter fields required 8 times longer than the control to begin runoff, which was verified by the runoff volume and soil moisture content at the end of the rainfall simulation. Allen and Mallarino (2008) conducted a similar study in 2008 at Boone and Marshalltown in Iowa and Minnesota in which swine slurry was used on Clarion soil and Tama silt loam under corn-soybean rotation for 20 years without any manure application. They observed greater runoff volumes in fertilized plots than the manured plots. Dolliver and Gupta (2008) used beef manure, hog manure on Rozetta silt loam having continuous corn crop at University of Wisconsin agricultural research station, Wisconsin and concluded that the runoff volume after rainfall was higher from no manure treatment, followed by hog and beef manure treatments. Therefore, it is evident that manure treatment reduced runoff and increased the infiltration capacity of soils. According to studies conducted by Long et al. (1975), Wood et al. (1999) and Vories et al. (1999), the runoff loss was significantly less in the fields treated with manure as compared to the fields without manure (Gilley and Risse, 2000). Manure application helps in reducing the surface runoff. In very cold regions, where the soil remains frozen for a longer span of time, application of manure can help in delaying the snowmelt by acting as insulating layer and thereby, reducing runoff, while in places where the weather is tropical or temperate, application of manure can help in improving soil aggregation and reducing the surface runoff.

2.4.5. Water quality

Manure application impacts water quality of the streams if it is not properly managed in the agricultural fields. Manure leads to nonpoint source pollution (NPS) which is difficult to identify and target for remediation (Sharpley and Wang, 2014). The NPS pollution is caused when water moves across the watershed as surface runoff, carrying with it the pollutants that are present on the land.

As the water drains from the land surface, it carries residues from the land, and surface runoff, especially under the first flush phenomena, is an important source of NPS pollutants (Tong and Chen, 2002). There exists some correlation between pollutant loading and the land use (Perry et al., 1996), which means that water pollution can be reduced using the proper land use management practices (Basnyat et al., 2000). Agricultural land has been identified as the major source of NPS pollutants. These pollutants can be in the form of such as sediments, nutrients, coliform bacteria, fertilizers, pesticides, inorganic salts, crop residues, and others. Intensive agricultural practices release considerable amounts of pollutants such as nitrogen and phosphorus into the streams (Monaghan et al., 2005). For instance, application of manure and inorganic fertilizers lead to heavy loss of nitrogen into the groundwater and high use of poultry litter leads to loss of phosphorus into the streams (Babiker et al., 2004; Burkart and Stoner, 2002). Other dominant sources of NPS pollution are residential and urban wastes (Basnyat et al., 2000). The sources of the NPS pollution lead to potential water quality issues. Poor quality of drinking water may lead to increased health hazards risks. The continuous accumulation of nutrients from the runoff into the streams may eventually lead to eutrophication. Sometimes, it is observed that if manure is applied at a higher rate than the required rate, it leads to more water impairment than manure applied at optimum required rate (Chinkuyu et al., 2002).

Table 2.1. This table shows the various manure and fertilizer treatment effects on surface runoff and water quality.

Treatment	References	Runoff	Water Quality
Manure applied on unfrozen soil	Rozemeijer et al. (2014)	—	Water quality was improved over a long period of time by manure application following the manure legislation.
	Pote et al. (2001)	The soil types in the study had high infiltration rates which reduced the runoff volumes. Thus, the authors suggested that application of manure in soils with high infiltration can reduce the runoff volume and thereby reduce the nutrient loss.	The nutrients (including TKN[†], ammonium nitrogen and TP) loss increased considerably after the application of swine manure slurry and the loss was almost doubled when the manure slurry rate was doubled.
	Laboski and Lamb (2004)	—	Manure application increased the P saturation which would reduce the sorption strength and ultimately produce very high risk of water impairment.
	Scott et al. (1998)	—	Manure application along with tile drainage led to an increased water quality problem as the total phosphorus and the soluble phosphorus

			concentrations increased considerably in the water.
Manure applied on frozen soil	Komiskey et al. (2011)	Runoff volumes were highly variable among the study years. However, there was no difference in the runoff depths among the basins.	Sediment loss from the basins was low (<22 kg ha^{-1}) due to which the nutrients associated with the sediments were also low.
	Williams et al. (2011)	As the soil was frozen, the infiltration capacity of the soil got reduced, due to which 78% of the snow cover melted ad contributed as surface runoff	A lot of TN was lost into the stream when the manure was applied prior to the snowfall event, while the applying manure on top of snow led to a reduction in the ammonium nitrogen loss into the streams but the phosphate and organic nitrogen losses were still high.
	Kongoli and Bland (2002)	Manure applied on snow covered field led to a decrease in the runoff as manure acted as an insulating layer and delayed the snowmelt.	___
	Klausner et al. (1976)	___	Manure applied on melting snow led to very high losses of inorganic nitrogen and phosphorus while manure applied on snow covered soil, or prior to snow fall did not transport as much nutrients into the soil.

No manure (Fertilizer) application	Campbell et al. (2016)	___	Excessive use of fertilizers led to nutrient loss into the Chesapeake Bay and led to very high water impairment and that was mostly due to the people who did not follow the fertilizer ordinance.
	Easton and Petrovic (2004)	The results showed that fertilizer application also led to an increase in the runoff volumes.	The results showed that the fertilizers with high Phosphate content had higher Phosphate losses into the water and also the nitrates and sediments.

†TKN, Total Kjeldahl nitrogen; TP, Total phosphorus; P, Phosphorus; TN, Total nitrogen

There are several specific ions whose presence in the water can lead to several kinds of diseases. Among those are nitrates, phosphates, heavy metals, and sediments those can pollute the water quality to a considerable extent that it is no more suitable for drinking purpose. Phosphates is major issue of concern when manure is applied on the fields and surface runoff carries phosphate with it. In the Netherlands, it was observed that the areas with high livestock concentrations had a high concentration of phosphates (accumulated from the manure) in the soil due to which there was a high concentration in the streams as well due to leaching or runoff from soils (Breeuwsma et al., 1995). The major nutrients of concern are nitrogen and phosphorus. If excessive amount of nitrogen is present in the water, it may lead to Methaemoglobinemia (blue baby syndrome) which is caused due to reduced ability of blood to carry the oxygen around the body, while if excessive amount of phosphate is present in the water, it may lead to eutrophication (death of water bodies) due to algal blooms. Another major concern regarding water quality is the presence of pathogens (may be fecal coliform bacteria) which may be present in the water as a result of manure from livestock (Hubbard et al., 2004). The accumulation of bacterial colonies in water can lead to several diseases such as cholera, dysentery, botulism, and various others. Thus, it is important for researchers to develop Best Management Practices so that manure application is not a threat to water quality. A study conducted by Meals (1996) in Vermont to reduce the sediment, nutrient loads in two different watersheds which impaired Lake Champlain, concluded that application of BMPs such as filter strips reduced the load of bacteria (by 50-75%), sediments (by 90%) and phosphorus (by 15%) coming from the animal waste. However, the P concentration in the runoff is still not reduced to a considerable level as a result of the prior 10-20 years of management, thus, it is the need of the hour to develop risk assessment indices and nonpoint source models to discover and target the conservation measures so that P runoff can be reduced up to a considerable limit. The use of “4R”, which means right rate, right time, right source and right placement of P, is very popular for improved agricultural productivity .On a watershed scale, the pollutant load depends on some factors such as volume of water flowing through the outlet, slope of the watershed, velocity of flow and rainfall intensity (Larsen et al., 2010). Thus, it can be concluded that the climate of a place also plays a vital role in determining the flow of pollutants in a stream. For instance, when there is a high intensity rainfall, it may lead to more sediment erosion, more nutrient loss into the stream and more bacterial population bloom in the streams. Since, climate is something, we cannot control, there is a growing interest among researchers to find out a way to reduce the nonpoint source pollutants, particularly in agriculture (like manuring, fertilization, etc) and this interest has gained popularity in the recent years because from the past few decades, water quality has not seen any improvement as expected even after applying the conservation practices so as to reduce the water pollution (Sharpley, 2016). As we know, winter manure application is a topic of discussion these days. There is a difference in opinion among different groups regarding benefits and concerns of winter manure application. The advantages reported for winter manure application are: requires less storage space for manure; ability to spread manure when there is less pressure to get the crop in the ground; spreading manure on frozen soil may reduce the soil compaction considerably. However, the disadvantages reported for winter manure application are: threats to water quality as a result of snowmelt and runoff; reduction in the nutrient content as ammonia is volatile. As water quality is threatened, winter manure application is no more considered environmentally acceptable (Fraser, 2000). Manure application rates also had a great impact on nutrient loss, as nutrient loss increases with an increase in rate of manure application (Pote et al., 2001). Chinkuyu et al (2002), the nitrate nitrogen was greater in manured soil (high application) than the manured soil (low application) and fertilizer applied soil. Same was the condition for Phosphate loss. Applying higher rates of manure resulted in highest nitrate and phosphate loss as compared to lower manure rates. Another study conducted by Ahmed et al. (2013) at Iowa State University Agronomy and Agricultural Engineering Research Center, Iowa, in a Nicollet soil (fine loamy, mixed, mesic Aquic Hapludolls), under a corn-soybean rotation, with two different rates of swine manure (single rate and double rate based on nitrogen rates) and three different application timings (fall injection, winter broadcast and spring injection), reported that nutrient losses due to runoff and potential water quality threats may be significantly lower in the spring and summer compared to fall and winter due to nutrient uptake by the crops, microbial activity, leaching and evapotranspiration during the growing season. Many studies conducted in the past have shown that livestock manure management, which includes the rate of manure to be applied, the method of manure application and the timing of manure application, may reduce the risk of water pollution, when the environmental conditions such as soil type, tillage practices, weather conditions and livestock feeding rations are not a limiting factor (Allen and Mallarino, 2006; Bakhsh et al., 2000; Kleinman and Sharpley, 2003; Pappas et al., 2008; Pote et al., 2001; Shigaki et al., 2007). Thus, these studies suggest that manure management is important in order to control the nonpoint source pollution taking place.

2.5. Simulating manure impacts on soil loss using RUSLE

Manure impacts on soils and runoff are site and environmental specific, and it takes years before one can know which management is beneficial in improving soils quality and reducing the runoff quality. Therefore, modeling tools such as Revised Universal Soil Loss Equation (RUSLE) are very beneficial in simulating the long-term benefits of conservation practices on soils and runoff. The RUSLE is an erosion prediction model which was basically designed for conservation planning. It may or may not give accurate results of sediment erosion but it estimates the value which may be close to the actual value (Foster et al., 2001). This model is based on the equation:

$$A = R*K*L*S*C*P$$

where, R is the rainfall erosivity factor, K is the soil erodibility factor, L and S are length and the steepness of the slope, respectively, C is the cropping and land-cover factor, and P is the support practice factor

The R factor is the rainfall – runoff erosivity factor. Keeping the other factors constant, the erosion losses from the rainfall is directly proportional to the intensity of the rainfall and the kinetic energy of the raindrops. Lower rainfall (<12 mm) is not considered significant as they do not add much to the rainfall erosivity computations. It varies greatly with location and for the USA, each state has an average value based on the amount of rainfall and the peak intensity sustained over a long period (Renard et al., 1997). The K factor is the measure of the susceptibility of the soil to erosion and it is an inherent property of the soil. Soils having a high clay content have lower K values as they are resistant to detachment while the soils that are sandy in texture again have lower K values as they allow lower runoff due to their infiltration rates. Medium textured soils such as the clay loams have comparatively K values due to their moderate susceptibility to detachment and produce moderate runoff (Renard et al., 1997). The effect of topography on erosion is accounted by the LS factor. The L factor is the length of the slope which is the distance from the origin of the overland flow to the end (outlets), and S is the steepness of the slope and accounts for the erosion occurring due to the slope steepness. Soil erosion from a slope largely depends on the vegetation density and the soil particle size (Renard et al., 1997). C factor is the cover management factor and is used to show the impacts of cropping and various management practices on soil erosion. It is one of the most important factors as it helps in comparing the various cropping and management practices for conservation planning. It takes into account the surface soil cover which intercepts the runoff and reduces the soil erosion (Renard et al., 1997). The P factor accounts for the impacts of the support practices such as strip cropping, contouring, etc. on sediment deposition (Renard et al., 1997).

RUSLE predicts the possible soil loss as a result of splash, sheet and rill erosion (Adugna et al., 2015). Several studies have been conducted in which RUSLE2 has been used to predict the soil loss from manured fields. A study conducted in Wisconsin by Good et al. (2012) used RUSLE2 model to predict the erosion and further used equations to predict the phosphorus load from the fields. RUSLE2 is an efficient tool and can predict the soil loss from manure managed fields. In the Northern Great Plains, several studies have been conducted to predict soil loss (Dalzell et al., 2013; Liebman, 2015; Liebman et al., 2015; Maalim and Melesse, 2013).

2.6. Summary

Manure application in croplands increases soils and crop productivity, however, if the application of manure is not managed properly, it can lead to serious environmental problems. The application of manure to the soils increases soil organic matter (SOM), hence improves soil health and crop productivity. However, there are various benefits and concerns involved with the application and management of livestock manure. Manure is good for soil sustainability and improving their physical and hydrological properties. It is a rich source of carbon which helps in the growth of microbial population in the soil. Thus, it is evident that manure is important to ensure soil conservation so that future generations can equally benefit from it. From previous discussions, it is evident that manure has a huge impact in improving the soil and water quality if managed efficiently. It can help in improving the soil structure, aggregation and porosity of soil leading to an increase in the infiltration capacity of soils. As the infiltration capacity is improved, it leads to a significant reduction in the surface runoff. If less water is washed off as runoff, it will also reduce the nutrient and sediment load flowing along with the runoff water into the streams. Manure management strategies and environmental conditions play an important role in determining the nutrient losses occurring as runoff from the watersheds. It is important for the hydrologists to develop Watershed Protection Plan so that most of nutrients are not allowed to enter the streams and pollute them. On a watershed scale, it would be better the farmers apply conservation practices or watershed protection plans which include livestock nutrient management, use of riparian buffers, grassed waterways, filter strips, etc in order to catch or stop the nutrients that are flowing through the watershed outlet. These strategies would significantly help in reducing the water impairment which is a major concern is today's era. Public awareness can also be of help as educating the common people about the importance of clean drinking water and the health hazards dealing with impaired water. However, it is seen that not much has been done with respect to winter manure application on water quality. Long term studies should be conducted so that impacts of manure on water quality can be documented in comparison to the fertilizer treatment. Moreover, in colder states where the soil remains frozen for more than 3 – 4 months, it is important to assess the impacts of winter manure application on soil and water quality, as storing manure for a longer time period would be difficult for the livestock producers. Thus, it is important for such states to develop management practices, so that the livestock producers need not store manure for a long time and also improve the soil and water quality simultaneously. Still a lot has to be done to document the manure management and its implications on environment.

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CHAPTER 3

MATERIALS AND METHODS

3.1. Study Watersheds

The experiment was conducted at field scale in Egan Township, Moody County, South Dakota. Three different watersheds (Fig. 3.1) named North Watershed (NW), South Watershed (SW) and East Watershed (CW) were established on Egan – Ethan complex and Wentworth – Egan complex, as determined from the Web Soil Survey. The area of the NW is 2.71 hectare, SW is 4.13 hectare, and control watershed (CW) has an area of 2.75 hectare. The three watersheds are present in the same field and have been managed with similar management practices and crops (corn-soybean rotation). The design of the watershed treatments was paired watershed design (Clausen and Spooner, 1993). The NW and the SW were treated with manure, and the treatments that were applied were: manure was spread on the NW to the one half of the watershed located lowest in the terrain while on the SW, manure was spread to the one half of the watershed located highest in the terrain. CW was left without any manure treatment (but received inorganic fertilizers in order to meet the requirements of the crops for their growth) and considered as the control watershed. This treatment was selected to test the hypothesis that the treatment on the SW should have less nutrient and sediment loss as compared to the NW as the distance between the manure treatment and the sampling point of the runoff water, i.e. the outlet of the watershed was more in the SW more time for the water to infiltrate and thereby, reducing nutrient and sediment loss. Manure was

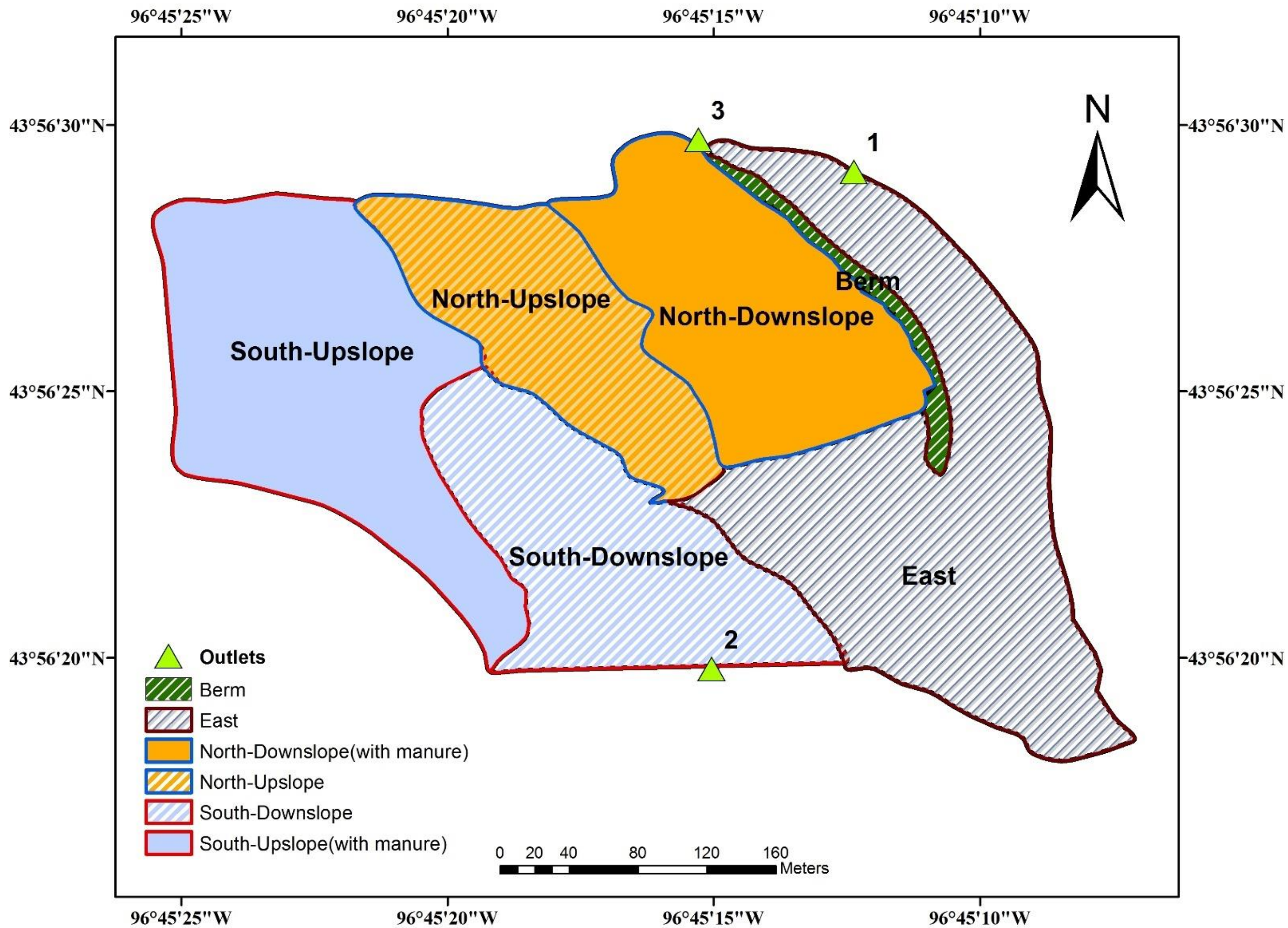

Fig. 3.1. The study watersheds at Colman, South Dakota

spread on the watersheds using a truck spreader (Fig. 3.2) and the uniformity of application was checked using a cross track calibration in 2012. The manure was sufficient to meet the nitrogen demands and nitrogen fertilizer was not as necessary.

3.2. Climate Data

The climate data, on a daily temporal scale were obtained from the National Climatic Data Center, National Oceanic and Atmospheric Administration (NCDC NOAA) website from the Flandreau, SD station which is located 16 km away from the study site. To check variation in the rainfall during the study period, annual average rainfall was estimated for the last 20 years and the long term average rainfall was compared to average at this station.

3.3. Soil Quality

Soil auger samples were collected in summer of 2015 from six different landscape positions, viz., NW upslope (no manure treatment), NW downslope (manure treatment), SW upslope (manure treatment), SW downslope (no manure treatment), CW upslope (control) and CW downslope (control) up to 4 depths (0 – 10, 10 – 20, 20 – 30 and 30 – 40 cm). From each landscape position samples were collected in 4 replications (Figure 3.3). A total of 96 samples were collected from the site and were packed in plastic zip lock bags and transported to the laboratory. The collected samples were air dried, crushed and sieved through a 2 mm sieve. The prepared samples were used to analyze soil organic matter, total nitrogen, Olsen phosphorus, pH and electrical conductivity. Water infiltration rate was also measured for all the six landscape positions with the double ring method (20 cm height, and 30 and 20 cm diameter for the inter and the outer rings) using

Fig. 3.2. Manure spread using a spreader in 2016

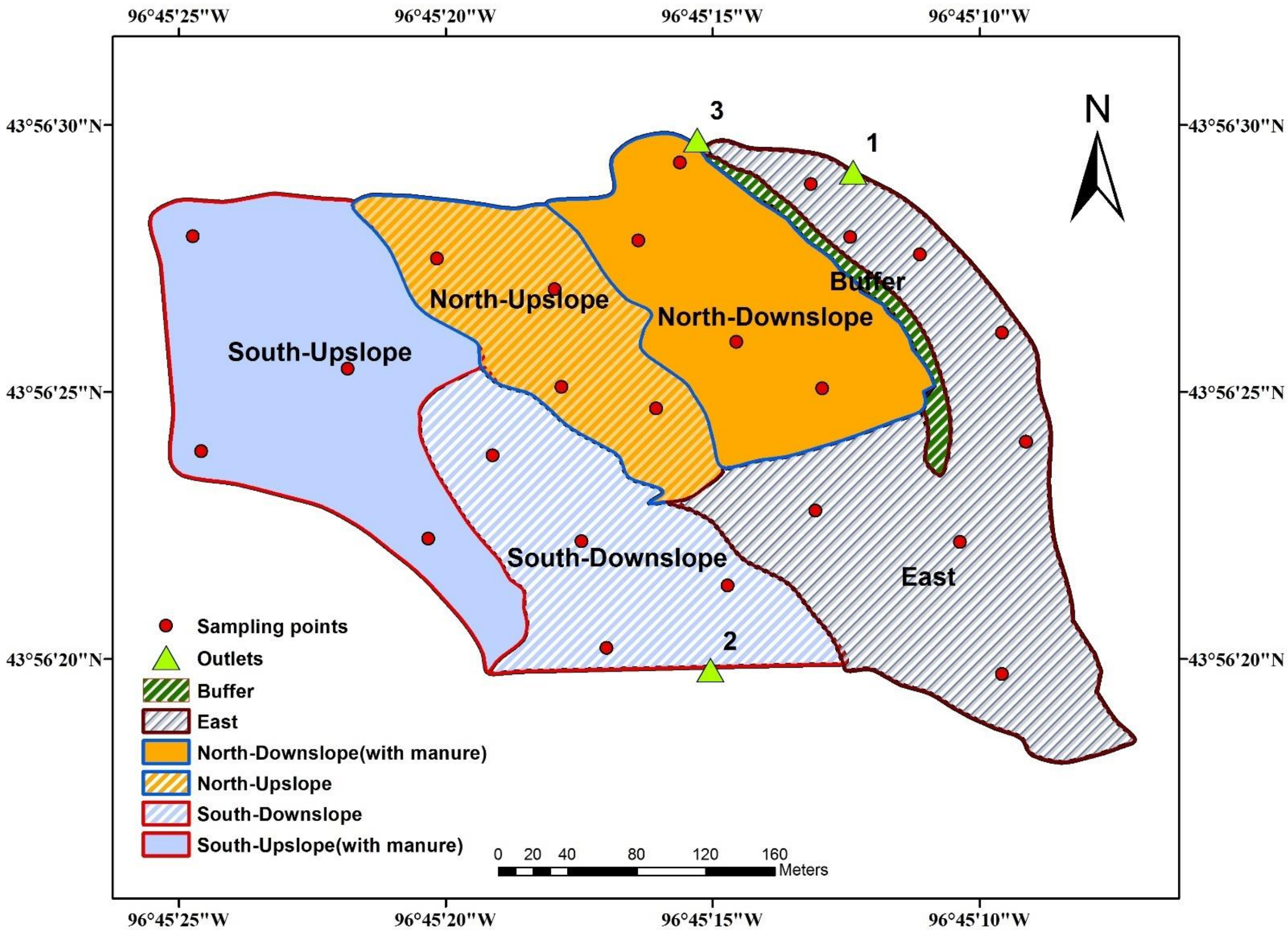

Figure 3.3 Study area map showing the soil sampling points

the ponded head method (Reynolds et al., 2002). Infiltration measurements were done in three replicates at each landscape position. Core samples were collected from 2 depths (0-10 cm and 10-20 cm) from all the landscape positions in two replicates. The cores were of 5 cm diameter and 5 cm length. The samples were sealed in plastic zip lock bags, transported to the lab and were analyzed immediately. Bulk density was analyzed using the core method (Grossman and Reinsch, 2002) for both the depths. Total nitrogen and carbon were determined using the TruSpec CHN Analyzer (LECO Corporation, St. Joseph, MI) and the inorganic carbon was determined using the hydrochloric acid method (Stetson et al., 2012). The difference between the total carbon and the inorganic carbon was soil organic carbon (Stetson et al., 2012). Soil available phosphorus was determined using the Olsen method (Olsen, 1954). Electrical conductivity (EC) and pH were measured using Orion star pH and EC meter using 1:1 and 1:2 soil: water ratio, respectively. Soil water retention (SWR) was determined using tension and pressure plate extractors (Klute and Dirksen, 1986). Intact soil cores were saturated using capillarity for more than 24 hours before determining the SWR at 0, -0.4, -1.0, -2.5, -5.0, -10.0 and -30 kPa matric potentials.

3.4. Surface runoff quantity

The H-flumes were installed at the outlet of each watershed to monitor the surface runoff from each watershed outlet. The peak flow was recorded with the help of H-flume and the depth of the water flowing through the flume was recorded by ultrasonic depth sensor (SR50A) (Campbell Scientific, Logan, UT). Due to extreme weather conditions in the state of South Dakota, monitoring of runoff was difficult because the water used to freeze before it came out of the flume which may have caused erroneous readings of the runoff. In addition to that, it was observed that sometimes the depth of water exceeded the normal depth of 18 inches, which could be due to some rodents or bovines or some other animals sitting onto them or standing next to the sensor which triggered the ultrasonic depth sensor to record the depth wrongly. To avoid this problem, a digital camera (Moultrie M80 GameSpy) (Moultrie, Birmingham, AL) was added near the outlet of each flume location. This addition helped to find out if the runoff was occurring and if the water froze within the flume. The power to the sampler was provided by a 12 V battery and the battery was recharged with the help of 10 W solar panel. Runoff for this study was monitored from 2011 to 2016. Runoff depth was converted into flow rate (cubic feet per second) using the exponential flow equation mentioned below (Brakensiek et al., 1979):

If the depth (x) was less than or equal to 0.75 ft, the flow equation used was:

$$\text{Flow rate in cfs} = 0.6933*(x^3) + 1.3559*(x^2) + 0.0568*(x) - 0.0003 \qquad (3.1)$$

If the depth (x) was greater than 0.75 ft (upto 1.5 ft), the flow equation used was:

$$\text{Flow rate in cfs} = 0.2851*(x^3) + 2.6216*(x^2) - 1.2703*(x) + 0.4597 \qquad (3.2)$$

Flow in $m^3\ s^{-1}$ = flow in cfs * 0.0283

3.5. Surface water quality

Water samples were collected by Teledyne ISCO automatic samplers (model number 6712) (ISCO, Lincoln, NE) during the years 2013 and 2014 and using Campbell Scientific (Campbell Scientific, Logan, UT) automatic samplers during 2015 and 2016. These samples were collected during each runoff event and placed in a cooler and transported to the South Dakota Agricultural Laboratories in Brookings, South Dakota. The samples were analyzed for total Kjeldahl nitrogen, nitrate nitrogen, ammonium nitrogen, total dissolved phosphorous, total phosphorus and total suspended solids. The samples were tested by the following standard methods. The total Kjeldahl nitrogen was estimated using the method provided by EPA 351.3 (Colorimetric, Titrimetric, Potentiometric method); ammonia nitrogen was tested by EPA 350.2 (Colorimetric, Titrimetric, Potentiometric Distillation Procedure); nitrate nitrogen by SM 4110B (Ion chromatography with chemical suppression of eluent conductivity); total phosphorous by SM 4500PE (Ascorbic Acid method); total dissolved phosphorous by SM 4500B&E (Sample digestion and Ascorbic acid method); total soluble solids by SM 2540D (Total solids dried at 103-105^{o}C) (Federation and Association, 2005). After getting all the results for each sample, the representative concentration of nutrients was calculated for each storm event for all the three watersheds. There were several storm events where numerous samples were collected and to represent the representative concentration of each pollutant in the sample, flow weighted mean concentration method was used in which mass load was calculated first (equation 3.3), followed by flow weighted mean concentration (equation 3.4) (Smith et al., 2003).

$$\text{Mass load} = \sum c\ q\ t \tag{3.3}$$

where, c = sample concentration (mg m^{-3})

q = instantaneous streamflow (m^3s^{-1})

t = time interval (s)

$$\text{Flow weighted mean concentration} = \frac{\text{Total mass load}}{\text{Total stream flow volume}} \tag{3.4}$$

3.6. Statistical analysis

Statistical analysis of water quality for the three watersheds was performed using SAS 9.3 software (SAS Institute, 2012). The distributions of the data sets was tested for composite normality using the Kolmogrov-Smirnov test and histogram method. Parallel line analysis was used for comparing the mean differences of each pair of water quality parameters (nitrate nitrogen, ammonia nitrogen, total Kjeldahl nitrogen and total dissolved phosphorus) under different watersheds as the data are time correlated values and interdependent. A log transformation was used when residuals were not normally distributed. In addition, an estimate for the least significant difference (Duncan's LSD) among treatments was obtained using the 'Mixed procedure' in SAS (2007) for the soil data to assess the treatments impact on measured parameters (soil pH, EC, available P, soil organic carbon, total nitrogen, soil water retention and infiltration rates). Statistical differences were declared significant at $\alpha = 0.05$ level.

3.7. RUSLE2 model

The RUSLE equation was used to predict the annual soil loss from the three watersheds. RUSLE2, being an empirical model, helped in estimating the soil loss after letting us apply the manure management as mentioned in the study site description. RUSLE has six parameters which help in measuring the annual soil loss.

$$A = R*K*LS*C*P \qquad (3.5)$$

where, A is the average annual soil loss (t ac^{-1} yr^{-1}), R is the rainfall erosivity factor, K is the soil erodibility factor, LS is the topographical factor which includes slope length and slope steepness, C is the vegetation cover and P is the conservation practices. LS, C and P factors are dimensionless.

For calculating the R factor for the equation in RUSLE2, as soon as we enter the location of the study area, it automatically takes up the R factor for that place. For out study area, the R factor picked by the model was 100.

Soil erodibility factor (K) is the susceptibility of the soil to erosion (Wischmeier and Smith, 1978). The K value depends on the soil properties (soil texture, soil structure, soil organic matter content, etc) (Wischmeier and Smith, 1978). For the K value as well, when we entered the soil series for the study area, it automatically took up the K factor for the soil and for our study area it took the alue as 0.26.

Slope length and slope steepness were determined using the digital elevation model using the 10m by 10m resolution in ArcGIS and LS factor was calculated using the following equation (Morgan, 2006):

$$LS = \left[\frac{Q_a M}{22.13}\right]^n \times (0.065 + 0.045 \times s + 0.0065 \times s^2 \qquad (3.6)$$

where, where Q_a denotes flow accumulation grid; s is grid slope in percentage; M is grid size; n has constant value of 0.2-0.5.

C factor which represents the soil cover, soil biomass, and soil disturbing activities on erosion was determined using the RUSLE guide tables (Morgan, 1995). For just soybeans, the C factor value was 0.39 while for the landscape positions which had manure treatment and the soybeans with them, the C factor was 0.34 (Gabriels et al., 2003) as C factor takes into account the surface soil cover which intercepts the runoff and reduces the soil erosion and in this present study, manure was applied (was not incorporated) so as check its impact on soil erosion and runoff.

P factor denotes the support practices and range between 0 to 1 (Renard et al., 1997). P is normally assumed to be unity. P value is decreased when we apply practices such as strip cropping, terracing and contouring. At the end, the soil erosion was calculated by multiplying all factors together. After calculating the soil loss, we created scenarios of increasing the residue cover on the watersheds so that they could trap the sediments and prevent soil erosion. Similarly, we tested how the installation of terraces as support practice to reduce the erosion. We chose these two practices as this would be easy for the producers to employ and does not require any additional expense.

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CHAPTER 4

RESULTS AND DISCUSSION

4.1. Climate and soil data

The amount of precipitation the study site received was 6% and 12% below the long-term mean 669 mm in 2013 and 2014, respectively. In the year 2015, the annual precipitation was 25% higher than the long-term average. The climatogram for the study area has been shown in Figure 4.1.

The soil data for the 2 depths (0 – 10 cm and 10 – 20 cm) is shown in Table 4.1 and 4.2, respectively. Soil pH for the 0 – 10 cm depth of north upslope and downslope were slightly acidic with the values of 5.8 and 6.3, respectively. However, soil pH for south upslope and downslope were 5.4 and 5.1, and 4.7 and 4.8 for east upslope and downslope, respectively. There were no significant differences observed in pH values between the landscape positions for each watershed, however it was observed that manure applied landscape positions had numerically higher pH values indicating that manure application increased the soil pH. For the 10 – 20 cm depth (Table 4.2), pH for all the landscape positions did not show any statistical significance. However, it was seen that manure treated landscape positions (north downslope and south upslope) showed an increased pH numerically, though statistically non-significant. A study conducted in China by Whalen et al. (2000) reported that application of manure in soils lead to an immediate and persistent effect on soil pH and showed an increase in the pH value, although the differences were not significant. Another study conducted by Walker et al.

(2004) in Southwestern Spain reported that application of manure showed a considerable increase in the soil pH.

It was observed that there was a significant buildup in the 0 - 10 cm depth of soil nutrients in the areas manure was applied (Table 4.1, Figure 4.2). The north downslope of the NW had higher total nitrogen (2.4 g kg^{-1}) compared to the north upslope (2.0 g kg^{-1}), although the difference was not statistically significant. At the SW, the south upslope had significantly higher (25% more) nitrogen content than the south downslope. There were no differences observed in the nitrogen content between upslope and downslope positions of the control watershed (i.e. CW). There were some statistical differences observed in the watersheds when comparing upslope and downslope (averaged across the watersheds) which may be due to the soybean crop grown during the sampling period (summer 2015) which helps in nitrogen fixation. For the second depth (10 – 20 cm), it was observed that there were no significant differences among the landscape positions of each watershed (Table 4.2), however, the manure treated landscape positions showed numerically high value as compared to the untreated ones. A long term (17 years) study conducted in China by He et al. (2015), concluded that manure significantly increased the nitrogen content in the soil. Similar results were reported by Mancinelli et al. (2013).

For soil available phosphorus in the 0 – 10 cm depth, there was a significant higher build up in the north downslope which was treated with manure than the north upslope, except in the SW (Table 4.1). The available P content was about 61% higher at the north upslope compared to the north downslope. At the SW, the manured south upslope had numerically higher available P content than the south downslope, but statistically insignificant (Table 4.1). This may be due to manure applied to these specific landscape positions. In the CW, the upslope was significantly lower than downslope which may be due to erosional losses from the upslope landscape position to downslope. In addition to that, it may be that the inorganic fertilizers (being soluble in water) may get dissolved in the runoff water and move towards the downslope which may lead to a greater concentration in the downslope. Manure application leads to an increase in available P content in the soil. For the second depth (Table 4.2), there was no significant difference observed in the watersheds except the NW. For the NW, soils in north upslope had significantly higher phosphorus content as compared to the north downslope. A study conducted by Tadesse et al. (2013) reported that application of manure led to a considerable increase in the available P (11.9 to 38.1 mg L^{-1}). Xue et al. (2013) also showed that application of manure on soils in North China Plains led to a considerable increase in the labile and non-labile P pools in the soil. Similar observations were reported by Waldrip et al. (2012), who indicated that organic dairy manure treated soils had higher P than the ones treated with inorganic fertilizers ($p<0.05$).

Soil organic carbon for the 0 – 10 cm depth, was significantly higher in the landscape positions treated with manure compared to untreated landscape position within a watershed (Table 4.1, Figure 4.3). North downslope had 42% higher SOC concentration than north upslope, while south upslope had 37% higher SOC content than the south downslope. For the CW, the downslope was numerically higher than the upslope although it was not statistically significant. For the second depth (Table 4.2), the landscape positions did not show any statistical differences in the SOC except the NW, in which soils in north downslope showed statistically higher SOC than the north upslope. Addition of manure increased the organic matter content of the soils. Similar results were also documented by Eghball et al. (2004) in Nebraska, USA where they reported that total C and total N increased after application of manure. Haynes and Naidu (1998) reported that addition of manure to soils leads to an increase in carbon content which ultimately increased soil microbial biomass and enzyme activity. An increase in microbial activity eventually lead to improvement in various soil properties such as water infiltration, porosity, and water holding capacity (Celik et al., 2004; Eghball et al., 2004; Liu et al., 2010). Similar results were reported by Xie et al. (2014). The results obtained in the present study were consistent with the published literature discussed above.

Electrical conductivity (EC) results did not show any significant differences in the landscape positions within a watershed. However, for the 0 - 10 cm depth (Table 4.1), it was noticed that manure treated landscape positions had numerically higher electrical conductivity than the untreated parts due to the accumulation of soluble salts in the soil (Turner, 2004). A similar trend was observed in the 10 – 20 cm depth (Table 4.2) of the soil profile with no significant differences observed in the landscape positions within the watersheds.

Soil bulk density results (Fig 4.4) also showed that manure application led to a decreased bulk density in the soils. North downslope and the south upslope positions had a lower bulk density value as compared to the north downslope and south upslope, respectively. This may be due to the fact that manure leads to soil aggregation which helped in reduction lowering the bulk density of soils. However, there were no significant differences observed in bulk density values within the watersheds.

The landscape positions treated with manure had higher infiltration rates (Table 4.3) compared to areas not receiving manure although the differences were not always statistically significant. The only statistically significant difference observed in the infiltration rates were in the NW, where north downslope showed increased infiltration rate (14%) compared to the north upslope. In the SW, infiltration rate in south upslope was numerically higher but there was no statistical difference. This may be due to the manure application which helped in the improvement of infiltration rates. For the CW, no statistical significance was observed. Manure improved soil organic matter which ultimately, increased soil porosity and hence improved water infiltration (Gholami et al., 2013). A study conducted by Peng et al. (2016) in China compared four different treatments (inorganic Nitrogen, Phosphorus and Potassium (NPK) fertilizer, NPK plus rice straw mulch, NPK plus rice straw derived biochar and NPK plus swine manure) and reported that NPK plus rice straw-derived biochar and NPK plus swine manure increased infiltration capacities compared to the other treatments due to increases in organic matter and improved soil properties.

4.2. Surface runoff

Surface runoff from the watersheds differed greatly due to the different treatments among the watersheds, their slope and orientation. However, it was observed that the runoff patterns were not the same in all the study watersheds for all 3 years of the monitoring period. In 2013 (Fig 4.5), SW had a total flow (21 mm) followed by CW (14 mm) and then NW (12 mm) collected during all the precipitation events, which was comparatively lower than the runoff measured during the previous years of the study **(**Adapted from Nathan Brandenburg MS thesis**)**. This may be because of the 6% less precipitation during this year as compared to the long term mean of 669 mm. No statistical difference was observed between the runoff depths across the three watersheds.

When statistically compared, NW and CW had no differences ($P<0.68$) and SW and CW had a P value of 0.53. The year 2014 received only one runoff event (Fig 4.6) throughout the year and the observed trend remained similar to the previous years were NW had a runoff of 15 mm, while SW and CW had runoff of 5 and 0.22 mm runoff, respectively. There was only a small amount of runoff in 2014 as it was the driest year of the study. The year 2015 (Fig 4.7) had very high intensity rainfall events with maximum of 20.3 cm (8-inch) rainfall received in a single storm event. The NW produced 23.5 mm of runoff, SW had 21 mm and CW had 20 mm. No statistical significance was observed between the runoff depths of NW and CW ($P<0.62$) and SW and CW ($P<0.87$). It was observed that for all the years, there was no significant difference in the runoff depths measured for the three watersheds. However, there were 5, 1 and 5 runoff sampling events in 2013, 2014 and 2015, respectively in the SW. All the study watersheds did not produce the same number of runoff events due to the difference in their treatments, orientation, slope, topography, etc.

The reduced runoff in 2015 compared to that of previous sampling years was partially due to differences in rainfall pattern and increased infiltration capacity of the soils that have gradually improved during the 5 years of experiment. Chinkuyu et al. (2002) studied manure application on runoff from a Nicollet loamy soil under a corn-soybean system and noted greater runoff in soils with fertilizer application than that of soils which received manure application. A similar field study was conducted by Kongoli and Bland (2002) at Agricultural Research Station, Madison, Wisconsin, in which dairy barn bedding with chopped corn stalks was used in an alfalfa crop. The authors reported that manure application slowed down snow melt in proportion to the application amount, as manure acts as an insulating layer and delays snow melt. This resulted in greater infiltration of water into the soil which reduces surface runoff. Based on studies conducted across various environmental and geographical settings, the runoff loss was less in the fields treated with manure compared to fields without manure (e.g., Gilley and Risse, 2000; Long et al., 1975; Vories et al., 1999; Wood et al., 1999).

4.3. Water quality

Nitrate Nitrogen: Nitrogen concentration was measured as nitrate nitrogen, for 2013, 2014 and 2015, and the data is shown in Fig. 4.8, 4.9, 4.10, respectively. In 2013 (Fig 4.8), nitrate concentration varied among the three watersheds. For comparison, the maximum nitrate nitrogen concentration in drinking water is 10 mg L^{-1} (US EPA 2012a). Thus, there were generally no nitrate concentration exceedances in the runoff water but for a few exceptions in the year 2015. In 2013, the trend was SW having the significantly less nitrate concentration followed by CW, and NW ($P<0.015$). On March 9, 2013, SW had 3.9 mg L^{-1} of nitrates in the runoff while CW and NW had 4.6 mg L^{-1} and 4.75 mg L^{-1}, respectively (Fig. 4.8). Likewise, On March 14, 26, 27 and 28, 2013, nitrate concentrations in the runoff samples were higher in NW and CW than that of the SW (Fig 4.8). The trend showed that NW had more concentration than the SW. This may be attributed to the fact that CW had no manure treatment due to which runoff was higher which carried higher nutrients loss. In addition, the inorganic fertilizers may have a higher solubility of ions that increased the nutrient loss in the CW. Similarly, the NW had manure application near the outlet, thus reducing the pathway length for transporting manure to the field edge. In 2014 (Fig 4.9), precipitation was 12% below the long-term average. Thus, there was very little runoff collected at the outlet of the study watersheds.

On June 16, 2014, there was considerable runoff in the NW and SW during which time one sample was collected from the NW and the SW, while no runoff sample was collected from CW. Based on these events, the NW had higher nitrate concentration in runoff compared to SW, which could not be statistically tested due to limited number of data points. This was because in the NW, manure application was near the outlet of the watershed which led to more nitrate concentration in the runoff leaving the watersheds. In 2015 (Fig 4.10), nitrate concentration values were low for June 6 and 7, 2015 but the trend remained as expected with SW having the least nutrient loss compared to that of other watersheds. On June 19 and 20, nitrate concentrations were 10.5 and 43% lower in SW compared to that in NW, respectively, on these days, whereas, no runoff was collected from CW on these sampling days. On July 6, 2015, the trend remained similar with SW samples having lower (4 mg L^{-1}) concentrations compared to NW (5 mg L^{-1}) and CW (5 mg L^{-1}). Due to the limited number of samples collected from the CW prevented us from applying statistical method in order to know the significant differences in the nitrate concentration of the runoff samples. The nitrate load across the three watersheds and for the three years (2013, 2014 and 2015) has been shown in Fig 4.11. The load was statistically similar across the three watersheds and for all the three years of study. According to Chinkuyu et al. (2002), the nitrate nitrogen was higher in manured soils with high application amount than manured soil with low application and fertilizer applied soil. Similar trend was observed by these researchers for the phosphate loss. Zhang et al. (1996) reported that fertilizer application to soils lead to an increase in the nitrate nitrogen content in the drinking water (300 mg L^{-1}).

Ammonium Nitrogen: Manure is a rich source of ammonium nitrogen and organic nitrogen (Hooda et al., 2000). Runoff samples in this study were also tested for ammonium nitrogen. In 2013 (Fig 4.12), the trend was NW and CW had higher ammonium loss than the SW and the results were statistically different. Ammonia loss from NW was significantly higher than that of CW ($P<0.02$), while there was no statistically significant difference in ammonia loss between SW and CW ($P<0.99$). This can be explained by the fact that this was the third year of the experiment, and manure application near the outlet over the years gradually increased ammonium build up in that part. It may also be attributed to the fact that since manure rate was within to the crop need requirement but the rainfall that occurred during that year was less, compared to the previous years may have increased the concentration of ammonia in runoff samples. Thus, the combination of manure application near the outlet and reduced rainfall led to the increased concentrations of ammonia in samples collected from the NW. A similar trend was observed in the year 2014 (Fig 4.13) with the NW having higher concentrations than the SW but statistical analysis was not performed due to just one sampling event in 2014. In 2015 (Fig 4.14), ammonium loss was low, below 1 mg L^{-1} in all three watersheds. This may be attributed to the fact that manure application in 2015 occurred late March due to absence of the snow cover, leading to easy volatilization of ammonia. On June 6 and 7, 2015, the CW had the highest ammonia loss, while NW and SW were roughly the same throughout the year. The ammonium nitrogen load across the three watersheds has been shown in Fig 4.15 and no differences were observed across the three watersheds and for all the three years of study.

Total Kjeldahl Nitrogen (TKN): When runoff occurs it may carry nitrogen in organic form with it into the water bodies and cause water quality threats. The trend of TKN loss was similar to the other nutrients, however, in 2013 TKN was not significantly different between NW and CW ($P<0.04$), while it was statistically similar between SW and CW ($P<0.72$) (Fig. 4.16). The low TKN in SW may be due to manure treatment on the upper 50% terrain in this watershed and the distance or nutrients to travel to the outlet was more from the manure application point. The NW had higher concentrations because the manure treatment was on the lower 50% terrain, near the outlet. Thus, when runoff occurred, nutrients in manure were quickly carried to the outlet of the watershed impaired the water quality. The CW, which was the control and had higher concentration of TKN in the runoff samples. This may be because this watershed had no manure in it, therefore, the runoff was more and carried all the fertilizers with it. For the years 2014 (Fig 4.17) and 2015 (Fig 4.18), trend in TKN coincided with that of previous years but there were limited number of sampling events in the CW, and statistical analysis was not performed. The Kjeldahl nitrogen load across the three watersheds has been shown in Fig 4.19. No statistical difference was observed across the three watersheds and the three years of study.

Total dissolved phosphorus: Phosphorus loss from the watersheds were measured as total dissolved phosphorus (TDP) which contains all soluble organic and inorganic forms of phosphorus present in the water sample after filtering. As expected, the TDP was lower in SW and the trend was the same for all the three watersheds. In 2013 (Fig 4.20), the TDP loss from the watersheds showed no statistical differences observed between SW and CW ($P<0.99$) but TDP from NW was statistically higher than from CW

(P<0.04). Again, this may be due to the combination of reduced rainfall and manure application near the outlet in the NW. However, for 2014 (Fig 4.21) and 2015 (Fig 4.22), the trend was similar to the previous years' trends with SW samples having the least concentration of TDP. Statistical analysis was not performed for these years due to the limited number of sampling events. Vadas et al. (2004), concluded the similar findings. The dissolved phosphorus load has been shown in Fig 4.23 and no statistical differences were observed across the three watersheds.

Total Phosphorus: The total phosphorus concentration in the surface runoff samples were followed a similar trend as the other nutrients. Surface runoff samples collected from the NW had a higher phosphorus loss than the CW (P<0.035) and no differences were observed between the SW and CW (P<0.93). SW water samples had the least phosphorus content as compared to the other two watersheds. On March 9, 2013 (Fig 4.24), the phosphorus loss was low as compared to the other days of sample collection. As we move ahead, we see there is an increase in the phosphorus loss from all the watersheds. This may be due to thawing of snow taking place as we move ahead. There were no significant differences observed between the samples of SW and CW while NW samples had significantly high concentration of TP than CW. In 2014 (Fig 4.25), just one sampling event took place in which no sample was collected from the CW. This may be due to topography of the CW. However, the total phosphorus loss from the NW and the CW, there was not much difference. We could not test the values statistically due to less number of data points in the whole year. Again, in 2015 (Fig 4.26), it was observed that NW water samples had higher phosphorus content as compared to the SW and CW. This may be again to the fact that manure application in NW near the outlet led to a higher loss of phosphorus. Again, we could not test the values statistically due to less number of data points available. Sharpley et al. (1994) reported that addition of manure to soils may lead to an increase in the phosphorus loss into the streams, thus, management of agricultural phosphorus is very important so as to reduce the loss into the streams and reduce the environmental concern that would arise as a result of phosphorus accumulation in the water. The total phosphorus load has been shown in Fig 4.27. No statistical difference was observed across the three watersheds.

Total Suspended Solids: TSS content in the surface runoff samples followed the same trend as that of the other nutrients with the NW being the highest among the three watersheds. In 2013 (Fig 4.28), the samples were collected during march. On march 9, 2013, it was observed that TSS loss from the three watershed was the least as compared to the other days of sample collection. As we move forward, it was observed that TSS increased which may due to thawing which made the soil loose and susceptible to move. The trend for TSS showed that NW samples were significantly higher than the CW which may be due to the shape and slope of the CW, while there was no significant difference between SW and CW. In 2014 (Fig 4.29), only one sample was collected but SW samples showed an increase in the TSS as compared to NW (no sample collected from CW). This may be due to larger area of SW than NW. The effect of rainfall or precipitation could not be taken into account as 2014 was the driest period of the study. We could not test the data for statistical significance due to an insufficient number of data points. In 2015 (Fig 4.30), again NW samples showed highest loss of TSS than the SW and CW. CW samples had comparatively lower TSS content due to the topography of the CW. CW is a long and kind of a flat watershed which may stop the sediments from moving to the outlet.

Another reason may be due to the sowing pattern in CW as the planting was done across the slope near the outlet which formed kind of a terrace and helped in trapping the sediments. The higher TSS in NW and SW was due to the very high intensity and frequent rainfall events. In addition to the topography of the watershed also helped in movement of sediments towards the outlet. It was observed that in 2013, when the samples were all collected during March, the TSS was lower as compared to 2014 and 2015, due to snowmelt while in 2014 and 2015 the samples were collected during June and July. In June and July, runoff occurred as a result of rainfall events which can accelerate erosion due to its impacts on the bare soil. Vegetation can reduce this impact but not completely. Thus, in 2014 and 2015, the TSS values were higher as compared to 2013. The sediment load across the three watersheds has been shown in Fig 4.31 and no differences were observed across the three watersheds.

4.4. Soil erosion estimation using RUSLE

As mentioned in the materials and methods section, soil erosion can be determined using the RUSLE equation in the RUSLE2 model. The six factor (R, K, L, S, C and P) were determined using the methods described before. The calculated factors have been shown in Table 4.4. It was observed that the R factor remained same for all the watersheds due to the small size of the watersheds which helped the rainfall to be similar among all of them. The K factor was also roughly the same due to similar soil texture throughout the watersheds. The LS factor was the most important part of the equation as it was highly variable among the three watersheds. It was observed that the north downslope having a higher LS factor contributed more to the soil loss even though it was treated with manure. This is coherent with our findings of the total suspended solids in the runoff water. Similarly, south upslope having a lower LS factor contributed less to the soil erosion. This shows that soil erosion was greatly impacted by the topography of the watersheds. Since CW did not have any treatment, we calculated the erosion for the whole watershed together. It was seen that LS factor was quite high but that was for the entire watershed and when you see the watershed physically, it is a long watershed and looks to be flat due to the which the soil loss was not that high. In 2015, the crop was soybean and using the land use map and the RUSLE guide tables, the soybean crop C factor came out to be 0.39 and soybean with manure was 0.34. The P factor was unity for all the watersheds as no support practices were applied to the watersheds.

The estimated soil erosion results are shown in Figure 4.32 and 4.33. It was seen that for the NW, north upslope had lower soil loss as compared to the north downslope due to the lower LS factor. For the SW, south upslope showed lower soil loss as compared to south downslope due to lower LS factor. Thus, it can be concluded that for this study, LS factor played a major role in determining the soil loss across the watersheds.

After creating the scenarios for the model like applying an increased residue cover on the fields and terracing the watersheds, it was observed that as the residue cover increased it led to a huge decrease in the soil erosion. After applying 20% residue cover (Figure 4.34), it was seen that the soil erosion decreased by 44 – 50 % across all the landscape positions. Again after applying 40% residue cover, the soil erosion further decreased over a range of 54 – 64 % in all the watersheds. Thus, it can be concluded that application of residue cover on the soil surface will help in decreasing the soil erosion as they will trap and sediments and prevent them from running into the streams. Another support practice was added to the watersheds (terracing) and the soil erosion was reduced (Figure 4.35) to half of the original estimated erosion as the P factor got reduced to 0.5 after the application of terracing. After seeing all the results, it can be concluded that application of conservation and support practices may be helpful in reducing the soil erosion in the watersheds.

Table 4.1. Soil chemical properties measured at upslope and downslope landscape positions of North, South, and East (Control) Watersheds from depth 0 – 10 cm in 2015.

Landscape positions		pH	Electrical Conductivity	Soil Organic Carbon	Available P	Total N
			---μS cm^{-1}---	---g kg^{-1}---	---mg kg^{-1}---	---g kg^{-1}---
North	Upslope (No Manure)	5.8[a†]	192.6[a]	17.1[b]	4.08[b]	2.00[a]
	Downslope (Manure)	6.3[a]	222.8[a]	24.4[a]	6.58[a]	2.40[a]
South	Upslope (Manure)	5.4[a]	321.8[a]	20.3[a]	3.93[a]	2.50[a]
	Downslope (No Manure)	5.1[a]	253.5[a]	14.8[b]	3.29[a]	2.00[b]
East	Upslope (No Manure)	4.7[a]	124.6[a]	9.00[a]	0.82[b]	1.70[a]
	Downslope (No Manure)	4.8[a]	155.1[a]	9.50[a]	2.60[a]	1.70[a]

[†]Similar letters indicate that there was no significant difference observed between the different landscape positions within the same watershed.

Table 4.2. Soil chemical properties measured at upslope and downslope landscape positions of North, South, and East (Control) Watersheds from depth 10 – 20 cm in 2015.

Landscape positions		pH	Electrical Conductivity	SOC†	Available P	Total N
			---µS cm⁻¹---	---g kg⁻¹---	---mg kg⁻¹---	---g kg⁻¹---
North	Upslope (No Manure)	6.5[a]	154.1[a]	6.85[b]	2.5[b]	1.4[a]
	Downslope (Manure)	6.8[a]	191.9[a]	12.0[a]	3.8[a]	1.5[a]
South	Upslope (Manure)	6.3[a]	229.5[a]	15.4[a]	3.2[a]	1.8[a]
	Downslope (No Manure)	5.7[a]	162.6[a]	14.6[a]	2.3[a]	1.6[a]
East	Upslope (No Manure)	5.3[a]	94.40[a]	4.11[a]	0.5[a]	1.0[a]
	Downslope (No Manure)	5.3[a]	133.3[a]	5.97[a]	0.7[a]	1.3[a]

†Similar letters indicate that there was no significant difference observed between the different landscape positions within the same watershed.

Table 4.3. Soil infiltration rates measured at upslope and downslope landscape positions of North, South, and East (Control) Watersheds in 2015.

Landscape positions		Infiltration Rate
		---mm hr^{-1}---
North	Upslope (No Manure)	144.4[b†]
	Downslope (Manure)	165.3[a]
South	Upslope (Manure)	195.5[a]
	Downslope (No Manure)	181.1[a]
East	Upslope (No Manure)	139.6[a]
	Downslope (No Manure)	144.8[a]
Slope	Upslope	159.8[a]
	Downslope	163.7[a]

†Similar letters indicate that there was no significant difference observed between the different landscape positions within the same watershed.

Table 4.4. The R, K, LS, C, P factors calculated for each watershed and the landscape positions.

Watershed	Treatment	R Factor	K Factor	LS Factor	C Factor	P Factor
North	Upslope	100	0.26	0.81	0.39	1
	Downlsope	100	0.26	1.23	0.34	1
South	Upslope	100	0.26	0.47	0.34	1
	Downslope	100	0.26	0.99	0.39	1
East	Upslope	100	0.26	0.45	0.39	1
	Downslope	100	0.26	0.60	0.39	1

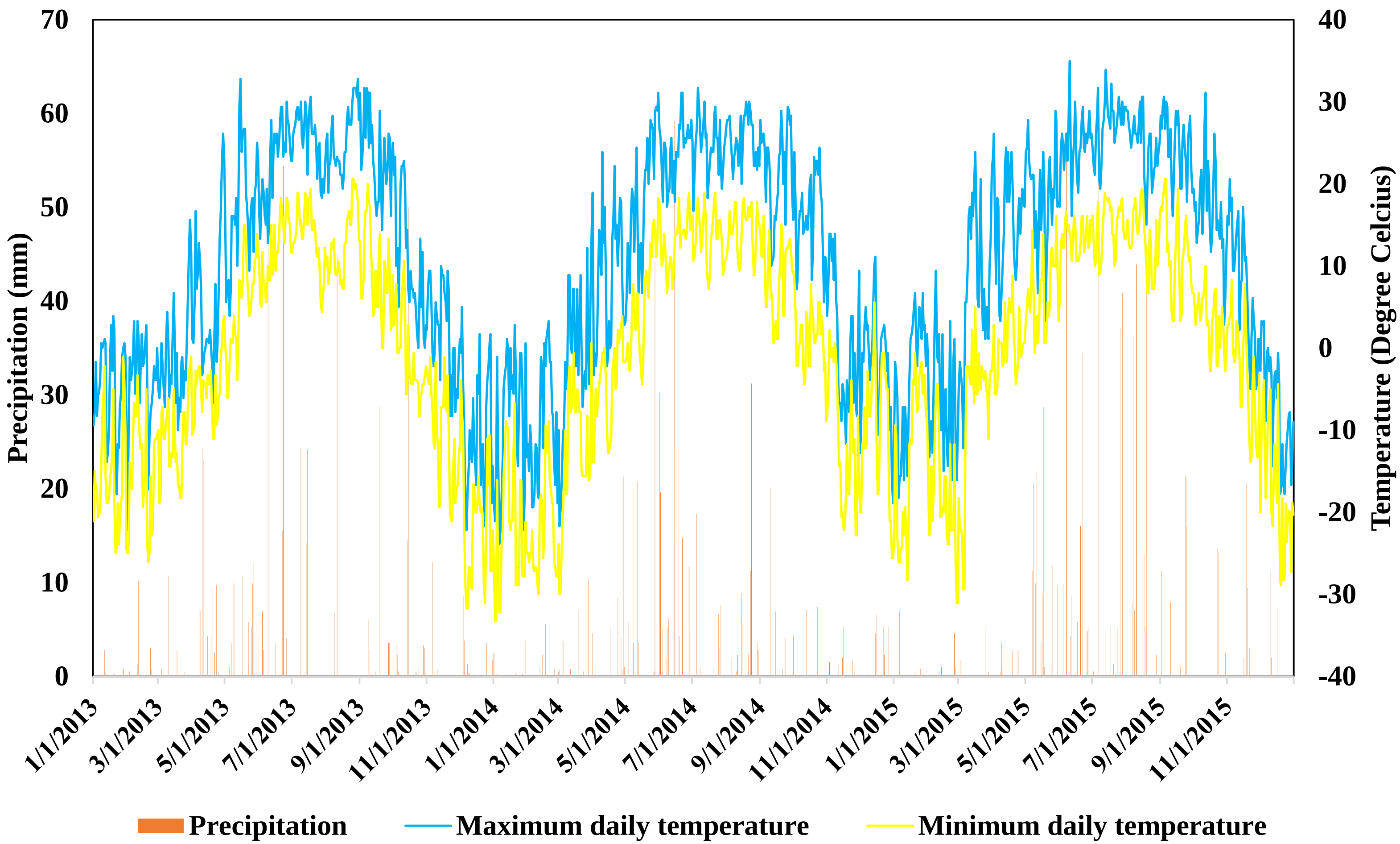

Figure 4.1 The climatogram for the study area for 2012-2015

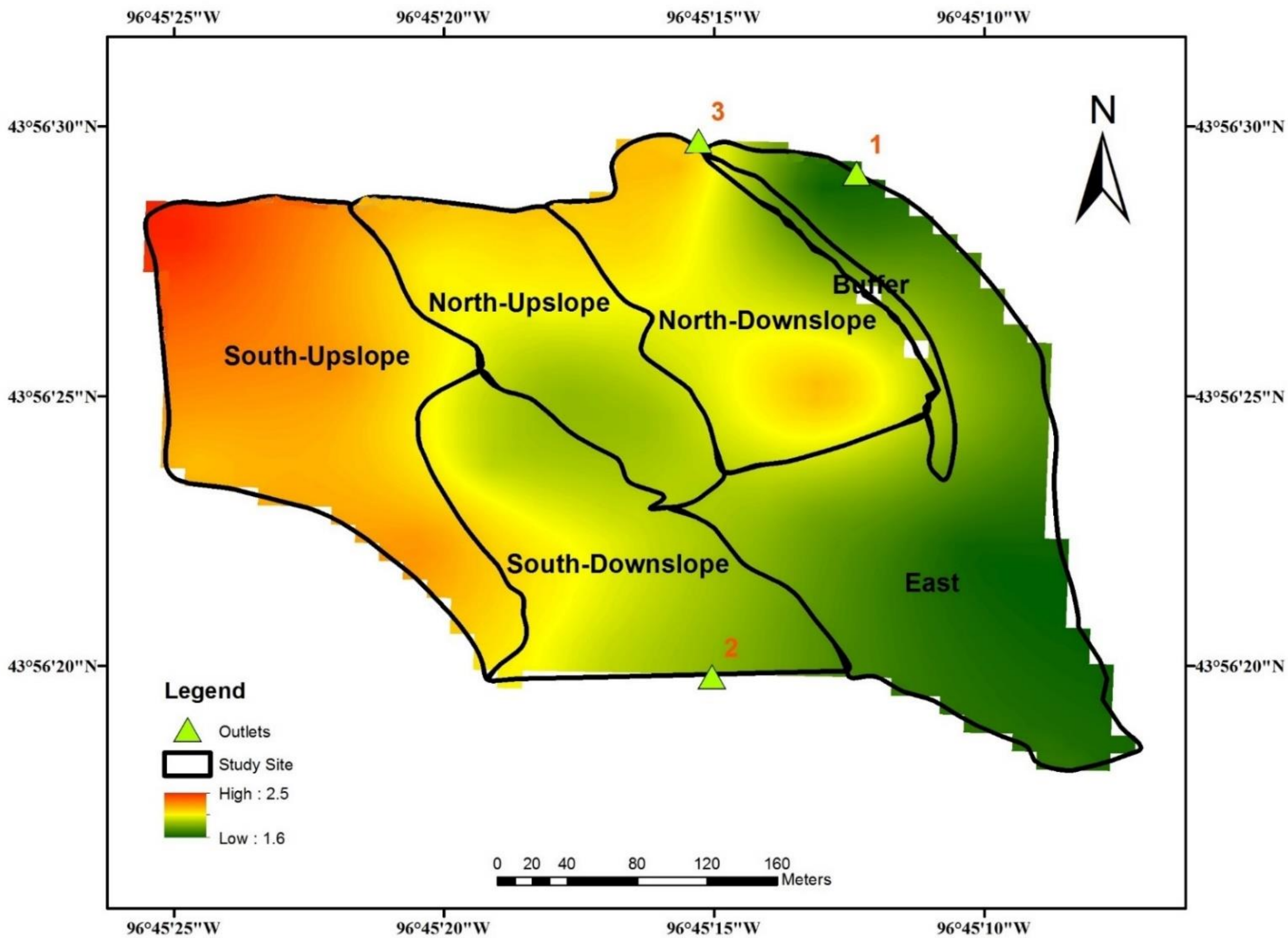

Figure 4.2 Spatial distribution of total nitrogen across the three watersheds

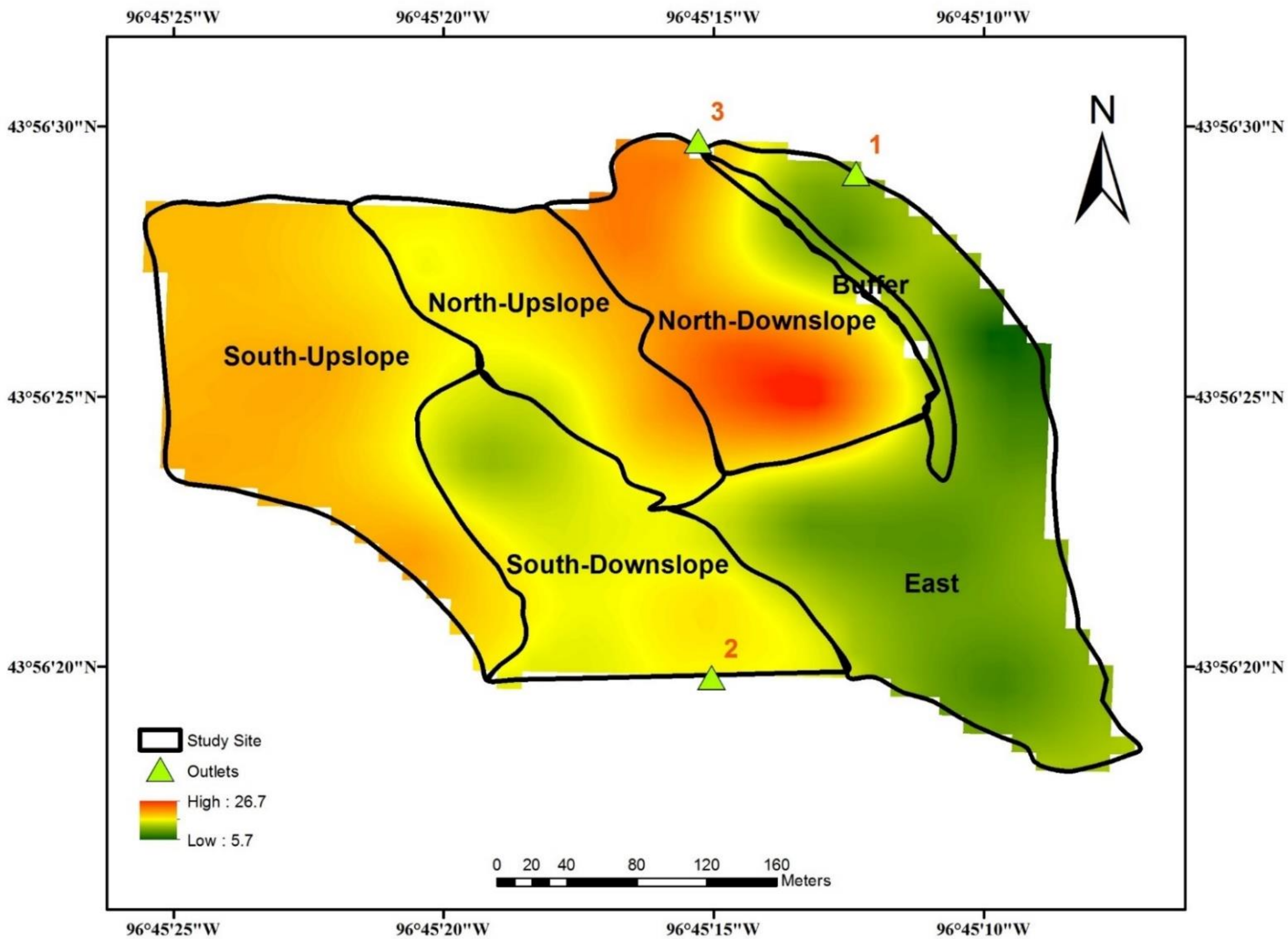

Figure 4.3 Spatial distribution of soil organic carbon across the three watersheds

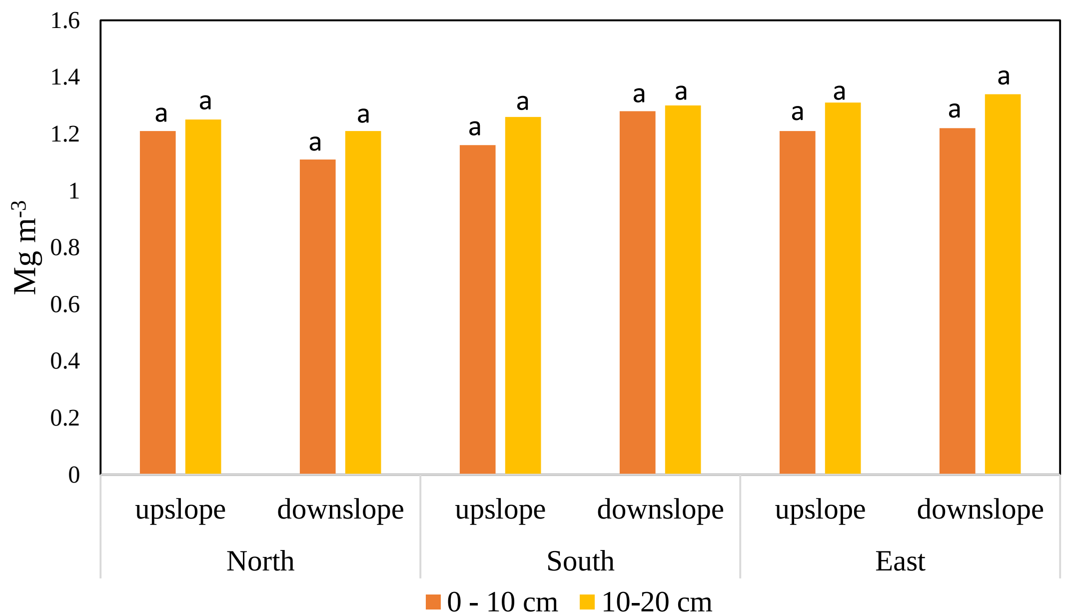

Figure 4.4 Soil bulk density measured at upslope and downslope landscape positions of North, South, and East (Control) Watersheds in 2015.

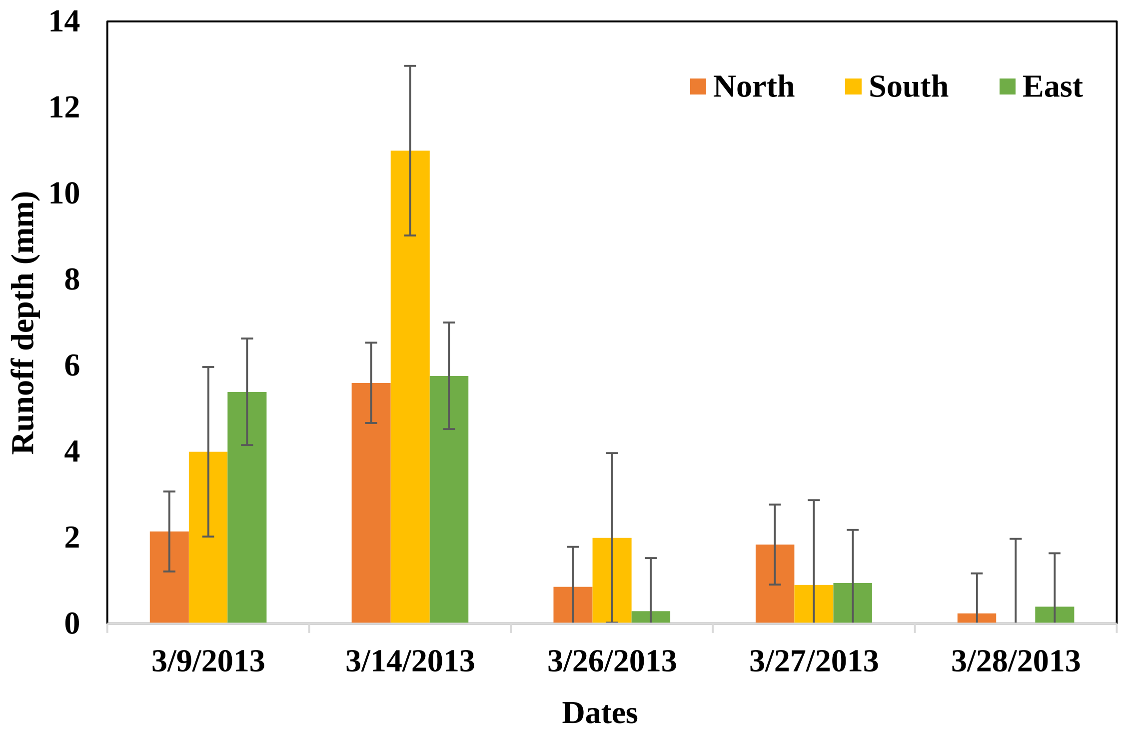

Figure 4.5 Runoff depths (mm) measured from the three watersheds during the storm events in 2013.

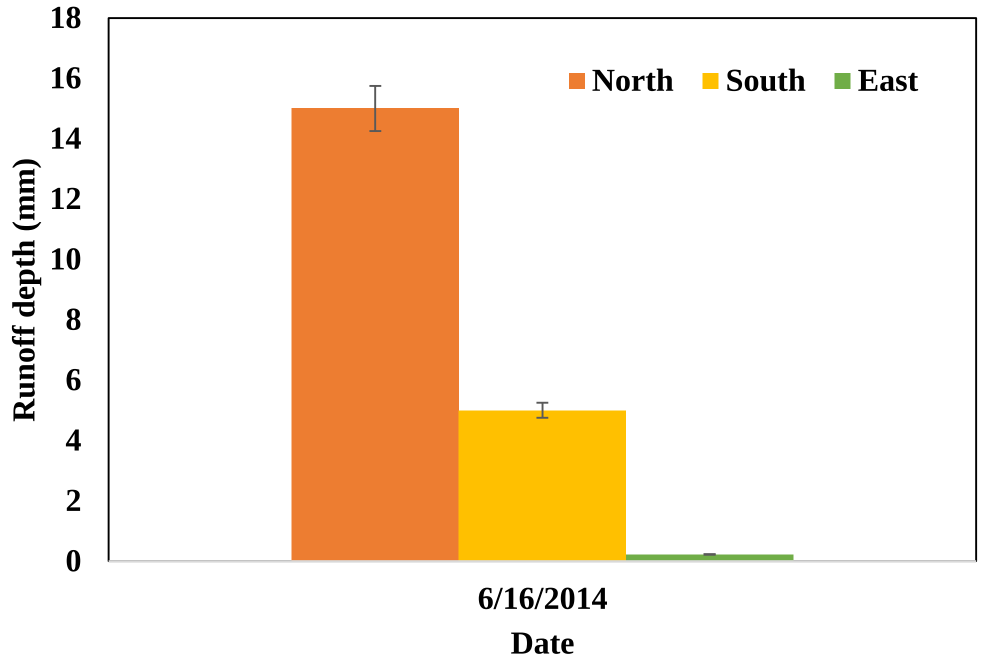

Fig 4.6 Runoff depths (mm) measured from the three watersheds during the storm event in 2014.

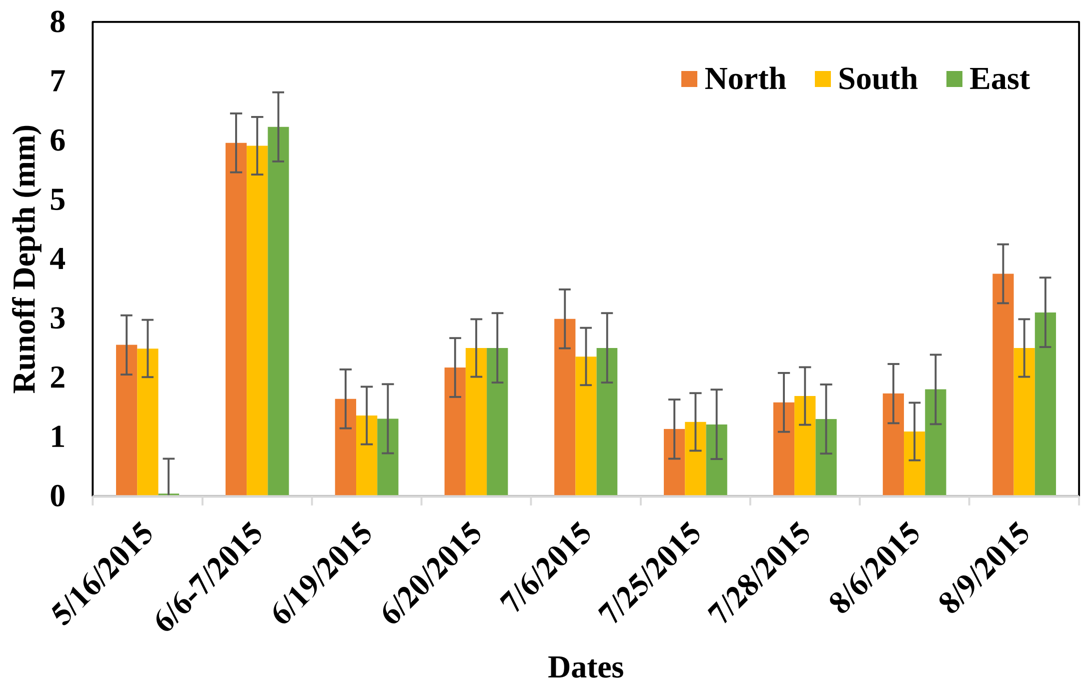

Fig 4.7 Runoff depths (mm) measured from the three watersheds during the storm events in 2015.

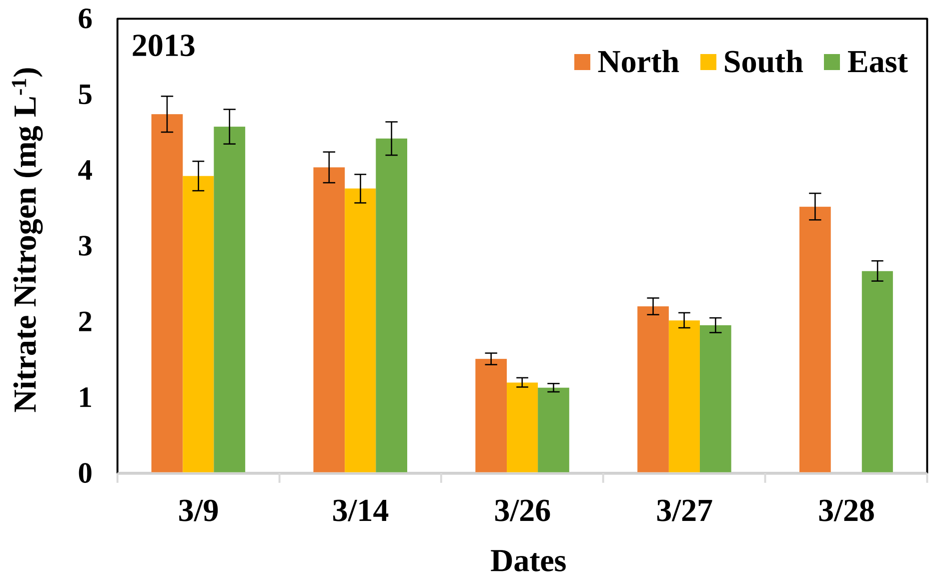

Figure 4.8 Nitrate nitrogen content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2013.

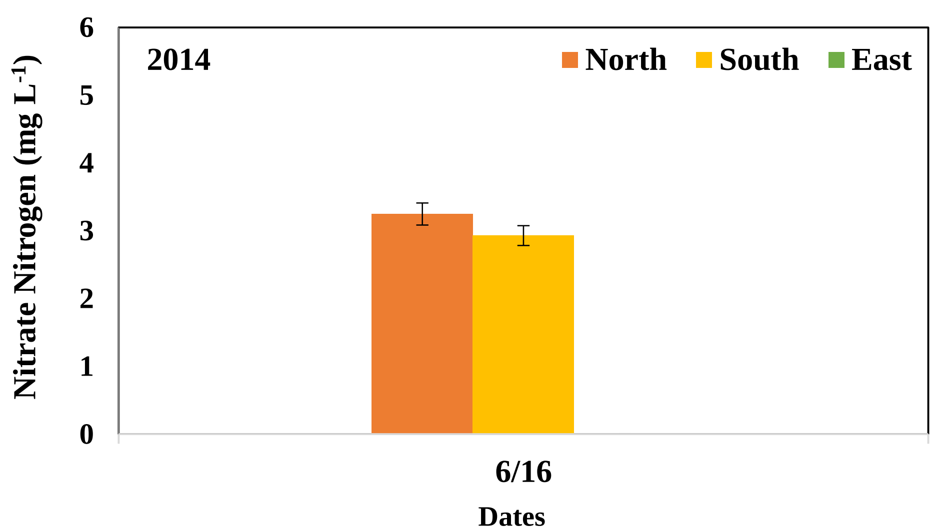

Figure 4.9 Nitrate nitrogen content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2014.

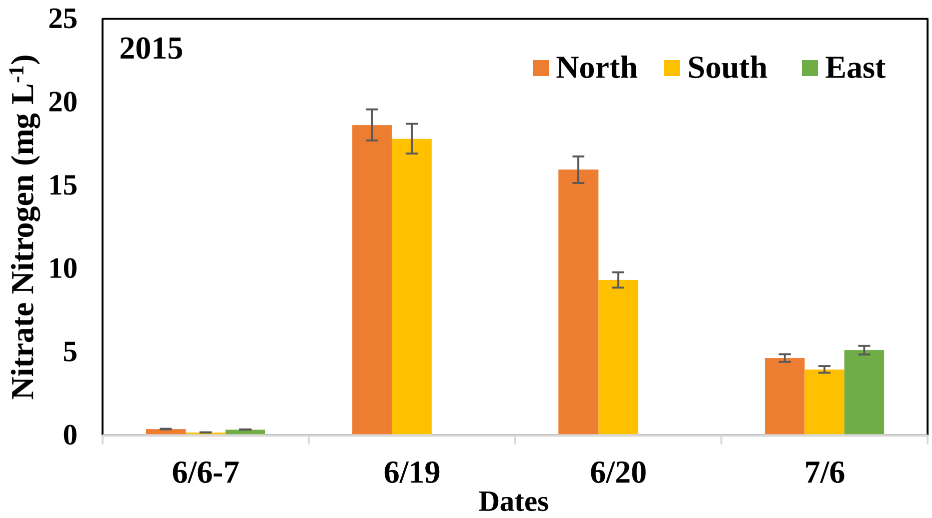

Figure 4.10 Nitrate nitrogen content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2015.

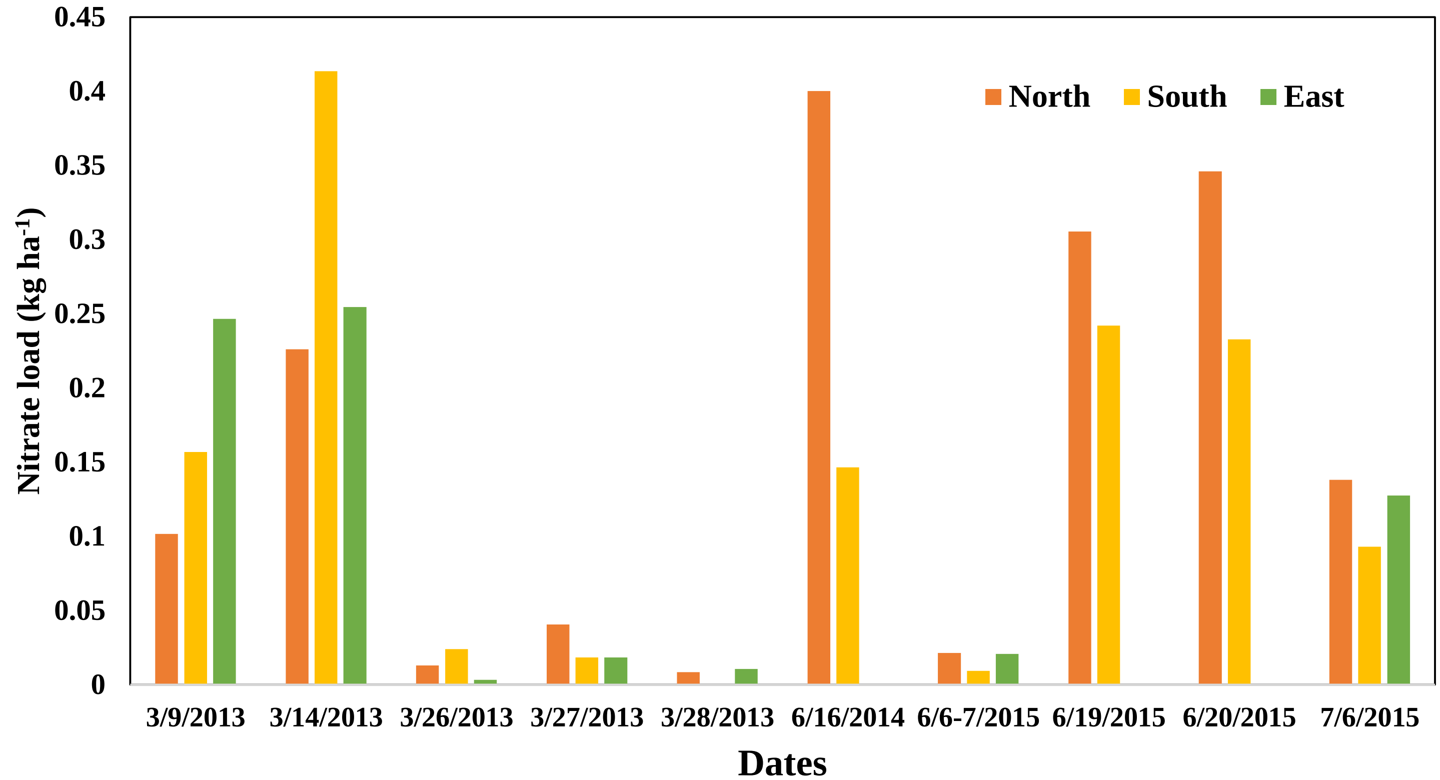

Figure 4.11 Nitrate nitrogen load (kg ha^{-1}) from the surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the years 2013-2015.

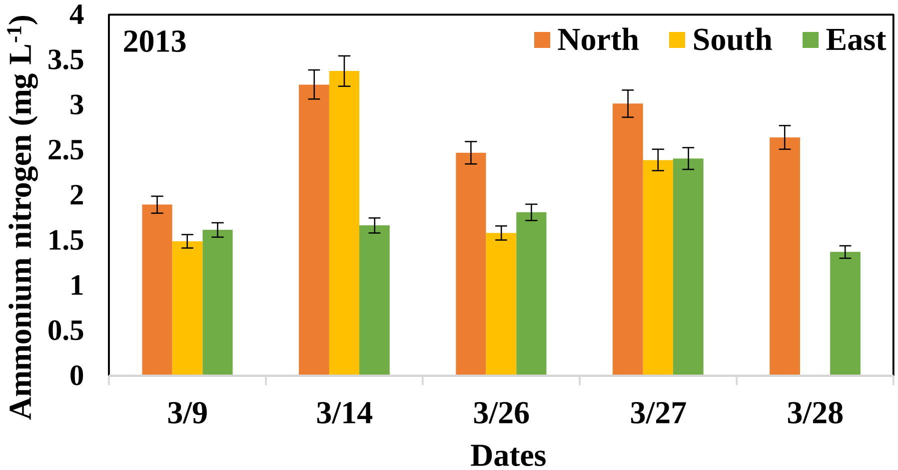

Figure 4.12 Ammonium nitrogen content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2013.

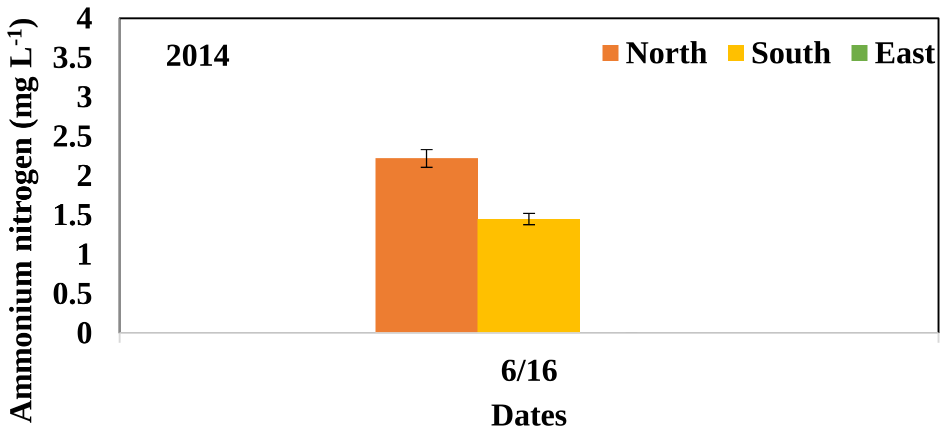

Figure 4.13 Ammonium nitrogen content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2014.

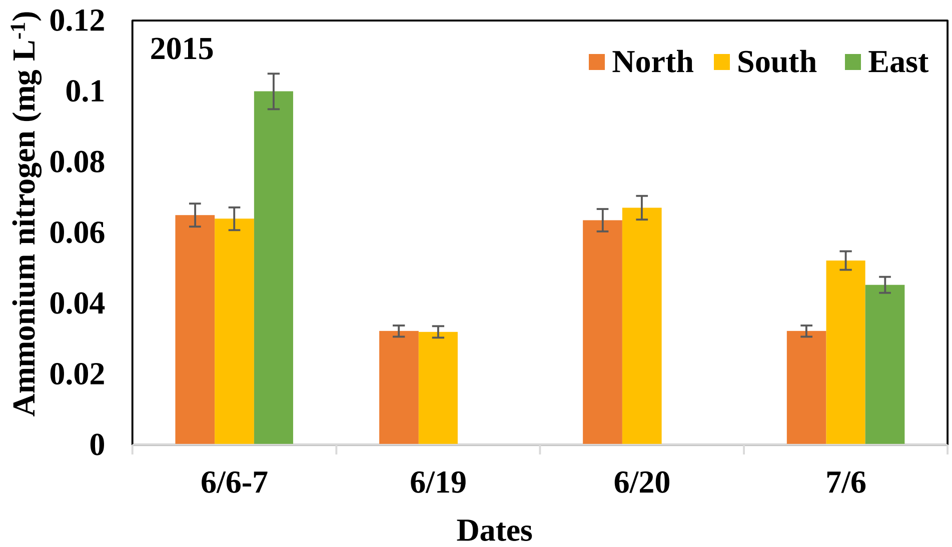

Figure 4.14 Ammonium nitrogen content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the years 2015.

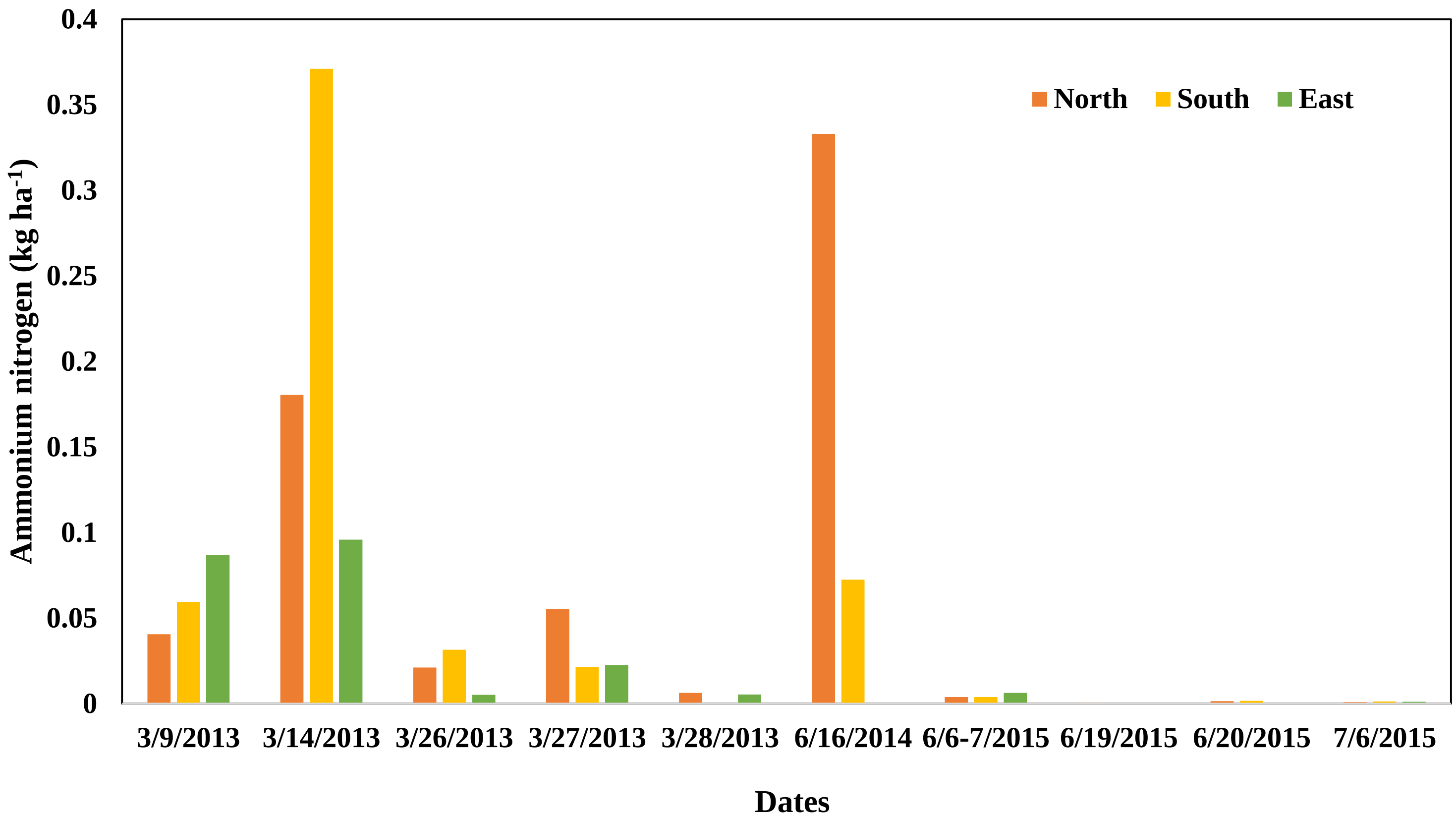

Figure 4.15 Ammonium nitrogen load (kg ha^{-1}) from the surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the years 2013-2015.

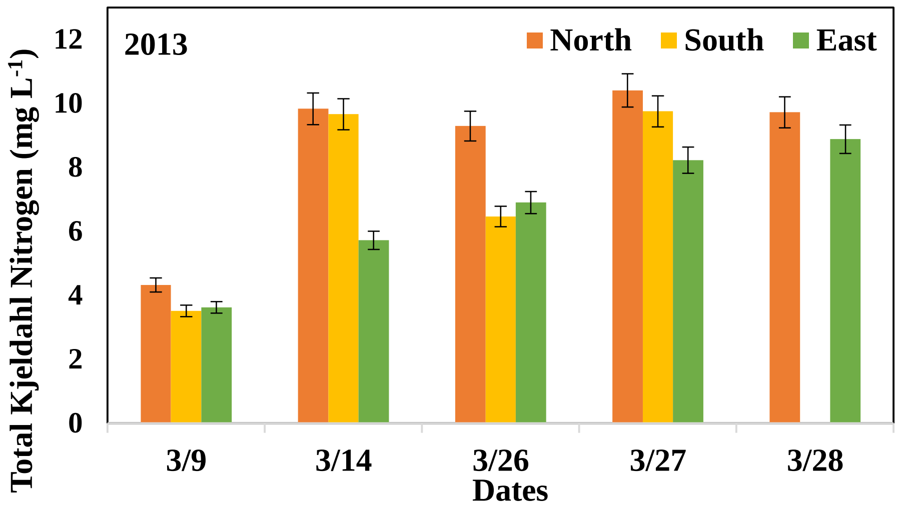

Figure 4.16 Total Kjeldahl nitrogen content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2013.

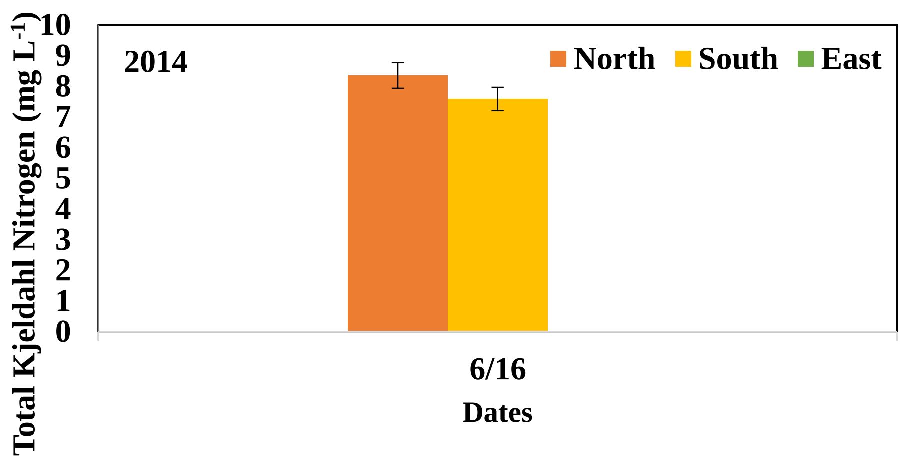

Figure 4.17 Total Kjeldahl nitrogen content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2014.

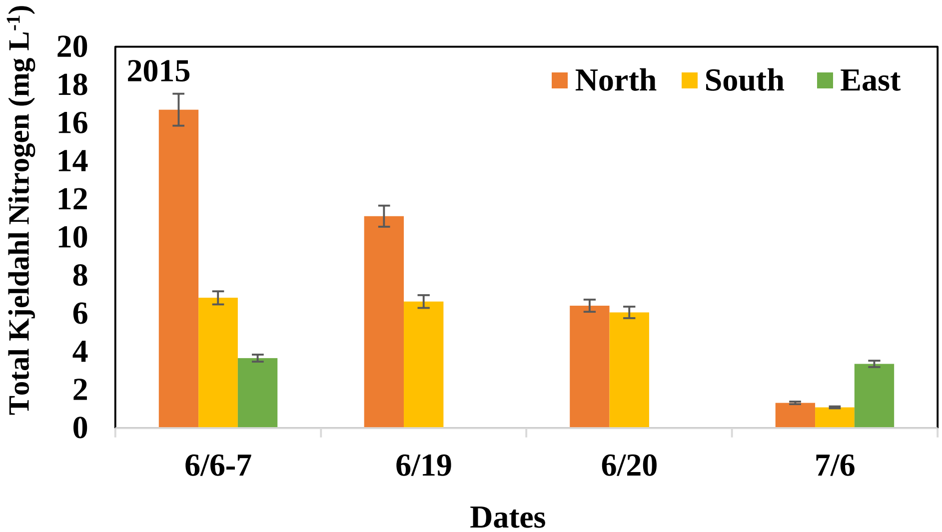

Figure 4.18 Total Kjeldahl nitrogen content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2013.

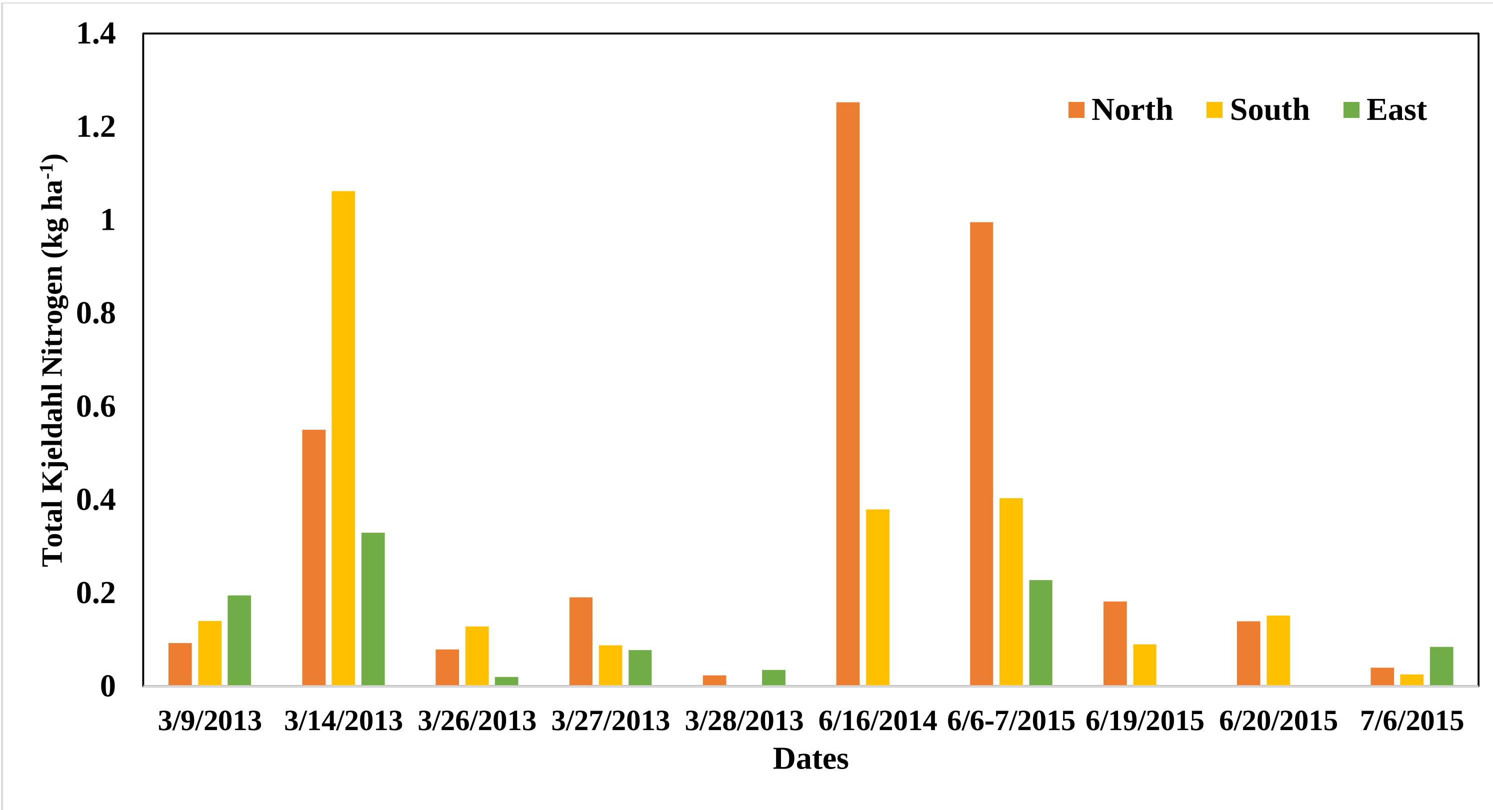

Figure 4.19 Total Kjeldahl nitrogen load (kg ha^{-1}) from the surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the years 2013-2015.

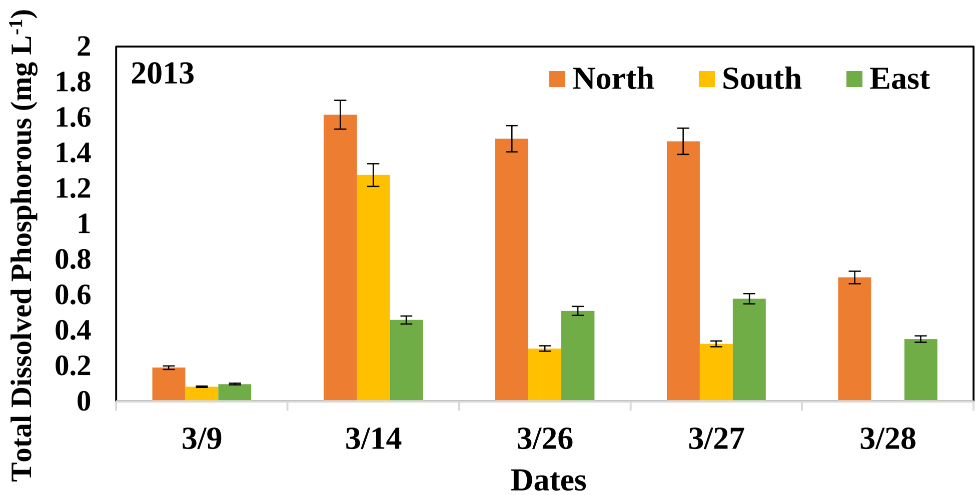

Figure 4.20 Total dissolved phosphorus content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2013.

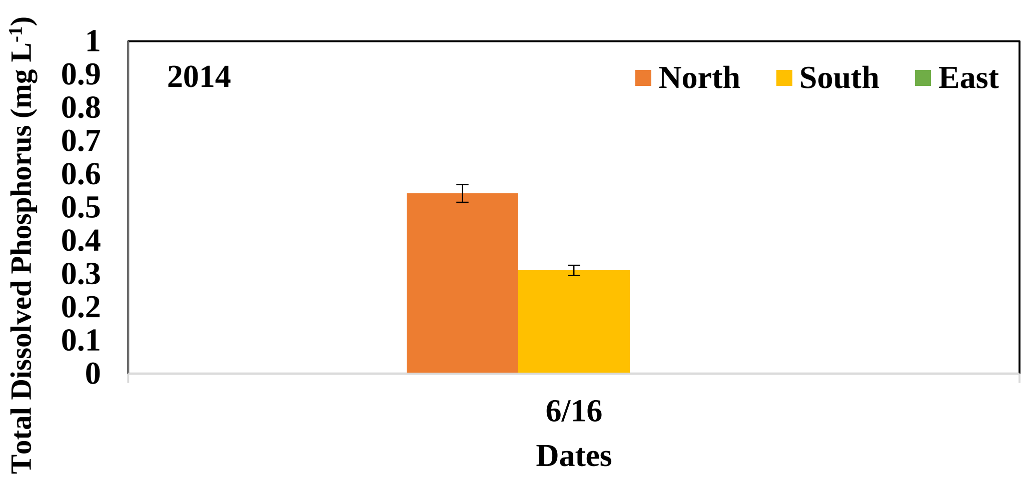

Figure 4.21 Total dissolved phosphorus content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2014.

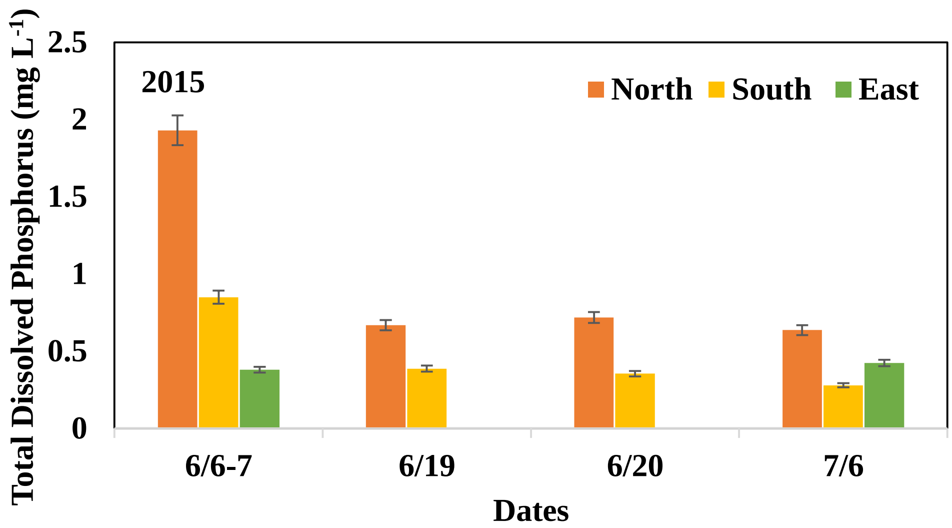

Figure 4.22 Total dissolved phosphorus content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2015.

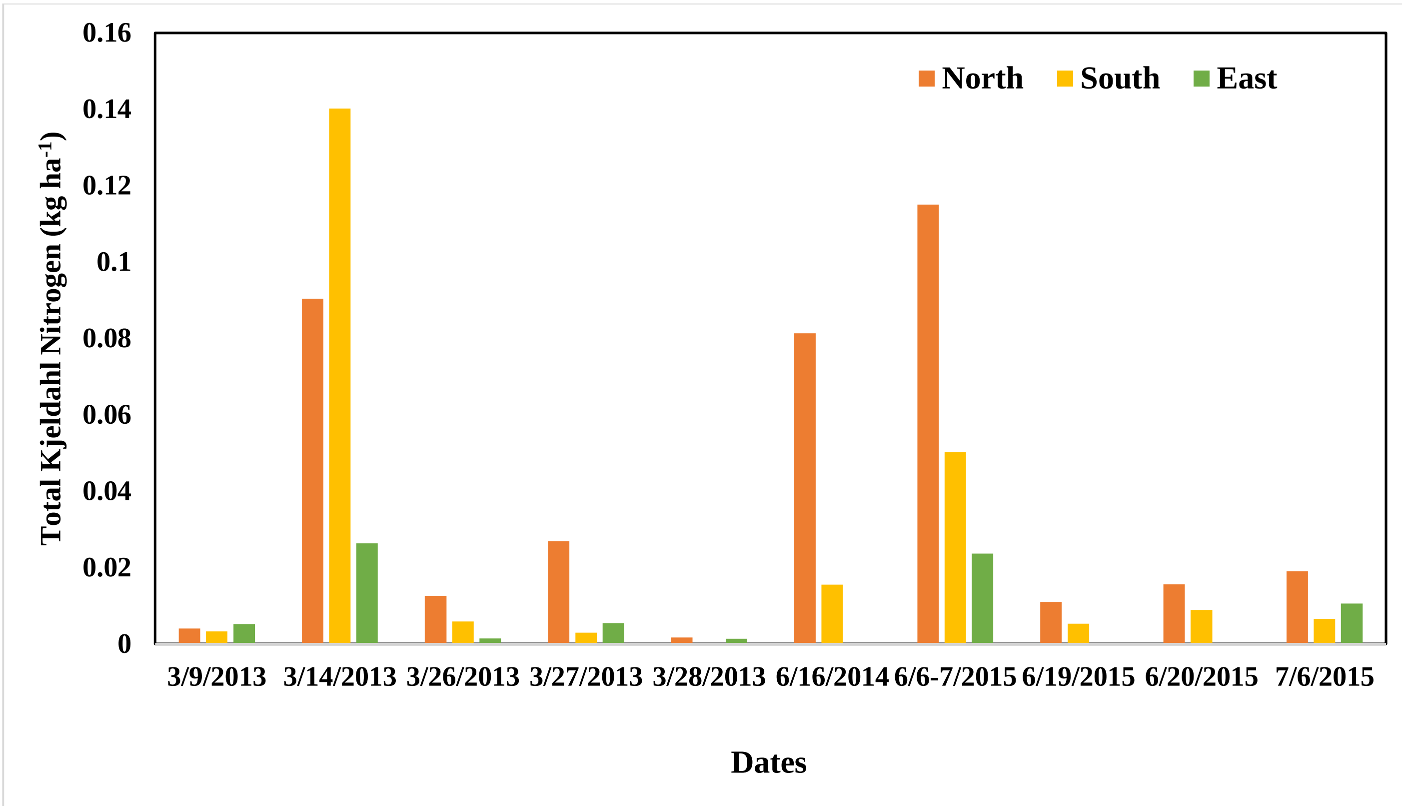

Figure 4.23 Total dissolved phosphorus load (kg ha^{-1}) from the surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the years 2013-2015.

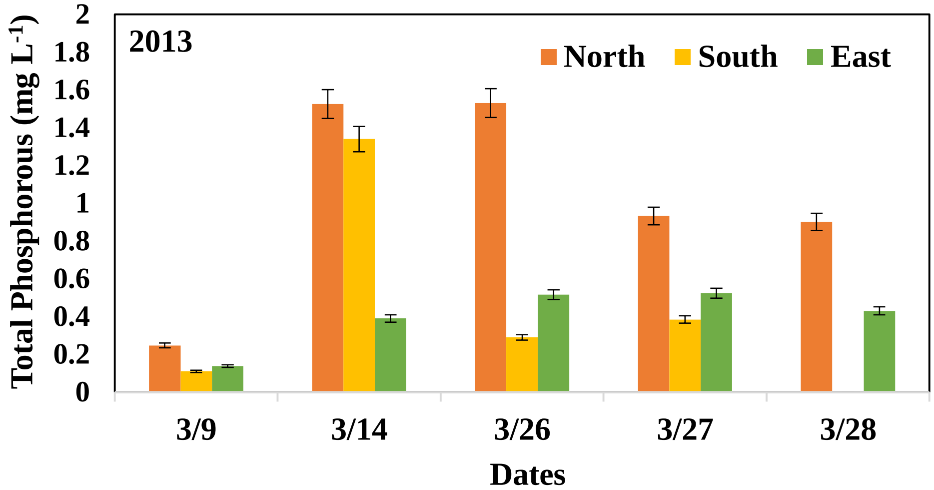

Figure 4.24 Total phosphorus content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2013.

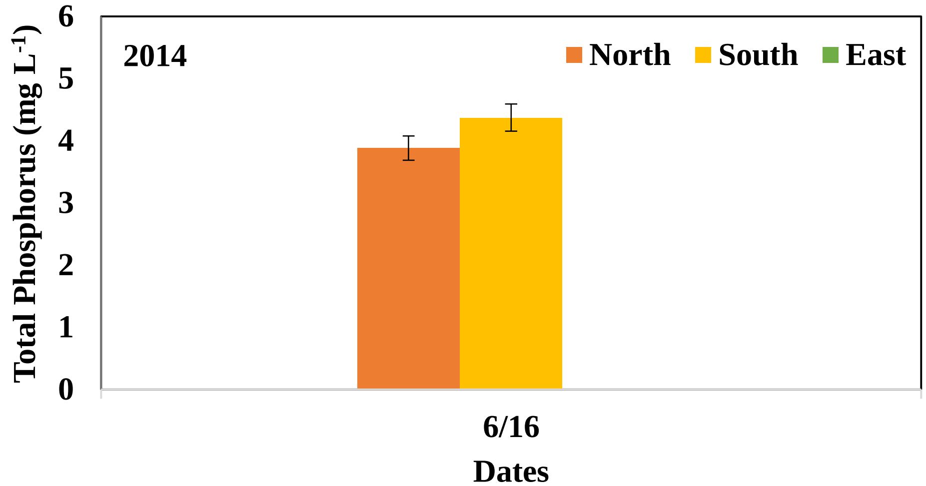

Figure 4.25 Total phosphorus content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at

downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2014.

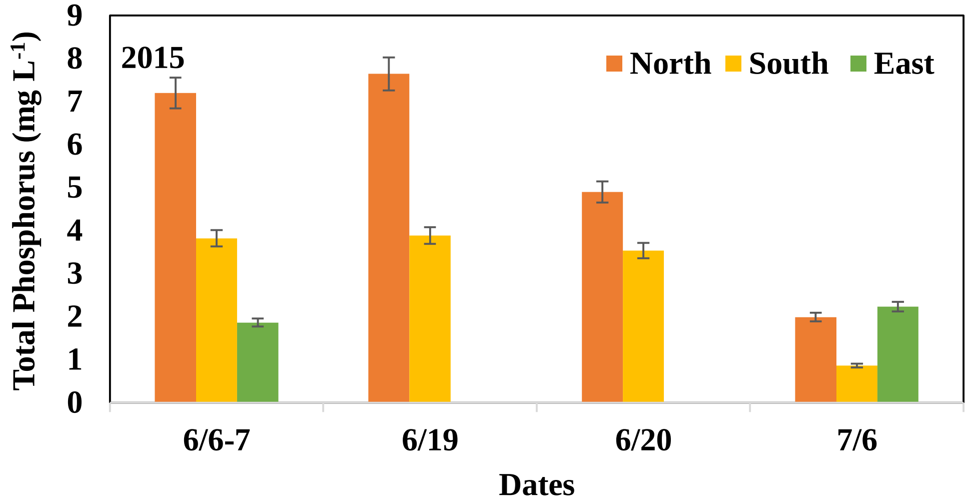

Figure 4.26 Total phosphorus content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2015.

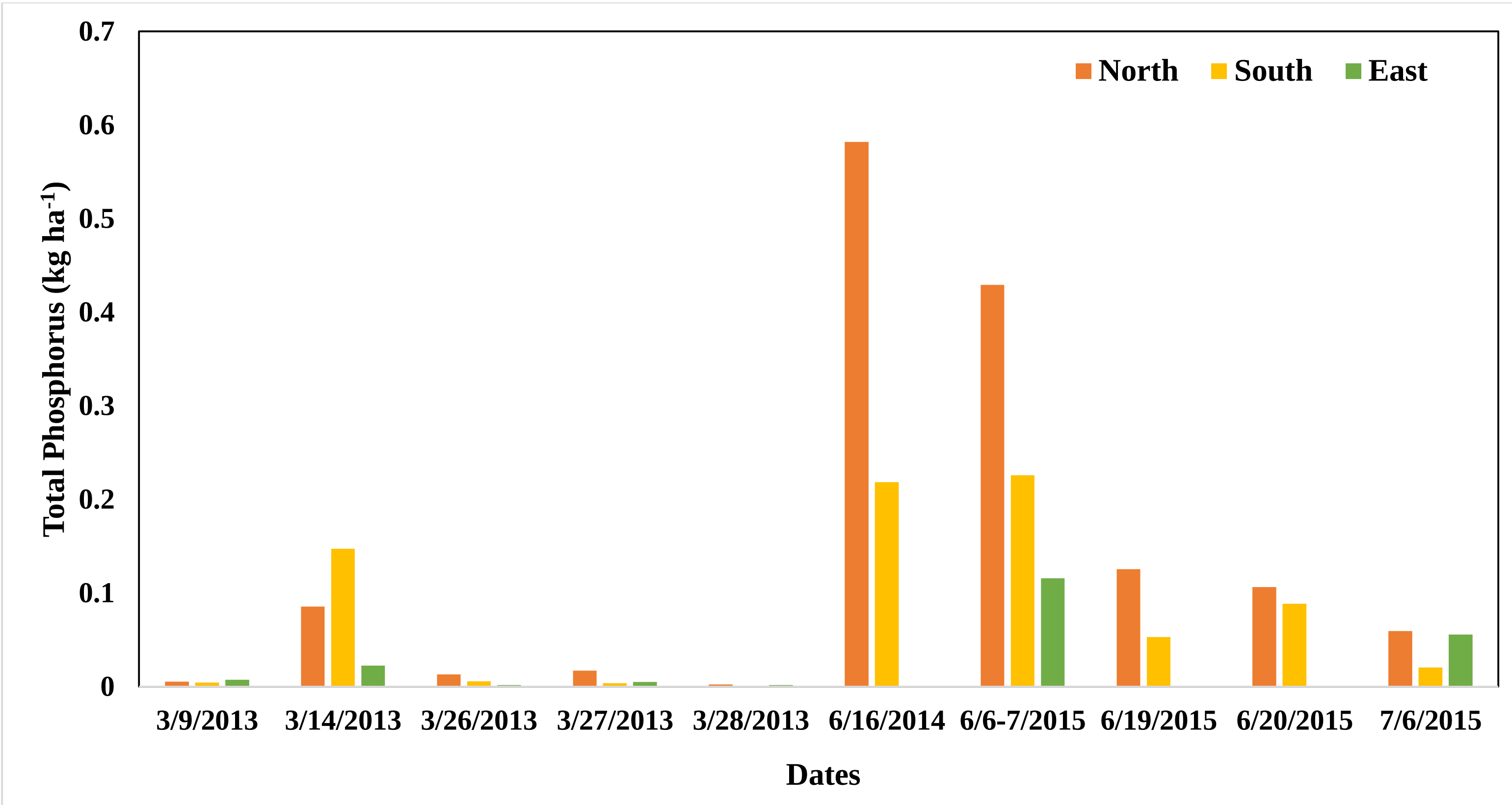

Figure 4.27 Total phosphorus load (kg ha^{-1}) from the surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the years 2013-2015.

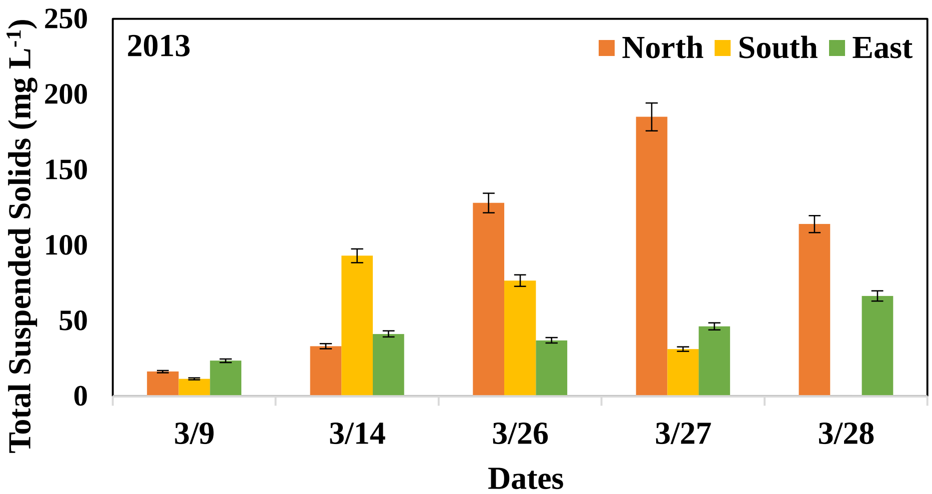

Figure 4.28 Total suspended solids content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2013.

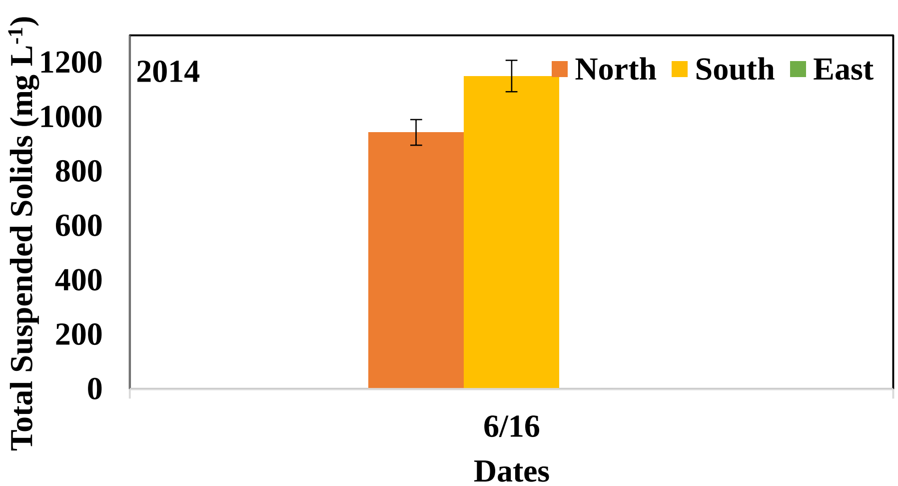

Figure 4.29 Total suspended solids content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south

and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2014.

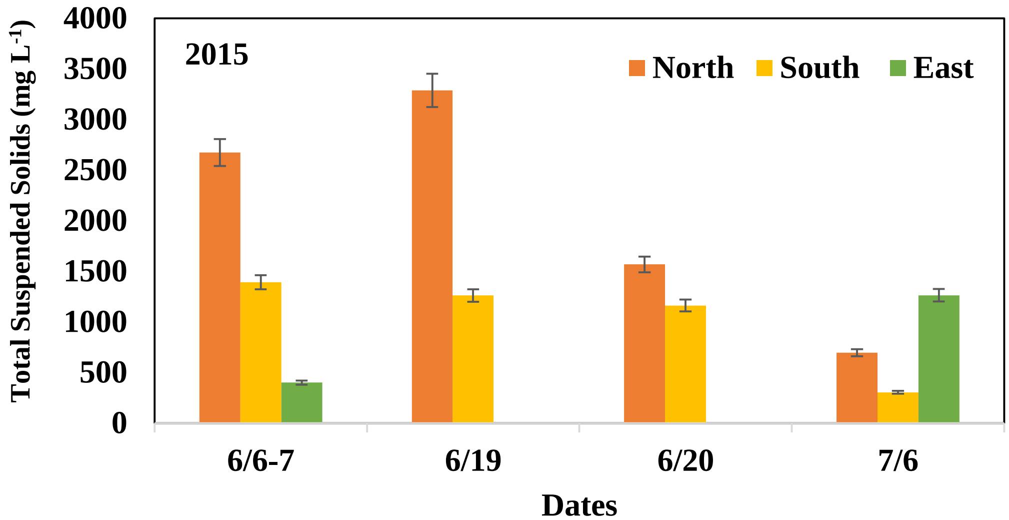

Figure 4.30 Total suspended solids content in surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the year 2015.

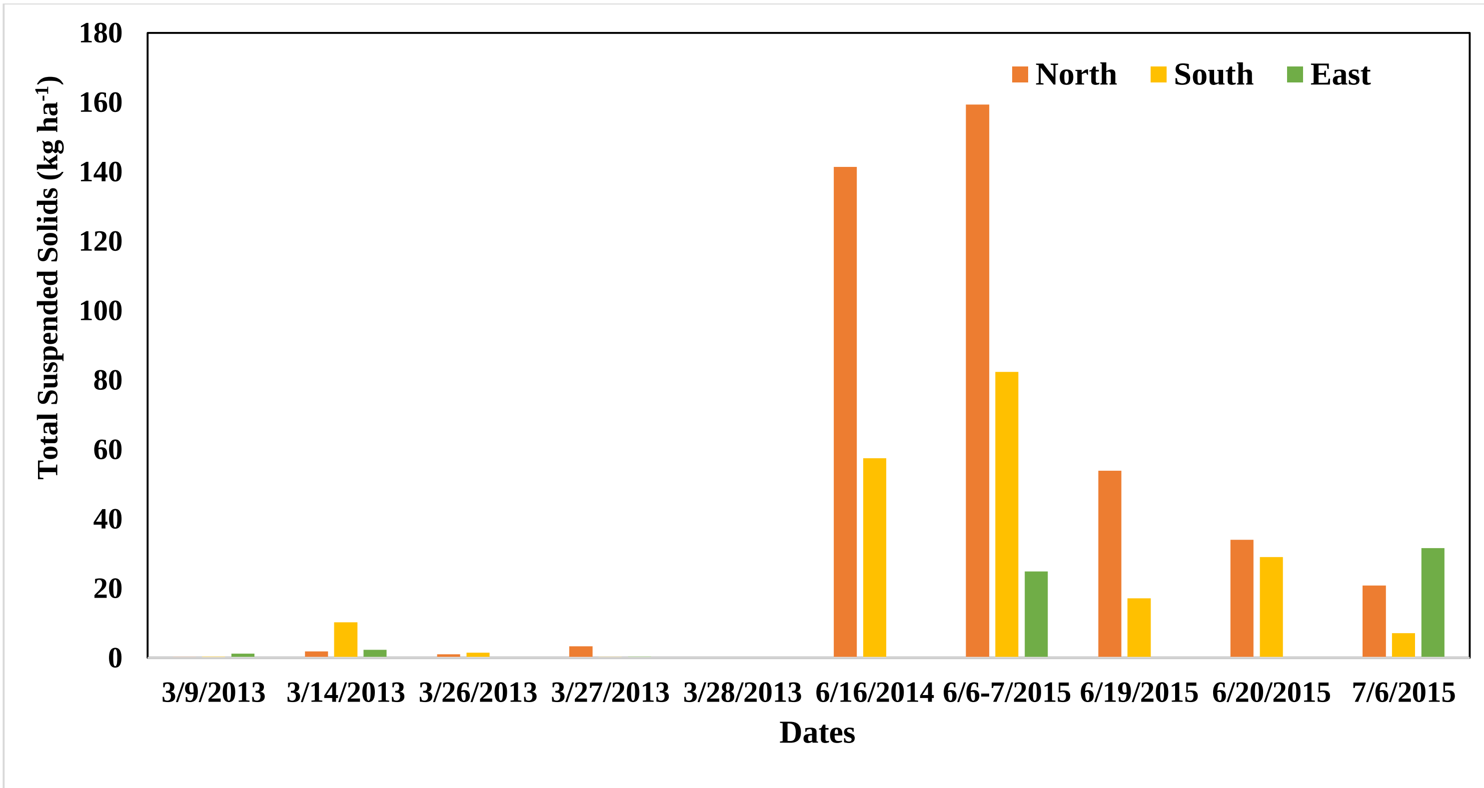

Figure 4.31 Total suspended solids load (kg ha^{-1}) from the surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at upslope in south and at downslope in north watershed) and managed without manure [i.e. control (east)] for the years 2013-2015.

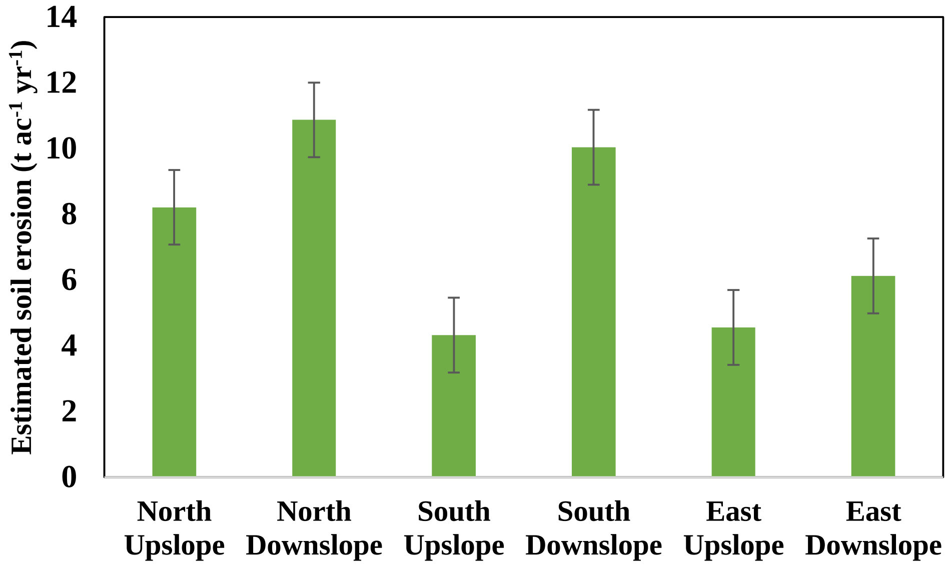

Figure 4.32 The estimated soil loss from the landscape positions of the watersheds.

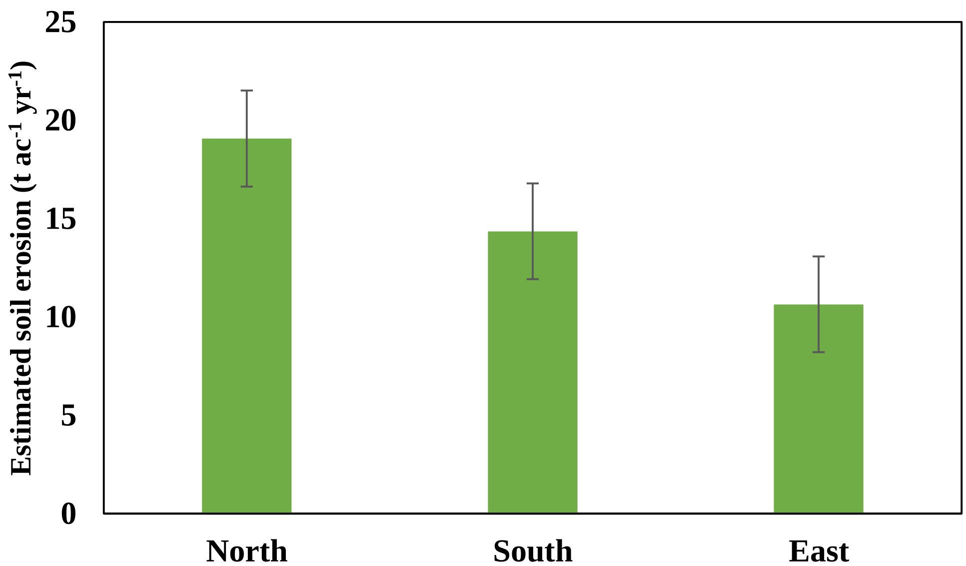

Figure 4.33 The estimated soil erosion from the three watersheds.

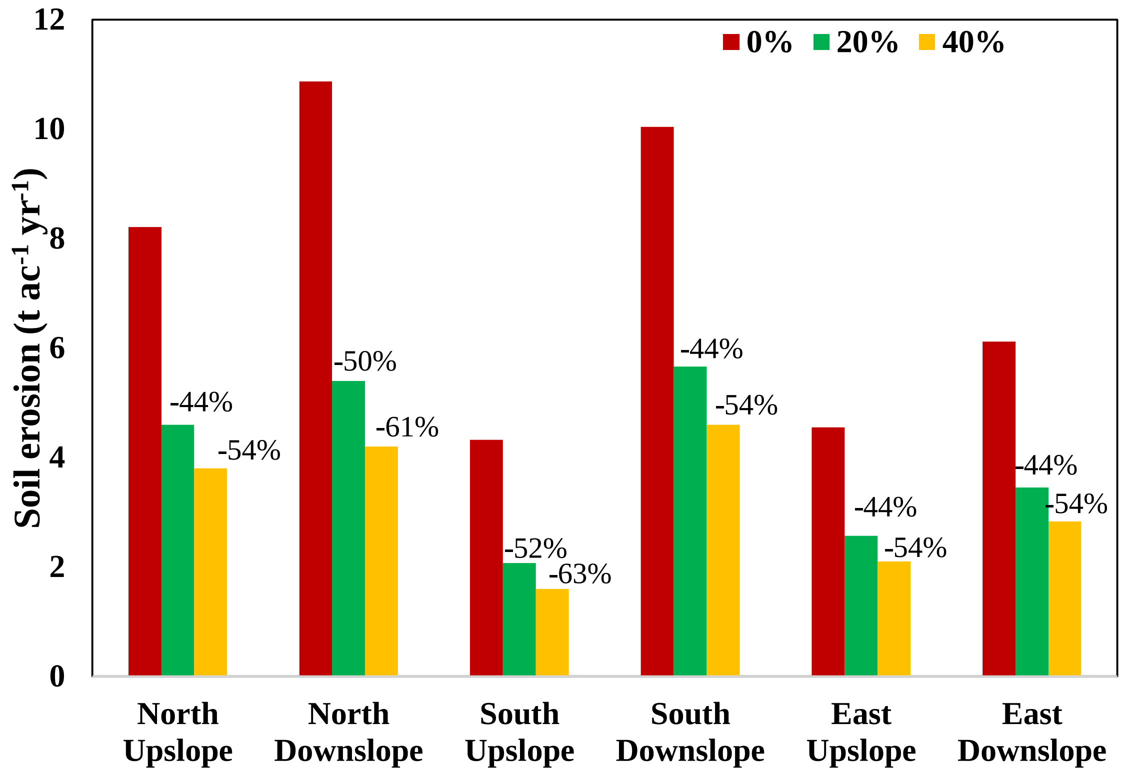

Figure 4.34 The estimated soil erosion by RUSLE after applying an increased residue cover as conservation practice (20% and 40%) on the watersheds

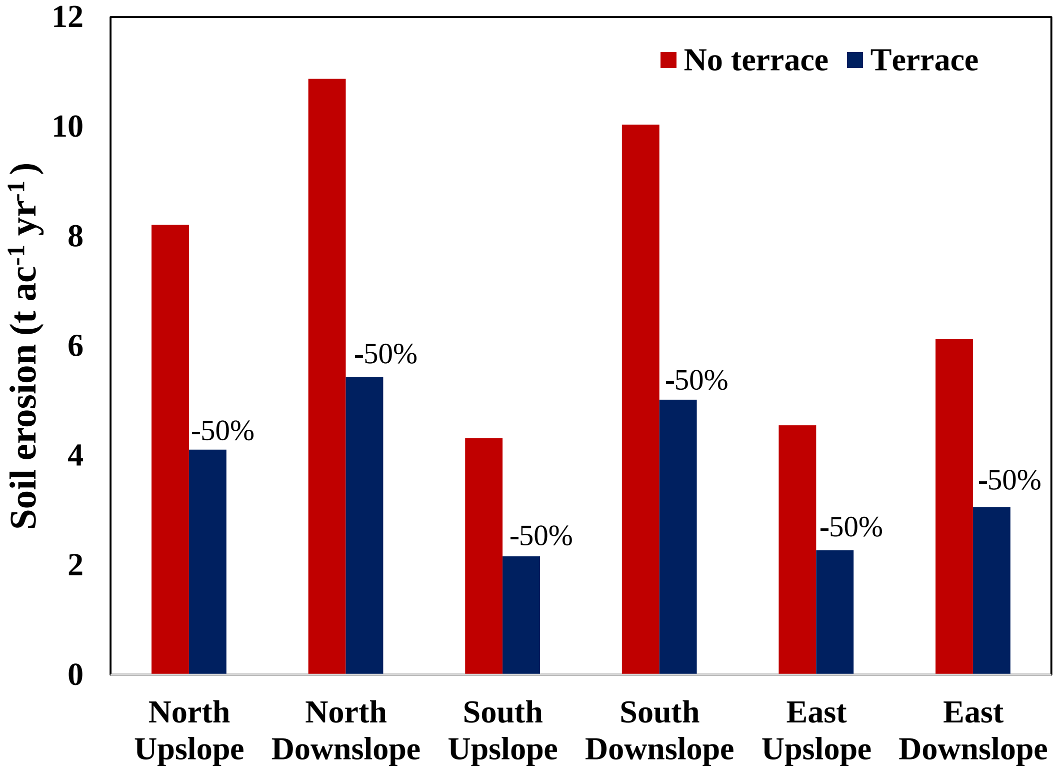

Figure 4.35 The estimated soil erosion by RUSLE after applying terraces as support practice on the watersheds

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CHAPTER 5

CONCLUSIONS

Managing farm waste for longer duration during extreme winters with frozen soils and snow cover is very difficult especially in areas such as South Dakota. A proper implementation of manure management in these areas is strongly encouraged for improving crop productivity, soils quality, and water quantity and quality. Therefore, the present study was conducted in the state of South Dakota with the specific objectives were to assess the manure application on soils and runoff quantity and quality. The three watersheds were studied; two (NW and SW) of them were treated with manure and the third one was the control (CW) watershed with no manure application. The manure was applied at the upper one-half of the SW and lower one-half of the NW. Soil samples were collected during the summer of 2015 for analyzing soil chemical and physical properties, and runoff quantity and quality data was collected from 2013 through 2015.

Results from this study showed that the application of manure, in general, improved selected soil properties such as soil water retention, organic carbon and water infiltration. These improved soil properties due to manure application reduced the runoff from the study watersheds, however, there is no specific trend in the runoff data was observed. The water quality results showed that the water samples from NW had the highest nutrient concentrations as compared to that of SW and the EW. This showed that manure spread on lower terrain (near the outlet) of the NW led to an increased nutrient loss which may increase the risks of eutrophication. It was also observed that the runoff depth from the three watersheds varied greatly and mostly depended on the topography, orientation and slope of the watersheds, and the precipitation occurring throughout the year. However, it cannot be concluded which treatment showed best results in terms of reduced runoff. This was mainly because the precipitation at the study watersheds was highly variable in all the three years. The RUSLE estimated soil erosion was varied with the manure application, residue cover and topography of the watershed. Soil erosion was the highest with no residue left on the ground, and it decreased with the increase in residue cover from 0 to 20 and 40%.

It can be concluded from this study that applying manure on higher terrain (away from the outlet) can reduce nutrient losses into the streams. However, a long-term monitoring of runoff and water quality is needed to assess the impacts of manure at watershed scale.

APPENDIX 1

A1.1. pH of soil for 0 – 10 and 10 – 20 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; TRT, treatment

0 - 10 cm				10 - 20 cm			
Plot ID	REP	pH	TRT	Plot ID	REP	pH	TRT
North Upslope	1	6.30	No manure	North Upslope	1	6.41	No manure
	2	5.21	No manure		2	5.89	No manure
	3	5.05	No manure		3	6.51	No manure
	4	5.14	No manure		4	7.32	No manure
North Downslope	1	5.89	Manure	North Downslope	1	7.01	Manure
	2	5.71	Manure		2	7.37	Manure
	3	6.78	Manure		3	6.96	Manure
	4	6.96	Manure		4	5.96	Manure
South Upslope	1	4.78	Manure	South Upslope	1	5.35	Manure
	2	5.10	Manure		2	6.35	Manure
	3	5.08	Manure		3	6.30	Manure
	4	5.55	Manure		4	7.06	Manure
South Downslope	1	7.36	No manure	South Downslope	1	7.72	No manure
	2	4.45	No manure		2	4.80	No manure
	3	4.75	No manure		3	5.24	No manure
	4	4.92	No manure		4	5.10	No manure
East Upslope	1	4.65	No manure	East Upslope	1	5.33	No manure
	2	4.85	No manure		2	5.26	No manure
	3	4.68	No manure		3	5.21	No manure
	4	4.73	No manure		4	5.36	No manure
East Downslope	1	4.80	No manure	East Downslope	1	5.23	No manure
	2	4.88	No manure		2	5.38	No manure
	3	4.73	No manure		3	5.24	No manure
	4	4.84	No manure		4	5.28	No manure

A1.2. pH of soil for 20 – 30 and 30 – 40 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; TRT, treatment

20 - 30 cm				30 - 40 cm			
Plot ID	REP	pH	TRT	Plot ID	REP	pH	TRT
North Upslope	1	6.55	No manure	North Upslope	1	6.69	No manure
	2	6.24	No manure		2	6.38	No manure
	3	6.65	No manure		3	6.66	No manure
	4	7.29	No manure		4	7.15	No manure
North Downslope	1	7.60	Manure	North Downslope	1	7.85	Manure
	2	7.51	Manure		2	7.82	Manure
	3	7.66	Manure		3	7.63	Manure
	4	7.05	Manure		4	7.69	Manure
South Upslope	1	6.02	Manure	South Upslope	1	7.81	Manure
	2	7.74	Manure		2	7.95	Manure
	3	7.67	Manure		3	7.94	Manure
	4	7.89	Manure		4	7.88	Manure
South Downslope	1	7.87	No manure	South Downslope	1	7.87	No manure
	2	5.85	No manure		2	6.27	No manure
	3	5.74	No manure		3	6.29	No manure
	4	5.37	No manure		4	5.53	No manure
East Upslope	1	7.22	No manure	East Upslope	1	6.12	No manure
	2	6.24	No manure		2	5.91	No manure
	3	5.78	No manure		3	5.85	No manure
	4	5.77	No manure		4	5.94	No manure
East Downslope	1	6.01	No manure	East Downslope	1	7.81	No manure
	2	5.77	No manure		2	7.68	No manure
	3	5.91	No manure		3	6.10	No manure
	4	5.81	No manure		4	5.81	No manure

A1.3. Electrical conductivity (μS cm^{-1}) of soil for 0-10 and 10 -20 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; EC, electrical conductivity; TRT, treatment

0 - 10 cm				10 - 20 cm			
Plot ID	REP	EC	TRT	Plot ID	REP	EC	TRT
North Upslope	1	158.1	No manure	North Upslope	1	158.3	No manure
	2	176.0	No manure		2	143.0	No manure
	3	183.1	No manure		3	153.8	No manure
	4	253.1	No manure		4	161.3	No manure
North Downslope	1	288.6	Manure	North Downslope	1	271.9	Manure
	2	223.0	Manure		2	169.5	Manure
	3	232.5	Manure		3	200.2	Manure
	4	147.0	Manure		4	126.0	Manure
South Upslope	1	324.9	Manure	South Upslope	1	95.38	Manure
	2	508.2	Manure		2	351.8	Manure
	3	236.2	Manure		3	291.4	Manure
	4	217.9	Manure		4	179.6	Manure
South Downslope	1	242.0	No manure	South Downslope	1	150.0	No manure
	2	552.7	No manure		2	220.1	No manure
	3	92.94	No manure		3	115.2	No manure
	4	126.3	No manure		4	165.0	No manure
East Upslope	1	90.92	No manure	East Upslope	1	80.00	No manure
	2	130.0	No manure		2	90.60	No manure
	3	141.6	No manure		3	103.3	No manure
	4	136.0	No manure		4	103.6	No manure
East Downslope	1	195.0	No manure	East Downslope	1	183.0	No manure
	2	109.7	No manure		2	120.0	No manure
	3	120.6	No manure		3	88.86	No manure
	4	195.0	No manure		4	141.2	No manure

A1.4. Electrical conductivity (μS cm^{-1}) of soil for 20-30 and 30 -40 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; EC, electrical conductivity; TRT, treatment

20 - 30 cm				30 - 40 cm			
Plot ID	REP	EC	TRT	Plot ID	REP	EC	TRT
North Upslope	1	89.25	No manure	North Upslope	1	72.11	No manure
	2	192.7	No manure		2	175.0	No manure
	3	103.5	No manure		3	118.3	No manure
	4	188.0	No manure		4	180.0	No manure
North Downslope	1	208.1	Manure	North Downslope	1	183.0	Manure
	2	192.3	Manure		2	179.3	Manure
	3	192.9	Manure		3	192.2	Manure
	4	149.2	Manure		4	176.8	Manure
South Upslope	1	248.2	Manure	South Upslope	1	61.62	Manure
	2	125.4	Manure		2	315.3	Manure
	3	292.1	Manure		3	292.8	Manure
	4	150.1	Manure		4	33.27	Manure
South Downslope	1	263.0	No manure	South Downslope	1	183.0	No manure
	2	103.0	No manure		2	129.7	No manure
	3	118.7	No manure		3	127.9	No manure
	4	88.96	No manure		4	69.37	No manure
East Upslope	1	69.28	No manure	East Upslope	1	85.61	No manure
	2	91.06	No manure		2	101.0	No manure
	3	87.17	No manure		3	83.54	No manure
	4	121.2	No manure		4	96.41	No manure
East Downslope	1	150.0	No manure	East Downslope	1	130.0	No manure
	2	130.0	No manure		2	163.1	No manure
	3	96.21	No manure		3	85.26	No manure
	4	150.0	No manure		4	140.0	No manure

A1.5. Soil bulk density (Mg m^{-3}) for 0-10 and 10-20 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; BD, bulk density; TRT, treatment

0 - 10 cm				10 - 20 cm			
Plot ID	REP	BD	TRT	Plot ID	REP	BD	TRT
North Upslope	1	1.21	No manure	North Upslope	1	1.15	No manure
	2	1.22	No manure		2	1.25	No manure
	3	1.21	No manure		3	1.32	No manure
	4	1.19	No manure		4	1.30	No manure
North Downslope	1	1.16	Manure	North Downslope	1	1.21	Manure
	2	1.01	Manure		2	1.19	Manure
	3	1.11	Manure		3	1.24	Manure
	4	1.20	Manure		4	1.23	Manure
South Upslope	1	1.21	Manure	South Upslope	1	1.37	Manure
	2	1.02	Manure		2	1.15	Manure
	3	1.13	Manure		3	1.15	Manure
	4	1.31	Manure		4	1.38	Manure
South Downslope	1	1.29	No manure	South Downslope	1	1.17	No manure
	2	1.34	No manure		2	1.29	No manure
	3	1.16	No manure		3	1.37	No manure
	4	1.35	No manure		4	1.37	No manure
East Upslope	1	1.20	No manure	East Upslope	1	1.30	No manure
	2	1.20	No manure		2	1.36	No manure
	3	1.18	No manure		3	1.24	No manure
	4	1.25	No manure		4	1.35	No manure
East Downslope	1	1.14	No manure	East Downslope	1	1.22	No manure
	2	1.19	No manure		2	1.41	No manure
	3	1.28	No manure		3	1.45	No manure
	4	1.30	No manure		4	1.28	No manure

A1.6. Soil organic carbon (g kg^{-1}) for 0-10 and 10-20 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; SOC, soil organic carbon; TRT, treatment

0 - 10 cm				10 - 20 cm			
Plot ID	REP	SOC	TRT	Plot ID	REP	SOC	TRT
North Upslope	1	20.30	No manure	North Upslope	1	7.20	No manure
	2	14.50	No manure		2	5.89	No manure
	3	15.60	No manure		3	10.0	No manure
	4	17.96	No manure		4	4.30	No manure
North Downslope	1	27.60	Manure	North Downslope	1	12.7	Manure
	2	24.30	Manure		2	9.57	Manure
	3	22.80	Manure		3	11.8	Manure
	4	22.90	Manure		4	14.2	Manure
South Upslope	1	20.00	Manure	South Upslope	1	14.8	Manure
	2	19.50	Manure		2	14.8	Manure
	3	20.50	Manure		3	14.6	Manure
	4	21.00	Manure		4	17.5	Manure
South Downslope	1	17.40	No manure	South Downslope	1	14.7	No manure
	2	15.20	No manure		2	12.1	No manure
	3	11.80	No manure		3	14.8	No manure
	4	14.80	No manure		4	16.9	No manure
East Upslope	1	8.80	No manure	East Upslope	1	4.30	No manure
	2	9.30	No manure		2	5.66	No manure
	3	8.30	No manure		3	3.49	No manure
	4	9.70	No manure		4	3.00	No manure
East Downslope	1	11.10	No manure	East Downslope	1	7.39	No manure
	2	12.60	No manure		2	3.99	No manure
	3	9.25	No manure		3	6.66	No manure
	4	5.10	No manure		4	5.87	No manure

A1.7. Soil organic carbon (g kg^{-1}) for 20-30 and 30-40 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; SOC, soil organic carbon; TRT, treatment

20 - 30 cm				30 - 40 cm			
Plot ID	REP	SOC	TRT	Plot ID	REP	SOC	TRT
North Upslope	1	3.69	No manure	North Upslope	1	0.11	No manure
	2	2.94	No manure		2	0.78	No manure
	3	1.28	No manure		3	0.78	No manure
	4	2.13	No manure		4	0.38	No manure
North Downslope	1	6.19	Manure	North Downslope	1	1.11	Manure
	2	5.13	Manure		2	0.83	Manure
	3	6.61	Manure		3	0.84	Manure
	4	4.6	Manure		4	0.87	Manure
South Upslope	1	10.1	Manure	South Upslope	1	4.5	Manure
	2	10.3	Manure		2	6	Manure
	3	9.6	Manure		3	6.66	Manure
	4	8.4	Manure		4	5.3	Manure
South Downslope	1	5.56	No manure	South Downslope	1	4.69	No manure
	2	5.7	No manure		2	5.38	No manure
	3	6.51	No manure		3	4.71	No manure
	4	7.6	No manure		4	5.3	No manure
East Upslope	1	3.87	No manure	East Upslope	1	1.4	No manure
	2	2.3	No manure		2	1.6	No manure
	3	1.57	No manure		3	1.2	No manure
	4	2.32	No manure		4	1.3	No manure
East Downslope	1	1.07	No manure	East Downslope	1	1.8	No manure
	2	3.2	No manure		2	1.6	No manure
	3	1.9	No manure		3	1.76	No manure
	4	2.7	No manure		4	1.1	No manure

A1.8. Total nitrogen (g kg^{-1}) in soil for 0-10 and 10-20 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; TN, total nitrogen; TRT, treatment

0 - 10 cm				10 - 20 cm			
Plot ID	REP	TN	TRT	Plot ID	REP	TN	TRT
North Upslope	1	1.90	No manure	North Upslope	1	1.60	No manure
	2	1.90	No manure		2	0.80	No manure
	3	2.00	No manure		3	1.20	No manure
	4	2.20	No manure		4	1.80	No manure
North Downslope	1	2.50	Manure	North Downslope	1	1.60	Manure
	2	2.10	Manure		2	1.59	Manure
	3	2.30	Manure		3	1.48	Manure
	4	2.50	Manure		4	1.20	Manure
South Upslope	1	2.50	Manure	South Upslope	1	1.98	Manure
	2	2.70	Manure		2	1.81	Manure
	3	2.20	Manure		3	1.63	Manure
	4	2.50	Manure		4	1.86	Manure
South Downslope	1	2.00	No manure	South Downslope	1	1.40	No manure
	2	2.00	No manure		2	1.59	No manure
	3	1.90	No manure		3	1.52	No manure
	4	2.20	No manure		4	2.07	No manure
East Upslope	1	1.80	No manure	East Upslope	1	1.12	No manure
	2	1.60	No manure		2	1.03	No manure
	3	1.70	No manure		3	0.76	No manure
	4	1.80	No manure		4	1.01	No manure
East Downslope	1	1.50	No manure	East Downslope	1	1.40	No manure
	2	1.90	No manure		2	1.56	No manure
	3	1.70	No manure		3	1.46	No manure
	4	1.80	No manure		4	0.93	No manure

A1.9. Total nitrogen (g kg^{-1}) in soil for 20-30 and 30-40 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; TN, total nitrogen; TRT, treatment

20 - 30 cm				30 - 40 cm			
Plot ID	REP	TN	TRT	Plot ID	REP	TN	TRT
North Upslope	1	0.88	No manure	North Upslope	1	0.40	No manure
	2	0.70	No manure		2	0.50	No manure
	3	0.66	No manure		3	0.60	No manure
	4	0.70	No manure		4	0.55	No manure
North Downslope	1	1.63	Manure	North Downslope	1	0.65	Manure
	2	1.59	Manure		2	0.87	Manure
	3	1.48	Manure		3	0.77	Manure
	4	1.19	Manure		4	0.48	Manure
South Upslope	1	0.94	Manure	South Upslope	1	0.65	Manure
	2	0.76	Manure		2	0.89	Manure
	3	0.71	Manure		3	0.44	Manure
	4	1.20	Manure		4	0.89	Manure
South Downslope	1	0.66	No manure	South Downslope	1	0.42	No manure
	2	1.17	No manure		2	0.51	No manure
	3	0.66	No manure		3	0.57	No manure
	4	1.20	No manure		4	0.54	No manure
East Upslope	1	0.65	No manure	East Upslope	1	0.85	No manure
	2	0.37	No manure		2	1.20	No manure
	3	0.49	No manure		3	0.90	No manure
	4	0.49	No manure		4	0.80	No manure
East Downslope	1	0.88	No manure	East Downslope	1	0.59	No manure
	2	1.36	No manure		2	0.69	No manure
	3	0.87	No manure		3	0.65	No manure
	4	0.79	No manure		4	0.86	No manure

A1.10. Available Phosphorus (mg kg^{-1}) in soil for 0-10 and 10-20 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; P, available phosphorus; TRT, treatment

0 - 10 cm				10 - 20 cm			
Plot ID	REP	P	TRT	Plot ID	REP	P	TRT
North Upslope	1	2.66	No manure	North Upslope	1	3.09	No manure
	2	3.40	No manure		2	2.59	No manure
	3	4.86	No manure		3	2.36	No manure
	4	5.41	No manure		4	2.05	No manure
North Downslope	1	6.81	Manure	North Downslope	1	4.00	Manure
	2	6.58	Manure		2	3.43	Manure
	3	6.82	Manure		3	3.90	Manure
	4	6.11	Manure		4	3.70	Manure
South Upslope	1	3.81	Manure	South Upslope	1	4.44	Manure
	2	3.71	Manure		2	3.56	Manure
	3	3.62	Manure		3	2.71	Manure
	4	4.57	Manure		4	2.01	Manure
South Downslope	1	3.26	No manure	South Downslope	1	3.45	No manure
	2	3.32	No manure		2	1.33	No manure
	3	3.29	No manure		3	2.83	No manure
	4	3.31	No manure		4	1.52	No manure
East Upslope	1	0.54	No manure	East Upslope	1	0.11	No manure
	2	0.97	No manure		2	0.91	No manure
	3	0.54	No manure		3	0.34	No manure
	4	1.21	No manure		4	0.69	No manure
East Downslope	1	2.10	No manure	East Downslope	1	1.49	No manure
	2	3.46	No manure		2	0.44	No manure
	3	2.45	No manure		3	0.40	No manure
	4	2.37	No manure		4	0.60	No manure

A1.11. Available Phosphorus (mg kg^{-1}) in soil for 20-30 and 30-40 cm depths for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; P, available phosphorus; TRT, treatment

20 - 30 cm				30 - 40 cm			
Plot ID	REP	P	TRT	Plot ID	REP	P	TRT
North Upslope	1	1.60	No manure	North Upslope	1	1.92	No manure
	2	3.26	No manure		2	3.94	No manure
	3	2.43	No manure		3	0.40	No manure
	4	0.36	No manure		4	0.11	No manure
North Downslope	1	3.36	Manure	North Downslope	1	0.20	Manure
	2	1.31	Manure		2	2.39	Manure
	3	3.04	Manure		3	2.57	Manure
	4	0.01	Manure		4	2.10	Manure
South Upslope	1	2.54	Manure	South Upslope	1	2.71	Manure
	2	3.90	Manure		2	2.94	Manure
	3	2.67	Manure		3	3.05	Manure
	4	2.00	Manure		4	1.91	Manure
South Downslope	1	1.63	No manure	South Downslope	1	4.13	No manure
	2	1.23	No manure		2	0.90	No manure
	3	1.20	No manure		3	1.03	No manure
	4	2.77	No manure		4	0.93	No manure
East Upslope	1	0.21	No manure	East Upslope	1	0.29	No manure
	2	1.72	No manure		2	0.00	No manure
	3	0.02	No manure		3	0.87	No manure
	4	1.60	No manure		4	0.42	No manure
East Downslope	1	1.35	No manure	East Downslope	1	0.67	No manure
	2	0.46	No manure		2	0.46	No manure
	3	0.67	No manure		3	0.31	No manure
	4	0.94	No manure		4	0.87	No manure

A1.12. Soil water retention (SWR, $m^3\ m^{-3}$) of soil for 0-10 cm depth for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; TRT, treatment

Plot ID	TRT	Pressure (-kPa)						
		0.01	-0.4	-1.0	-2.5	-5.0	-10.0	-30.0
NU	No manure	0.57	0.55	0.51	0.48	0.44	0.42	0.37
ND	Manure	0.51	0.51	0.49	0.47	0.45	0.43	0.40
SU	Manure	0.52	0.51	0.49	0.47	0.45	0.43	0.38
SD	No manure	0.56	0.55	0.52	0.48	0.43	0.42	0.36
EU	No manure	0.55	0.54	0.52	0.49	0.45	0.42	0.38
ED	No manure	0.49	0.48	0.46	0.44	0.41	0.40	0.35

NU, North Upslope; ND, North Downslope; SU, South Upslope; SD, South Downslope; EU, East Upslope; ED, East Downslope

A1.13. Soil water retention (SWR, $m^3\ m^{-3}$) of soil for 10-20 cm depth for the six landscape positions with manure and no manure treatment.

Plot ID, the landscape positions; REP, replication; TRT, treatment

Plot ID	TRT	Soil Pressure (-kPa)						
		0.01	-0.4	-1.0	-2.5	-5.0	-10.0	-30.0
NU	No manure	0.52	0.50	0.47	0.43	0.39	0.37	0.32
ND	Manure	0.52	0.50	0.48	0.45	0.42	0.41	0.35
SU	Manure	0.52	0.51	0.48	0.45	0.42	0.41	0.34
SD	No manure	0.53	0.51	0.48	0.43	0.41	0.39	0.33
EU	No manure	0.53	0.52	0.49	0.46	0.43	0.42	0.36
ED	No manure	0.48	0.47	0.44	0.41	0.39	0.38	0.34

NU, North Upslope; ND, North Downslope; SU, South Upslope; SD, South Downslope; EU, East Upslope; ED, East Downslope

APPENDIX 2

A2.1. Nutrient concentration (mg L^{-1}) in the surface runoff samples collected during the three years 2013, 2014 and 2015 from the North watershed.

Dates	NO_3	NH_4	TKN	TDP	TP	TSS
3/9/2013	4.74	1.90	4.32	0.19	0.25	16.25
3/14/2013	4.04	3.23	9.83	1.62	1.53	33.10
3/26/2013	1.51	2.47	9.29	1.48	1.53	128.00
3/27/2013	2.21	3.02	10.40	1.47	0.93	185.10
3/28/2013	3.52	2.64	9.72	0.70	0.90	114.00
6/16/2014	3.25	2.22	8.35	0.54	3.88	943.00
6/6-7/2015	0.36	0.07	16.70	1.93	7.20	2674.00
6/19/2015	18.62	0.03	11.11	0.67	7.64	3287.21
6/20/2015	15.94	0.06	6.42	0.72	4.90	1568.36
7/6/2015	4.62	0.03	1.33	0.64	1.99	697.19

NO_3, Nitrate nitrogen; NH_4, Ammonium nitrogen; TKN, Total Kjeldahl nitrogen; TDP, Total dissolved phosphorus; TP, Total phosphorus; TSS, Total suspended solids

A2.2. Nutrient concentration (mg L^{-1}) in the surface runoff samples collected during the three years 2013, 2014 and 2015 from the South watershed.

Dates	NO_3	NH_4	TKN	TDP	TP	TSS
3/9/2013	3.93	1.49	3.51	0.08	0.11	11.50
3/14/2013	3.76	3.38	9.66	1.28	1.34	93.00
3/26/2013	1.20	1.58	6.46	0.30	0.29	76.50
3/27/2013	2.02	2.39	9.75	0.32	0.38	31.15
3/28/2013	x	x	x	x	x	x
6/16/2014	2.93	1.45	7.59	0.31	4.37	1150.00
6/6-7/2015	0.16	0.06	6.83	0.85	3.82	1393.60
6/19/2015	17.80	0.03	6.64	0.39	3.89	1260.88
6/20/2015	9.31	0.07	6.07	0.35	3.54	1161.73
7/6/2015	3.94	0.05	1.08	0.28	0.86	304.65

NO_3, Nitrate nitrogen; NH_4, Ammonium nitrogen; TKN, Total Kjeldahl nitrogen; TDP, Total dissolved phosphorus; TP, Total phosphorus; TSS, Total suspended solids; x, no data

A2.3. Nutrient concentration (mg L^{-1}) in the surface runoff samples collected during the three years 2013, 2014 and 2015 from the East watershed.

Dates	NO_3	NH_4	TKN	TDP	TP	TSS
3/9/2013	4.58	1.62	3.62	0.10	0.14	23.50
3/14/2013	4.42	1.67	5.72	0.46	0.39	41.25
3/26/2013	1.13	1.81	6.90	0.51	0.52	37.00
3/27/2013	1.96	2.41	8.22	0.58	0.52	46.20
3/28/2013	2.67	1.37	8.88	0.35	0.43	66.40
6/16/2014	x	x	x	x	x	x
6/6-7/2015	0.33	0.10	3.66	0.38	1.86	400.55
6/19/2015	x	x	x	x	x	x
6/20/2015	x	x	x	x	x	x
7/6/2015	5.10	0.05	3.37	0.42	2.23	1263.83

NO_3, Nitrate nitrogen; NH_4, Ammonium nitrogen; TKN, Total Kjeldahl nitrogen; TDP, Total dissolved phosphorus; TP, Total phosphorus; TSS, Total suspended solids; x, no data

APPENDIX 3

A3.1. SAS codes used for analysis of water quality parameters;

```
proc import datafile='E:\Chapter

1\SAS\sasd1.csv' out=NO3;run;
```

Codes used to compare the North and the East

watershed

```
/*NE*/
data ne;set NO3;
where trt="N" or trt="E";
run;

proc glm data=ne;
class trt;
model NO3=trt time trt*time/ss3 solution;
run;

proc glm data=ne;
class trt;
model NO3=trt time /ss3 solution;
run;

/*SE*/
data se;set NO3;
where trt="S" or trt="E";
run;

proc glm data=se;
```

```
class trt;
model NO3=trt time trt*time/ss3 solution;
run;

proc glm data=se;
class trt;
model NO3=trt time /ss3 solution;
run;
```

A3.2. SAS codes used for comparing the Soils parameters;

```
Data;
Input TRT$  REP SOC;
Cards;

;
proc glm;
class TRT REP ;
model   SOC = TRT REP*TRT ;
test h=TRT e=REP*TRT;
means TRT/duncan alpha=0.05 e=REP*TRT;


PROC PRINT;
RUN;
```

SOC, soil organic carbon; REP, replicates; TRT, treatment

A3.3. Pictures taken during soil sampling and analysis;

Figure 3.3.1. Soil sampling during October 2015

Figure 3.3.2. Saturation of soil cores for analysis of the soil water retention

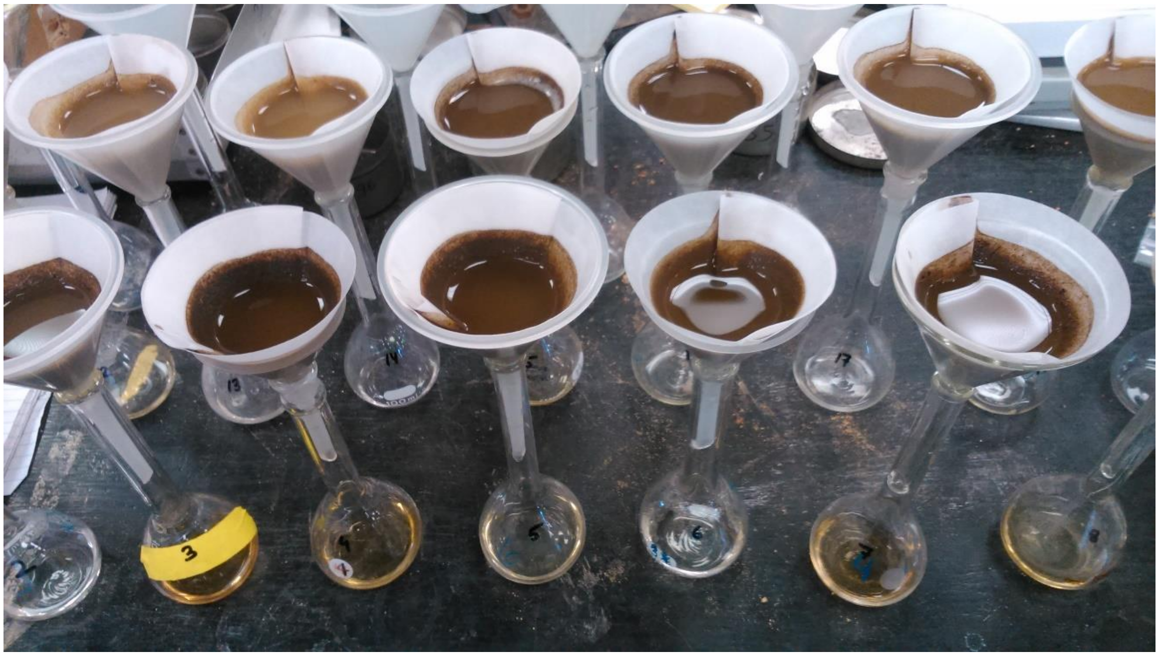

Figure 3.3.3. Extraction of soil samples for the analysis of available phosphorus

Figure 3.3.4. Extracted soil samples ready to be analyzed for available phosphorus

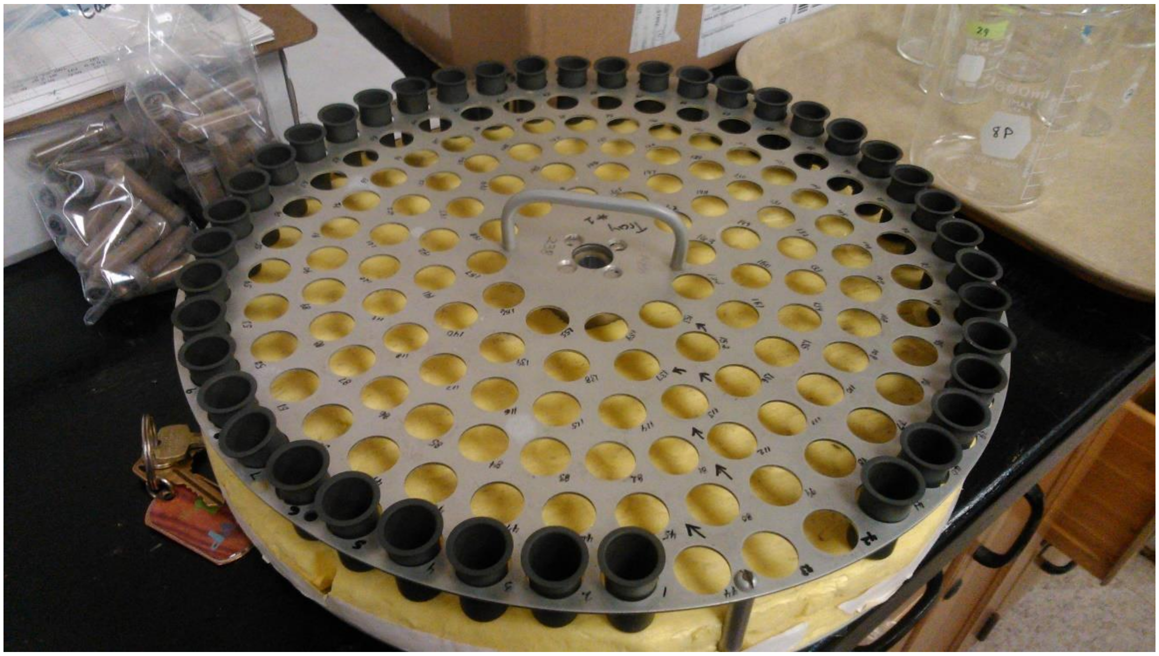

Figure 3.3.5. Samples weighed for the total carbon and total nitrogen analysis

Figure 3.3.6. Analysis of soil inorganic carbon

A3.4. Pictures taken during spreading manure at the watersheds,

Figure 3.4.1. Manure spread during 2016

A3.5. Pictures taken during water sampling;

Figure 3.5.1. The set up at the outlet of each watershed

Figure 3.5.2. Collection of water samples after the storm events in 2015

Figure 3.5.3. Cleaning the clogged flume after the storm events

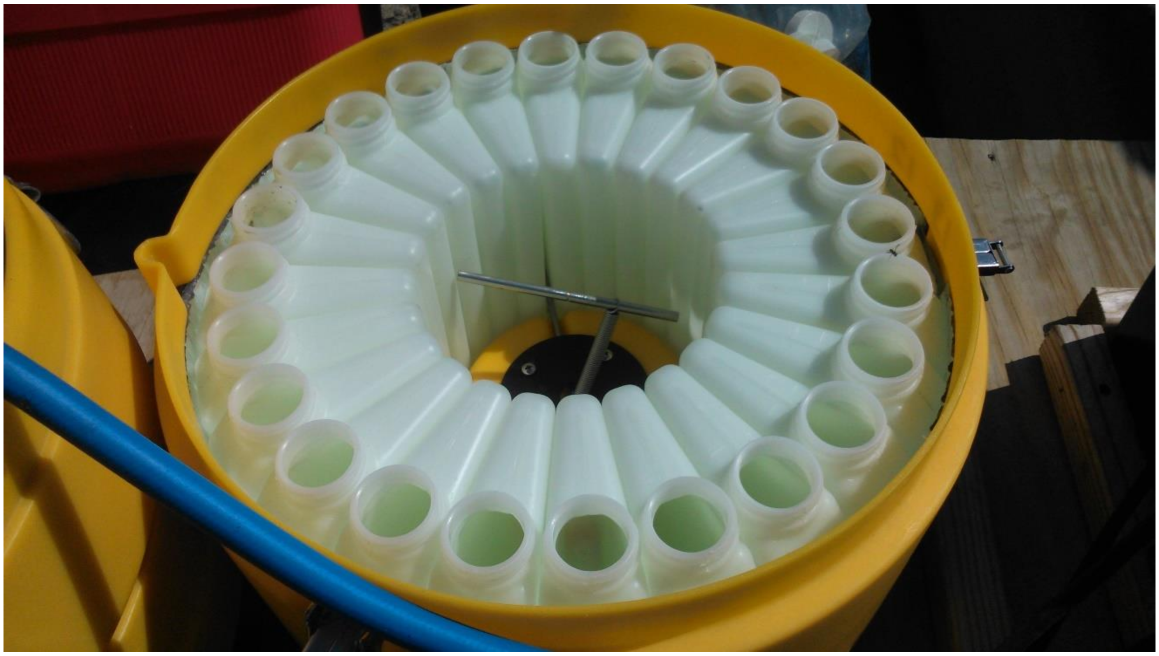

Figure 3.5.6. The inside picture of the automatic sampler containing 24 bottles

VITA

Shikha Singh was born in India to Kalendra Bahadur Singh and Kiran Singh. She received her Bachelors in Agriculture Sciences in 2014 from Punjab Agricultural University, Punjab, India. For her graduate studies, she joined and received MS in Plant Sciences, emphasizing in Soil Science at South Dakota State University in Spring 2015 under the supervision of Dr. Sandeep Kumar. She would be starting her PhD at the University of Tennessee, Knoxville from Spring 2017.