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Response of Winter Manure Application on Surface Runoff Water Quantity and Quality from Small Watersheds in South Dakota

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Abstract Manure application on frozen soil, which is a common practice in the upper Midwest of USA, results in degraded soil and water quality. During snowmelt or precipitation events, water runoff carries nutrients into nearby streams and impairs the water quality. There is a need, therefore, to identify improved management of manure application in the soils. This study was conducted to assess water quality impacts associated following manure application during winter months when soil is completely covered with snow. The study site included three watersheds, named south (SW), east (CW), and north (NW) managed with a corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation located in South Dakota. The SW and NW were used as treatment, and CW as the control watershed. The treatments included manure application on the upper half of the SW and lower half of the NW, and CW received no manure application. This study showed that manure improved soil properties including infiltration rate and organic matter. Nitrogen and phosphorus losses in the surface runoff were higher from NW compared to that of SW. The CW had similar nutrient losses compared to the NW with slight differences. It can be concluded that maintaining a setback distance can help in improving the environmental quality as well as managing the agricultural wastes during the winter months.

Keywords Manure · Surface runoff · Soil properties · Organic matter · Water quality · Watersheds · Nitrogen and phosphorus

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1 Introduction

Appropriate and recurring manure application typically increase soil organic matter (SOM) and crop productivity, and also improve soil health (Maillard and Angers 2014). Manure can contribute to economical gain through increased crop productivity and environmental benefits through improved soil resilience to variations in climate, cropping, and management practices (Kongoli and Bland 2002). However, when not applied in the appropriate amount at appropriate landscape position and time, manure can impair water quality of receiving streams. To minimize the risk of movement of manure towards surface water, several US states are recommended to establish minimum setback distances between the point of manure application and waterbody (US EPA 2013). The effects of manure entering the streams may result in nutrient enrichment, or eutrophication of surface waters, and add pathogens rendering the water unsafe for immersion or drinking (Haack et al. 2015).

Manure application on frozen soils may increase the risk of impaired water quality of the streams. During snowmelt or high intensity precipitation events, surface water runoff can carry manure into nearby streams. Therefore, it is generally not recommended to spread liquid manure on frozen soils, whereas regulation may allow solid manure to be applied on frozen soils on certain physical conditions of the field those vary from one state to the other. As the soil is frozen (and often covered with snow), the practice of spreading manure on the top of frozen ground creates a potential water quality problem, in that—when the ground thaws in the spring—snow melt runoff is unable to infiltrate the soil but runs off as surface runoff instead, potentially washing the manure with it to the stream. However, in the upper Midwest of USA, with a large number of cattle operations, it may be difficult for farmers to store manure during the winter period. The risk of soil compaction by heavy equipment is reduced when the soil is frozen compared to wet soils in the fall or spring. Also, it may lead to concentrated spills into the streams which may harm the streams to a greater extent. Many factors should be considered while determining the impacts associated with spreading manure on frozen soil, which include climatic factors, type of manure, amount of manure being spread, timing of spreading, location of spreading, tillage and field management, and crop yield.

Runoff is influenced mainly by manure type and application method, soil type, slope, ground cover, and precipitation (Gilley and Risse 2000; Sauer et al. 1999). Long-term application of manure tends to reduce runoff and soil loss (Bushee et al. 1999). The runoff produced due to natural precipitation events from long-term field-scale plots is one way to identify the effect of manure on runoff (Gilley and Risse 2000). Further, understanding the relationships between runoff water quantity and quality versus type, timing, rates, and methods of manure applications will help in developing best manure management practices for improved water quality (Klingberg 2008). Therefore, the present study was based on the hypothesis that manure spread in the higher terrain and farther from outlet results in less impairment to water quality than the manure spread on lower terrain and near the outlet.

The objective of this study was to investigate the impacts of manure application on runoff and runoff water quality at small watershed scale. Study treatments were selected to test the hypothesis that a watershed received manure application on the upper terrain may have less nutrient and sediment loss as compared to that of another watershed that received manure application on the lower terrain as the distance between the manure treatment and the sampling point of the runoff water, i.e. the outlet of the watershed was larger in the former watershed and it take more time for the water to infiltrate and thereby, reducing nutrient and sediment loss.

2 Materials and Methods

2.1 Study Watersheds

The study watersheds were located in Moody County, South Dakota. Three different watersheds viz. North Watershed (NW), South Watershed (SW), and East Watershed (control watershed, CW) (Fig. 1) were established on Egan-Ethan complex (fine-silty, mixed, superactive, mesic Udic Haplustolls) soil type. The area and the average slopes of the NW, SW, and CW were 2.71, 4.13, and 2.75 ha, and 13, 8, and 16%, respectively. This study was designed following the paired watershed design (Clausen and Spooner 1993). The study watersheds have similar soil types and managed with corn-soybean rotation. During 2011 through 2015, manure was spread once per year at the lower half of the NW while it was spread at the upper half of the SW. No manure was applied at the CW and considered as the control watershed. Manure was spread on the watersheds based on the crop to be grown, soil, and manure nutrient content. The manure was sufficient to meet the nitrogen demands, and nitrogen fertilizer was not necessary. Areas not receiving manure were fertilized with inorganic fertilizer at the same nitrogen and phosphorus rates.

2.2 Climate Data

The climate data was collected 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 our study area. Past 20 years annual rainfall data was collected and mean value was estimated for the last 20 years and comparison between the long-term average and annual average was made to check the difference in rainfall during the study period.

2.3 Soil Characterization

Soil characterization was conducted to see the differences among the soils from different watersheds. Soil samples

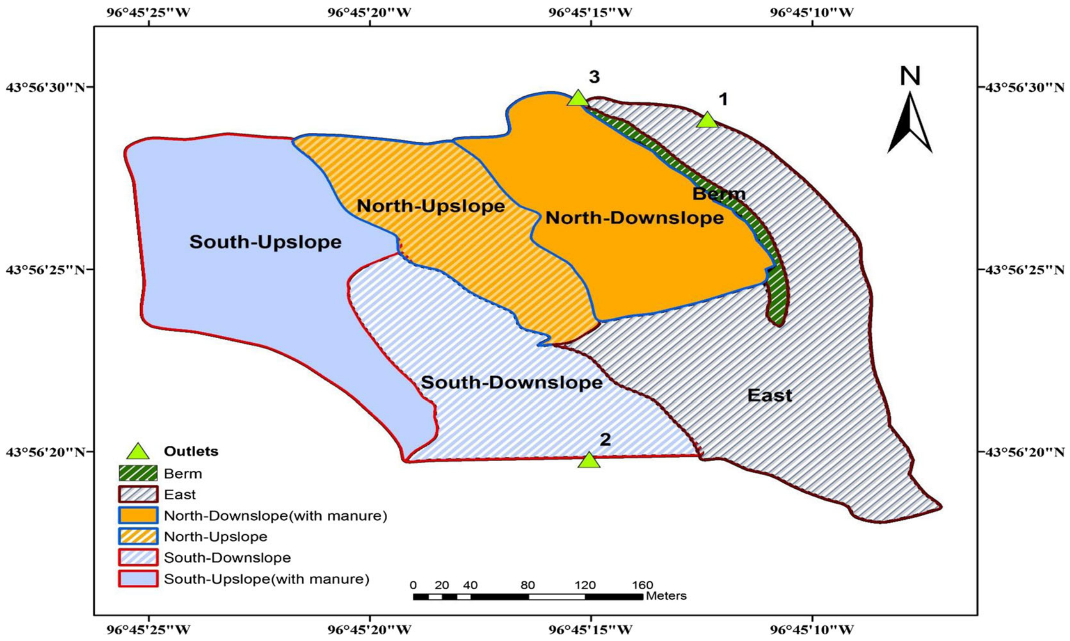

Fig. 1 The paired watershed design used in the study with north, south, and east watersheds managed with manure (manure applied at the upslope in south and at the downslope in north watershed) and control (east) watershed (no manure application)

were collected in summer of 2015 from six different landscape positions, viz., NW upslope, NW downslope, SW upslope, SW downslope, CW upslope, and downslope. The samples were collected in four replications from each landscape position of each watershed. Soil samples were air dried, crushed, and sieved through a 2-mm sieve. The prepared samples were used to analyze soil organic carbon, total nitrogen, Olsen phosphorus, and pH. Water infiltration rate was also measured for all the six landscape positions using the double ring method (Reynolds et al. 2002) in four replications for 2015. The total nitrogen and carbon concentrations were determined using the TruSpec CHN Analyzer, and soil inorganic carbon was determined using the hydrochloric acid method. Soil organic carbon was calculated as the difference between the total carbon and the inorganic carbon (Stetson et al. 2012). Soil available phosphorus was determined using the Olsen method (Olsen 1954), and soil pH was measured in a 1:1 soil water suspension using the pH meter.

2.4 Surface Runoff

H-flumes were installed at the outlet of each watershed to monitor the surface runoff for 2011 through 2015. The peak flow was recorded with the help of H-flume and depth of the water flowing through the flume was recorded by ultrasonic depth sensor (Campbell Scientific SR50A). A digital camera (Moultrie M80 GameSpy) was installed near the outlet of each flume to collect photographic documentation of flow conditions during periods of equipment malfunction due to, e.g., diurnal freeze-thaw conditions.

2.5 Water Quality

Water samples were collected by Teledyne ISCO automatic samplers (model number 6712) for 2011 through 2013 and using Campbell Scientific automatic samplers in 2015. However, in 2014, samples were collected manually when there was a runoff event. Water samples were collected within the H-flume. Sample events were initiated based on changes in flow rates. 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 runoff water samples were analyzed for total Kjeldahl nitrogen, nitrate nitrogen, ammonia-N, and total dissolved phosphorous. Water samples were analyzed using the standard methods for the examination of water and wastewater (American Public Health Association 2005).

2.6 Statistical Analysis

Statistical analysis of water quality from the three watersheds was performed using SAS 9.3 software (SAS

Institute 2012). The distributions of the data sets were tested for composite normality using the Kolmogorov-Smirnov test and histogram method. Parallel line analysis was used for comparing each pair of water quality parameters 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, soil data was analyzed using the SAS software (Duncan's LSD) to assess the treatment impacts on measured parameters.

3 Results and Discussion

3.1 Climate and Soil Data

The study site received 14 and 0.4% more precipitation in 2011 and 2012, respectively, than that of the long-term (1991–2010) average (669 mm). The amount of precipitation was 6 and 12% below the long-term mean in 2013 and 2014, respectively. There was only a small amount of runoff in 2014 as it was the driest year of the study. In the year 2015, the annual precipitation was 25% higher than the long-term average. All the study watersheds did not produce the same number of runoff samples for water quality analysis. For instance, the NW, SW, and CW produced 15, 15, and 14 composite runoff water samples across the entire period of study.

Soil pH of north upslope and downslope was slightly acidic with the values of 5.8 and 6.3, respectively (Table 1). There were no significant differences observed in pH value between the landscape positions of each watershed; however, it was observed that manure applied landscape positions had numerically higher pH value indicating that manure application increased the pH. A study conducted by Whalen et al. (2000) and Walker et al. (2004) reported that application of manure in soils led to increased pH. It was observed that there was a significant buildup of soil nutrients in the landscape positions those were treated with manure. Soil nitrogen (Table 1) was higher in the landscape positions that were treated with manure. North downslope had numerically higher nitrogen (2.4 g kg^{-1}) compared to the north upslope (2.0 g kg^{-1}), although the differences were not significant. In the SW, the south upslope (2.5 g kg^{-1}) had significantly higher (25%) nitrogen content than the south downslope (2.0 g kg^{-1}). There was a significant higher soil available phosphorus in the north downslope (6.58 mg kg^{-1}) which was treated with manure than the north upslope (4.08 mg kg^{-1}) (Table 1). The available phosphorus content was about 61% higher in the north downslope than the north upslope, while in the SW, it was observed that south upslope (being treated with manure) had numerically higher available P content (3.93 mg kg^{-1}) than the south downslope (3.29 mg kg^{-1}), but statistically insignificant. This may be due to the manure treatment applied to these specific landscape positions. In the CW, it was observed that East upslope (0.82 mg kg^{-1}) was significantly lower than East downslope (2.5 mg kg^{-1}) which may be due to erosional losses from the upslope landscape position to the downslope. Manure application leads to an increase in the available phosphorus content in the soil. A study conducted by Tadesse et al. (2013) studied the impacts of manure and fertilizer application on physico-chemical properties of soil in Ethiopia, and reported that application of manure led to a considerable increase in the available phosphorus (11.9 to 38.1 mg L^{-1}). Another study conducted by Xue et al. (2013) in North China Plain reported that application of

Table 1 Soil hydrochemical 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	SOC (g kg^{-1})	Available P (mg kg^{-1})	Total N (g kg^{-1})	Infiltration rate (mm h^{-1})
North	Upslope (no manure)	5.8[a]	17.1[b]	4.08[b]	2.00[a]	144.4[b]
	Downslope (manure)	6.3[a]	24.4[a]	6.58[a]	2.40[a]	165.3[a]
South	Upslope (manure)	5.4[a]	20.3[a]	3.93[a]	2.50[a]	195.5[a]
	Downslope (no manure)	5.1[a]	14.8[b]	3.29[a]	2.00[b]	181.1[a]
East	Upslope (no manure)	4.7[a]	9.00[a]	0.82[b]	1.70[a]	139.6[a]
	Downslope (no manure)	4.8[a]	9.50[a]	2.60[a]	1.70[a]	144.8[a]

SOC, Soil organic carbon; *P*, Phosphorus; *N*, Nitrogen Similar letters indicate that there was no significant difference observed between the different landscape positions within the same watershed.

manure in soils led to a considerable increase in the labile and non-labile phosphorus pools in the soil. Soil organic carbon was significantly higher in the landscape positions treated with manure when compared to untreated landscape position within a watershed (Table 1). North downslope (24.4 g kg^{-1}) had 42% higher SOC concentrations than the north upslope (17.1 g kg^{-1}), while south upslope (20.3 g kg^{-1}) had 37% higher SOC content than the south downslope (14.8 g kg^{-1}). For the CW, SOC at the downslope (9.5 g kg^{-1}) position was numerically higher than that at the upslope (9.0 g kg^{-1}), although it was not statistically significant. Addition of manure improved organic matter of the soils. Haynes and Naidu (1998) reported that addition of manure to soils leads to an increase in the carbon content. The landscape positions treated with manure had higher infiltration rates than the one with no manure application; however, differences were not always significant. The SW upslope (195.5 mm h^{-1}) had numerically higher infiltration rate compared to the downslope (181.1 mm h^{-1}) (Table 1). The infiltration rates at the re north downslope (165.3 mm h^{-1}) were 14% higher as compared to the north upslope (144.4 mm h^{-1}) in the NW. This may be due to the manure application which enhanced the infiltration rates. For the CW, no significant differences were observed. Manure improved soil organic matter which ultimately, increased soil porosity and hence improved the water infiltration (Gholami et al. 2013).

3.2 Surface Runoff

Surface runoff from the watersheds differed greatly due to the manure treatments (Table 2). In 2011, when the annual rainfall was 14% greater than the long-term mean, the flow was maximum (64 mm) in the CW watershed followed by SW (34.9 mm) and NW (30 mm). Similar trend was observed in 2012, with CW having higher flow (59 mm) followed by SW (32 mm) and NW (17 mm). However, a slight change in trends of runoff was observed in 2013 and 2014. In 2013, SW had the maximum flow (17.9 mm) followed by CW (12.8 mm) and NW (10.6 mm) (Table 2). This may be because of the 6% less precipitation during in 2013 than the long-term mean (669 mm). In 2014, only one runoff event was received and the observed trend in runoff was similar to that of 2011 and 2012 where NW had the maximum runoff (15 mm) followed by SW (5 mm) and CW (0.22 mm) (Table 2). However, very high intensity rainfall events were observed in 2015 with maximum (20.3 cm) rainfall received in a single storm event. In this year, the NW received flow of 23.5 mm, SW of 21 mm, and CW of 20 mm (Table 2). The reduced runoff in 2015 than that from previous sampling years was partially due to the differences in rainfall pattern and increased infiltration capacity of the soils that had been improved during the 5 years of the experiment. Chinkuyu et al. (2002) studied manure application on runoff from a Nicollet loamy soil under a corn-soybean system. They observed greater runoff in fertilizer applied soil than that of manure applied because manure increases the infiltration capacity of soil and hence decreases the runoff. A similar field study conducted by Kongoli and Bland (2002) in Wisconsin reported that the manure application slowed down the snow melt, as it acts as an insulating layer and delays snow melt. This resulted in greater infiltration of water into the soil which reduces the runoff. Therefore, it is evident that manure treatment reduced runoff and increased the infiltration capacity of soils. According to studies conducted across various environmental settings (Vories et al. 1999; Wood et al. 1999), the runoff loss was less in the fields treated with manure as compared to the fields without manure (Gilley and Risse 2000).

Table 2 Cumulative surface runoff collected from north, south, and east (control) watersheds from 2011 through 2015

Year	Cumulative runoff (mm)			
	Precipitation (mm)	North	South	East
2011	762	30.3	34.9	63.9
2012	672	16.6	32.5	59.0
2013	629	10.6	17.9	12.8
2014	589	15.0	5.00	0.22
2015	836	23.5	21.0	20.0

3.3 Water Quality

Nitrate Nitrogen Nitrogen concentration was measured as nitrate nitrogen, ammonia-N, and Total Kjeldahl Nitrogen, and the data are shown in Figs. 2, 3, and 4. In 2011, nitrate concentration was highly variable among the three watersheds. The trend showed that runoff water samples from the NW had more nitrate concentration than that of SW. On March 16, 2011, the SW had the lowest concentration (0.5 mg L^{-1}) followed by NW (0.9 mg L^{-1}) and CW (1.23 mg L^{-1}) (Fig. 2). It was observed that, for all the other sampling events in 2011,

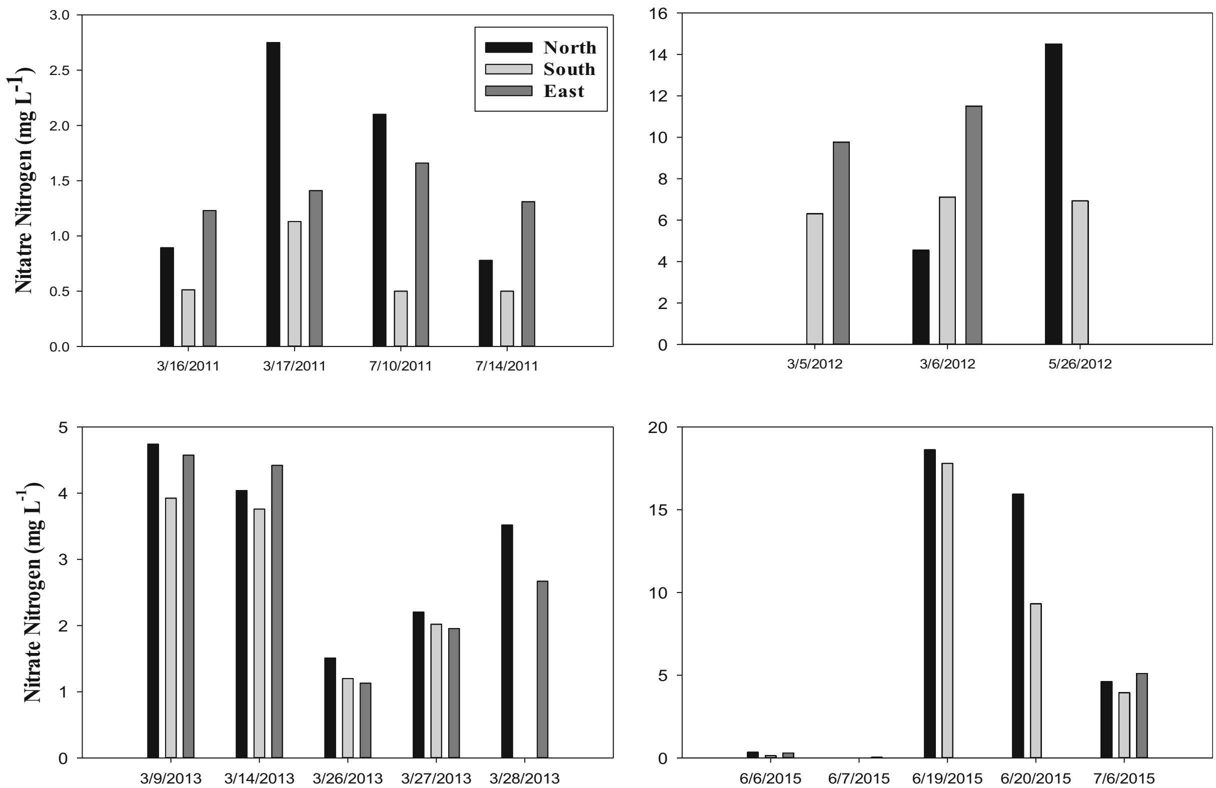

Fig. 2 The nitrate nitrogen content of surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at the upslope in south and at the downslope in north watershed) and control (east) watershed (no manure application) for the years 2011, 2012, 2013, and 2015. Note: There was only one event in 2014 and hence not shown in the figure

SW water samples had the least concentration of the nitrate nitrogen. The data showed that the samples collected from the NW and CW had no significant difference in the nitrate concentration for the 2011, while SW and CW water samples had a significant difference (P < 0.05) in the nitrate concentration with the SW had significantly lower concentrations than that of CW (Fig. 2). This may be attributed to the fact that CW had no manure treatment and hence had higher runoff 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. For comparison, the maximum nitrate nitrogen concentration in drinking water is 10 mg L^{-1} (US EPA 2012). Thus, there were generally no nitrate concentrations exceedances in the runoff water but for a few exceptions in 2012 and 2015. In 2012, the comparison for nitrate concentration data could not be made easily as all the three watersheds did not have runoff on the same day. However, there were few days in which the runoff events coincided among the three watersheds, and water quality analysis revealed that the water samples from the CW had more nitrate concentration than that of SW and NW as observed on March 5 and 6, 2012 (Fig. 2). This may be due to the non-uniform runoff events across the three watersheds. However, the samples' concentrations from NW and the CW could not be compared statistically for nitrate concentration due to less number of data points, while the water samples' concentrations from SW and CW were significantly different (P < 0.05) with SW having lower nitrate concentration than the CW. In 2013, the trend was very much expected with SW water samples having the significantly less nitrate concentration followed by water samples from CW and NW. In 2013, samples from the NW and CW did not have significant differences while water samples collected from SW had significantly lower (P < 0.01) nitrate concentration than that of CW. In 2014, precipitation was 12% below the long-term average. Thus, there was very little runoff collected

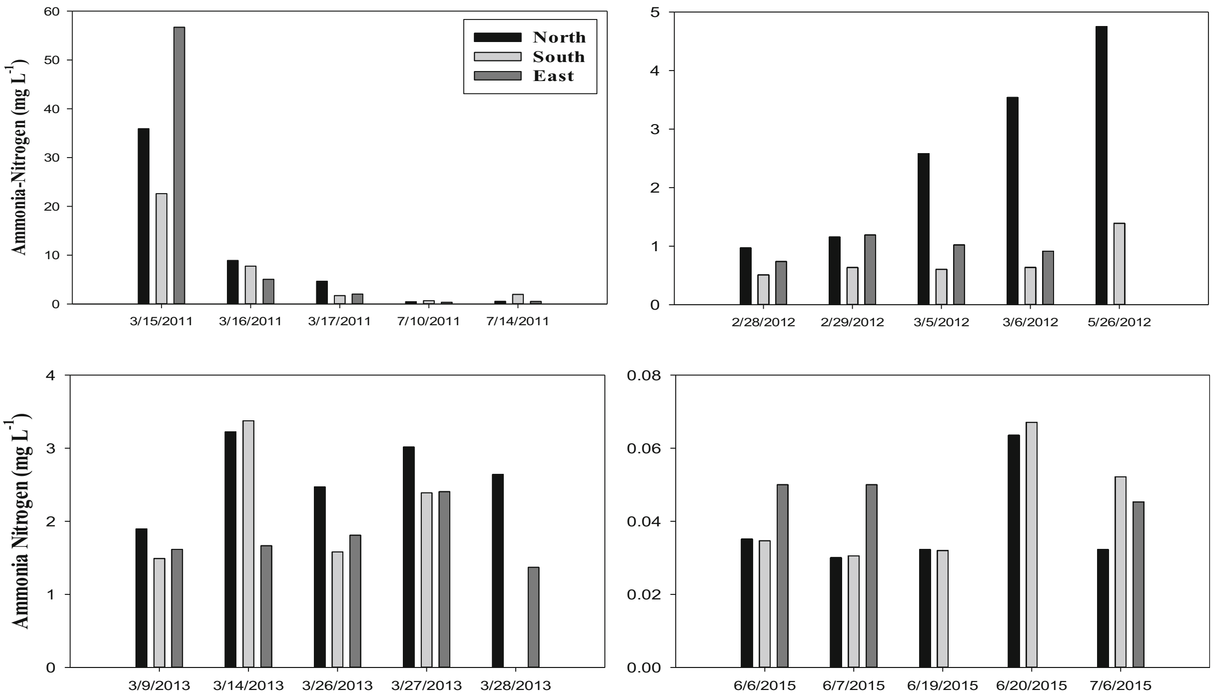

Fig. 3 The ammonium nitrogen content of surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at the upslope in south and at the downslope in north watershed) and control (east) watershed (no manure application) for the 2011, 2012, 2013, and 2015. Note: There was only one event in 2014 and hence not shown in the figure

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 water samples from NW had higher nitrate concentration compared to that of SW which could not be statistically tested due to limited number of data points. This was due to the reason that manure application in NW was near the outlet which led to more nitrate concentration in the runoff. In 2015, nitrate concentration values were lower 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 (Fig. 2). On June 19 and 20, nitrate concentrations were 10.5 and 43% lower in SW compared to that in NW, respectively, whereas no runoff was collected from CW on these sampling days. 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. According to Chinkuyu et al. (2002), the nitrate nitrogen was higher in fertilizer applied soil than manured soil. Similar trend was observed by these researchers for the phosphate loss. Zhang et al. (1996) reported that fertilizer application to soils leads to increased nitrate nitrogen content in the drinking water (300 mg L^{-1}).

Ammonia-N Manure is a rich source of ammonia-N and organic nitrogen (Hooda et al. 2000). The runoff samples in this study were also tested for ammonia-N (Fig. 3). In 2011, the ammonia-N concentration was the lowest in the runoff samples from SW. On March 15, 2011, it was observed that the runoff water ammonia-N content was highest in CW (56.7 mg L^{-1}), followed by NW (35.9 mg L^{-1}) and SW (22.6 mg L^{-1}). This may be attributed to the fact that the first runoff event was observed during this day (March 15) which carried larger amount of ammonia with it into the stream. The ammonia loss was lower or almost the same in the subsequent days after March 15 from the watersheds. However, the trend was very much similar to what we expected but ammonia-N was not statistically significant among the watersheds (Fig. 3). In 2012, it was observed that the water samples from the SW had the least ammonia-N concentration. Comparing the three

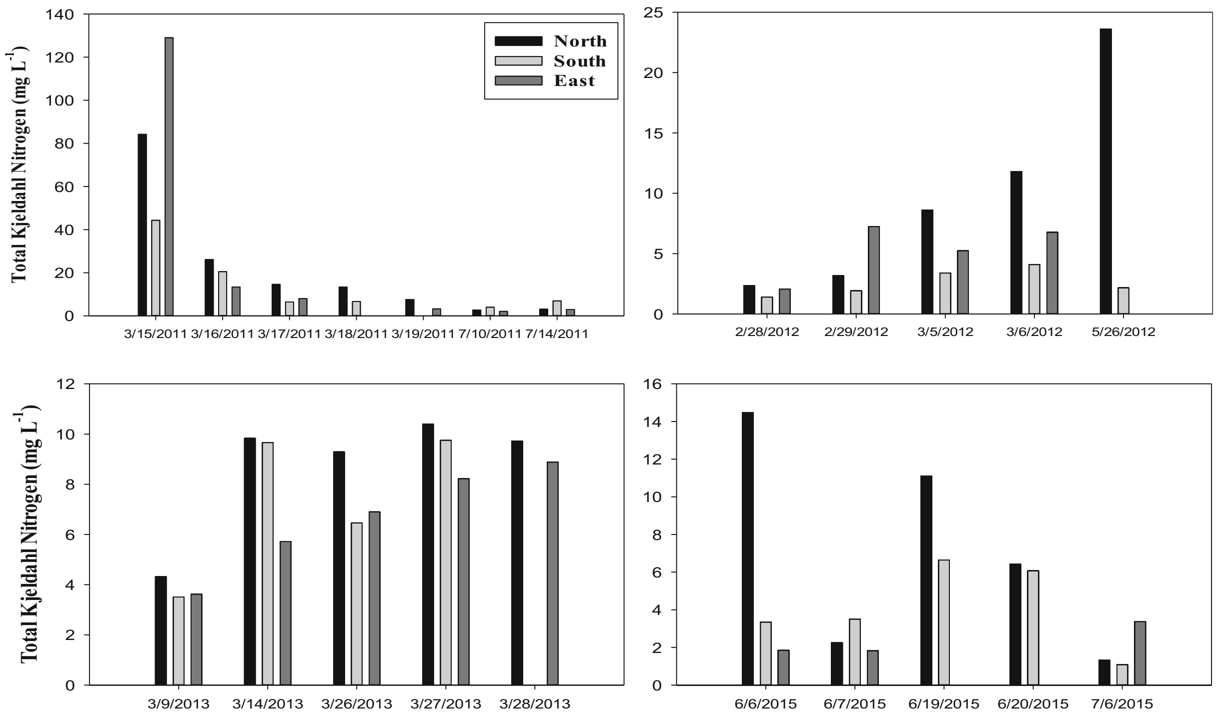

Fig. 4 The Total Kjeldahl Nitrogen content of surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at the upslope in south and at the downslope in north watershed) and control (east) watershed (no manure application) for the 2011, 2012, 2013, and 2015. Note: There was only one event in 2014 and hence not shown in the figure

watersheds, it was observed that ammonia-N concentrations of the runoff samples from NW and CW were not significantly different, even though NW showed higher concentrations of ammonia-N. There was a significant difference ($P < 0.02$) in ammonia-N concentrations in the runoff samples from SW and CW, and SW had significantly lower concentration than that of CW. In 2013, it was observed that the trend was similar and the ammonia-N loss in runoff from NW was significantly higher ($P < 0.02$) than the CW while there was no difference between runoff samples' ammonia-N concentration from SW and CW. Since 2013 was the third year of the experiment, manure application near the outlet increased the ammonia-N build up in that part, due to which when runoff occurred, it carried most of the ammonia-N with it. It may also be attributed to the fact that since manure rate was according to the crop requirement need but the rainfall that occurred during that year was less which may also increase the concentration of ammonia-N in the runoff samples. Thus, reduced rainfall and manure application near the outlet led to the increased concentrations of ammonia-N in samples collected from the NW. A very similar trend was observed in 2014 with the NW runoff sample having higher concentrations of ammonium nitrogen than that of SW, but due to just one sampling event in 2014, the statistical significance could not be tested. However, in 2015, the loss of ammonium nitrogen was very less, even below 1 mg L^{-1} from all the watersheds. This may be attributed to the fact that the manure application in this year was delayed due to weather conditions and the manure was spread during late March. Thus, due to absence of the snow cover, ammonia-N got easily volatilized. On June 6 and 7, 2015, the runoff samples from the CW had the highest ammonia-N loss while the concentration from NW and SW was about the same throughout the year. A study conducted by Berka et al. (2001) reported that application of manure and fertilizers led to contamination of water by ammonia-N.

Total Kjeldahl Nitrogen Total Kjeldahl Nitrogen (TKN) is the measure of the organic nitrogen which should undergo mineralization in order to become available. When runoff occurs, it may carry the Kjeldahl nitrogen with it into the water bodies and cause water quality threats. In all the 5 years of study, the expected trend was

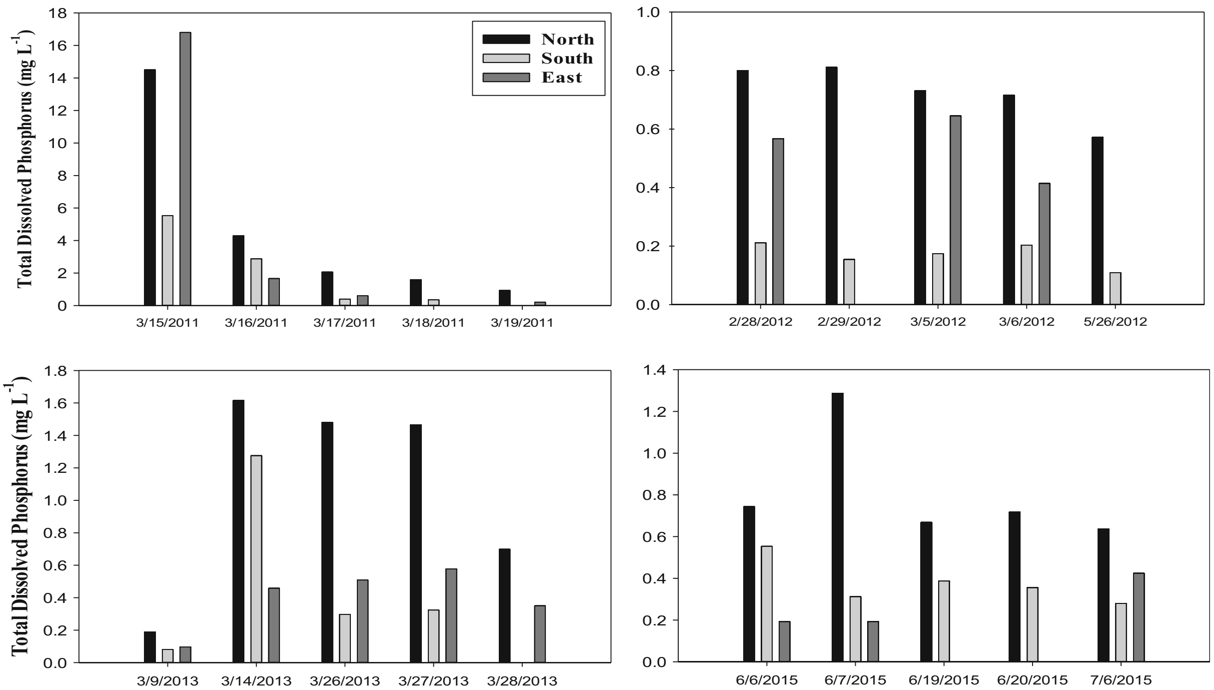

Fig. 5 The total dissolved phosphorous content of surface runoff monitored from small watersheds (north and south) managed with manure (manure applied at the upslope in south and at the downslope in north watershed) and control (east) watershed (no manure application) for the 2011, 2012, 2013, and 2015. Note: There was only one event in 2014 and hence not shown in the figure

followed as shown in Fig. 4. The SW had the least concentration of TKN. For 2011, no significant difference in TKN concentrations was observed among the three watersheds (Fig. 4). However, in 2012 and 2013, it was observed that TKN concentrations in the runoff water samples were not significant between NW and CW, while it was statistically different ($P < 0.04$) between SW and CW. The TKN was lower in the runoff samples from SW may be because the SW had the manure treatment on the upper 50% terrain and the outlet was far from the manure application. Thus, when runoff occurred, the nutrients from manure would have to travel a long distance to reach the outlet. For 2014 and 2015, the statistical significance could not be tested due to less number of sampling events in the CW, even though the trend coincided with that of previous years'.

Phosphorus The phosphorus losses from the watersheds were measured as total dissolved phosphorus (TDP) which contains all the soluble organic and inorganic forms of phosphorus present in the water sample. In 2011, the runoff samples from the SW had the least loss of TDP throughout the year as compared to the NW and CW (Fig. 5). The TDP concentrations were about three times higher in runoff samples from NW and CW as compared to that of SW (Fig. 5). However, there were few exceptions in the trend such as that observed on March 16, 2011 when CW sample concentration was less than that of SW but values were statistically insignificant. There was no statistical difference observed between NW vs. CW and also SW vs. CW. The trend remained consistent in 2012, 2013, 2014, and 2015. The TDP loss in 2012 from NW and the CW was similar but it was significantly lower in SW than the CW ($P < 0.02$). In 2013, it was observed that the runoff samples concentrations had no statistical differences in SW and CW but it was statistically higher ($P < 0.04$) in NW than that of CW. This may be due to the reduced rainfall and manure application near the outlet in the NW. During 2014 and 2015, the trend was similar to the previous years' trends; however, the statistical significance could not be determined due to the less number of sampling events in these years. Results similar to the present study were reported by Chinkuyu et al. (2002). Sharpley and Wang (2014) reported that intense use of fertilizers in agricultural systems leads to an increase in phosphorus losses and eutrophication.

4 Conclusions

Spreading manure on agricultural lands has positive and negative impacts on soils and environmental quality. Data from this study showed that manure application improved organic matter content of the soils which helped in retaining the soil nutrients and also improved soil physical and hydrological properties. Due to the manure application, there is a significant buildup of the soil nutrients in the manure-treated areas, which subsequently improved the infiltration capacity of the soils. Manure application at different landscape positions in the watershed impacted the runoff and water quality. The runoff water quality was better in the watersheds where a setback distance was observed between the manure application and the outlet of the watersheds through which the nutrients entered the streams. However, a very high nutrients loss was observed in the watersheds which did not observe a setback distance between the outlets and the manure-applied areas. It was also observed that the application of inorganic fertilizers also led to water impairment due to the presence of mobile ions that are present in the inorganic fertilizers in order to make them readily available to the plants. Thus, it can be concluded from this study that maintaining a setback distance would help in improving the environmental quality as well as managing the agricultural wastes during the winter months in colder states such as South Dakota.

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