SUB-SURFACE DRAINAGE AND NITROGEN FERTILIZER MANAGEMENT INFLUENCES ON SUGARBEET YIELD AND SOIL NITROGEN DYNAMICS UNDER SILTY-CLAY SOIL

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INTRODUCTION

Drainage and flooding are critical problems in the Red River Valley (RRV) of North Dakota and Minnesota due to the flat topography and dominant poorly drained clay soils (Jin et al., 2008). Installing subsurface drainage can reduce the chance of water logging and prevent saturation by lowering the water table. Shifting water and temperature regimes influence the below ground nitrogen (N) dynamics (Bouwman et al., 2010).On the other hand, a considerable amount of soil available N can potentially be lost through the tile drains as NO_3^--N (Jaynes & Colvin, 2006). Moreover, decreasing soil water content through sub-surface drainage may increase N loss as NH_3 volatilization (Clay et al., 1990). Poorly-drained soils in the Red River Valley that warrant targeted N management include soils with high clay content. Knowledge of the trade-offs between N_2O emissions, NO_3 leaching and NH_3 volatilization from N fertilizer management practices and crop yield under subsurface drainage is therefore an essential requirement (Millar et al., 2010).

OBJECTIVES

This research experiment determined how N fertilizer management practices influenced (1) sugarbeet yield and quality, (2) inorganic soil N availability, (3) denitrification loss of N in the form of nitrous oxide (N_2O), (4) soil solution nitrate (NO_3)-N concentration, and (5) ammonia (NH_3) volatilization loss of N from soils under sugarbeet (*Beta vulgaris (L.)*) production.

MATERIALS AND METHODS

Field experiment was conducted during 2012-2013 growing season at NDSU research site (46.932°N, 96.858°W) near Fargo, ND on a Fargo-Ryan silty clay soil complex. The soil is classified as fine, smectitic, superactive, frigid, Typic Epiaquerts (Soil Survey Staff, 2013). A Randomized Complete Block design was laid out with four replicates in split-plot arrangement with (1) subsurface drainage and (2) undrained conditions as the main plot factors and nitrogen management practices: (1) control (0 N), (2) 146 kg N ha^{-1} (130 lb N $acre^{-1}$), (3) 180 kg N ha^{-1} (160 lb N $acre^{-1}$), (4) 146 kg N ha^{-1} with instinct as the sub plot factors in both years. Fertilizer-N was applied in the form of urea. Each sub-plot measured 6.1 m (20 feet) long by 3.4 m (11 feet) wide. The required rates of urea fertilizers were uniformly broadcasted with hand on May 10th and May 29th respectively in 2012 and 2013. The fertilizers were then incorporated using Triple K field cultivator with rolling basket. On the same day, sugarbeet variety Crystal 985 Roundup Ready was planted with a John Deere Max Emerge II planter. The seeds were placed 3.2 cm (1.2 inch) deep with 56 cm (22 inch) row spacing and 7.6 cm (3 inch) in-row spacing. Roundup herbicide (35 L ha^{-1}) was applied for weed control. Subsamples of the sugarbeet roots were sent to American Crystal Sugar Quality Tare Lab, East Grand Forks, MN for quality analysis. The monthly precipitation events and monthly average air temperatures throughout the sugarbeet growing seasons (2012 and 2013) are shown in Table 1.

Table 1. Monthly precipitation totals average monthly temperatures during the growing season for 2012 and 2013, and 32-year long term average at the research site recorded by Fargo NDAWN weather station.

Month	Precipitation (mm)			Temperature (°C)		
	32-Year	Growing seasons		32-Year	Growing seasons	
	Average	2012	2013	Average	2012	2013
April	35	29	43	7	9	1
May	71	43	141	14	16	14
June	99	57	199	19	21	19
July	71	30	26	22	25	22
August	65	21	12	21	21	22
September	65	1	106	15	15	18
October	55	62	112	8	7	7
Total	461	244	641	†15	†16	†15

†Growing season average temperatures

Plant Sampling and analyses: Tissue N concentration in sugarbeet tops were measured on July 30th during 2013 growing season. Within each plot, 25 to 30 fully developed recently matured leaves were sampled and dried at 65°C for a week. The dried samples were grinded in a Thomas Wily mill to pass a 2 mm screen and subsamples were sent to ©Agvise laboratories, Northwood, ND for total N determination. Sugarbeet leaf chlorophyll readings were also taken using a hand held chlorophyll meter SPAD-502 Plus (Konica Minolta Optics, Inc., Japan) on August 12 during the 2013 growing season.

Soil Sampling and analyses: Before planting, soil cores (3.6 cm diameter) up to a depth of 120 cm were collected per block in order to determine initial soil inorganic N levels. After planting, soil samples were collected from the upper 30 cm soil profilewith 15 cm increments for both growing season. Two soil cores (2 cm diameter) were collected and composited for each sub-plot. Field moist soil samples (6.5 g) were extracted with 25 mL of 2M KCl in the laboratory. The extracts were for inorganic N (NH_4^+-N and NO_3^--N) contents using a Automated Timberline TL2800 Ammonia Analyzer. Soil moisture content was determined by gravimetric weight loss on heating a sub sample at 105°C for 24 h and used to calculate the bulk density of the soil cores and to convert the inorganic N concentrations on dry weight basis. Water filled pore space (WFPS) - presented in Fig.1 - was calculated from the equation:

$$\text{WFPS} = (\text{SWC} \times \text{BD}) / (1 - (\text{BD}/\text{PD}))$$

where, SWC is the soil water content ($g\ g^{-1}$), BD is the bulk density ($Mg\ m^{-3}$), and PD is the particle density ($2.65\ Mg\ m^{-3}$).

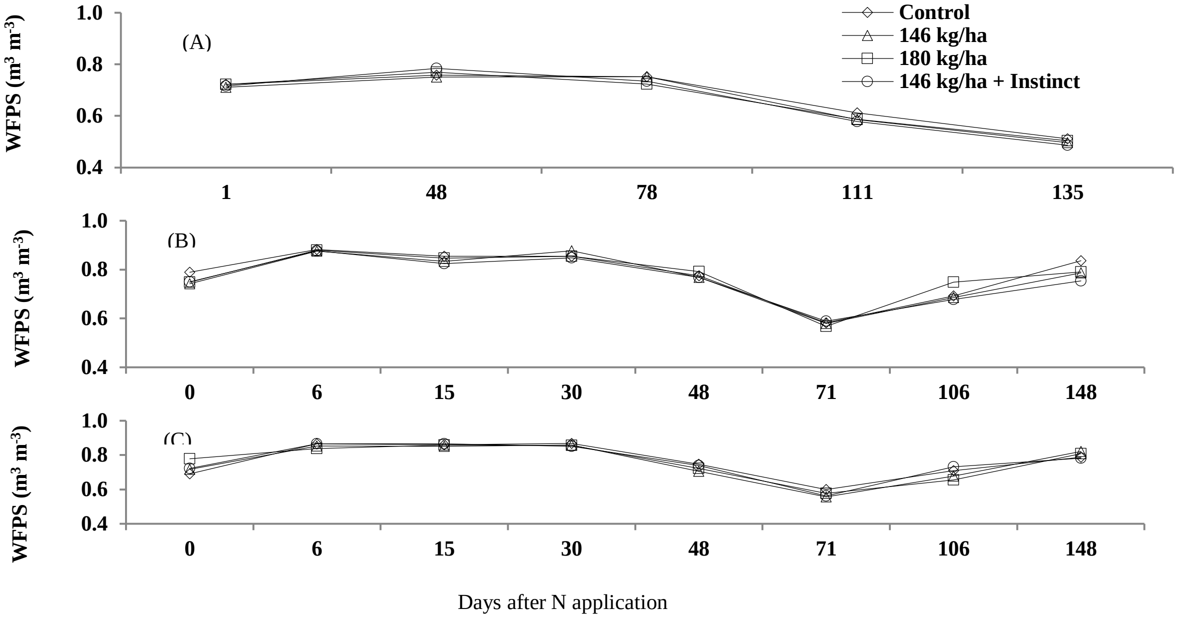

Fig.1. Water filled pore space (WFPS, $m^3\ m^{-3}$) measured during sugarbeet growing seasons for all the N-management plots in (A) 2012, (B) 2013, undrained condition, and (C) 2013, drained condition.

Net N mineralized between the successive soil sampling dates were calculated by subtracting the soil (0-30 cm depth) inorganic-N contents (NH_4^+-N + NO_3^--N) in the preceding date from that of the succeeding date. A positive difference represented net N mineralization, while a negative difference indicated net immobilization during the period. Net N mineralization was measured for 4 and 7 periods respectively in 2012 and 2013. Finally, cumulative net N mineralized (Nmin) during a growing season was then computed as the sum of net N mineralized across the individual periods.

$$\text{Nmin} = \sum (N_f - N_i)$$

where, N_i and N_f are the total inorganic-N contents for consecutive ith and fth days, respectively.

Table 2. Sugarbeet petiole-N concentrations (%) and leaf chlorophyll readings measured during 2013 growing season on July 30 and August 12, respectively. Different lower case letters within the same column indicate significant difference at 90% significance level.

N-fertilizers	Petiole-N Concentration		SPAD meter reading	
	Undrained	Drained	Undrained	Drained
	----------------%------------------		-----------Spad Units---------	
Control	[†]4.54 ± 0.04	4.52 ± 0.05	39.9 ± 1.21	40.9 ± 0.88
146 kg ha^{-1}	4.55 ± 0.05	4.54 ± 0.13	41.0 ± 1.06	42.4 ± 1.12
180 kg ha^{-1}	4.43 ± 0.06	4.61 ± 0.06	41.4 ± 0.62	42.8 ± 0.67
146 kg ha^{-1} + Instinct	4.62 ± 0.03	4.63 ± 0.05	41.7 ± 1.05	42.5 ± 1.26
LSD (P<0.10)	n.s.	n.s.	n.s.	n.s.

[†] Values are mean ± standard errors (n=4); n.s. signifies no significant differences.

In 2012, N_2O emission rate from surface soil was measured using semi-permanent vented static PVC chamber following the GRACEnet project protocol outlined by Parkin and Venterea (2010). Gas samples were collected on 7-, 24-, 28-, 35-, 42-, 54-, and 73-d after fertilizer application. The samples were analyzed for N_2O concentration using a Dani Master GC. Samples of the soil solution at 60 cm depth were collected using suction lysimeters and extracted 6 times (26-, 29-, 33-, 36-, 40-, and 54-d after N-application) during 2013 sugarbeet growing season. A lysimeter was installed in the middle of each plot in between the sugarbeet rows. In 2013, NH_3-N volatilization losses were measured using semi-static open chambers (Jantalia et al., 2012).

Statistical Analyses: Data were analyzed using an RCBD with a split plot arrangement with drainage and nitrogen fertilizer management as main factors for the analysis of variance as calculated by SAS PROC MIXED process. Mean separations were tested using Fisher's least significant difference at alpha level=0.10.

RESULTS AND DISCUSSION

Sugarbeet yield and quality parameters:

Management of N-application had no effect on beet yield in 2012 growing season (Table 2). Percentage of sugar loss to molasses (SLM%) significantly increased with high N application rate of 180 kg ha^{-1} than recommended rate of 146 kg ha^{-1} or control.

Table 3. Nitrogen fertilizer management effect on sugarbeet yields and quality parameters during 2012 growing season. Least significant difference (LSD) values provided for P<0.10; n.s. indicates no significant difference.

Treatments	Root Yield (Tons/acre)	[†]SLM (%)	Net Sucrose (%)	[§]Gross Ton ($/ton)	[¶]Gross Acre ($/acre)
Control	21.2	1.65^{c}	16.8	64.2	1357
146 kg ha^{-1}	21.4	1.80^{bc}	16. 8	64.2	1407
180 kg ha^{-1}	21.1	1.95^{a}	15.9	58.7	1304
146 kg ha^{-1} + Instinct	20.2	1.85^{ab}	16.8	64.4	1311
LSD (P<0.10)	n.s.	0.15	n.s.	n.s.	n.s.

[†]SLM = Sucrose Loss to Molasses, a measure of impurity content; [§]Gross Ton = Gross Revenue per Ton; [¶]Gross Acre = Gross Revenue per Acre.

The average root yield, SLM%, net sucrose concentration along with the estimated gross revenues of sugarbeet for 2013 growing season as influenced by subsurface drainage and N-fertilizer managements are presented in Table 4. Sugarbeet root yields ranged from 36.7 to 40.1 Mg ha^{-1} (16.4 to 17.9 tons acre^{-1}) and from 35.8 to 41.0 Mg ha^{-1} (16.0 to 18.3 tons acre^{-1}) under undrained and drained plots, respectively. The root yield and quality parameters were not influenced by either subsurface drainage managements or N-fertilizers in 2013 (Table 4). The measured water filled pore space (WFPS) across the plots were found to be similar throughout the 2013 growing season, regardless of drainage (Fig.1), confirming little or no response of subsurface drainage on lowering soil water content during excessive wet soil condition.

Table 4. Drainage and N-fertilizer management effects on sugarbeet yields and quality parameters during 2013 growing seasons. Different lower case letters within the same column and row for a yield parameter indicate significant difference at 90% significance level.

N-treatment	Root Yield		[†]SLM		Net Sucrose		[§]Gross Ton		[¶]Gross Acre	
	[ǂ]U	[*]D	U	D	U	D	U	D	U	D
	---tons/acre---		-------------------%-----------------				-----$/ton----		---$/acre---	
Control	17.6	16.4	1.54	1.69	14.5	14.4	50.9	50.1	893	817
146 kg ha^{-1}	17.9	18.3	1.58	1.81	14.3	13.5	49.3	44.6	880	813
180 kg ha^{-1}	16.4	16.0	1.73	1.68	13.9	13.9	47.5	46.8	780	764
146 kg ha^{-1} + Instinct	17.7	16.5	1.74	1.67	13.8	14.3	46.2	49.1	816	808

[†]SLM = Sucrose Loss to Molasses, a measure of impurity content; [§]Gross Ton = Gross Revenue per Ton; [¶]Gross Acre = Gross Revenue per Acre; [ǂ]U = Undrained; and [*]D = Drained.

Cumulative net N-mineralization:

Nitrogen fertilizers significantly influenced cumulative net N-mineralization (Nmin) during 2012 growing season (Table 5). As expected, Nmin was the lowest with the control plots and averaged 86 kg ha^{-1} which is nearly 42% of the recommended N-rate (146 kg ha^{-1}) in beets. In 2013, drainage had no significant effect on Nmin. Studies have pointed out that soil microbial activity and net N mineralization fluctuates with soil water content and temperature (Guntinas et al., 2012). Similar to 2012, Nmin was significantly influenced by N-fertilizers in 2013 (Table 5).

Table 5. Cumulative net N-mineralized (kg/ha) from N-fertilizers as affected by drainage managements during 2012 and 2013 sugarbeet growing seasons. Least significant difference (LSD) values provided for P<0.10.

N-fertilizer	[†]2012	2013	
		Undrained	Drained
Control	[ǂ]86 ± 26^{c}	88 ± 8^{b}	76 ± 21^{c}
146 kg ha^{-1}	182 ± 31^{b}	198 ± 19^{a}	157 ± 62^{b}
180 kg ha^{-1}	290 ± 47^{a}	304 ± 75^{a}	292 ± 36^{a}
146 kg ha^{-1} + Instinct	249 ± 31^{ab}	214 ± 4^{a}	186 ± 30^{b}
LSD (P<0.10)	73	101	52

[†]Drainage effects in this year was not considered; [ǂ] Values are means ± standard errors (2012: n=8; 2013: n=4).

Nitrous oxide emissions:

Fertilizer-N management effect on soil N_2O-N loss was not significant throughout the 2012 growing season (Fig.2) mainly because of high variations of residual N among replications (Hatch et al., 1999; Sistani et al., 2011). The control plot had always the lowest N_2O-N loss compared with treatments with fertilizer-N application. Among different fertilizer-N application treatments, soils with higher fertilizer N application rate (180 kg ha^{-1}) released more N_2O-N loss than recommended dose (146 kg ha^{-1}) and with instinct application.

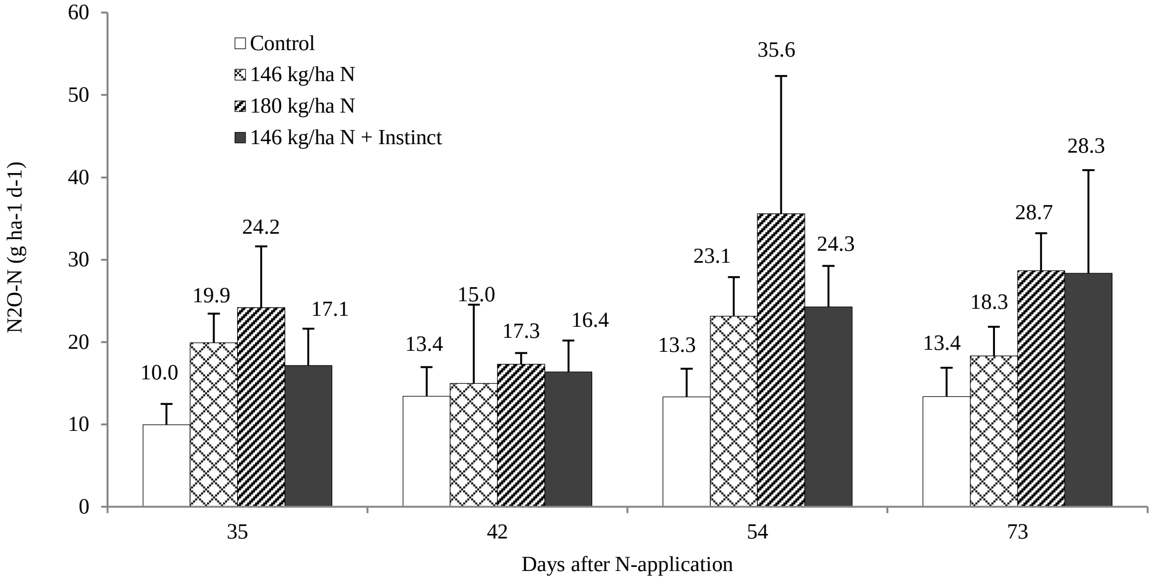

Fig.2. Soil N_2O fluxes as influenced by N-fertilizer managements during 2012 sugarbeet growing season. Bars indicate standard errors (n=4).

Soil solution nitrate concentration:

Drainage and N-fertilizer managements significantly influenced cumulative soil solution NO_3-N concentrations (Table 6). Soil solution NO_3 level was significantly lower under drained plots than undrained plots across 146 kg ha^{-1} N-fertilizer treatment.

Table 6. Influence of drainage and N-fertilizer managements on cumulative NO_3-N concentrations (mg L^{-1}) in soil water at 60 cm depth measured during 2013 sugarbeet growing season. P<0.10; n.s. signifies no significant differences

N-fertilizer	Drainage		LSD (P<0.10)
	Undrained	Drained	
	--------------------Cumulative NO_3-N (mg L^{-1})------------------		
Control	[†]138 ± 42 ^{b}	112 ± 11 ^{c}	n.s.
146 kg ha^{-1}	379 ± 39 ^{aA}	203 ± 61 ^{bB}	116
180 kg ha^{-1}	343 ± 83 ^{a}	229 ± 40 ^{ab}	n.s.
146 kg ha^{-1} + Instinct	423 ± 151 ^{a}	327 ± 12 ^{a}	n.s.
LSD (P<0.10)	198	103	-

[†]Values are means ± standard error (n=4).

As expected, control treatments had the lowest NO_3-N concentrations under drained condition. Application of the recommended N-rate (146 kg ha^{-1}) resulted in only slight increases in NO_3-N concentration in soil solution as compared to control treatment under drained condition. In contrast, application of 180 kg ha^{-1} N or 146 kg ha^{-1} N with instinct significantly increased NO_3-N concentrations than the control treatment under drained plots, the former two being not different with each other. And, application of N-rate of 146 kg ha^{-1} or 180 kg ha^{-1} also produced similar NO_3-N concentrations.

Ammonia volatilization:

Nitrogen fertilizer application significantly influenced cumulative NH_3-N volatilization losses under both undrained and drained conditions (Fig.3). On average, the urea-N fertilizer treatments had twice as much cumulative NH_3-N losses as that of the control plots. A higher NH_3-N emission is expected from urea N-fertilized treatments due to greater availability of mineral N, particularly NH_4^+ substrate in the fertilized plots (data not shown). Ammonia-N emissions were slightly greater from the soils applied with higher N-fertilizer rate (180 kg/ha) than with the recommended rate (146 kg ha^{-1}), regardless of drainage managements; however, the differences were not statistically significant (Fig.4). On the other hand, drainage did not influence the cumulative volatilization losses of NH_3-N across all N-fertilizer treatments (Fig.3). When averaged across the drainage managements, between 2 to 8 weeks after the application of urea-N fertilizers, about 0.41 and 0.43 % of total N applied was lost as NH_3-N, respectively from 146 kg ha^{-1} N and 180 kg ha^{-1} N treatments over the control treatment.

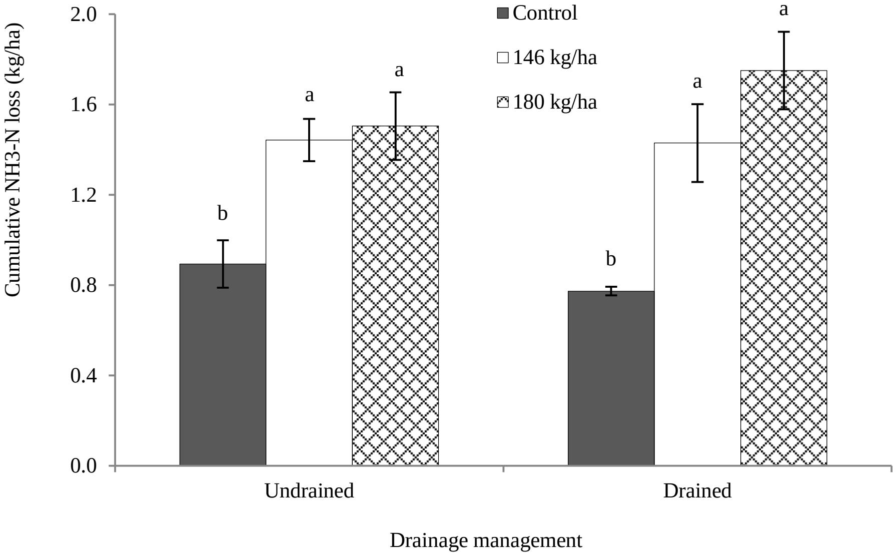

Fig.3.Cumulative NH_3-N loss from N-fertilizers under undrained and drained plots during 2013 sugarbeet growing season. Bars represent standard errors (n=4). Different lowercase letters within each drainage management indicate significant differences at 0.10 significance level.

CONCLUSIONS

Considerable amount of soil organic N is expected to be mineralized and thereby influences soil mineral-N availability under high clay soil. Over-application of fertilizer-N under poorly drained soils did not increase beet yields but exhibits a possibility of greater amount of N-losses from the rooting zone through volatilization, leaching, and denitrification. Nitrogen fertilizer recommendations under high clay soils, therefore, need to consider organic N-mineralization from soil - not only to attain optimum return but also to minimize potential N-losses. However, the magnitude of N-loss from different N-sources under subsurface drainage managements deserves further investigation.

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