DRAINAGE AND NITROGEN MANAGEMENT AFFECTS SOIL HEALTH AND SOIL PROPERTIES

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ABSTRACT

The subsurface drainage and nitrogen (N) fertilizer management practices are known to improve crop yield in the Midwest U.S. However, the combined effect of fertilizer source and drainage system is uncertain in poorly drained claypan soils. A 5-year study in Missouri evaluated the impact of different N fertilizer management practices in free drained (FD) and non-drained (ND) soils on soil properties at 0-6-,6-12, 12-24-, and 24-36 in. soil depths. The N fertilizer treatments included Fall AA + Ns (fall applied 170 lbs N ac^{-1} anhydrous ammonia [AA] + nitrapyrin at 0.4 L ai ac^{-1}), spring AA (preplant AA at 170 lbs N ac^{-1}), TD urea [37 lbs N ac^{-1} SuperU plus 112 lbs N ac^{-1} as ESN at a 25:75% blend), and a NTC (non-treated control). In FD soils, application of TD urea and spring AA increased OM content 10% and 13%, respectively, compared to the NTC. Through increased crop production with FD, the N fertilizer application improved soil properties with increased soil OM and OC content. In this study, no adverse effects on soil properties were observed from N fertilizer application at different timings and different amounts. This study suggests that synergetic effect of N fertilization and soil drainage can improve soil fertility by increasing soil CEC, OM, and OC content.

INTRODUCTION

Midwestern United States farmers rely on key fertilizer inputs and management of soil drainage to maintain productivity and profitability. Subsurface tile drainage is used extensively throughout the Midwest U.S. to lower the water table and drain waterlogged soils. Installation of subsurface drainage enhance root growth and thus increase crop nutrient uptake which results in higher yield production. A number of studies in the Midwest U.S. reported an increase in corn (*Zea mays* L.) and soybean (*Glycine max*) yield (Kaur et al., 2022)

Saturated soil conditions influence soil N cycling due to higher environmental loss through leaching and N diffusion by denitrification. To improve nutrient use efficiency and sustainable crop production, best management practices such as 4R nutrient stewardship framework is being promoted in conjunction with drainage water management technology. The 4R nutrient stewardship framework promotes the application of nutrients using the right source at the right rate, right place and right time (Johnston & Bruulsema, 2014). In the Midwest U.S., crop productivity has been enhanced both through drainage water management (Nelson & Smoot 2012, Kaur et al., 2021) and N fertilization management (Nelson et al., 2009), which together may have different impacts on nutrient cycling and soil health. The objective of this research was to evaluate the impacts of N management systems on soil health indicators in drained and non-drained claypan soils.

METHODS

A 5-year (2017-2022) study was conducted at the University of Missouri Lee Greenley Jr. Memorial Research Center near Novelty, MO. The soil was a Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs), which contains a claypan subsurface layer at a depth of approximately 0.6 m (Nash et al., 2015). In this study, we evaluated the impacts of different N fertilizer management practices in free drained (FD) and non-drained (ND) soils on soil properties at 0-15,15-30, 30-60, and 60-90 cm soil depths. The fertilizer treatments included a fall AA + NI (fall applied 170 lbs N ac^{-1} anhydrous ammonia [AA] + nitrapyrin at 0.4 L ai ac^{-1}), spring AA (preplant anhydrous ammonia at 170 lbs N ac^{-1}), TD urea [topdressed urea included 37 lbs N ac^{-1} SuperU plus 112 lbs N ac^{-1} as ESN at a 25:75% blend), and a NTC (non-treated control). All fertilizer treatments were applied to ND and FD plots except the TD urea treatment that was only applied to the FD plots. The field was in corn-soybean rotation, with corn was planted in 2017, 2019, & 2021, and soybean was planted in 2018 and 2020.

In fall of 2017-2021, soil samples were collected at 0-6-, 6-12-, 12-24-, 24-36 inches soil depth using a Giddings probe (Windsor, CO). Collected soil samples were analyzed by the MU Soil and Plant Testing Lab using standard soil testing analytical procedures for Missouri (Nathan et al., 2006). The samples were analyzed for different soil fertility parameters including soil pH, calcium (Ca), magnesium (Mg), potassium (K), organic matter (OM), total carbon, total nitrogen (TN), and soil texture.

The effect of different fertilizer treatments and drainage management was evaluated using a generalized linear mixed model. The fertilizer source was analyzed as a nested factor in drainage, replication as a random effect, year and depth factor as a fixed effect. The P-values from analysis of variance are reported in Table 1.

RESULTS

Soil bulk density, pH, Ca, Mg, K, CEC, NO_3-N, Bray-I P, OM, TOC, TN, silt, and clay content varied significantly ($P < 0.0001$) with fertilizer source in different drainage systems. In ND soils, fertilizer application did not affect soil pH, Ca, Mg, Bray I P, OM, TOC, silt, or clay content. In FD soil, N fertilization increased soil pH, CEC, Ca, Mg, K, and Bray I P compared to the NTC (Table 2). Application of spring AA and TD urea increased soil pH due to hydrolysis of applied fertilizer. The soil pH was highest at 6–12-inch soil and lowest was observed ta 24-36 in soil depth. Soil test Ca increased and Mg was reduced with fertilizer application compared to the NTC (Table 2). This could be attributed to change in cation exchange sites with the addition of NH_4^+ in soil. In addition, different drainage management systems affect dry-wet alteration which affects fixing capacity of cations (Zhang et al., 2009). Drainage and nitrogen fertilization practices significantly affected the availability of soil Bray-I P (*P* =0.0003). Non-drained NTC plots had 34% higher soil P compared to the FD NTC plots (Table 2).

Improved soil aeration and increased plant growth with FD increased soil OM 10-13% in TD urea and spring AA fertilizer treatments compared to the NTC. The FD system improves the crop which resulted in higher amount of crop residue added to the soil. Similarly, TOC in the FD treatments increased 27% and 35% with TD urea and spring AA, respectively, compared to the NTC. At deeper soil depths soil OM and TOC reduced significantly in FD plots (Table 3). Increased aeration with rapid drainage in FD system accelerated mineralization of OM. Total N in soil was significantly higher with TD urea and spring AA application in FD plots (P = 0.0236) compared to other treatments and varied significantly with soil depth (P < 0.0001) and over years which changed at different soil depths (Table 3). Lower TN in ND treatments shows increased N loss through leaching or denitrification during flooded conditions.

The combination of different fertilizer source and drainage management affected soil texture with a significant change in silt and clay content (Table 3). The silt content was reduced by 7% in fall AA + NI in compared to the NTC in FD soils. Whereas, the clay content increased by 10-14 FD % compared to the NTC. The changes in soil texture were probability due to variation in soil cations with fertilizer application causing the dispersion of soil particles. Moreover, rapid wetting and drying of soil with FD system affects the structural stability of soil which resulted in variation in the soil texture over years.

CONCLUSION

In this study, installation of subsurface drainage with N fertilizer application has been shown to affect different soil properties. Overall, the FD and N fertilizer source effected the movement of cations and increased pH, Bray-I P, TOC, OM, and total N content in soil. There was no significant effect of N fertilizer source in ND soils. A significant depth and year effects showed significant seasonal variability in N fertilizer source and application timing. A future research work on soil microbial properties will help in understanding the management of 4R N management.

Table 1. Significance of the effects of experimental factors and their interactions on soil bulk density (BD), pH, cation exchange capacity (CEC), calcium (Ca), magnesium (Mg), potassium (K), phosphorus (Bray I P), nitrate (NO_3-N), organic matter (OM), total organic carbon (TOC), total nitrogen (TN), and soil texture in different soil layers over years as resulting from analysis of variance (ANOVA).

Source of Variation	DF	BD	pH	CEC	Ca	Mg	K	Bray 1 P	NO_3-N	OM	TOC	TN	Sand	Silt	Clay
		---------- *P*-values ----------													
Drainage(Fert)	6	0.1964	0.0229	0.0062	0.0023	0.0026	<0.0001	<0.0001	<0.0001	0.0017	<0.0001	0.0005	0.3342	0.0091	0.0117
Year	4	<0.0001	0.073	<0.0001	0.002	<0.0001	<0.0001	0.0191	<0.0001	<0.0001	0.5063	<0.0001	<0.0001	0.322	<0.0001
Depth	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Year x depth	12	<0.0001	0.3029	<0.0001	0.0038	<0.0001	0.2527	0.7758	<0.0001	0.4399	0.6971	0.0017	0.0241	0.5558	0.3277
Drainage(Fert)*Year	24	0.9831	0.9998	1	1	0.9992	0.9967	0.9973	<0.0001	0.7944	0.9978	0.7162	0.65	0.9804	0.9832
Drainage(Fert)*Depth	18	0.1751	0.0002	0.0211	0.0014	<0.0001	0.0244	0.0558	0.005	0.4458	0.0407	0.1587	0.3623	0.5533	0.2197
Drainage(Fert)*Year*Depth	84	0.9946	1	0.5655	0.9283	0.2318	1	1	0.1117	0.9995	1	0.5014	0.2933	1	1

Table 2. Mean soil pH, cation exchange capacity (CEC), calcium (Ca), magnesium (Mg), potassium (K), and bray I phosphorus (Bray I P) as influenced by drainage and fertilizer treatments, soil depths (0-6, 6-12, 12-24, 24-36 in.), and year (2017-2021) effect. Within a column means followed by same letters are not significantly different at α = 0.05.

Drainage†	Fertilizer‡	Sampling depth	Year	pH	CEC	Ca	Mg	K	Bray 1 P
		in			cmol kg^{-1}	--------------------kg ha^{-1}--------------------			
FD	NTC			5.5 c	20 c	7007 b	1289 b	419 d	51 c
	TD urea			5.7 ab	22 ab	8100 a	1398 ab	575 a	81 a
	Fall AA+Ns			5.6 abc	22 ab	7790 a	1494 a	508 bc	65 bc
	Spring AA			5.7 a	21 bc	7719 a	1285 b	553 ab	80 a
ND	NTC			5.6 abc	20 c	8011 a	1454 ab	573 a	67 abc
	Fall AA+Ns			5.5 c	23 a	7684 a	1456 ab	542 abc	71 ab
	Spring AA			5.5 bc	22 ab	7572 ab	1443 ab	497 c	60 bc
p-value				0.0229	0.0062	0.0023	0.0026	<0.0001	<0.0001
		0-6		5.9 a	17 c	6098 d	663 d	684 a	133 a
		6-12		6.2 b	18 c	7081 c	860 c	429 d	60 b
		12-24		5.2 c	27 a	8233 b	1714 b	473 c	28 c
		24-36		5.1 c	25 b	9579 a	2372 a	533 b	54 b
		p-value		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
			2017	5.5 b	23.9 a	8220 a	1488 a	580 a	69 b
			2018	5.6 ab	21.2 c	7704 bc	1273 b	579 ab	80 a
			2019	5.5 b	22.7 b	7689 bc	1489 a	537 bc	65 b
			2020	5.6 ab	19.2 d	7302 c	1269 b	433 d	64 b
			2021	5.7 a	21.3 c	7825 ab	1491 a	520 c	70 b
			p-value	0.0703	< 0.0001	0.002	< 0.0001	< 0.0001	0.0191

† FD, free drainage; ND, no drainage

‡ NTC, non-treated control; TD urea, SuperU and ESN top dress application; Fall AA+Ns, fall anhydrous ammonia + nitrapyrin; spring AA, pre-plant anhydrous ammonia

Table 3. Mean soil organic matter (OM), total organic carbon (TOC), total nitrogen (TN), silt, clay, and bulk density (BD) as a function of drainage(fertilizer), depth, and year effect. Within a column, different letters indicate a significant difference at α = 0.05.

Treatment†	Fertilizer‡	Sampling depth	Year	OM	TOC	TN	Silt	Clay	BD
		in		-----------------------g kg^{-1}				---------------------------	mg cm^{-3}
FD	NTC			19.5 c	8.9 c	1 bc	559 a	309 c	1.4 ab
	TD urea			21.5 ab	11.3 a	1.1 a	540 abc	341 ab	1.4 a
	Fall AA+Ns			20.3 bc	9.3 bc	1.0 b	521 bc	353 ab	1.4 a
	Spring AA			22 a	12 a	1.1 a	550 ab	330 bc	1.41 ab
ND	NTC			20.4 bc	10 b	1 bc	523 bc	346 ab	1.4 a
	Fall AA+Ns			20.3 bc	9.5 bc	1 b	511 c	353 ab	1.3 b
	Spring AA			19.6 c	9.1 bc	1 b	517 c	359 a	1.3 b
p-value				0.0017	<0.0001	0.0005	0.0091	0.0117	0.0255
		0-6		27.8 a	16.2 a	1.5 a	628 a	231 d	1.3 c
		6-12		22.1 b	12.2 b	1.1 b	584 b	283 c	1.4 b
		12-24		20.2 c	8.2 c	0.9 c	431 d	444 a	1.3 b
		24-36		12.3 d	3.8 d	0.5 d	487 c	408 b	1.6 a
		p-value		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
			2017	20.5 bc	9.6	1.1 ab	533	379 a	1.36 c
			2018	21.5 ab	10.3	1.1 bc	534	347 b	1.4 b
			2019	19.6 cd	10.3	1.1 c	524	322 b	1.37 c
			2020	22.5 a	10.4	0.7 d	546	337 b	1.46 a
			2021	19 d	10	1.2 a	525	324 b	
			p-value	< 0.0001	0.5063	< 0.0001	0.3220	< 0.0001	< 0.0001

† FD, free drainage; ND, no drainage

‡ NTC, non-treated control; TD urea, SuperU and ESN top dress application; Fall AA+Ns, fall anhydrous ammonia + nitrapyrin; spring AA, pre-plant anhydrous ammonia

References

Johnston, A. M., & Bruulsema, T. W. (2014). 4R nutrient stewardship for improved nutrient use efficiency. *Procedia Engineering*, *83*, 365-370.

Kaur, H., Nelson, K. A., & Singh, G. (2021). Subsurface drainage and subirrigation for increased corn production in riverbottom soils. *Agronomy Journal*. https://doi.org/10.1002/agj2.20887

Kaur, H., Nelson, K. A., & Singh, G. (2022). Subsurface drainage and nitrogen management affects corn and soybean yield in claypan soils in upstate Missouri. *Field Day Annual Report 2022* (1) 36. https://extension.missouri.edu/

Nash, P., Motavalli, P., Nelson, K., & Kremer, R. (2015). Ammonia and nitrous oxide gas loss with subsurface drainage and polymer-coated urea fertilizer in a poorly drained soil. *Journal of Soil and Water Conservation*, *70*(4), 267-275.

Nelson, K. A., Paniagua, S. M., & Motavalli, P. P. (2009). Effect of polymer coated urea, irrigation, and drainage on nitrogen utilization and yield of corn in a claypan soil. *Agronomy Journal*, *101*(3), 681-687.

Nelson, K. A., & Smoot, R. L. (2012). Corn hybrid response to water management practices on claypan soil. *International Journal of Agronomy*, *2012*.

Nistor, A. P., & Lowenberg-DeBoer, J. (2007). Drainage water management impact on farm proftability. *Journal of Soil and Water Conservation*, *62*(6), 443-446.

Skaggs, R. W., Fausey, N. R., & Evans, R. O. (2012). Drainage water management. *Journal of Soil and Water Conservation, 67*(6), 167A-172A.

Zhang, H., Xu, M., Zhang, W., & He, X. (2009). Factors affecting potassium fixation in seven soils under 15-year long-term fertilization. *Chinese Science Bulletin*, *54*(10), 1773-1780. https://doi.org/10.1007/s11434-009-0164-9