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Soil physicochemical properties influenced by nitrogen sources and rates in the central Great Plains

M.M. Mikha, A.K. Obour, V. Kumar, and P.W. Stahlman

Abstract: Land application of beef cattle (*Bos turus*) manure is a management strategy that can supply essential plant nutrients, enhance land sustainability, and maintain environmental quality. The objectives of this study were to evaluate (1) soil chemical properties and (2) temporal changes in soil nutrient dynamics as influenced by tillage practices (no-tillage [NT] and conventional tillage [CT]) and nitrogen (N) sources (manure and commercial fertilizer; urea) at two application rates (high 134 kg N ha^{-1} y^{-1} [120 lb ac^{-1} yr^{-1}] and low 67 kg N ha^{-1} y^{-1} [60 lb ac^{-1} yr^{-1}]) for both N sources. An unfertilized control treatment with no N added was also included within each tillage treatment. The study was conducted on an Armo silt loam (fine-loamy, mixed, mesic Entic Haplustolls) at Kansas State University Agriculture Research Center near Hays, Kansas, from 2006 to 2016. Soil samples were taken annually at 0 to 15 cm (0 to 6 in) depth prior to spring field operations. Across tillage, soil pH, total N (TN), extractable phosphorus (P), potassium (K), and sodium (Na) were influenced by N source, N rate, and sampling time. The high manure rate treatments increased soil TN by an average of 19% compared with the commercial N fertilizer and control treatments. Eliminating tillage enhanced soil TN accumulation in the top 15 cm of soil by approximately 9% more than CT. Extractable soil P measured in 2016 increased by approximately 401% compared with 2006. Similarly, soil P increased by approximately 331% with high manure and by 66% with low manure compared with commercial fertilizer treatments. Manure addition at high and low rates had 43% and 20% increase in soil available K, respectively, compared with commercial fertilizer treatments. The observed temporal variability in soil extractable P, K, and Na were mostly related to manure addition. The increase in N rates strengthens the relationship between soil electrical conductivity (EC) and soil nitrates (NO_3), especially with commercial fertilizer where the changes in soil EC were 2.8-fold greater than the manure treatments. The significant ($p < 0.05$) changes in soil chemical properties influenced by the management interaction throughout the years (time × tillage × N sources) may take longer than 10 years to be observed in the dryland cropping system of the Great Plains region. However, growers should take extra care to prevent soil P and Na accumulation, specifically when cattle manure is being added to meet the N requirement for crop production.

Key words: nitrogen fertilizer sources and rates—nutrient management—soil science—tillage

Adoption of no-tillage (NT) with reduced fallow frequency is a common crop production practice among dryland producers in the central Great Plains region (Smika and Wicks 1968; Anderson et al. 1999; Halvorson et al. 2002a, 2002b; Schlegel et al. 2017). In the region where the current study was conducted, changes in land management and the adaptation of NT occurred after the 1930s due to the momentous Dust Bowl (Tanaka and Aase 1989; Janzen 2001; Stewart 2004; Li et al. 2007; Hansen et al. 2012). Several croplands in the region lost their topsoil and their productivity to wind erosion as a consequence of continuous tillage and prolonged drought conditions that cumulated with the dust storms (Tanaka and Aase 1989; Stewart 2004; Larney and Angers 2012). Therefore, management practices such as NT and manure amendments that enhance soil sustainability in some eroded cropland affected by the Dust Bowl are being slowly implemented. The adoption of NT in this region has also added several benefits to the croplands over conventional tillage (CT) practices. Some benefits of NT include improving soil water retention (Peterson et al. 1996; Stone and Schlegel 2006; Blanco-Canqui et al. 2015), enhancing soil physical properties (Mikha and Rice 2004; Jin et al. 2011; Mikha et al. 2013, 2015, 2017b), increasing soil organic matter (SOM) and soil available nutrients (Thomas et al. 2007; Deubel et al. 2011; Mikha et al. 2013), positively supporting soil microbial activity and functioning (Acosta-Martínez et al. 2007), and decreasing soil erodibility (Blanco-Canqui et al. 2009).

Usage of manure as an organic amendment can enhance soil nutrient status for crop production (Diacono and Montemurro 2010; Mohammadi et al. 2011; Mikha et al. 2017a) and soil biogeochemical cycling (Acosta-Martínez et al. 2011). Manure application has also been found to improve soil physical properties such as soil aggregation and enhance SOM conservation (Mikha et al. 2015; Miller et al. 2015; Padbhushan et al. 2016; Mikha et al. 2017b). The positive influence of manure addition on soil physical aspects are associated with soil quality such as decreased soil bulk density (BD), increased water holding capacity, improved soil hydraulic properties, and enhanced soil aggregate stability (Arriaga and Lowery 2003; Mikha and Rice 2004; Gill et al. 2009; Mikha et al. 2015, 2017b) that would improve land sustainability for crop production. In addition, multiple years of manure applications were found to improve soil properties such as soil organic carbon (SOC), soil potassium (K), and extractable phosphorus (P), contributing to increased plant nutrient availability, plant nutrient uptake, and crop yields (Griffin et al. 2002; Butler and Muir 2006; Diacono and Montemurro 2010; Sistani et al. 2010; Mikha et al. 2014, 2017a). Previous research reported residual soil nutrients could be maintained for many years after manure application has been discontinued (Larney et al. 2011; Obour et al. 2017).

Maysoon M. Mikha (corresponding author) is a research soil scientist for USDA Agricultural Research Service, Central Great Plains Research Station, Akron, Colorado. **Augustine K. Obour** is a soil scientist, **Vipan Kumar** is a weed scientist, and **Phillip W. Stahlman** is a weed scientist at Kansas State University, Agricultural Research Center, Hays, Kansas.

Manure and fertilizer addition were found to decrease soil pH with increasing the nitrogen (N) rates (Mikha et al. 2006, 2017a; Fageria et al. 2010; Das et al. 2012). The reduction in soil pH associated with commercial fertilizer was found to be associated with the nitrification process of ammonium (NH_4^+) to nitrate (NO_3^-) that resulted in hydrogen ions (H^+) production; whereas, the production of carbon dioxide (CO_2) associated with manure decomposition could form carbonic acid (H_2CO_3) during the interaction with soil water that could contributed to the reduction in soil pH (Chang et al. 1991; Bolan and Hedley 2003; Fageria et al. 2010). Management practices that increase SOM, improve nutrient dynamics, and decrease soil pH are desirable practices due to the calcareous nature of the soil in this eroded study site. Soil nutrient dynamics, solubility, and availability are believed to be partially controlled by the calcareous nature of the soil (Sposito 1989). Soil electrical conductivity (EC) is one of the properties that could increase with increasing manure application (Turner et al. 2010; Das et al. 2012; Mikha et al. 2017b).

The temporal changes in soil nutrient content as influenced by different rates of manure and commercial fertilizers need to be studied further in the eroded drylands that lost their productivity to the 1930s historic wind erosion event. In-depth knowledge on the temporal changes in soil nutrient dynamics associated with organic amendments could further improve management practices to maintain productivity and sustainability of land use. We hypothesize that annual applications of manure would have a greater effect on temporal changes in soil nutrients compared with commercial fertilizer additions. Objectives of this study were (1) to determine the influence of NT and CT and N sources (commercial fertilizer and beef manure) at two rates—low N rate of 67 kg N ha^{-1} y^{-1} (60 lb ac^{-1} yr^{-1}) and high N rate of 134 kg N ha^{-1} y^{-1} (120 lb ac^{-1} yr^{-1})—on soil chemical properties after 10 years of management; and (2) quantify the temporal changes in soil nutrient dynamics associated with 10 years of annual manure addition.

Materials and Methods

Study Design. The study was established in 2006 at the Kansas State University Agriculture Research Center near Hays, Kansas. Soil type was Armo silt loam (fine-loamy, mixed, mesic Entic Haplustolls). The elevation of the experimental site is approximately 606 m (1,988 ft) above sea level and it is located at 38°52' N latitude and 99°19' W longitude. The slope of the study site ranges from 1% to 3%. Long-term mean annual precipitation, averaged across 144 years, is about 560 mm (22 in) as reported by Obour et al. (2017). The total study area was approximately 0.85 ha (2.1 ac) including the alleyways. The experimental area was divided into four replications (blocks) at approximately 13.7 m (45 ft) long and 64 m (210 ft) wide with alleyways of 9.7 m (32 ft) separating the blocks. Each block was divided into 10 individual plots of 6.4 m (21 ft) wide × 13.7 m (45 ft) long.

The treatments consisted of two tillage practices, NT and CT; two N sources; commercial fertilizer (F) that consisted of urea (46-0-0) and beef manure (M); and two N rates—low N (fertilizer [FL] and manure [ML]) rate applied at 67 kg N ha^{-1} y^{-1} (60 lb ac^{-1} yr^{-1}) and high N (fertilizer [FH] and manure [MH]) rate added at 134 kg N ha^{-1} y^{-1} (120 lb ac^{-1} yr^{-1}). The control treatment (no N addition) was also included within each tillage treatment and each block. The CT treatment was performed in spring of every year as subsurface sweep tillage and/or disking at the depth of 15 to 16 cm (6 in) after manure application. Before planting, the soil surface associated with the CT treatment was smoothed for seedbed preparation. In the NT treatments, urea and manure were broadcast and not incorporated to eliminate soil disturbance except for seed planting. Throughout the study period, commercial fertilizer and the control plots did not receive any P fertilization, unlike the manure treatments where P is one of the minerals already present in manure.

The beef manure was added with the assumption that 25% of organic N resulting from manure mineralization, and 100% of manure inorganic N, would be available for crop production during the year of application (Gilbertson et al. 1979). Every year before manure application, manure was analyzed for organic and inorganic N content to calculate the amount of manure addition corresponding to 67 kg manure N ha^{-1} (60 lb ac^{-1}) for the low manure N rate and 134 kg manure N ha^{-1} (120 lb ac^{-1}) for the high manure N rate. Annual application of a constant amount of manure N resulted in different manure mass applied each year. Manure moisture content, the amount of organic N, and the available inorganic N all contributed to the manure mass applied in each year. Due to variations in annual manure characteristics mentioned earlier and degree of manure decomposition, the mass of applied manure for the low manure N rate ranged from 11 to 15 Mg manure ha^{-1} y^{-1} (4.9 to 6.7 tn ac^{-1} yr^{-1}) and from 22 to 30 Mg manure ha^{-1} y^{-1} (9.8 to 13.4 tn ac^{-1} yr^{-1}) for the high manure N rate.

Weed control in NT plots was achieved with crop specific herbicide application. In CT treatments, weeds were controlled by combination of herbicides and sweep tillage using V-blade to 8 cm (approximately 3.1 in) depth; approximately two to three tillage operations were done when needed. Additional details of cropping systems and associated management for weed control are reported in Mikha et al. (2014).

Soil Sampling and Laboratory Analyses. Annually (from 2006 to 2016) during the spring month (March) and before N application, three random soil samples were collected at 0 to 15 cm (0 to 6 in) depth from each plot. A composite sample was taken for soil nutrient analysis and one sample was taken to evaluate soil BD. Soil BD was evaluated using the core procedure as outlined by Grossman and Reinsch (2002). In 2016, the majority of soil BD samples were damaged during the transportation from the study site. Therefore, the soil BD evaluated in 2013 was used to calculate the nutrient mass associated with 2016 sampling. All soil sampling was accomplished using a hydraulic probe (Forestry Supplies, Inc. Jackson, Mississippi) with a 2.5 cm (0.98 in) diameter core. In this study, soil P concentration was determined using Olsen sodium bicarbonate extraction method (Frank et al. 1998) because of the calcareous nature of the soil with pH ranging from 7.8 to 8.1.

Statistical Analyses. Tillage treatments were considered as whole plots that were randomized as a complete block design in four replications using analysis of variance (ANOVA). The PROC MIXED of SAS ver. 9.2 (SAS Institute Inc. 2006) was used for the analysis of variance. The five N treatments (FL and ML, FH and MH, and C) were considered as a subplot randomized within each tillage whole plot. The study period (time) was analyzed as a repeated measure. The protected *F* test was used to perform multiple comparisons of means that evaluate the treatment differences. Unless noted otherwise, all results were considered significantly different at $p < 0.05$. Linear regression and correlation analyses between soil NO_3-N and soil EC were generated for each N treatment (manure and commercial fertilizer) average across tillage treatments and study period (time).

Table 1

Statistical significance of the main and interaction effects of tillage, nitrogen treatments, and sampling date (years) on soil chemical properties from 2006 to 2016 at 0 to 15 cm depth.

Source of variation	Soil properties: pH	Bulk density	Total N	P	K	Na
Years (Y)	***	**	***	***	***	*
Tillage (T)	NS	*	**	**	NS	NS
Nitrogen treatment (N)	***	**	***	***	***	***
Y × T	**	NS	**	**	***	NS
Y × N	NS	**	***	***	***	***
T × N	NS	NS	NS	NS	NS	NS
Y × T × N	NS	NS	NS	**	NS	NS

Notes: NS = not significant. N = nitrogen. P = phosphorus. K = potassium. Na = sodium.

*Significant at $p < 0.1$.

**Significant at $p < 0.05$.

***Significant at $p < 0.0001$.

Results and Discussion

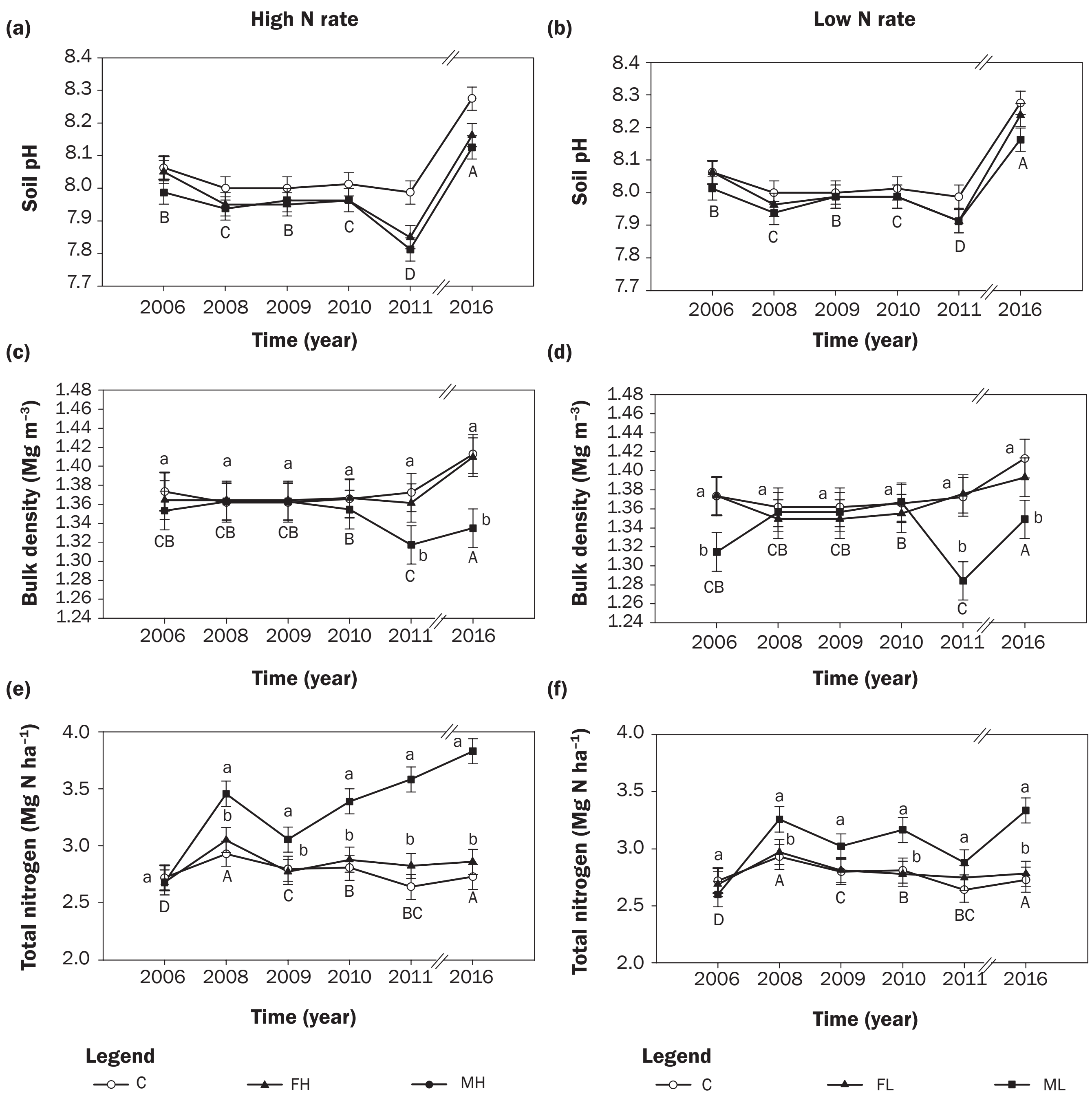
Averaged across N treatments and tillage practices, study period (time) and N sources significantly influenced soil parameters measured at 0 to 15 cm (0 to 6 in) depth (table 1, figures 1 and 2). Soil TN and extractable P were the only properties that were significantly influenced by tillage treatments. Soil BD and soil available Na were not influenced by the study period interaction with tillage treatments (figures 1 and 2). Across time and tillage, applying N as manure or commercial fertilizer had significant effect on all measured soil properties (figure 3). A significant interaction between time and N treatments was also observed with all the properties measured except soil pH (figures 1 and 2). Averaged across time and N treatments, tillage practice had a significant effect on TN ($p = 0.0336$) and soil P ($p = 0.0218$), but not on soil BD, pH, K, or Na content. More details on the influence of N type, N rate, and tillage treatments throughout the study period on different soil nutrients and parameters studied are discussed below.

Soil pH. The temporal changes in soil pH were observed (figures 1a and 1b). Averaged across tillage and N treatments, soil pH decreased by 0.06 units from 2008 to 2010 compared with the initial pH at 2006. In 2011, soil pH further decreased by 0.14 units compared with initial results of 2006. The pH reduction was mostly observed with fertilizer and manure treatment compared with the control. The reduction in soil pH over the first five years of the study period could be mainly due to acidifying cations contributed from N additions from manure or commercial fertilizer compared with the unfertilized control treatment (figure 3). However, soil pH increased in 2016 sampling by 0.16 units compared with the initial (figures 1a and 1b). The increase in soil pH could be related to lower potential SOM mineralization associated with low precipitation throughout 2015 (before the spring sampling in 2016). Total precipitation in 2015 was 502 mm (19.7 in), which was approximately 11% lower than the 144-year-average precipitation (563 mm [22 in]) in this study site. The low precipitation could hinder manure decomposition and commercial fertilizer N nitrification. Previous research reported that changes in soil pH are associated with the acidification effects resulting from manure decomposition and commercial fertilizer N nitrification (Chang et al. 1991; Bolan and Hedley 2003; Villamil and Nafziger 2015; Conceição de Sousa et al. 2017). Averaged across tillage and study period, soil pH was influenced by N rate where soil pH was lower by 1% (0.09 unit) with high N and by 0.6% (0.04 unit) with low N rate compared with the control treatment (figure 3a). Similarly, previous research reported a reduction in soil pH with increasing N rates (Mikha et al. 2006; Fageria et al. 2010; Das et al. 2012; Villamil and Nafziger 2015; Conceição de Sousa et al. 2017; Moinoddini et al. 2017). Throughout the 10 years of the study period, the reduction in soil pH associated with organic amendments or commercial fertilizer addition was likely related to the acidification effects resulting from manure decomposition and commercial fertilizer N nitrification (Chang et al. 1991; Bolan and Hedley 2003; Villamil and Nafziger 2015; Conceição de Sousa et al. 2017). The reduction in soil pH due to management in the current study appears to be small and not biologically significant. However, in calcareous soils where the soil system is overwhelmed with carbonates, a small reduction in soil pH could improve soil nutrient dynamics and nutrient availability for crop uptake. The results generated from this study show that the usage of high N rate reduced soil pH in this calcareous eroded study site. However, it will take a relatively longer time before substantial change in soil pH will be detected due to the high buffering capacity of the calcareous soil at the study site.

Soil Bulk Density. Soil BD at 0 to 15 cm (0 to 6 in) was not influenced by study period (time) or by tillage treatments, but it was significantly influenced ($p = 0.0054$) by N treatments (figure 3b). Time × N treatment interaction was significant ($p = 0.0063$), but the temporal effect on soil BD was inconsistent (figures 1c and 1d). Changes in soil BD can occur slowly in NT or reduced tillage systems, as we observed in this study. Soil BD evaluation can be influenced by several factors including soil moisture content at the time of sampling, soil compaction from farming equipment, and sampling techniques used by the operators (Mikha et al. 2006). The inconsistencies and greater variability in BD measurements observed in this study could possibly be related to some of the factors mentioned earlier. It is also possibly due to the initial differences in BD among the experimental units (figures 1c and 1d). Notwithstanding, compared with the other commercial fertilizer treatments, applying manure (at high or low rates) resulted in a significant reduction in soil BD measured 5 years and 10 years after commencement of the study (figures 1c and 1d). The reduction in BD observed in this study could be related to multiple years of annual manure addition that altered some aspect of soil quality related to the reduction of soil BD such as enhanced soil aggregate stability and soil porosity in addition to increased SOM. Previous research also documented the reduction in soil BD with organic amendments due to

Figure 1

Soil properties measured from 2006 to 2016 at the 0 to 15 cm depth as influenced by nitrogen (N) treatments. C represents control with no N (was added in all the figures for comparison purposes); FH and MH represent fertilizer and manure at high rate (134 kg N ha^{-1} y^{-1}); and FL and ML represent fertilizer and manure at low rate (67 kg N ha^{-1} y^{-1}). (a) and (b) represent soil acidity (pH); (c) and (d) represent soil bulk density (BD); and (e) and (f) represent soil total N (TN). Error bars represent standard error of the mean. Lowercase letters represent significant ($p < 0.05$) differences among the N-treatments across tillage and time within each measurement. Uppercase letters represent significant ($p < 0.05$) differences in time across tillage and N treatments within each measurement.

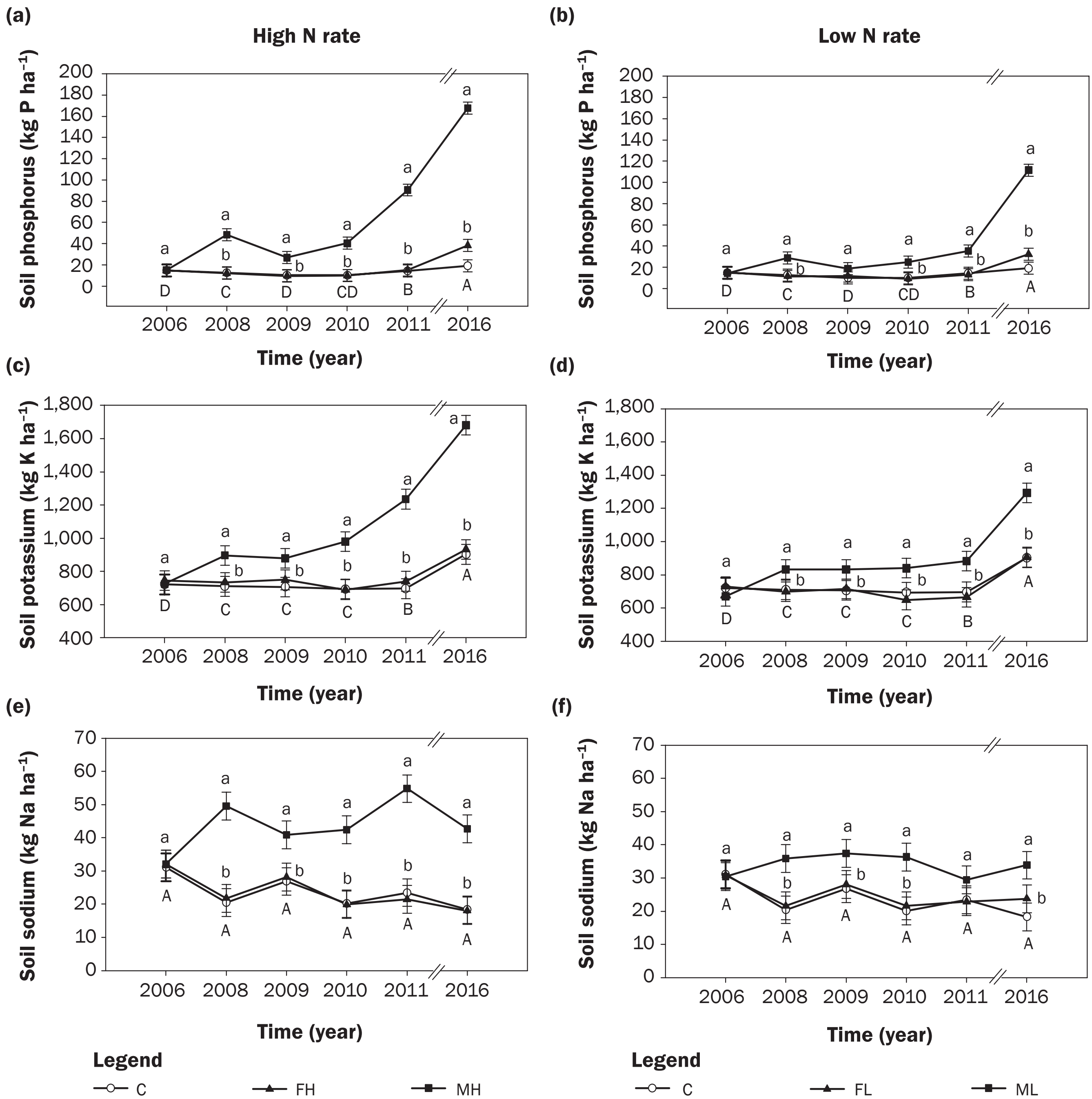


improved soil aggregation and aggregate stability, increased SOM, and enhanced soil porosity (Yilmaz and Alagöz 2010; Sharma et al. 2014; Miller et al. 2015; Padbhushan et al. 2016).

Soil Total Nitrogen. Manure addition at the high N rate significantly ($p < 0.0001$) increased soil TN at 0 to 15 cm (0 to 6 in) depth by an average of 19% compared with commercial fertilizer (high and low rates) and control treatments and by approximately 9% more than the LM treatment (figure 3b). The study period (time) and the interaction of time × N treatments greatly ($p < 0.0001$) increased soil TN with continuous manure

Figure 2

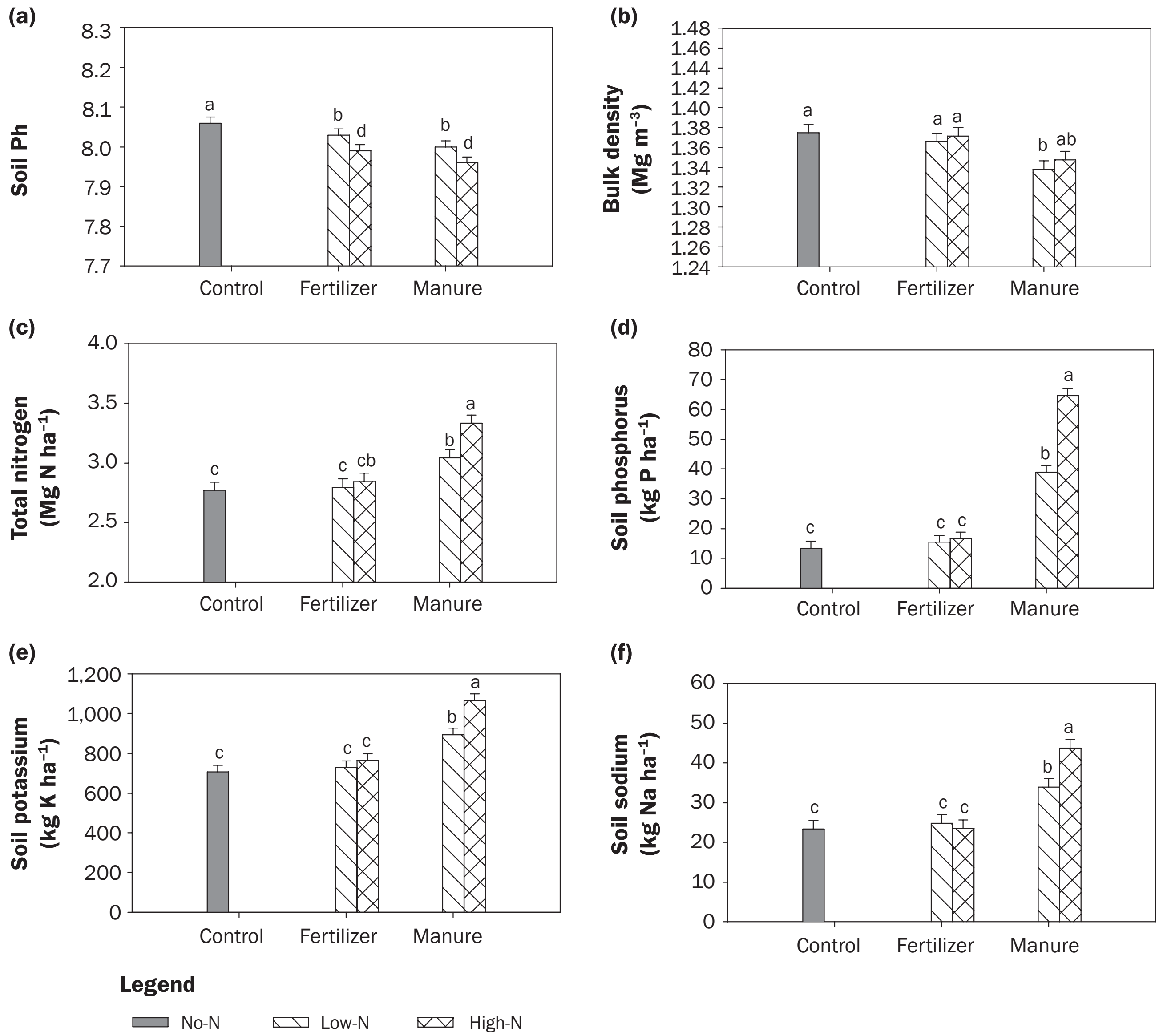
Soil properties measured from 2006 to 2016 at the 0 to 15 cm depth as influenced by nitrogen (N) treatments. C represents control with no N (was added in all the figures for comparison purposes); FH and MH represent fertilizer and manure at high (134 kg N ha^{-1} y^{-1}) rate; and FL and ML represent fertilizer and manure at low (67 kg N ha^{-1} y^{-1}) rate. (a) and (b) represent soil phosphorus (P); (c) and (d) represent soil potassium (K); and (e) and (f) represent soil sodium (Na). Error bars represent standard error of the mean. Lowercase letters represent significant ($p < 0.05$) differences among the N-treatments across tillage and time within each measurement. Uppercase letters represent significant ($p < 0.05$) differences in time across tillage and N treatments within each measurement.



application through time (figures 1e and 1f). This finding agrees with research results that showed an increase in soil TN with multiple years of annual organic amendments compared with commercial fertilizer or control treatments (Mikha and Rice 2004; Dai et al. 2013; Naderi et al. 2016; Mikha et al. 2017a, 2017b). The temporal variability in soil TN was not different among the commercial fertilizer treatments (high and low rates) and the unfertilized control. However, temporal variability associated with manure rates (high and low) were observed to be different than the other treatments after three years of manure application (figures 1e and 1f).

Figure 3

Soil properties at the 0 to 15 cm depth average across tillage and time (2006 to 2016) as influenced by nitrogen (N) treatments (Control represents treatment with no N; Low-N and High-N represent N addition at high and low rates, respectively). Error bars represent standard error. Lowercase letters represent significant ($p < 0.05$) differences among the N treatments within each measurement.



After 10 years of management across tillage treatments and time, TN content associated with commercial fertilizer treatments was not different from the control treatment that had no N added. This indicates that organic amendment is an important management strategy to increase SOM and thus improve soil TN content in this semiarid site. Soil organic matter, in general, increased with the addition of organic amendments because of the extra organic matter associated with manure added annually compared with commercial fertilizer treatment where the only organic matter addition was associated with crop residue and root biomass (Larney et al. 2011; Brar et al. 2013; Blanco-Canqui et al. 2015; Mikha et al. 2017b). Averaged across time and N treatments, tillage significantly ($p = 0.0407$) influenced soil TN where NT contained approximately 8% higher TN than CT. Increased soil TN with NT was expected because of minimal soil disturbance and less organic amendment and crop residue mixing that led to reduced SOM decomposition. It has been previously documented that NT protects the soil surface from wind and water erosion, enhances soil structural properties, and preserves SOM and aggregate-associated organic matter from rapid decomposition (Mikha and Rice 2004; Blanco-Canqui et al. 2009; Alijani et al. 2012; Mikha et al. 2013; Naderi et al. 2016).

Soil Extractable Phosphorus. Soil extractable P measured at 0 to 15 cm (0 to 6 in) was significantly influenced by time ($p < 0.0001$), N treatments ($p < 0.0001$), time × N treatments interaction ($p < 0.0001$), and by tillage ($p = 0.0218$). Averaged across N and tillage treatments, the temporal changes in soil extractable P content were observed (figures 2a and 2b). The temporal variability in soil extractable P was mostly related to the inclusion of manure treatments (high and low rates) rather than the commercial fertilizer and control treatments. There were no observed differences in temporal changes in soil extractable P among commercial fertilizer (high and low rates) and control treatments. This was expected because in this study, no commercial P fertilizer was added to the commercial N fertilizer treatments or the unfertilized control. The temporal changes in soil extractable P associated with manure treatments were related to the different levels of extractable P content associated with annual manure addition. The manure chemical analysis and P content was previously reported in Mikha et al. (2014). Averaged across N treatments and tillage, soil extractable P increased in 2016 by approximately 401% compared with 2006 and by approximately 119% compared with 2011. Averaged across tillage and time, applying manure at a high rate greatly increased soil extractable P by approximately 331% compared with commercial fertilizer (high and low rates) and control treatments and by approximately 66% compared with manure at a low rate (figure 3d). Similarly, the low rate of manure significantly increased soil extractable P (38.9 kg P ha^{-1} [37.4 lb P ac^{-1}]) by approximately 159% compared with soil extractable P associated with commercial fertilizer (high and low rates) and control treatments (15 kg P ha^{-1} [13.5 lb P ac^{-1}]). Increase of soil extractable P with 10 annual applications of manure was supported by previous studies that documented an increase in soil extractable P with increasing manure application rates (Whalen and Chang 2001; Leytem et al. 2005; Sistani et al. 2010). Acknowledging P accumulation risk, especially near the soil surface, is important to prevent potential P losses in the runoff (Kleinman and Sharpley 2003; Sistani et al. 2010). The majority of the previous reports were generated from the management practices located in the east part of the United States where the mean annual precipitation exceeds the precipitation in the central and the west part of the country. Thus, the risk of P runoff associated with cropland management is more critical in the east than the west section of the country where our study site is located. The mean annual precipitation of 560 mm (22 in) made the risk of P runoff unlikely to occur, but not impossible due to rain intensity. Therefore, care needs to be taken to manage soil P content when applying cattle manure to avoid P accumulation. It is also important to mention that in this study, manure was added to meet the N requirement for crop production without considering the manure extractable P content; this assumption led to increased extractable P with manure treatments as manure rates increased (figure 3d). A best management practice could be reducing manure addition frequency or reducing manure application rates to prevent P accumulations and avoid the risk of P runoff.

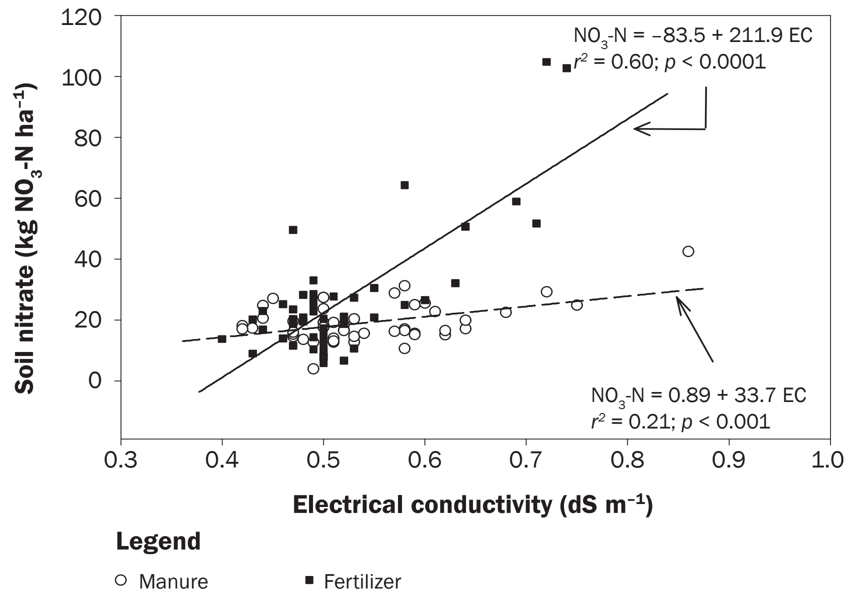
Soil Extractable Potassium. Soil extractable K content was significantly ($p < 0.0001$) affected by sampling time. For example, soil available K measured in 2016 was approximately 59% more than that measured in 2006 and 48% greater than that between 2008 and 2011 (figures 2c and 2d). The temporal increase in soil available K was probably related to accumulation of K with manure applied throughout the 10 years of the study period. The temporal changes in K associated with manure treatments (high and low rates) were greater than that of the commercial fertilizer or control treatments (figures 2c and 2d). The two-way interaction of time × N treatments was significant ($p < 0.0001$), and it was mainly associated with manure additions (figures 2c and 2d). As expected, K present in the beef cattle manure contributed to the increase in soil K content associated with manure treatments compared with commercial fertilizer and control treatments. The commercial fertilizer treatments (high and low rates) received no K as commercial fertilizer. Therefore, temporal variability for commercial fertilizer (high and low rates) and the control treatments were similar from 2006 to 2016 (figures 2c and 2d). The increase in soil K associated with commercial fertilizer and control treatments in 2016, observed in this study, could be related to the K accumulation associated with excess amount of extractable K that already existed as part of the original soil mineralogical composition, which exceeded crop need. The data generated from this study showed that the amount of soil K associated with commercial fertilizer and control is more than sufficient for crop production in the semiarid Great Plains. Therefore, the added K associated with manure caused an excess amount of soil K that could not necessarily benefit the crop production. In this study, soil available K content with commercial N fertilizer treatments were not different from the unfertilized control treatment (figures 2c and 2d). These data agree with previously reported research that documented no soil K response to commercial fertilizer N addition at any rate compared with control (Shahaboddin et al. 2017; Chen et al. 2018). Averaged across time and tillage, manure treatment at the high rate substantially ($p < 0.0001$) increased soil available K by an average of 43% compared with commercial fertilizer (high and low rates) and control treatments and by approximately 19% compared with manure at the low rate. Similarly, low rate of manure addition increased soil K by an average of 20% compared with commercial fertilizer (high and low rates) and control treatments (figure 3e). Data generated from this study indicate a positive relationship between manure application rate and soil available K.

Soil Extractable Sodium. Extractable Na was greatly ($p < 0.0001$) affected by N treatments and by the two-way interaction of N treatments × time ($p < 0.0001$). The temporal variation was observed with manure treatments (high and low rates), and it was significantly greater than commercial fertilizer (high and low rates) and control treatments. Whereas, the temporal changes in soil Na associated with commercial fertilizer (high and low rates) and control treatments were similar (figures 2e and 2f). Similar to the other soil nutrients evaluated in this study, the manure Na content contributed to the temporal soil Na compared with commercial fertilizer and control treatments. Averaged across time and tillage, the addition of high rate of manure increased soil Na by an average of 83% compared with commercial fertilizer (high and low rates) and control treatments and by approximately 29% compared with manure at the low rate. Likewise, the addition of low rate of manure increased soil Na by an average of 42% compared with commercial fertilizer (high and low rates) and control treatments (figure 3f). Chen et al. (2018) also reported an increase with soil Na as manure application rate increased, whereas addition of commercial N fertilizer (NPK) at different rates did not increase the soil Na level compared to the control treatment. The positive relationship between soil Na content and manure treatments needs to be closely monitored to prevent Na buildup to levels that could affect future crop and soil productivity.

Relationship between Electrical Conductivity and Nitrate-Nitrogen. The relationship between soil EC and soil NO_3-N was performed for 2006, 2008, and 2009 data. In 2010 and 2011, soil NO_3-N was evaluated to be less than 2 kg N ha^{-1} (1.8 lb N ac^{-1}), where the relationship between EC and NO_3-N did not hold; therefore, the 2010 and 2011 data were eliminated from the correlation. The low soil NO_3-N in 2010 and 2011, observed in this study, and the high EC reported in Mikha et al. (2014), indicated that the increase in soil EC was not exclusively related to NO_3-N presence in soil. Soil EC of 2016 was not included in the relationship because of the measurement gap and loss of the measurement's continuity from 2011 to 2016. A positive and significant relationship between soil EC and soil NO_3-N was observed (figure 4). This relationship was greatly influenced by the N source applied. The slope of the line associated with commercial fertilizer was 6.3-fold greater than the slope of the line associated with manure application. The significant correlation between EC and soil NO_3-N (r^2 = 0.6 for commercial fertilizer and r^2 = 0.21 for manure) indicates that soil EC increased as soil N content increased. Yanai et al. (1996) concluded that the strong and positive relationship between soil EC and NO_3-N could be related to the fact that NO_3-N is present in high quantities in soil solution, compared to other anions, and it is hardly absorbed by soil matrix due to its negative charge; thus, NO_3-N concentration exhibits the major influence on soil solution decomposition. The greater influence of NO_3-N associated with commercial fertilizer on changes in soil EC compared with manure could be related to the fact that the commercial fertilizer contained only N (urea) while manure contained other nutrients (ions) such as calcium (Ca^{++}), magnesium (Mg^{++}), Na^+, and chlorine (Cl^-) that could contribute to the changes in soil EC. The positive relationship, specifically with commercial fertilizer treatment, agrees with Mikha et al. (2006) who reported a significant positive correlation (r^2 = 0.63) between soil EC and soil NO_3-N in a multilocational study in the central Great Plains region. Similarly, Smith and Doran (1996) observed a positive correlation of r^2 = 0.74 between soil EC and soil NO_3-N. Previous research documented an increase in soil EC with increasing N additions from commercial fertilizer or manure (Chang et al. 1991; Turner et al. 2010; Das et al. 2012). However, the relationship between EC and NO_3-N requires further investigation to understand the influence of manure associated nutrients (cation and anion) on soil EC.

Figure 4

Relationship between soil electrical conductivity (EC) and soil nitrate-nitrogen (NO_3-N) at 0 to 15 cm depth as influenced by fertilizer and manure addition.



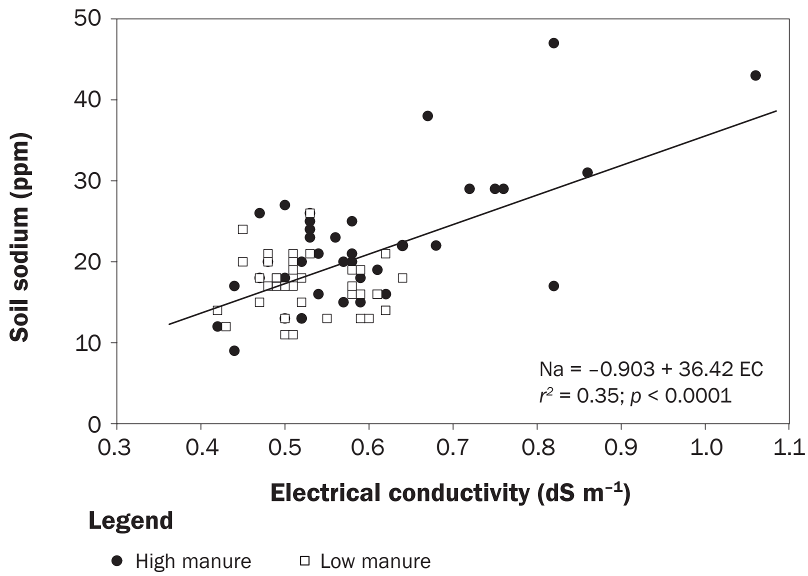
Relationship between Electrical Conductivity and Sodium. To evaluate the influence of soil Na in changing soil EC, the correlation between soil EC and soil Na (ppm) was performed from 2006 to 2011 for manure treatments because no synthetic Na was added to the commercial fertilizer treatments (figure 5). A significant (p < 0.0001) and positive correlation was observed between EC and Na with r^2 = 0.35 indicating that soil EC increased as manure rates increased. Nevertheless, the correlation between soil EC and manure-associated Na is not particularly strong, indicating that not only one specific nutrient influences soil EC, but it could be the combinations of several nutrients associated with manure. Our finding requires further investigation in multiple study sites with different soil types and multiple years of manure addition.

Summary and Conclusions

The temporal changes of the majority of soil parameters were significant except for soil BD and Na. Across the study period, the addition of manure greatly enhanced soil nutrient status and decreased soil BD compared with commercial fertilizer and control treatments. Increasing N application rates decreased soil pH irrespective of N source. Applying manure increased accumulation of residual soil P regardless of manure application rate, possibly due to manure additions that were based on crop N requirement. A positive correlation was observed between soil NO_3-N and soil EC. This relationship was stronger with commercial fertilizer than manure, indicating that manure nutrient content, other than NO_3-N, could contribute to the changes in soil EC. A positive correlation was observed between soil Na and soil EC in manure treatments. Our data showed that changes in soil EC with manure treatments could be related to the combination of manure-associated nutrients. Results supported our hypothesis that the temporal changes in soil nutrient dynamics were more pronounced with manure than commercial fertilizer treatments. In general, careful selection of manure application rates and frequency is needed to prevent soil P and Na accumulation, specifically when manure is being added to meet the N requirement for crop production. A suggestion for the site management could be to reduce manure application frequency or choose a manure rate to prevent excess nutrient accumulation, such as N, P, K, and Na, and prevent the risk of nutrient runoff or leaching.

Figure 5

Relationship between soil electrical conductivity (EC) and soil sodium (Na) at 0 to 15 cm depth as influenced by manure rates.



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