FINAL PROJECT REPORT TO
The Division of Soil Conservation and Water Quality of the Iowa Department of Agriculture and Land Stewardship and Calcium Products Inc.
March 2020

High Gypsum Application Rates Impact on Soil Cation Balance, Water Soluble Phosphorus, Soil Physical Properties, and Crop Yield

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INTRODUCTION AND REVIEW OF OBJECTIVES

Gypsum (calcium sulfate) has been used for decades to supply sulfur (S) to crops in Iowa and other states. Gypsum also has been used in states with poorer soils (weathered, sandy, or extremely acid) to supply calcium (Ca) to crops, and also to alleviate excess sodium (Na) and improve physical properties in saline or strongly alkaline soils. During the late 2000s, however, increased interest developed all over the country for using gypsum rates much higher than needed to supply S for crops to further increase crop yield by improving soil physical properties and cation balance, and reducing dissolved phosphorus (P) loss from fields especially with no-till management. Moreover, research in some other states began studying the potential value of soil amendments such as alum (aluminum sulfate) and gypsum rates higher than needed to supply S for crops to reduce dissolved phosphorus (P) loss from fields through surface runoff and subsurface tile drainage. Therefore, farmers, soil conservationists, and nutrient management planners have been asking numerous questions about these issues. Furthermore, a National Resources Conservation Service (NRCS) national conservation practice standard had been released in 2015 (Code 333, Amending Soil Properties with Gypsum Products). However, researchers and technical NRCS personnel in Iowa and other states of the western Corn Belt were uncertain if gypsum applied to our rich prairie soils other than to supply S for crops would have the other benefits shown by research in the eastern states due to lack of local research.

Therefore, three complementary projects began to be implemented from fall 2015 to fall 2016 by Iowa State University (ISU) researchers to study the potential benefits of high gypsum rates I Iowa. An ongoing project lead by Dr. Matthew Helmers and Dr. Antonio Mallarino is investigating at a northeast Iowa site effects of one ton/acre of gypsum on dissolved P loss with subsurface tile drainage when it is applied every other year to continuous corn managed with tillage and liquid swine manure applied according to the nitrogen (N) needs of corn. An ongoing study developed by Dr. Antonio Mallarino and Dr. Mazhar Haq has used field rainfall simulations on two no-till fields with soybean residue to study dissolved and sediment-bound P loss with surface runoff as affected by several rates of granulated or powdered gypsum and the time between the application and a runoff event caused by rainfall or snowmelt.

This three-year project was developed to assess effects of several strategies for gypsum application rates and frequency on crop yield and selected chemical and physical properties in two Iowa soils managed with no-till corn-soybean rotations. Work began in 2016 with seed funding from Calcium Products. Additional funding from the State Soil Conservation and Water Quality Grant Program of the Division of Soil Conservation and Water Quality (Iowa Department of Agriculture and Land Stewardship) allowed for completing the project with evaluations in 2017 and 2018.

SUMMARY OF PROCEDURES

The project developed two 3-year field trials with similar treatments for a rotation soybean-corn-soybean with no-tillage. One trial was at the ISU Northeast Iowa Research and Demonstration Farm (NERF) in Floyd County (near Nashua) on an area with Floyd loam soil and the other at the ISU Sorenson research farm in Boone County (near Ames) on an area with Clarion loam soil. Both sites had long histories of corn-soybean rotations managed with tillage. The no-till management began after harvesting the 2015 corn crop and before treatments were first applied. Soil samples were taken before applying the treatments from depths of 0-6 and 6-12 inches to characterize the sites. Table 1 shows the test results.

Table 1. Initial soil properties at two research sites. †

	NERF		Boone	
	Depth (inches)		Depth (inches)	
Measurement	0-6	6-12	0-6	6-12
Bray P, ppm	14	5	8	3
M3 P, ppm	16	4	8	3
Olsen P, ppm	8	6	6	4
WEP, ppm	2	1	2	1
SO_4, ppm	4	3	3	3
pH	5.6	5.3	5.6	5.7
OM, %	4.1	3.8	3.4	3.2
K, ppm	191	79	119	77
Ca, ppm	2105	2123	1908	2152
Mg, ppm	294	282	268	291
Na, ppm	16	11	8	11
CEC, meq/100 g	19	21	17	19
Base saturation, %	71	64	72	72
Ca saturation, %	55	52	57	58
Sand, %	43	-	50	-
Silt, %	37	-	33	-
Clay, %	20	-	17	-
Texture	loam	-	loam	-

† M3, Mehlich-3; WEP, water-extractable P; OM, organic matter; CEC, cation exchange capacity.

Soil samples were analyzed for texture, organic matter, P by the Bray-1, Olsen, and Mehlich-3, and water-extraction methods, sulfur-sulfate (SO_4-S) by the monocalcium phosphate method, pH, buffer pH; and the ammonium-acetate extractable cations potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na). Organic matter was analyzed by combustion (Wang and Anderson, 1998). Water-extractable P was measured with a method used for water quality P research in the state and elsewhere (Pote et al., 1996) and the other analyses followed procedures recommended by the North-Central Region Committee for Soil and Plant Analyses (NCERA-13) (Brown, 1998). Soil cation exchange capacity (CEC), total base saturation, and Ca saturation were estimated from buffer pH and extractable cations as suggested by the NCERA-13 committee that is commonly used by soil-testing laboratories to estimate these soil properties.

The first gypsum treatments were applied in fall 2015 at NERF and in spring 2016 at Boone. Plot size was 30 by 50 feet, and treatments randomized to each of three blocks (replications) were 0, 250, 500, 1,000, 2,000, and 4,000 lb/acre of granulated calcium sulfate hydrate provided by Calcium Products. The 250-lb rate applied 43 lb S/acre, which is within the high end of range of rates recommended for corn or soybean in the north central region (Sawyer, 2016). The two highest rates were among rates being suggested for reducing dissolved P loss from fields and improving soil physical and chemical properties by the national NRCS conservation practice standard Code 333. Initial soil-test P was very low or low at the sites, so P fertilizer at 135 lb P_2O_5/acre (granulated triple superphosphate) was spread every year at the same time that gypsum was applied. After harvest of the first-year soybean in fall 2016, all plots were split into two halves to apply additional treatments in 2017 and 2018. No additional gypsum was applied to one half of each plot whereas the same rates applied the first year were reapplied to the other half. Therefore, the trials had 18 plots in 2016 and 36 plots in 2017 and 2018.

Soil and plant samples were taken each year at the V5 to V6 growth stage of both crops (in June) to assess potential treatment effects early in the season on soil P and sulfate and on plant growth and nutrient uptake. The soil samples (12-core composite samples) were taken from a 6-inch depth, and the P and sulfate analysis methods used were those described before. The plant samples (ten plants per plot) were cut at one-inch level from the ground, dried, weighed to measure dry matter yield, and ground for tissue analyses. Tissue samples were analyzed by the nitric acid-hydrogen peroxide procedure for total N, P, K, Ca, Mg, S, boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn). The nutrient uptake was calculated from the measured plant dry weight and nutrient concentrations. Corn and soybean grain was harvested from all plots with plot combines to evaluate the yield response to the treatments. After grain harvest, soil samples were collected from all plots from depths of 0-6 and 6-12 inches and were analyzed using methods described before.

In spring 2018 we collected soil samples for soil aggregate stability measurements before planting the final soybean crop in both fields (on April 27 at NERF and May 14 at Boone). As the proposal indicated, to adjust costs to the budget available, seven contrasting gypsum treatments were sampled. We collected three soil samples from each of the three replications of treatments receiving no gypsum; single initial applications of 1,000, 2,000, and 4,000 lb/acre; and annual applications of 250, 2,000, and 4,000 lb/acre. Undisturbed soil samples were collected from a depth 0-6 inches. Procedures used were those described by Guzman and Al-Kaisi (2011), who slightly modified procedures first suggested by Kemper and Rosenau (1986). The moist samples were prepared for analysis by gently sieving them through a screen with ¼-inch openings and subsequently air drying. A subsample was taken from each sample to determine soil moisture of the air-dried samples by drying the subsamples in an oven at 105 °C. Another 100-g of air-dried soil was sieved using a wet sieving apparatus through seven screen sizes to measure different soil aggregate sizes (>4, 2-4, 1-2, 0.5-1, 0.25-0.5, 0.053-0.25, and <0.053 mm. The sieved soil was dried at 105 °C, weighed, and the weights were adjusted to the oven-dried soil moisture content. Results were expressed as it is usually done by calculating mean weight diameter (MWD) and the percentage of aggregates with a diameter of 1.0 mm or larger. Greater MWD values and greater percentage of aggregates > 1.0 mm indicate better and more stable soil structure.

RESULTS

Results for the First Year (Soybean, 2016)

Table 2 shows results of analyses of soil samples collected in June 2016 from a 6-inch depth at both sites. It must be remembered that gypsum treatments were applied in fall 2015 at NERF and in spring 2016 at Boone. As expected, gypsum increased soil sulfate at both sites, and levels increased exponentially as the gypsum rate increased. The much lower soil sulfate levels at NERF compared with Boone, may be explained by the combined effects of three processes given the longer time between gypsum application and the soil sampling at NERF (previous fall) than at Boone (in the spring). At NERF, gypsum may have solubilized sooner and significant amounts of the released sulfate may have leached to deeper layers or may have been transformed into organic forms by soil microorganisms. All three processes have been shown to occur in other S studies with gypsum. Accumulated rainfall between the gypsum application dates to the June soil sampling was 22.8 inches at NERF and 9.2 inches at Boone.

Gypsum did not affect Bray, Olsen, or Mehlich-3 soil P at any site but slightly reduced water-extractable P at both sites. At NERF, only a small reduction by the highest gypsum rate was statistically significant. At Boone, gypsum reduced water-extractable P exponentially to a minimum as the rate increased from 8 ppm for the control to 2 ppm for the highest rate. The reason for higher water-extractable P at NERF but a reduction only by the highest gypsum rate cannot be explained with certainty. Perhaps gypsum had only a temporary effect because it was applied the previous fall 2015 at NERF but in spring 2016 at Boone.

Table 2. Gypsum effects on soil P and S in June 2016 at a depth of 0 to 6 inches.

Location	Gypsum	Bray P	Mehlich3 P	Olsen P	WEP†	SO_4-S
	lb/acre	ppm				
NERF	0	34	41	23	12a	4
	250	28	33	19	9a	5
	500	33	38	21	11a	5
	1000	42	46	29	12a	8
	2000	33	38	20	9a	15
	4000	28	33	18	7b	33
	Statistics‡	NS	NS	NS	*	** Exp
Boone	0	25	29	18	8a	5
	250	23	27	16	5b	13
	500	15	19	12	3bc	29
	1000	21	26	16	4bc	40
	2000	24	29	16	3bc	125
	4000	19	24	14	2c	161
	Statistics	NS	NS	NS	*	** Exp

† WEP, water-extractable P; ‡ NS, not significant; * and **, significant at $P \leq 0.05$ or $P \leq 0.01$; Exp, exponential trend. Values in a column followed by a similar letter do not differ.

Table 3 shows results of tissue analyses of soybean plants sampled in June 2016 at the V5-V6 growth stage. At NERF, gypsum increased exponentially S plant concentration and the intermediate rates maximized Mg concentration, but did not affect the concentration of other nutrients. Two or three highest gypsum rates decreased plant dry weight. The nutrient accumulation in plant tissue combines results of plant weight and tissue nutrient concentration. Gypsum increased the accumulation of several nutrients (N, P, Ca, Mg, B, Ca, Cu, and Fe) but did not affect others (K, S, Mn, and Zn). At Boone, gypsum increased plant S concentration exponentially, the highest rate increased Zn concentration, but did not affect concentrations of other nutrients. Gypsum did not affect plant weight, the highest rates increased S accumulation, the lowest rate maximized accumulation of Mg, N, and P, but did not affect other nutrients. Increased early plant S concentration by gypsum was expected, and increases in accumulation of S and other nutrients would be reasonable if plant dry weight or nutrient concentrations had been increased. Gypsum did not increase plant weight at any site, however, and at NERF the highest rates decreased plant weight, which was not expected and for which there is no obvious explanation. At both sites, low or intermediate gypsum rates maximized Mg, N, and P accumulation, but we cannot explain with certainty why the higher rates did not, especially at Boone where gypsum did not affect plant dry weight.

Table 3. Gypsum effects on soybean plants sampled at the V5-V6 growth stage in June 2016 at two research sites.

	NERF Site							Boone Site						
	Gypsum Rate (lb/acre)							Gypsum Rate (lb/acre)						
Measurement	0	250	500	1000	2000	4000	Stat†	0	250	500	1000	2000	4000	Stat†
N %	3.90	3.90	3.69	3.43	3.27	3.59	NS	3.81	3.81	3.55	3.66	3.74	3.67	NS
P %	0.32	0.31	0.31	0.31	0.30	0.29	NS	0.34	0.33	0.32	0.33	0.33	0.33	NS
K %	2.68	2.50	2.66	2.53	2.64	2.45	NS	1.81	1.66	1.85	1.86	1.84	1.97	NS
Mg %	0.35bc	0.36ba	0.38a	0.36ba	0.33c	0.34bc	*	0.48	0.53	0.45	0.47	0.44	0.46	NS
Ca %	1.23	1.21	1.24	1.19	1.15	1.24	NS	1.73	1.85	1.78	1.81	1.79	1.82	NS
S %	0.24c	0.24c	0.26bc	0.27bc	0.28b	0.30a	*	0.25c	0.26c	0.30bc	0.29bc	0.34ab	0.36a	*
B ppm	35	36	34	36	35	34	NS	38	36	38	35	39	37	NS
Zn ppm	29	28	31	32	29	29	NS	36bc	34c	39ba	36bc	41a	43a	*
Mn ppm	57	58	59	68	64	61	NS	66	62	66	67	73	75	NS
Fe ppm	161	157	168	148	138	146	NS	150	149	157	177	159	179	NS
Cu ppm	8.0	7.7	8.0	7.7	7.3	7.7	NS	7.3	7.7	7.7	7.3	7.3	7.7	NS
DW g/10 plants	27a	25ba	28a	22bc	22bc	20c	*	23.0	27.1	21.6	22.7	22.7	24.0	NS
N g/10 plants	1.07a	0.98a	1.04a	0.76b	0.72b	0.72b	*	0.88b	1.03a	0.77b	0.83b	0.85b	0.89ba	*
P g/10 plants	0.09a	0.08ba	0.09a	0.07ba	0.07b	0.06b	*	0.08c	0.09b	0.07b	0.07bc	0.07bc	0.08ba	NS
K g/10 plants	0.74	0.63	0.75	0.57	0.60	0.50	NS	0.42	0.45	0.40	0.42	0.42	0.47	NS
Mg g/10 plants	0.10a	0.09ba	0.11a	0.08bc	0.07c	0.07c	*	0.11b	0.14a	0.10b	0.11b	0.10b	0.11b	*
Ca g/10 plants	0.34a	0.31ba	0.35a	0.27b	0.26b	0.25b	*	0.40	0.50	0.38	0.41	0.41	0.44	NS
S g/10 plants	0.07	0.06	0.07	0.06	0.06	0.06	NS	0.06c	0.07b	0.06c	0.07b	0.08ba	0.09a	*
B mg/10 plants	0.98a	0.90bac	0.96ba	0.80bdc	0.78dc	0.68d	*	0.87	0.98	0.82	0.80	0.88	0.89	NS
Zn mg/10 plants	0.81	0.71	0.88	0.70	0.66	0.59	NS	0.83	0.92	0.83	0.81	0.94	1.02	NS
Mn mg/10 plants	1.60	1.47	1.68	1.48	1.40	1.25	NS	1.50	1.67	1.41	1.52	1.66	1.80	NS
Fe mg/10 plants	4.47ba	4.03bac	4.77a	3.27bc	3.05c	2.93c	*	3.50	4.04	3.40	4.00	3.61	4.34	NS
Cu mg/10 plants	0.22a	0.19ba	0.23a	0.17bc	0.16bc	0.15c	*	0.17	0.21	0.17	0.17	0.17	0.19	NS

† Statistics: ns not significant; *, significant at $P \leq 0.05$.

Gypsum did not affect soybean grain yield significantly but numerically was lowest for the two highest gypsum rates (Table 4). A small and not significant yield decrease at NERF matches the statistically significant decrease observed for early plant growth (Table 3). Prior Iowa research has shown no soybean yield decreases caused by gypsum, but the highest rate used was only about 500 lb/acre.

Table 4. Gypsum effect on soybean grain yield in 2016 at two sites.

Site	Gypsum Rate	Grain Yield
	lb/acre	bu/acre
NERF	0	74.1
	250	73.1
	500	74.3
	1000	74.1
	2000	72.6
	4000	72.2
	Statistics†	NS
Boone	0	64.3
	250	63.6
	500	61.6
	1000	63.3
	2000	60.0
	4000	59.5
	Statistics	NS

† NS, no significant differences at $P \leq 0.05$ or $P \leq 0.10$.

Soil-test results from the post-harvest soil sampling in fall 2016 from depths of 0-6 and 6-12 inches in Appendix Table A1 show that gypsum had no statistically significant effect on most measurements at NERF with the only exception of soil sulfate, but at Boone gypsum affected sulfate in both depths and also extractable Mg and water-extractable P in the 6-inch depth. Results for sulfate from both sites are better visualized in Fig. 1, which shows that gypsum increased sulfate exponentially for the 6-inch depth and linearly for the depth of 6-12 inches at both sites. Increased sulfate at the depth of 6-12 inches indicates significant leaching from the top 6-inch depth. With the highest gypsum rate, sulfate in the 6-12 inches layer was higher than in the 6-inch layer at NERF but the inverse happened at Boone. This result agrees with results for the June 6-inch sampling, when there was less sulfate at NERF due to a longer time and more rainfall between the gypsum application and the sampling date. The accumulated rainfall between the gypsum application dates and the fall 2016 sampling date was higher at NERF (32.0 inches) than at Boone (20.7 inches).

Figure 2 shows that at Boone gypsum decreased both soil water-extractable P and extractable Mg in the top 6-inch depth exponentially to a minimum. The continuous model was statistically stronger for Mg. than for P, however. The decrease of water-extractable P was mainly observed for the two highest gypsum rates, and agrees with a decreased for the previous June soil sampling at this site, but the reduction in the fall was very small (2 ppm less) and the overall levels were much smaller. A lack of gypsum effects on extractable soil Ca, Ca saturation, or CEC should not be surprising. These soils are medium textured, have high organic matter, and high Ca levels in the cation exchange complex. Even with the 4000-lb gypsum rate, the amount of Ca added is of little significance compared with amounts of exchangeable Ca, and small differences are difficult to detect given the usual variability in soils with liming histories (although no lime had been applied at least six years prior to this study).

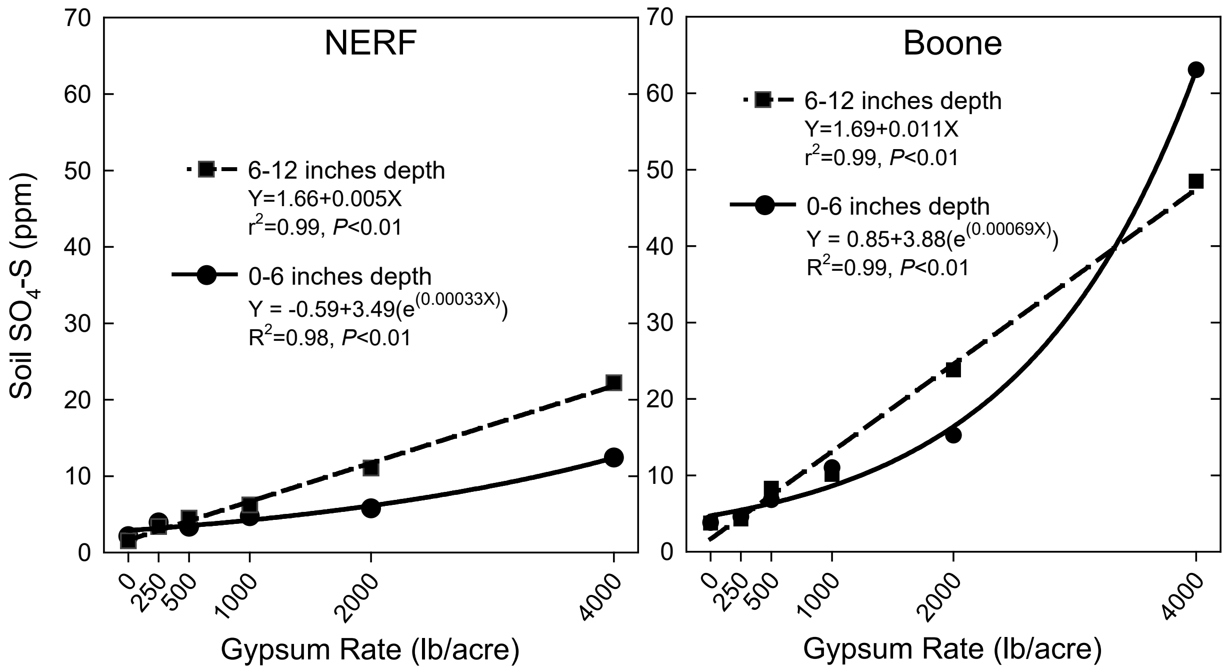

Fig. 1. Gypsum application effects on soil sulfate-S in fall 2016 in two soil depths at two sites.

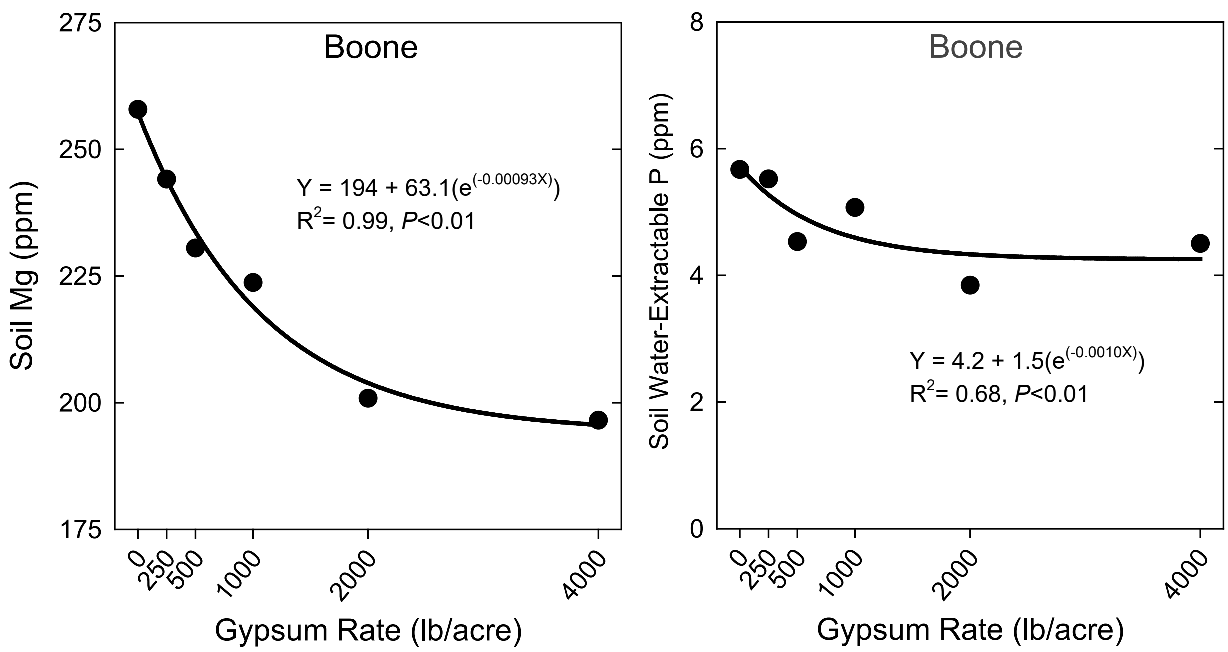

Fig. 2. Gypsum application effects on soil extractable Mg and water-extractable P in fall 2016 for a 6-inch depth at Boone.

Results for the Second Year (Corn, 2017)

Table 5 shows soil-test results from samples taken in June 2017 at the V5-V6 corn stage. Gypsum did not affect soil P measured by any method; not even with 8,000 lb gypsum applied over two years. In June 2016, gypsum had slightly reduced water-extractable P at both sites but not P measured by Bray-1, Olsen, or Mehlich-3 tests.

Table 5. Soil P and S (0-6 inches) in June 2017 at two sites as affected by gypsum application.

Location	Gypsum Rate Year 1	Gypsum Rate Year 2	Soil-Test P Bray P	Soil-Test P Mehlich-3 P	Soil-Test P Olsen P	Soil-Test P WEP†	SO_4-S
	-------- lb/acre -------		--------------------------- ppm			--------------------------------	
NERF	0	0	52	51	31	13	5
	250	0	54	51	36	13	5
	500	0	57	57	37	15	5
	1000	0	56	54	34	13	7
	2000	0	54	51	33	14	8
	4000	0	49	51	22	12	8
	250	250	60	57	38	15	7
	500	500	49	47	29	12	7
	1000	1000	61	59	44	14	13
	2000	2000	71	68	34	14	41
	4000	4000	52	50	25	12	65
	Statistics‡		NS	NS	NS	NS	** Exp
Boone	0	0	67	67	48	17	5
	250	0	67	65	44	17	6
	500	0	56	57	35	14	6
	1000	0	54	52	36	12	8
	2000	0	73	71	51	18	8
	4000	0	51	51	38	11	18
	250	250	58	58	43	14	6
	500	500	72	72	48	17	6
	1000	1000	74	75	44	16	7
	2000	2000	58	58	40	14	39
	4000	4000	69	67	47	11	68
	Statistics		NS	NS	NS	NS	** Exp

† WEP, water-extractable P; ‡ NS, not significant; **, significant at $P \leq 0.01$; Exp, exponential increasing trend. Values in a column followed by a similar letter do not differ.

Gypsum increased soil sulfate exponentially to very high values at both sites as the application rate increased (Table 5). However, the residual soil sulfate from gypsum applied only for the first-year was very little at NERF (only 3 ppm higher for the highest rate) and was substantial at Boone only for the highest rate (12 ppm higher from the background).

Gypsum application did not affect any measurement done for the aboveground portion of corn plants sampled at the V5-V6 growth stage in June 2017 at both sites, which were sampled at the same time soil was sampled. Appendix Tables A2 and A3 show the results of all measurements, including plant dry weight and both nutrient concentration and accumulation in the tissue. There was no statistically significant treatment effect even when the analyses of variance included an orthogonal comparison of the plots receiving no gypsum any year with the average of all plots receiving gypsum or the average of the highest gypsum rates. The lack of significant results this year is in contrast with some of last year results with soybean. We cannot explain with certainty the reason gypsum increased soybean S concentration and uptake the previous year but not in corn this year, when the highest initial and annual gypsum rates increased soil sulfate (Table 5). The plant S concentration in corn and soybean at the V5-V6 growth stage was approximately similar at NERF but slightly higher for corn at Boone.

Table 6 shows that gypsum did not affect corn grain yield significantly at either site. Corn yield was high, above average for these farms. Soybean yield results from the previous year also showed no gypsum effects. The lack of yield response to gypsum at Boone agree with little or no corn or soybean response at previous studies in central Iowa using gypsum rates to up to 500 lb/acre. We expected a yield response to gypsum at NERF because some experiments in northeast Iowa have shown corn and alfalfa yield responses to S rates commonly used for crops with gypsum or other sources. The results should not be considered anomalous, however. Previous research showed no response to S in some fields and a response mainly in eroded slopes with low organic matter, which is not the case in this study.

Table 6. Gypsum effect on corn grain yield in 2017 at two sites.

Gypsum Application Rate		Corn Grain Yield	
1st Year	2nd Year	NERF	Boone
------ lb gypsum/acre -----		----------- bu/acre ---------	
0	0	231	247
250	0	235	246
500	0	232	242
1000	0	233	245
2000	0	231	234
4000	0	238	242
250	250	236	244
500	500	233	237
1000	1000	232	248
2000	2000	238	252
4000	4000	231	245
Statistics †		NS	NS

† NS, no significant differences at $P \leq 0.05$ or $P \leq 0.10$.

Results of soil analyses of samples collected from depths of 0-6 and 6-12 inches after corn harvest and before applying the gypsum treatments for the 2018 showed no statistically significant gypsum effects for most measurements. Appendix Tables A4 and A5 show results for all measurements. One exception was soil sulfate for both depths at both sites, and results are better visualized in Fig. 3. Residual sulfate from the initial gypsum applications for 2016 was low at both sites but increased as the gypsum rate increased and, was higher for the depth of 6-12 inches. The annual gypsum rates also increased soil sulfate and levels also were higher for the depth of 6-12 inches, which indicates significant leaching. At Boone, however, soil sulfate in the 6-12 layer was 2-3 ppm higher than in the 6-inch layer even for the control that received no gypsum since the beginning of the study. For the highest annual rate (8000 lb/acre total), sulfate in both soil depths were much higher at NERF than at Boone. This difference is unexpected because sulfate from the June samples from a 6-inch depth for this rate was approximately similar at both sites (Table 5).

Rainfall between the June and fall sampling dates does not explain this result because it was higher at NERF (20.3 inches) than at Boone (14.2 inches). Corn grain yield was 15 bu/acre higher at Boone than at NERF (Table 6), and neither S concentration and removal with grain harvest nor S concentrations and accumulation in vegetative plant parts were measured. The usually small S concentration in corn grain (about 0.05 lb/bu) cannot explain the soil sulfate difference, and it is unlikely that S accumulation in vegetative plant parts could explain it either. Lower sulfate for the annual highest gypsum rate in both soil depths at Boone might be explained by greater immobilization of inorganic S by soil microorganisms or random variability.

Gypsum also affected a few other measurements only at the 6-inch depth at both sites. At NERF (Appendix Table A4), only the highest annual 4000-lb rate increased extractable Ca, decreased extractable Mg, and increased Ca saturation compared with the control. At Boone (Appendix Table A5), the two highest annual rates increased Ca compared with the control and the highest annual rate decreased Mg compared with the control. The effects of gypsum increasing Ca and decreasing Mg coupled with small effects and high variability due to high soil Ca levels explain no significant gypsum effects on total bases and CEC at both sites and also on Ca saturation at Boone.

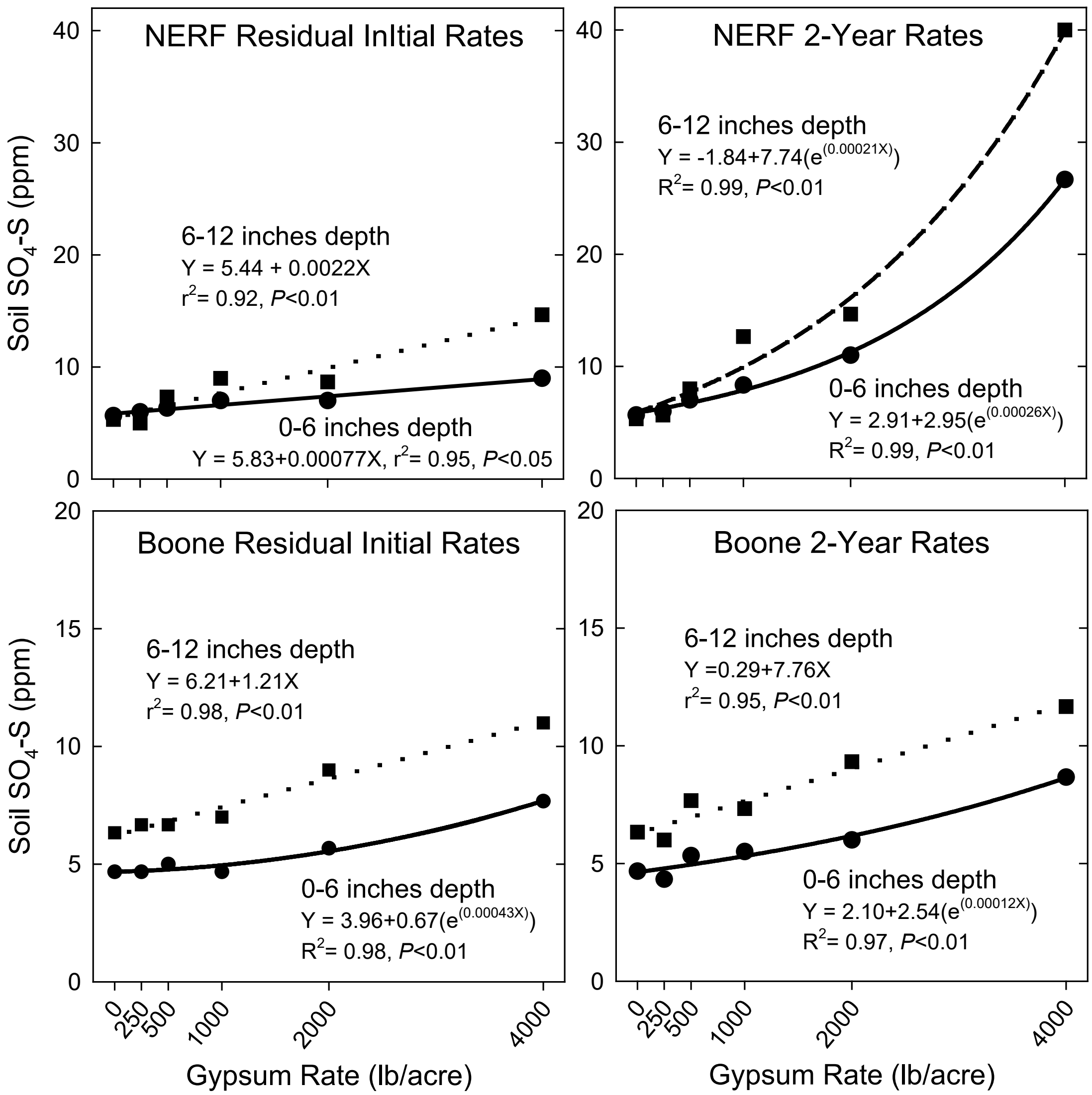

Fig. 3. Soil sulfate-S in fall 2017 after harvesting corn in two sampling depths at two sites as affected by gypsum applied only for the 2016 crop year or for both the 2016 and 2017 crop years.

Results for the Third Year (Soybean, 2018)

Table 7 shows results of analyses of soil samples collected in June 2018 from a 6-inch depth from both sites. Gypsum did not affect soil P measured by any of the four test methods at any site. It is remarkable that gypsum did not affect soil P even with the highest annual rate (a total of 12,000 lb/acre). Results from the 6-inch samples taken in June 2016 showed that gypsum reduced water-extractable P in both sites and also in fall 2017 at Boone (although by a very small amount), but did not affect soil P by any other method at any sampling date.

Soil sulfate was very low and did not differ between gypsum rates applied once at the beginning of the 3-year study. At the end second year (in fall 2017) there were elevated sulfate levels mainly from the highest gypsum annual rate and in a depth of 6-12 inches (Fig. 3). The annual gypsum treatments greatly increased soil sulfate levels, however (Table 7). At both sites, soil sulfate for annual rates of 250 and 500 lb gypsum/acre were 2-3 ppm higher than for the control but the small differences were not statistically significant. On the other hand, annual rates of 1,000 lb/acre or higher greatly increased sulfate levels. Sulfate levels for the annual 4000-lb rate were higher at NERF (71 ppm) than at Boone (50 ppm). This difference cannot be explained because rainfall from fall 2017 until the June 2018 sampling date was similar at both sites (18.0 and 18.1 inches).

Table 7. Gypsum effects on soil P tested with four methods and S at a 6-inch depth in June 2018.

	Gypsum Rate			Soil Test P†				
Location	Year 1	Year 2	Year 3	Bray P	Mehlich-3 P	Olsen P	WEP	SO_4-S
	----------- lb/acre ---------			--------------------------- ppm --------------------------				
NERF	0	0	0	64	62	36	17	4
	250	0	0	62	62	32	15	5
	500	0	0	63	61	30	17	5
	1000	0	0	71	73	39	17	6
	2000	0	0	67	62	31	15	5
	4000	0	0	75	76	39	18	6
	250	250	250	61	61	31	15	6
	500	500	500	60	59	31	14	8
	1000	1000	1000	67	66	34	16	20
	2000	2000	2000	79	76	40	16	30
	4000	4000	4000	62	62	34	12	71
	Statistics‡			NS	NS	NS	NS	** Exp
Boone	0	0	0	68	63	35	19	4
	250	0	0	59	60	30	14	4
	500	0	0	52	49	26	13	4
	1000	0	0	70	68	35	20	4
	2000	0	0	81	80	41	21	5
	4000	0	0	62	57	29	15	7
	250	250	250	59	56	31	16	7
	500	500	500	70	66	35	18	7
	1000	1000	1000	73	66	33	16	22
	2000	2000	2000	68	63	33	14	32
	4000	4000	4000	68	67	38	14	50
	Statistics			NS	NS	NS	NS	** Exp

† WEP, water-extractable P; NS, not significant; **, significant at $P \leq 0.01$; Exp, exponential increasing trend. Values in a column followed by a similar letter do not differ.

Results of analyses of the aboveground portion of soybean plants sampled at the V6 growth stage in June 2018 from both sites showed very few statistically significant effects of gypsum for measurements at both sites. At NERF (Appendix Table A6), there were significant treatment effects only for S and B concentrations. The higher S concentrations for most gypsum treatments compared with the control are reasonable. However, the small differences for B concentrations do not have a reasonable explanation and could have resulted from random variation. At Boone (Appendix Table A7), there were significant effects only for S and Mn concentrations. Higher S concentrations for most gypsum treatments compared with the control are reasonable. However, the differences for Mn concentrations were not consistent with amounts or timing of gypsum application, do not have reasonable explanation, and could have resulted from random variation. The plant nutrient uptake was not statistically significant for any measurement at any site. The few significant results for gypsum effects on soybean young plants this year agree with results for corn in 2017, when there were no gypsum effects for any nutrient, not even for S. In 2016, gypsum application increased the concentrations of S and a few nutrients in soybean tissue but had inconsistent effects on plant dry weight and nutrient accumulation.

Table 8 shows that in 2018, the gypsum did not affect soybean grain yield significantly at NERF, where yield was high (63 to 68 bu/acre). There was no yield response in the previous two years of this site either. At Boone, however, gypsum increased soybean yield, where excessive rainfall in spring and early summer severely limited yield. No yield increases were observed at this site in the previous two years. The statistical differences allow for few clear interpretations of the results. Numerically, yield for the control is the lowest (36.2 bu/acre) is statistically similar to yields for the single initial 250-lb gypsum rate (41.5 bu/acre) and the annual 250-lb rate (42.2 bu/acre). Yield for the annual 1000-lb rate is numerically the highest, but is statistically similar to single initial rates of 500 and 2000 lb/acre and to annual rates of 500 and 2000 lb/acre. An orthogonal contrast (not shown) comparing yield of the control with the average yield of all other treatments was the only statistically significant of several pairwise comparisons tried. Therefore, we conclude that there was a crop response to S supplied by gypsum but rate or frequency of application effects were inconclusive.

Table 8. Gypsum effect on soybean grain yield in 2018 at two sites.

Gypsum Application Rate			Soybean Grain Yield	
1st Year	2nd Year	2nd Year	NERF	Boone
----------- lb gypsum/acre ---------			-------- bu/acre -------	
0	0	0	63.0	36.2 d
250	0	0	65.3	41.5 cd
500	0	0	67.5	49.0 ab
1000	0	0	63.5	43.5 bc
2000	0	0	64.0	48.8 ab
4000	0	0	63.5	44.1 bc
250	250	250	67.7	42.2 cd
500	500	500	66.9	47.3 abc
1000	1000	1000	62.5	50.9 a
2000	2000	2000	63.7	47.8 abc
4000	4000	4000	65.7	43.7 bc
Statistical significance†			NS	**

**, significant at $P \leq 0.05$. † NS, no significant difference; numbers in a column followed by one or more common letters do not differ.

Appendix Tables A8 (NERF) and A9 (Boone) show results and statistics for all measurements on soil samples taken from depths of 0-6 and 6-12 inches in fall 2018 after soybean harvest. Gypsum had statistically significant effects on soil sulfate in both depths at both sites but only for a few other measurements and in the 6-inch depth.

Figure 4 shows that at both sites, soil sulfate in the 6-inch depth was very low (4 to 6 ppm) for all rates applied only at the beginning of the study, which indicates little residual effects. However, the gypsum annual rates greatly increased sulfate in both depths at both sites. Sulfate at NERF for annual rates of 1000 to 4000 lb/acre were much higher for the depth of 6-12 inches, which indicates significant leaching from the surface layer. At Boone, sulfate was approximately similar for both soil depths similar to the depth of 6-12 inches at NERF. This result can be explained by rainfall at each site. Rainfall from fall 2017 to the June 2018 sampling date was similar for both sites, but rainfall from June to the fall sampling date was more at NERF (36.1 mm) than at Boone (27.2 mm).

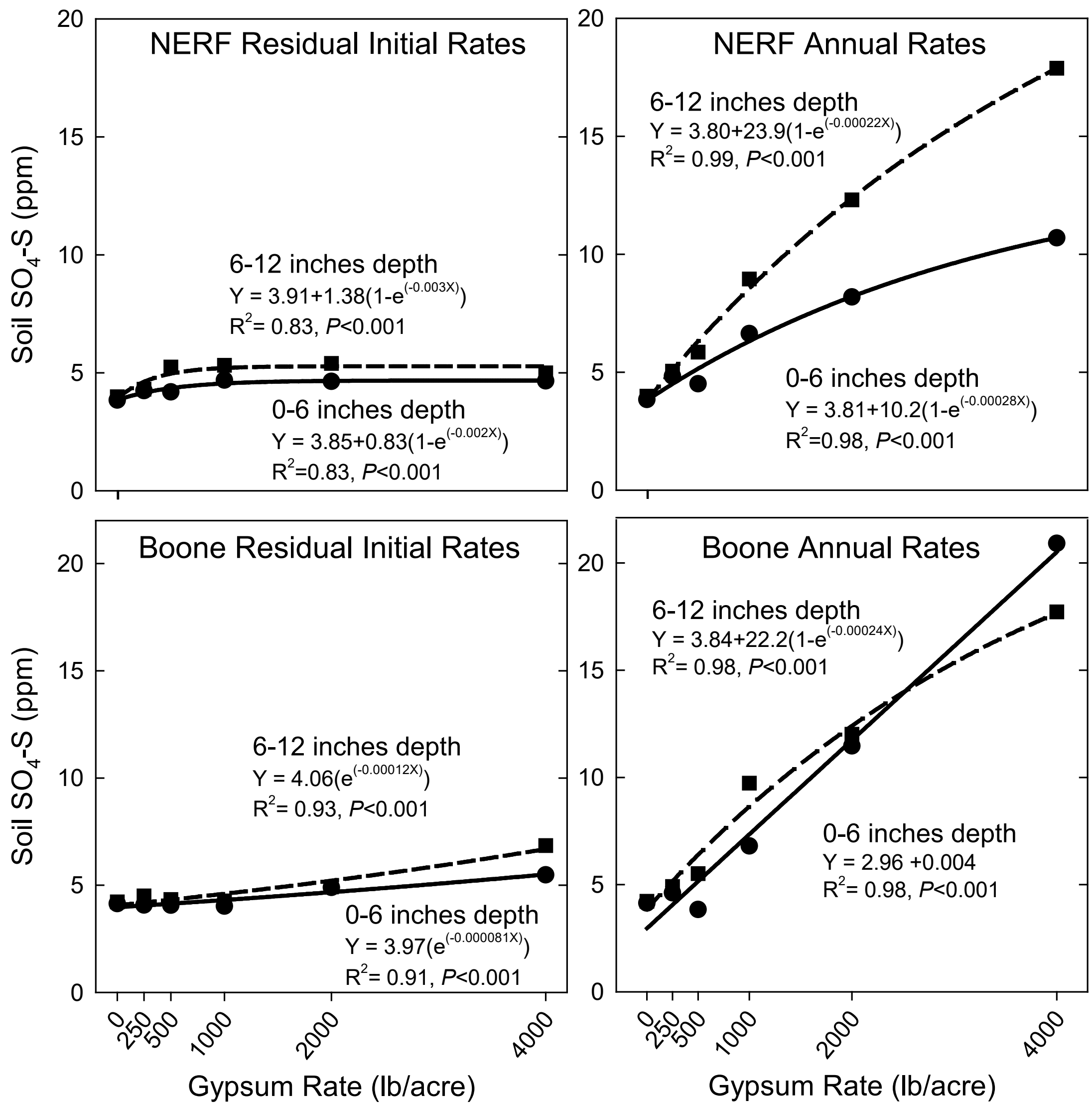

Fig. 4. Soil sulfate-S in fall 2018 after harvesting corn in two sampling depths at two sites as affected by gypsum applied only for the 2016 crop year or annually for the 2016, 2017, and 2018 crop years.

Figure 5 shows results for the other soil measurements that were affected by gypsum application at NERF. Gypsum increased extractable Ca and Ca saturation but decreased extractable Mg. In spite of a Ca linear response to increasing single initial gypsum rates and an exponential response to increasing annual rates, the only major difference in both cases was between the initial and annual 4000-lb rates (2401 to 2430 ppm) compared with the control that received no gypsum since the beginning of the study (1915 ppm). A Ca significant increase by the highest single initial gypsum rate is noteworthy because an apparent increase by this rate in fall 2017 did not reach statistical significance. Extractable Mg decreased as the gypsum rates increased with trends exponential to a minimum for the single initial and annual rates. The Ca increases were approximately similar for the single initial or annual gypsum rates, but the Mg decreases were more pronounced for the annual rates and especially for the two highest rates. The Ca saturation was increased by a residual effect of the single initial gypsum rate, but the increase by the highest annual rate was much larger.

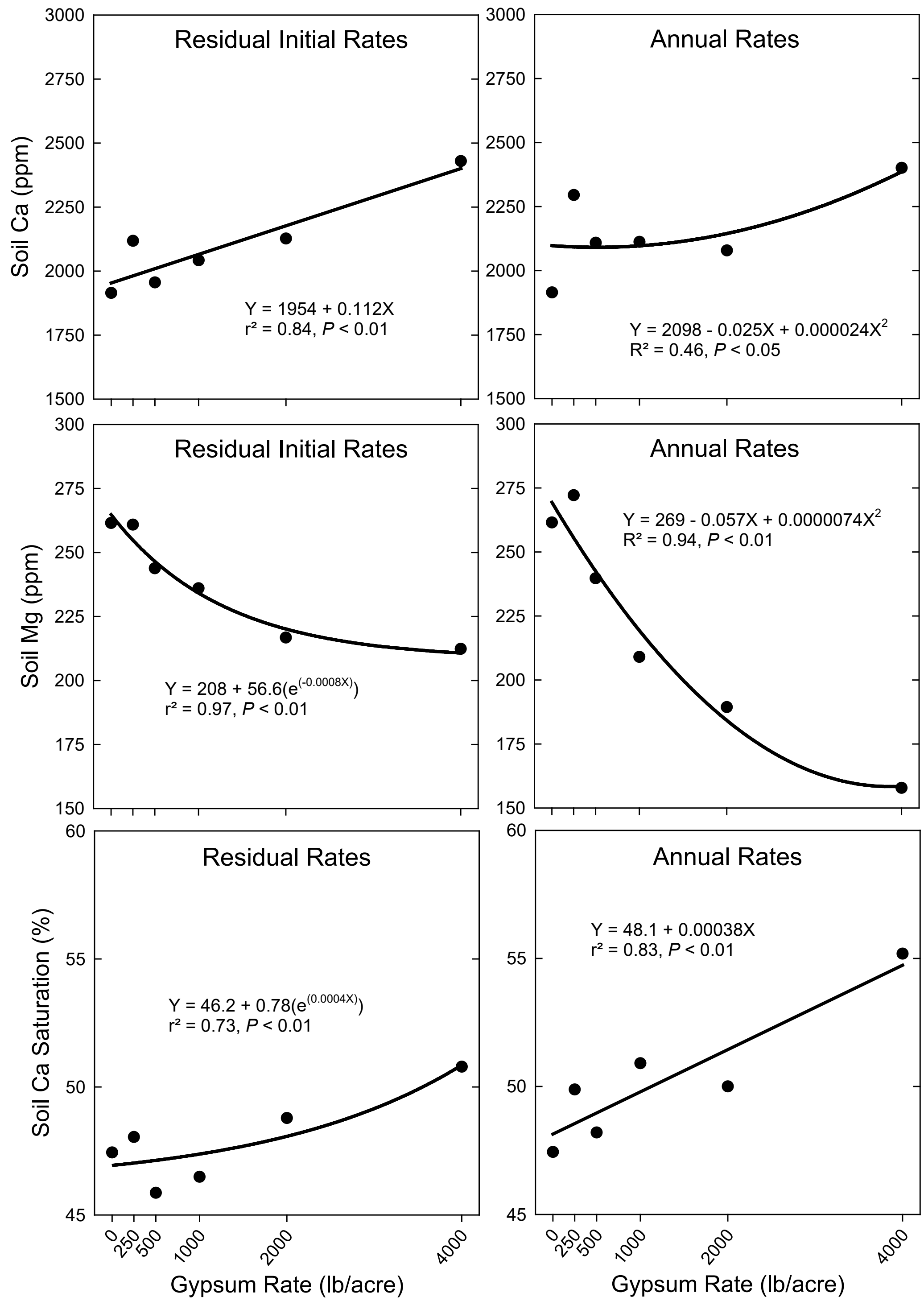

Fig. 5. Soil Ca, Mg, and Ca saturation for a depth of 0-6 inches at NERF as affected by gypsum applied only for the 2016 crop year or annually for the 2016, 2017, and 2018 crop years.

At Boone, in addition to sulfate at both soil depths, gypsum had statistically significant effects on extractable Ca and Mg, total bases, both base and Ca saturation, and pH in the top 0-6 inches depth (Appendix Table 9). Figure 6 shows that gypsum increased Ca and Ca saturation but decreased Mg, as was also the case for NERF. There were significant residual effects of the single initial gypsum rates on the three measurements, but mainly for the two highest rates. The increasing or decreasing effects of gypsum were much larger for the annual rates.

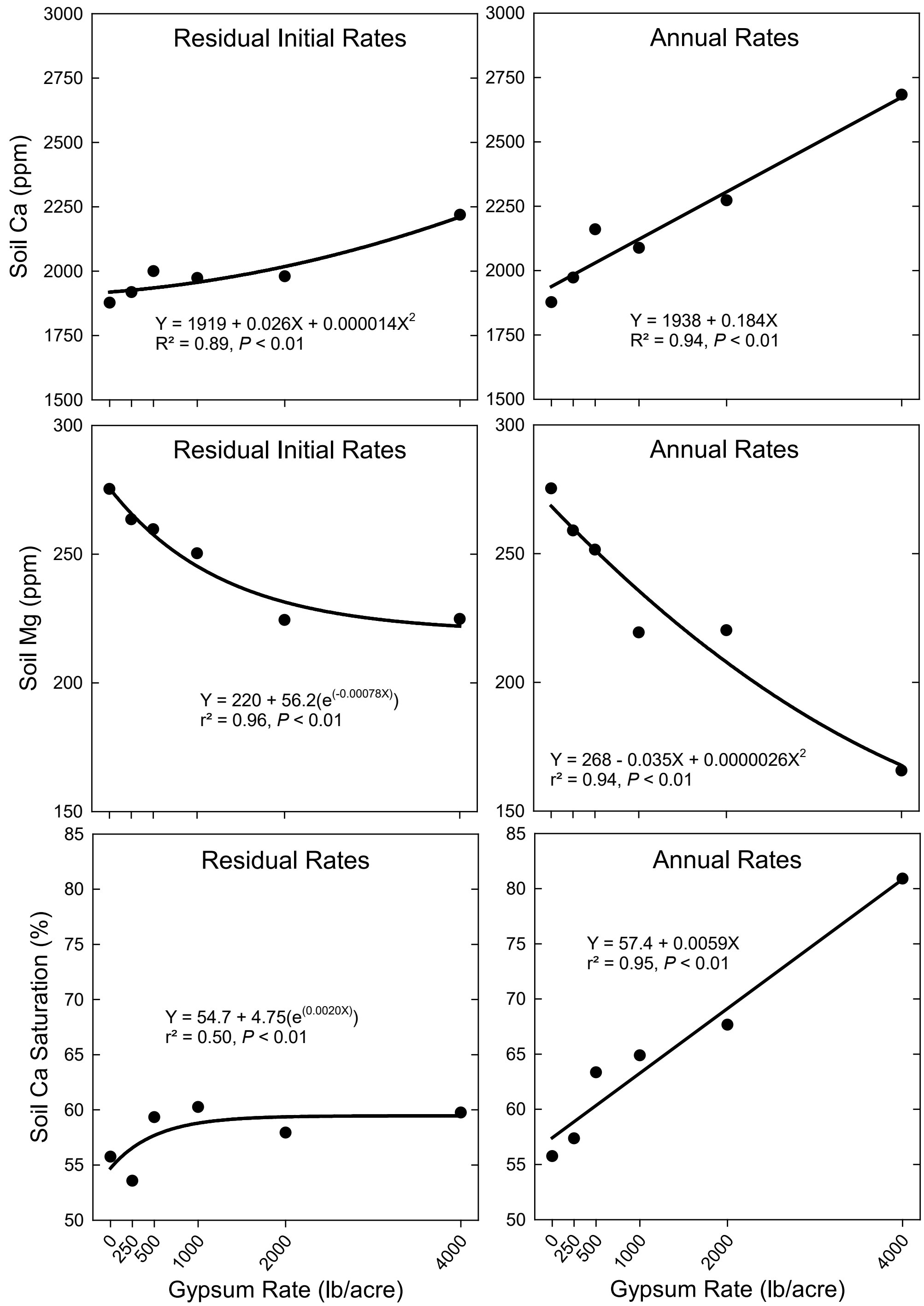

Fig. 6. Soil Ca, Mg, and Ca saturation for a depth of 0-6 inches at Boone as affected by gypsum applied only for the 2016 crop year or annually for the 2016, 2017, and 2018 crop years.

Figure 7 shows that there was a residual effect from the single initial gypsum rates only for total bases (and only from 4000-lb rate) but not for base saturation or pH. The gypsum annual rates increased all three measurements, although the increases were small and there was the usually high variability common in fields with liming histories. Therefore, it should not be surprising that soil CEC was not affected by gypsum, especially considering increases in Ca but decreases in Mg. Gypsum annual rates increased soil pH with a curvilinear trend, although data points in the figure and statistics in Appendix Table 9 show that only pH for the two annual rates was higher (pH 6.1 and 6.2) compared with other rates (5.7 to 6.0). This was the only instance gypsum affected pH across the two sites. Gypsum application normally does not change pH in non-sodic soils of Iowa and the Midwest. However, these exceptionally high gypsum rates applied consecutively during three years did increase pH slightly.

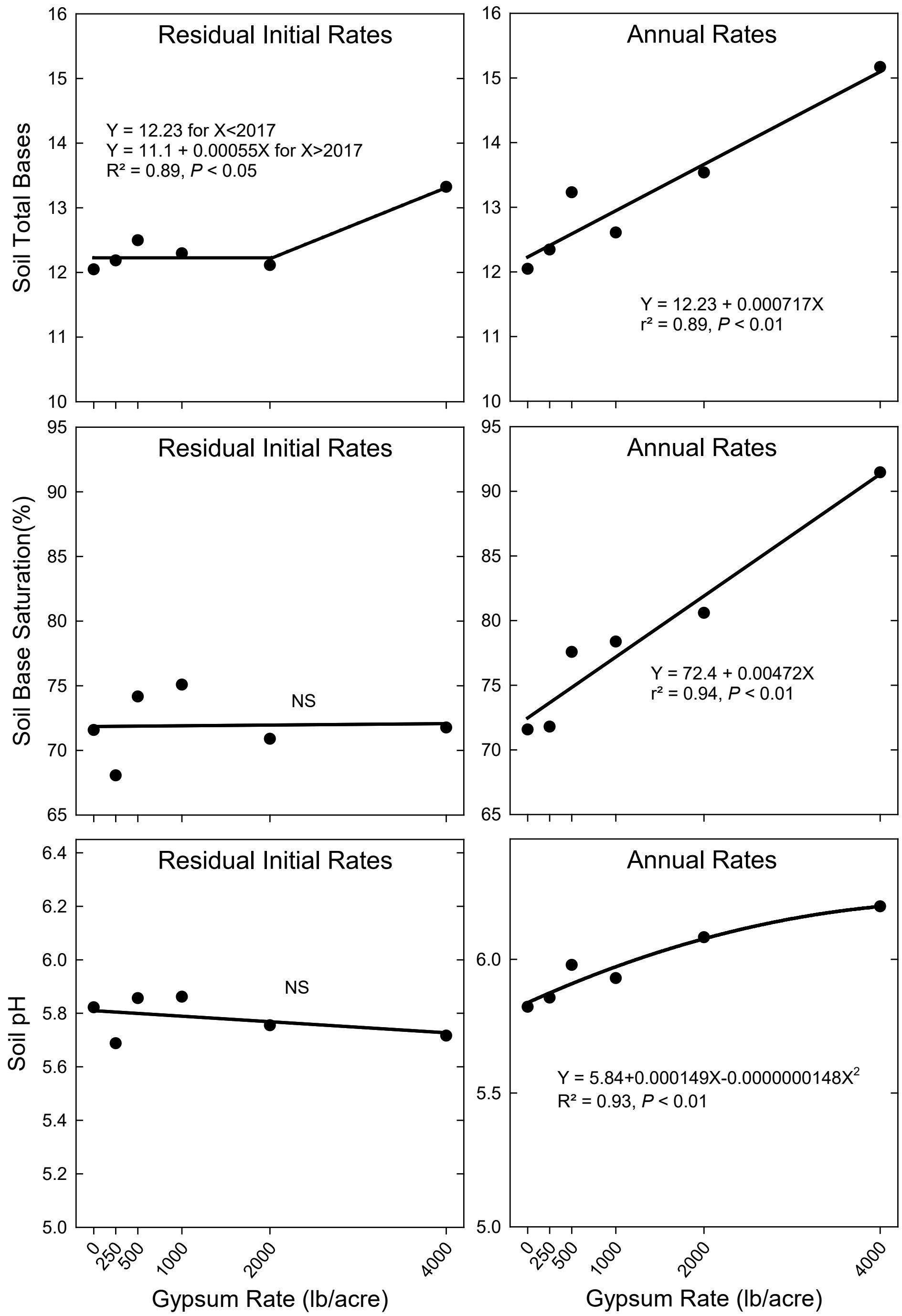

Fig. 7. Soil total bases and base saturation for a depth of 0-6 inches at Boone as affected by gypsum applied only for the 2016 crop year or annually for the 2016, 2017, and 2018 crop years.

Figure 8 shows results of the aggregate stability measurements by expressing the results for both sites as mean weight diameter (MWD) and the percentage of aggregates with a diameter of 1.0 mm or larger. Aggregate stability of untreated soil or treated soil as indicated by both forms of expression was better at NERF than at Boone. Gypsum did not clearly affect any aggregate stability measurement at Boone, and small apparent differences were not statistically significant. At NERF, however, gypsum application did improve aggregate stability. Gypsum single initial or annual rates of 2000 or 4000 lb/acre increased MWD compared to the control, and effects of annual application of the 250-lb rate or the single initial 1000-lb rate were intermediate. Gypsum annual application of 250 lb/acre and single initial or annual rates of 2000 or 4000 lb/acre increased the percentage of aggregates with a diameter of 1.0 mm or larger compared with the control, and the effect of a single initial 1000-lb rate was intermediate.

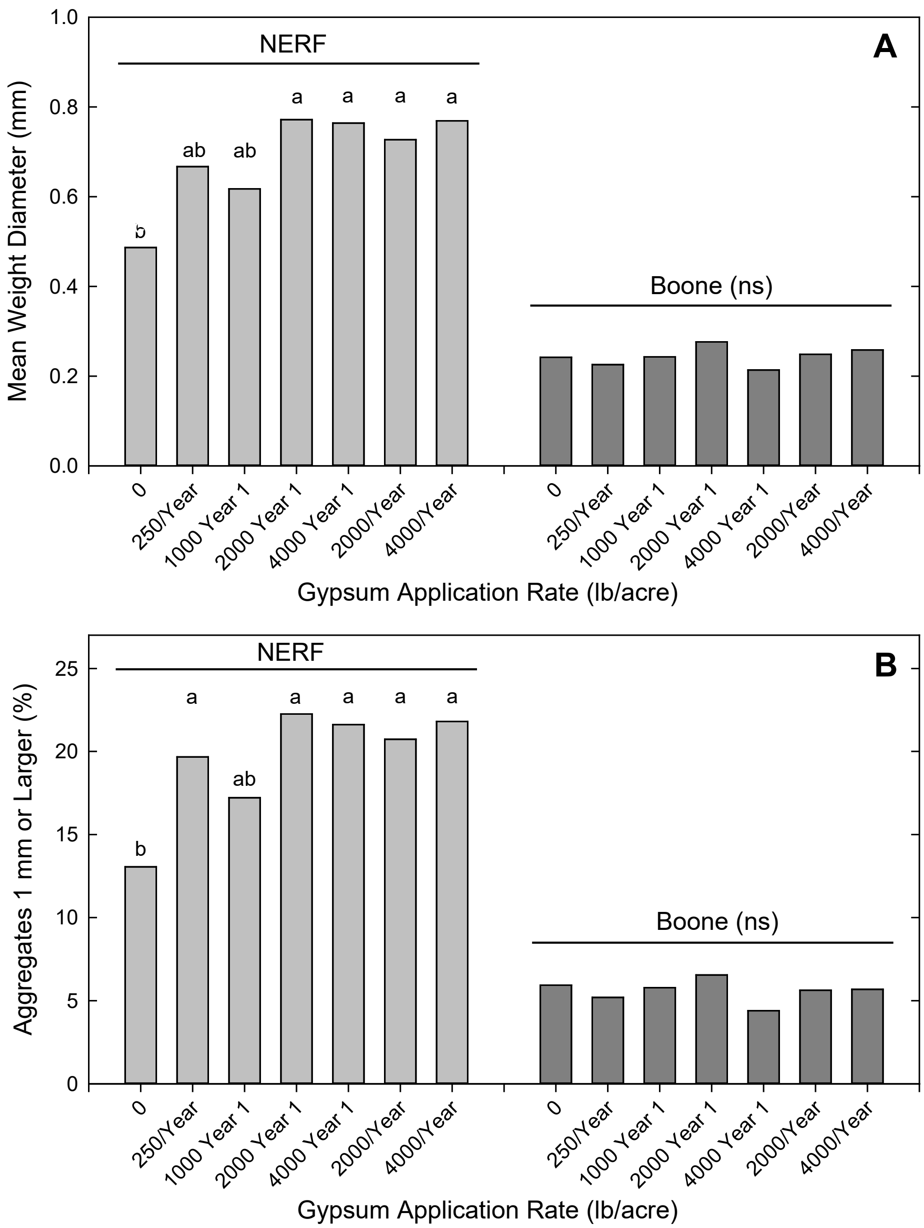

Figure 8. Effects of gypsum single initial and annual applications over three years on soil aggregate stability evaluated by mean weight diameter (A) and the percentage of aggregates with ≥1.0 mm diameter (B). Bars with similar letters indicate no differences at $P \leq 0.05$; NS, not significant.

There is no clear explanation for gypsum significant improvement of aggregate stability at NERF but not at Boone, especially when the overall aggregate stability was better at NERF than at Boone. Initial soil organic matter and extractable Ca were greater at NERF (4.1% and 2,105 ppm) than at Boone (3.4% and 1,908 ppm), so these soil properties would suggest a potentially higher effect of gypsum at Boone. However, soil texture, calcium percent saturation, and base percent saturation were approximately the same for both sites. Before this study, both sites had been managed with tillage and corn-soybean rotations for many decades. Perhaps unmeasured soil properties could have explained the differences between the two sites.

SUMMARY AND DISCUSSION

The study consisted of applying several combinations of single and annual gypsum rates including a control with no gypsum applied and ranging from a single initial rate of 250 lb/acre to an annual rate of 4000 lb/acre in two 3-year trials. The sites were at ISU research and demonstration farms in Boone County (Sorenson farm, near Ames, Clarion soil) and at the northeast research farm (NERF) in Floyd County (near Nashua, Floyd soil). The crops were soybean in 2016, corn in 2017, and soybean in 2018 managed with no-tillage. Potential gypsum effects were evaluated by several soil and crop measurements during the three years of the study.

Gypsum increased crop yield only the last year (soybean) at Boone, with no clear differences between the application rates. Gypsum had small, infrequent, and inconsistent effects on plant growth at the V6 growth stage and on concentrations or accumulation in plant tissue of S and other nutrients. Iowa research has shown corn and soybean responses to S fertilization supplied by gypsum or other sources, and seldom rates higher than about 30 lb S/acre applied every other year were needed to maximize yield. In corn, yield increases were observed in about 50% of the trials but soybean responses were less frequent.

Increasing gypsum rates increased exponentially sulfate-S in the top 6-inches of soil in late spring and in the fall after crop harvest. The background postharvest soil sulfate levels usually were 2 to 6 ppm and increased levels s by single or annual rates 2000 and 4000 lb/acre ranged from about 20 to 60 ppm depending on site and year. There was significant sulfate leaching from the top 6-inches of soil to a depth of 6 to 12 inches (the deepest soil layer sampled) with single or annual gypsum of 1000 lb/acre or higher. Gypsum rates of 1000 lb/acre or higher applied only once for the first crop-year resulted in significant sulfate increases in both soil sampling depths compared with lower rates or the control in the first and second years after the application, but very little after three years. Annual gypsum applications of 500 lb/acre resulted in moderate to large sulfate increases in both soil depths each year.

Gypsum rates applied only for the first year (not even the 4000-lb rate) did not affect soil extractable Ca and Mg, total bases, CEC, base saturation, and Ca saturation at one site (NERF) but decreased Mg in the top 6-inch depth at the other site (Boone). This should not be a surprising result for the vast majority of Iowa soils that are prairie derived soils with usually high Ca levels in the cation exchange complex and in some cases high calcium carbonate (although the two soils of the study did not have free calcium carbonate in the top layers). In the second year, there were significant gypsum effects only for the top 6-inch depth, and annual rates of 2000 and 4000 lb/acre increased extractable Ca at Boone but only the highest rate increased both Ca and Ca saturation at NERF, whereas the highest rate decreased Mg at both sites. In the third year, accumulated rates during three years results in more clear increases of these soil properties mainly with the annual rates but only for the top 6-inch soil depth. At NERF gypsum increased Ca and Ca saturation and decreased Mg, whereas at Boone gypsum increased Ca, total bases, base saturation and Ca saturation, and pH but decreased Mg.

The effects of gypsum at increasing Ca and decreasing Mg coupled with small magnitude of effects and high variability due to high soil Ca levels may explain that total bases was increased only at one site and only by accumulated rates of 6000 and 12000 lb/acre of gypsum during three years, and that CEC was not affected. The amount of Ca added even with the very high applied gypsum rates represented a small fraction of the exchangeable Ca in the soils. Also, since all Iowa soils except the calcareous ones have been limed frequently, the Ca levels probably are similar or higher than native levels and, moreover, liming caused high small- and large-scale spatial variability of extractable cations and pH that make difficult the detection of small changes.

A consistent result from every year of the study was that gypsum single initial or annual application rates of 500 lb/acre or higher reduced soil extractable Mg significantly. Research in some states have shown that high gypsum application rates decrease Na or Mg in soils with excessive levels of these elements through leaching, because Ca has higher ionic potential than Mg or Na and results in partial replacement of these two cations from the exchange complex . In fact, gypsum amendment is recommended to alleviate Na or Mg excess in those soils. The same cation exchange process could result in increased crop uptake and removal of Mg with harvest, which could decrease Mg levels. The methods used in the study do not allow for a clear explanation of this result, however. The Mg concentrations in the soil depth of 6 to 12 inches did not show evidence of Mg leaching, as it did for sulfate. The analysis of young plants at the V5-V6 stage did not show increased Mg concentration or uptake with gypsum application. Precipitation of magnesium sulfate may have occurred but is unlikely to explain reduced Mg because this compound is much more soluble than calcium sulfate. Unfortunatelly, the budget did not allow for tissue analysis of whole plants at the end of the season or subsoil sampling and analysis. The gypsum effect at decreasing soil extractable Mg likely was of no consequence for the crops of the study because even the lowest observed concentrations were higher than minimum levels considered optimum in a few states of the north central region. Iowa State University does not have soil-test interpretations for Mg because no deficiency has been documented for field crops in the state.

Gypsum application did not affect soil-test P measured by the routine tests used in Iowa for crop production and the P index (Bray 1, Mehlich-3, and Olsen). Gypsum reduced water-extractable soil P of the top 6-inch depth at both sites in the June 2016 soil sampling and only slightly in one site in fall 2016 but not in the other two years. Soil-test P values by the three routine test methods were mostly optimum to high according to Iowa interpretations categories in 2016, but were high to very high in 2017 and 2018 (as high as three times the optimum levels suggested for crops). Since the crop and soil management was similar in all three years, including application of P fertilizer every time gypsum was applied, there is no clear explanation for small effects only the first year. The results do suggest, however, that at least in these soils with these management practices and properties, high rates of gypsum are unlikely to decrease dissolved P loss with surface runoff or tile drainage by much or frequently.

Gypsum application improved aggregate stability measurements at one site (NERF) but had no effect at the other site (Boone). At NERF, gypsum single initial or annual rates of 2000 or 4000 lb/acre increased aggregate stability compared to the control whereas annual application of the 250-lb rate or the single initial 1000-lb rate were intermediate. There is no clear explanation for gypsum significant improvement of aggregate stability at NERF but not at Boone, especially when the overall aggregate stability indices, soil organic matter, and extractable Ca were slightly greater at NERF than at Boone.

CONCLUSIONS

The results of this three-year project at two sites showed that gypsum application rates higher than recommended to supply S for crops have a potential to improve soil physical properties in largely undetermined conditions, that improved aggregate stability and induced changes in extractable soil cations were not well related to crop yield, and that soil dissolved P seldom was reduced. Perhaps gypsum can have greater and more frequent benefits in soils with worse physical properties, lower Ca levels, and/or higher soil P concentrations.

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APPENDIX TABLES

Table A1. Gypsum effects on soil-test values after the soybean harvest in fall 2016 at NERF and Boone sites.

		Gypsum Rate (lb/acre)													
Depth		NERF							Boone						
inches	Measurement	0	250	500	1000	2000	4000	Stats†	0	250	500	1000	2000	4000	Stats
0-6	Bray P, ppm	26	30	26	23	24	22	NS	20	19	17	20	17	20	NS
	M3 P, ppm	27	33	27	24	27	24	NS	22	21	17	21	18	21	NS
	Olsen P, ppm	13	15	13	11	12	10	NS	11	10	9	11	9	11	NS
	WEP, ppm	6.5	7.3	6.5	5.8	5.8	6.0	NS	5.7	5.5	4.6	5.0	3.8	4.5	* Exp
	SO_4, ppm	2	4	3	5	6	12	** Exp	4	5	7	11	15	63	** Exp
	K, ppm	212	195	193	199	201	183	NS	111	122	107	108	109	109	NS
	Ca, ppm	2364	2387	2221	2058	2355	2536	NS	2015	1943	2096	1946	1876	2025	NS
	Mg, ppm	275	278	262	231	224	243	NS	258	244	230	224	201	197	* Exp
	Na, ppm	15	14	12	14	15	13	NS	13	15	13	15	15	13	NS
	pH	5.4	5.3	5.4	5.3	5.3	5.4	NS	5.6	5.5	5.5	5.6	5.5	5.4	NS
	Total bases, %	15	15	14	13	14	15	NS	13	12	13	12	11	12	NS
	CEC, %	21	22	20	19	21	21	NS	16	15	17	15	14	15	NS
	Base sat., %	69	68	70	67	69	73	NS	80	77	73	78	80	77	NS
	Ca sat., %	56	55	56	54	57	61	NS	65	62	61	64	66	65	NS
6-12	Bray P, ppm	5	4	4	5	5	5	NS	2	2	2	3	2	2	NS
	M3 P, ppm	6	6	5	6	5	5	NS	4	3	4	4	4	4	NS
	Olsen P, ppm	3	2	2	3	3	3	NS	2	2	1	2	2	2	NS
	WEP, ppm	2.5	2.0	1.9	2.3	2.2	1.8		2.0	2.3	2.3	2.1	1.9	1.8	NS
	SO_4, ppm	2	3	5	6	11	22	** Lin	4	4	8	10	24	48	** Lin
	K, ppm	97	78	82	87	77	96	NS	68	68	71	66	70	67	NS
	Ca, ppm	2398	2398	2123	2283	2272	2684	NS	2362	2149	2259	1997	2009	2073	NS
	Mg, ppm	271	265	242	254	243	298	NS	270	272	281	238	240	251	NS
	Na, ppm	16	16	16	17	19	16	NS	15	15	18	15	16	16	NS
	pH	5.3	5.3	5.2	5.2	5.2	5.3	NS	5.7	5.4	5.6	5.5	5.5	5.4	NS
	Total bases, %	15	14	13	14	14	16	NS	14	13	14	12	12	13	NS
	CEC, %	22	23	22	22	22	24	NS	18	18	18	16	17	18	NS
	Base sat., %	66	62	57	63	61	68	NS	80	72	78	74	74	72	NS
	Ca sat., %	54	52	47	52	51	57	NS	67	58	64	61	61	59	NS

† Stat, statistics; NS, not significant; * or **, significant at $P \leq 0.01$ or $P \leq 0.05$; Exp or Lin, exponential or linear trend. Values in a column followed by a similar letter do not differ.

Table A2. Gypsum effect on nutrient concentration of corn plants (V5-V6 growth stage) in 2017 at NERF.

	Gypsum Rate Applied in Year 1 (lb/acre)											
	0	250	500	1000	2000	4000	250	500	1000	2000	4000	
	Gypsum Rate Applied in Year 2 (lb/acre)											
Measurement	0	0	0	0	0	0	250	500	1000	2000	4000	Stats†
P %	0.42	0.40	0.42	0.40	0.40	0.37	0.38	0.42	0.40	0.39	0.40	NS
K %	1.74	1.68	1.61	1.55	1.61	2.04	1.50	2.01	1.90	1.64	1.68	NS
Mg %	0.61	0.55	0.66	0.62	0.62	0.57	0.58	0.57	0.56	0.60	0.62	NS
Ca %	0.79	0.69	0.80	0.76	0.73	0.74	0.72	0.72	0.71	0.75	0.80	NS
S %	0.27	0.28	0.27	0.26	0.26	0.25	0.26	0.25	0.26	0.27	0.26	NS
B ppm	6.67	6.67	7.00	6.67	7.00	6.00	6.67	6.33	6.33	7.00	6.33	NS
Zn ppm	38	35	39	40	39	40	35	40	38	43	40	NS
Mn ppm	149	128	147	149	139	134	128	148	146	158	149	NS
Fe ppm	184	172	234	200	169	163	196	248	209	201	199	NS
Cu ppm	11	11	11	11	11	10	10	11	10	11	11	NS
DW g/10 plants	29	29	27	32	29	32	31	25	28	30	23	NS
P g/10 plants	0.12	0.12	0.11	0.13	0.12	0.12	0.12	0.11	0.11	0.12	0.09	NS
K g/10 plants	0.51	0.49	0.43	0.50	0.48	0.64	0.46	0.54	0.54	0.50	0.38	NS
Mg g/10 plants	0.18	0.16	0.17	0.20	0.18	0.18	0.17	0.14	0.16	0.18	0.14	NS
Ca g/10 plants	0.23	0.20	0.21	0.24	0.22	0.23	0.22	0.18	0.20	0.23	0.18	NS
S g/10 plants	0.08	0.08	0.07	0.08	0.08	0.08	0.08	0.06	0.07	0.08	0.06	NS
B mg/10 plants	1.92	1.99	1.88	2.14	2.06	1.90	2.04	1.59	1.81	2.12	1.46	NS
Zn mg/10 plants	10.9	10.1	10.5	12.8	11.2	12.5	10.7	10.3	10.6	13.1	9.0	NS
Mn mg/10 plants	44	37	40	47	41	43	39	37	41	48	34	NS
Fe mg/10 plants	53	50	63	63	49	52	60	64	59	61	45	NS
Cu mg/10 plants	3.32	3.35	3.04	3.53	3.09	3.25	3.14	2.75	2.95	3.22	2.51	NS

† Stat, statistics; NS, not significant at $P \leq 0.05$.

Table A3. Gypsum effect on nutrient concentration of corn plants (V5-V6 growth stage) in 2017 at Boone.

	Gypsum Rate Applied in Year 1 (lb/acre)											
	0	250	500	1000	2000	4000	250	500	1000	2000	4000	
	Gypsum Rate Applied in Year 2 (lb/acre)											
Measurement	0	0	0	0	0	0	250	500	1000	2000	4000	Stat†
P %	0.47	0.46	0.46	0.44	0.45	0.46	0.46	0.46	0.46	0.45	0.46	NS
K %	4.07	4.08	3.99	3.97	4.07	4.31	4.33	3.89	4.18	4.04	4.24	NS
Mg %	0.29	0.29	0.29	0.27	0.28	0.24	0.26	0.28	0.28	0.27	0.26	NS
Ca %	0.59	0.58	0.57	0.54	0.60	0.55	0.57	0.57	0.59	0.59	0.54	NS
S %	0.35	0.32	0.28	0.28	0.43	0.48	0.45	0.29	0.35	0.35	0.28	NS
B ppm	7.67	7.67	7.67	7.33	7.67	7.00	7.33	7.33	7.33	7.67	7.00	NS
Zn ppm	37	39	37	39	38	41	40	37	43	33	40	NS
Mn ppm	115	111	119	120	131	123	122	129	127	122	133	NS
Fe ppm	255	218	299	227	333	221	180	276	219	251	372	NS
Cu ppm	12	13	12	12	13	12	12	12	12	12	12	NS
DW g/10 plants	53	48	59	56	64	62	41	59	54	59	64	NS
P g/10 plants	0.25	0.22	0.27	0.25	0.29	0.28	0.19	0.27	0.25	0.27	0.30	NS
K g/10 plants	2.17	1.99	2.34	2.23	2.61	2.68	1.80	2.32	2.22	2.39	2.71	NS
Mg g/10 plants	0.15	0.13	0.17	0.15	0.18	0.15	0.11	0.17	0.15	0.16	0.16	NS
Ca g/10 plants	0.31	0.27	0.34	0.30	0.39	0.34	0.24	0.33	0.32	0.35	0.34	NS
S g/10 plants	0.19	0.15	0.16	0.16	0.27	0.30	0.19	0.17	0.19	0.20	0.18	NS
B mg/10 plants	4.06	3.65	4.53	4.03	4.93	4.32	3.04	4.31	3.97	4.52	4.46	NS
Zn mg/10 plants	19.8	18.3	21.6	22.7	24.2	25.6	16.4	22.3	22.9	19.7	25.7	NS
Mn mg/10 plants	62	54	69	67	85	77	50	78	68	72	86	NS
Fe mg/10 plants	131	109	174	117	218	134	74	170	117	149	242	NS
Cu mg/10 plants	6.55	6.01	6.89	6.78	8.37	7.40	4.99	6.87	6.26	6.88	7.45	NS

† Stat, statistics; NS, not significant at $P \leq 0.05$.

Table A4. Gypsum effects on soil-test values for two depths after the corn harvest in fall 2017 at NERF.

		Gypsum Rate Applied in Year 1 (lb/acre)											
		0	250	500	1000	2000	4000	250	500	1000	2000	4000	
Depth		Gypsum Rate Applied in Year 2 (lb/acre)											
inches	Measurement	0	0	0	0	0	0	250	500	1000	2000	4000	Stat†
0-6	Bray P, ppm	47	35	48	47	47	46	32	42	46	41	38	NS
	M3 P, ppm	48	35	52	49	48	49	31	45	46	42	42	NS
	Olsen P, ppm	32	26	24	24	27	26	20	31	24	36	22	NS
	WEP, ppm	12	10	11	11	11	13	10	10	12	10	10	NS
	SO_4, ppm	6b	6b	6b	7b	7b	9b	6b	7b	8	11ab	27b	**
	K, ppm	263	248	273	239	253	262	257	250	242	236	260	NS
	Ca, ppm	2348	2556	2212b	2124	2145	2660	2586	2296	2284	2299	2809	‡
	Mg, ppm	300	337	272	258	265	274	328	293	268	258	237	‡
	Na, ppm	14	15	13	20	16	25	13	12	17	24	14	NS
	pH	5.4	5.4	5.3	5.2	5.3	5.4	5.4	5.3	5.3	5.5	5.5	NS
	Total bases, %	15	16	14	13	13	16	16	15	14	14	17	NS
	CEC, %	19	19	17	20	17	20	20	18	20	19	19	NS
	Base sat., %	80	85	81	68	78	80	81	80	71	77	87	NS
	Ca sat., %	63	67	63	54	62	65	64	63	57	62	73	‡
6-12	Bray P, ppm	7	5	7	7	7	6	6	7	7	7	6	NS
	M3 P, ppm	7	5	6	6	7	5	4	6	6	7	5	NS
	Olsen P, ppm	4	3	4	4	4	4	3	7	4	5	6	NS
	WEP, ppm	2	3	4	4	4	3	4	5	3	4	3	NS
	SO_4, ppm	5c	5c	7bc	9bc	9bc	15b	6c	8bc	13b	15b	40a	**
	K, ppm	122	102	113	113	115	126	110	106	109	113	125	NS
	Ca, ppm	2358	2414	2251	2424	2232	2628	2426	2309	2308	2422	2558	NS
	Mg, ppm	311	333	305	309	300	348	340	313	314	327	333	NS
	Na, ppm	20	18	17	13	16	13	22	13	18	21	18	NS
	pH	5.4	5.5	5.1	5.3	5.3	5.5	5.5	5.4	5.3	5.4	5.2	NS
	Total bases, %	15	15	14	15	14	16	15	14	14	15	16	NS
	CEC, %	20	15	22	19	18	21	18	17	18	15	22	NS
	Base sat., %	74	100	66	82	79	79	85	88	82	100	75	NS
	Ca sat., %	59	83	52	66	63	64	67	70	65	81	60	NS

† Stat, statistics; NS, not significant; **, significant at $P \leq 0.01$; ‡ Significant orthogonal contrast between the control and the 4000-lb annual rate ($P \leq 0.05$).

Table A5. Gypsum effects on soil-test values for two depths after the corn harvest in fall 2017 at Boone.

	Gypsum Rate Applied in Year 1 (lb/acre)											
	0	250	500	1000	2000	4000	250	500	1000	2000	4000	
Depth	Gypsum Rate Applied in Year 2 (lb/acre)											
inches / Measurement	0	0	0	0	0	0	250	500	1000	2000	4000	Stat†
0-6 Bray P, ppm	30	49	34	38	45	44	36	41	50	39	42	NS
M3 P, ppm	30	55	36	45	52	47	35	40	49	43	45	NS
Olsen P, ppm	16	27	19	20	21	28	17	23	26	24	26	NS
WEP, ppm	11	16	13	11	13	15	11	14	17	12	14	NS
SO_4, ppm	5bc	5bc	5bc	5bc	6bc	8a	4c	5bc	5bc	6bc	9a	**
K, ppm	149	181	154	163	162	171	138	149	168	157	153	NS
Ca, ppm	2146	2003	2248	2150	2030	2291	1930	2289	2398	2540	2516	§
Mg, ppm	326	307	326	312	275	288	293	321	297	285	247	‡
Na, ppm	15	15	12	10	11	11	14	17	11	16	14	NS
pH	5.8	5.8	5.8	5.8	5.7	5.7	6.0	6.0	6.1	6.1	6.3	NS
Total bases, %	14	13	14	14	13	14	12	15	15	16	15	NS
CEC, %	14	14	15	14	15	18	15	13	15	15	15	NS
Base sat., %	97	97	95	96	88	80	86	100	100	100	100	NS
Ca sat., %	75	74	74	75	69	64	67	86	82	83	84	NS
6-12 Bray P, ppm	5	8	6	7	6	6	5	7	6	5	7	NS
M3 P, ppm	5	7	5	5	5	6	4	6	5	4	6	NS
Olsen P, ppm	2	4	3	2	2	3	2	4	3	2	4	NS
WEP, ppm	4	6	5	6	4	6	5	4	4	4	5	NS
SO_4, ppm	6c	7bc	7bc	7bc	9ab	11a	6c	8b	7bc	9ab	12a	**
K, ppm	114	113	108	111	104	119	111	118	97	100	100	NS
Ca, ppm	2359	2259	2302	2228	2094	2402	2331	2434	2103	2234	2176	NS
Mg, ppm	344	334	332	337	298	345	347	351	299	320	313	NS
Na, ppm	20	17	18	18	16	17	20	17	20	15	17	NS
pH	5.8	5.7	5.9	5.8	5.7	5.6	5.8	5.9	5.8	5.7	5.7	NS
Total bases, %	15	14	15	14	13	15	58	15	13	14	14	NS
CEC, %	19	16	16	16	16	18	60	16	15	17	16	NS
Base sat., %	81	88	91	89	88	85	94	94	94	84	88	NS
Ca sat., %	64	69	72	69	70	67	50	74	74	67	69	NS

† Stat, statistics; NS, not significant; **, significant at $P \leq 0.01$; ‡ or §, significant orthogonal contrasts between the control and the highest annual rate or the two highest annual rates ($P \leq 0.05$).

Table A6. Gypsum effect on the nutrient concentration of soybean plants (V5-V6 growth stage) in 2018 at NERF.

	Gypsum Rate Applied in Year 1 (lb/acre)											
	0	250	500	1000	2000	4000	250	500	1000	2000	4000	
	Gypsum Rate Applied in Year 2 and 3 (lb/acre)											
Measurement	0	0	0	0	0	0	250	500	1000	2000	4000	Stat†
P %	0.32	0.34	0.32	0.32	0.32	0.33	0.33	0.34	0.31	0.31	0.33	NS
K %	2.63	2.43	2.64	2.62	2.56	2.7	2.41	2.6	2.32	2.44	2.41	NS
Mg %	0.41	0.45	0.41	0.39	0.37	0.36	0.44	0.42	0.40	0.40	0.40	NS
Ca %	1.46	1.54	1.48	1.47	1.5	1.58	1.49	1.44	1.45	1.46	1.55	NS
S %	0.26c	0.29b	0.29b	0.31b	0.33ab	0.37a	0.27bc	0.27bc	0.27bc	0.28bc	0.35a	*
B ppm	32b	34ab	32	34ab	34ab	34ab	35a	35a	34ab	33ab	36a	*
Zn ppm	28	29	30	33	34	33	29	31	33	34	30	NS
Mn ppm	64	68	63	76	78	73	66	83	74	75	77	NS
Fe ppm	159	191	162	170	252	182	207	182	196	176	160	NS
Cu ppm	9	8	8	8	8	8	8	8	7	8	8	NS
DW g/10 plants	16	15	16	14	14	14	16	15	14	13	14	NS
P g/10 plants	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	NS
K g/10 plants	0.42	0.36	0.42	0.37	0.37	0.39	0.39	0.38	0.34	0.32	0.34	NS
Mg g/10 plants	0.07	0.07	0.07	0.05	0.05	0.05	0.07	0.06	0.06	0.05	0.06	NS
Ca g/10 plants	0.23	0.23	0.23	0.21	0.22	0.23	0.24	0.21	0.21	0.19	0.22	NS
S g/10 plants	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	NS
B mg/10 plants	0.51	0.5	0.51	0.48	0.49	0.49	0.56	0.51	0.49	0.43	0.5	NS
Zn mg/10 plants	0.44	0.43	0.47	0.47	0.5	0.47	0.46	0.46	0.47	0.44	0.42	NS
Mn mg/10	0.98	0.98	1	1.08	1.1	1.04	1.03	1.2	1.06	0.98	1.04	NS
Fe mg/10 plants	2.53	2.84	2.57	2.41	3.53	2.62	3.36	2.67	2.8	2.29	2.22	NS
Cu mg/10 plants	0.14	0.12	0.12	0.11	0.12	0.11	0.13	0.12	0.1	0.11	0.11	NS

† Stat, statistics; NS, not significant; *, significant at $P \leq 0.05$.

Tab/le A7. Gypsum effect on nutrient concentration of soybean plants (V5-V6 growth stage) in 2018 at Boone.

	Gypsum Rate Applied in Year 1 (lb/acre)												
	0	250	500	1000	2000	4000	0	250	500	1000	2000	4000	
	Gypsum Rate Applied in Year 2 and 3 (lb/acre)												
Measurement	0	0	0	0	0	0	2000	250	500	1000	2000	4000	Stat†
P %	0.42	0.43	0.42	0.44	0.4	0.42	0.4	0.39	0.43	0.43	0.43	0.42	NS
K %	2.39	2.53	2.2	2.66	2.49	2.62	2.57	2.38	2.29	2.59	2.48	2.33	NS
Mg %	0.52	0.47	0.5	0.46	0.46	0.44	0.44	0.48	0.5	0.47	0.5	0.48	NS
Ca %	1.67	1.56	1.68	1.63	1.66	1.74	1.62	1.58	1.71	1.62	1.67	1.72	NS
S %	0.25c	0.26bc	0.28b	0.30ab	0.31ab	0.34a	0.31ab	0.25c	0.28b	0.26bc	0.26bc	0.28b	*
B ppm	40	39	42	41	39	39	38	39	42	41	42	43	NS
Zn ppm	41	42	44	41	42	43	42	41	47	42	42	44	NS
Mn ppm	121b	121b	128b	114c	88d	91d	99cd	135a	128b	121b	121b	119bc	*
Fe ppm	167	143	161	152	140	163	153	182	158	158	150	175	NS
Cu ppm	10	8	8	9	9	9	8	9	8	8	8	10	NS
DW g/10 plants	21	20	20	19	17	18	19	24	19	21	21	22	NS
P g/10 plants	0.09	0.09	0.08	0.09	0.07	0.08	0.07	0.09	0.08	0.09	0.09	0.09	NS
K g/10 plants	0.5	0.52	0.45	0.52	0.43	0.47	0.48	0.57	0.44	0.54	0.51	0.52	NS
Mg g/10 plants	0.11	0.1	0.1	0.09	0.08	0.08	0.08	0.12	0.1	0.1	0.1	0.11	NS
Ca g/10 plants	0.35	0.32	0.34	0.32	0.28	0.31	0.31	0.38	0.33	0.34	0.34	0.39	NS
S g/10 plants	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.05	0.06	0.05	0.06	NS
B mg/10 plants	0.83	0.8	0.83	0.79	0.67	0.71	0.72	0.95	0.81	0.86	0.86	0.95	NS
Zn mg/10 plants	0.87	0.85	0.87	0.79	0.71	0.79	0.79	0.99	0.91	0.88	0.87	0.98	NS
Mn mg/10 plants	2.56	2.4	2.48	2.19	1.49	1.65	1.88	3.29	2.42	2.6	2.51	2.66	NS
Fe mg/10 plants	3.47	2.94	3.29	2.96	2.36	2.98	2.89	4.43	3.14	3.42	3.09	3.92	NS
Cu mg/10 plants	0.2	0.16	0.17	0.17	0.15	0.17	0.16	0.21	0.15	0.17	0.17	0.23	NS

† NS, not significant $P \leq 0.05$.

Table A8. Gypsum effects on soil-test values for two depths after the corn harvest in fall 2018 at NERF.

		Gypsum Rate Applied in Year 1 (lb/acre)											
		0	250	500	1000	2000	4000	250	500	1000	2000	4000	
Depth		Gypsum Rate Applied in Years 2 and 3 (lb/acre)											
inches	Measurement	0	0	0	0	0	0	250	500	1000	2000	4000	Stat†
0-6	Bray P, ppm	52	47	58	57	42	49	51	48	50	56	50	NS
	M3 P, ppm	50	43	52	55	39	45	45	45	49	51	45	NS
	Olsen P, ppm	27	22	27	28	20	26	23	23	24	25	27	NS
	WEP, ppm	13	9	13	12	8	10	10	11	10	10	10	NS
	SO_4, ppm	4d	4d	4d	5cd	5cd	5cd	5cd	5cd	7bc	8b	11a	**
	K, ppm	219	201	219	209	207	193	228	194	195	199	191	NS
	Ca, ppm	1915c	2118ab	1956bc	2042abc	2127abc	2430a	2295ab	2109ab	2112abc	2079abc	2401ab	*
	Mg, ppm	262a	261a	244ab	236ab	217abc	212abc	272a	240ab	209abc	189bc	158c	*
	Na, ppm	9	9	9	9	10	9	9	8	8	8	8	NS
	pH	5.7	5.5	5.4	5.4	5.4	5.4	5.5	5.4	5.4	5.5	5.5	NS
	Total bases, %	12	13	12	13	13	14	14	13	13	12	14	NS
	CEC, %	20	22	21	22	22	24	23	22	21	21	22	NS
	Base sat., %	61	60	58	58	60	60	62	60	62	60	64	NS
	Ca sat., %	47ab	48ab	46b	46ab	49ab	51ab	50ab	48ab	51ab	50ab	55a	NS
6-12	Bray P, ppm	9	8	12	11	8	9	9	11	8	10	8	NS
	M3 P, ppm	6	6	8	7	5	6	6	7	5	6	5	NS
	Olsen P, ppm	4	3	4	4	3	4	3	4	4	4	3	NS
	WEP, ppm	1.2	1.2	1.2	1.3	1.1	1.3	1.2	1.1	1.2	1.2	1.1	NS
	SO_4, ppm	4d	4d	5d	5d	5d	5d	5d	6dc	9bc	12b	18a	**
	K, ppm	94	81	90	93	88	103	88	82	82	92	98	NS
	Ca, ppm	2035	2047	1969	2172	2106	2471	2275	2093	2172	2028	2342	NS
	Mg, ppm	278	264	245	266	267	298	290	258	263	259	277	NS
	Na, ppm	11	12	15	17	13	13	13	13	13	16	11	NS
	pH	5.6	5.5	5.4	5.5	5.5	5.6	5.6	5.5	5.6	5.4	5.4	NS
	Total bases, %	13	13	12	13	13	15	14	13	13	13	14	NS
	CEC, %	21	22	22	23	22	24	22	22	22	22	24	NS
	Base sat., %	61	58	55	59	58	63	63	57	61	57	60	NS
	Ca sat., %	49	47	45	48	47	52	51	47	50	46	49	NS

† Stat, statistics; NS, not significant; * or **, significant at $P \leq 0.05$ or $P \leq 0.010$.

Table A9. Gypsum effects on soil-test values for two depths after the corn harvest in fall 2018 at Boone.

		Gypsum Rate Applied in Year 1 (lb/acre)											
		0	250	500	1000	2000	4000	250	500	1000	2000	4000	
Depth		Gypsum Rate Applied in Years 2 and 3 (lb/acre)											
inches	Measurement	0	0	0	0	0	0	250	500	1000	2000	4000	Stat†
0-6	Bray P, ppm	52	50	40	50	57	41	40	51	54	52	58	NS
	M3 P, ppm	48	47	37	50	53	36	36	48	51	51	62	NS
	Olsen P, ppm	27	26	21	23	29	22	20	25	27	30	36	NS
	WEP, ppm	13	11	10	12	15	9	9	11	13	12	15	NS
	SO_4, ppm	4c	4c	4c	4c	5c	5c	5c	4c	7bc	11b	21a	**
	K, ppm	142	153	127	132	130	135	124	126	129	125	137	NS
	Ca, ppm	1877b	1918b	2000b	1973b	1980b	2219b	1973b	2160b	2088b	2273ab	2683a	*
	Mg, ppm	275a	264a	260a	250a	224ab	225a	259a	252a	219ab	220ab	166b	*
	Na, ppm	10	10	10	9	9	10	9	10	10	11	10	NS
	pH	5.8bcd	5.7cd	5.9bcd	5.9bcd	5.8cd	5.7cd	5.9bcd	6.0abc	5.9bcd	6.1ab	6.2a	*
	Total bases, %	12b	12b	12b	12b	12b	13ab	12b	13ab	13ab	14a	15	+
	CEC, %	17	18	17	16	17	19	17	17	16	17	17	NS
	Base sat., %	72cd	68d	74cbd	75cbd	71cd	72cd	72cd	78cb	78cb	81b	92a	NS
	Ca sat., %	56de	53e	59cde	60bcde	58cde	60bcde	57cde	63bcd	65bc	68b	82a	*
6-12	Bray P, ppm	9	10	7	10	11	12	8	10	9	9	10	NS
	M3 P, ppm	6	5	4	6	5	7	4	7	4	4	6	NS
	Olsen P, ppm	4	4	3	4	4	5	3	4	3	3	4	NS
	WEP, ppm	1.4	2.1	1.7	1.9	1.9	1.8	1.5	1.5	1.9	1.5	1.8	NS
	SO_4, ppm	4d	4d	4d	4d	5d	7cd	5d	6cd	10bc	12b	18a	**
	K, ppm	90	85	89	84	80	87	85	86	77	76	83	NS
	Ca, ppm	2344	2156	2446	2311	2213	2291	2331	2384	2194	2038	2187	NS
	Mg, ppm	294	287	311	294	261	282	299	299	272	263	270	NS
	Na, ppm	14	14	14	13	14	12	13	12	14	14	13	NS
	pH	5.9	5.8	5.9	5.9	5.8	5.7	5.8	5.9	5.7	5.7	5.6	NS
	Total bases, %	14	13	15	14	13	14	14	15	13	13	13	NS
	CEC, %	20	20	21	20	19	21	20	20	20	19	20	NS
	Base sat., %	74	68	73	73	71	67	70	74	68	66	67	NS
	Ca sat., %	60	55	60	59	58	55	57	60	55	54	55	NS

† Stat, statistics; NS, not significant; +, * or **, significant at $P \leq 0.10$, $P \leq 0.05$, or $P \leq 0.01$.