Effect of a Lime-amended Biosolids on Crop Production

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This report summarizes the findings from the four years of a field research study that was conducted from 2006 - 2009 to determine the effect of a biosolids, co-mingled with water treatment lime solids, on the growth, soil test, nutrient uptake, and yield of corn and soybean. The study was conducted at the Arlington Agricultural Research Station with material supplied by the Appleton Wastewater Treatment Facility, which was applied in the spring of 2006.

Procedure

A small plot study was established on a Plano silt loam soil at the Arlington Agricultural Research Station in May 2006. Separate corn and soybean plots were set up in a randomized complete block treatment arrangement containing four replications. Plot size was 10 x 30 ft. (four crop rows). The corn and soybean areas were treated identically with biosolids and were rotated so that each crop could be evaluated each year. Materials were hand-applied in April 2006 prior to planting and were incorporated by chisel plowing to a depth of eight inches. A field cultivator was used following chisel plowing to further mix the material and establish a seedbed. No additional biosolids treatments were applied in succeeding years. The plot site was chisel plowed and tilled once with a field cultivator each spring prior to planting.

A list of treatments is shown in Table 1. The biosolids treatments approximate a range of application rates from very low to that which supplied 100 % of the corn N recommendation for 2006. Nitrogen fertilizer was applied variably to the corn in 2006 to provide adequate N nutrition. These rates supplied incremental amounts of lime, which were expected to adjust the pH across a relatively wide range. Nitrogen fertilizer was uniformly applied to the entire corn plot area (UAN 28% in 2007 and urea in 2008 and 2009) to supply 140 lb N/a. Thus, there was no attempt to balance the residual N from the biosolids that could have confounded the interpretation of results related to the liming effect. Starter fertilizer was applied with the planter to both the corn and soybean in all years at a rate of 150 lb 9-23-30/a.

Corn and soybean with maturity levels appropriate for southern Wisconsin were planted in 30 in. rows at a population of 35,000 and 175,000 seeds per acre, respectively following tillage each year in early May. Standard rootworm insecticide (Force) was applied with the planter in the corn study. Conventional herbicide treatments were used to control weeds.

Table 1. Treatments applied in 2006 lime-amended biosolids study, Arlington, Wis.

Trmt No.	Material	Amount	2006 N fert.	2006 N fert.
		lb/plot	lb/a	g urea/plot
1	Control	--	153	1040
2	5 t/a wet	69	134	911
3	10 t/a wet	138	115	782
4	20 t/a wet	276	77	523
5	40 t/a wet	552	0	0
6	Aglime to pH 6.6	59	153	1040

Note: Biosolids application rates calculated on an analysis of 1.60 % TKN, 0.85 NH_4-N, and 31.3% solids. Assuming availability of 25% org. N and 100% NH_4-N this provides 12.2 lb available N/ton dry matter (3.2 ton fresh). Total N applied to all plots was 149 lb N/a of which 9 lb N/a was applied in starter. Supplemental N fertilizer applied to corn only. Starter was applied to both corn and soybean.

A description of the data collected each year is shown below:

Data type	Method
Population	Count viable plants in the middle 30 ft. of the middle two rows at the six leaf stage.
Soil samples	Ten cores (0-6 in.) per plot 12 weeks after planting analyzed for pH, organic matter, P, and K.
Mid-season leaf samples	Collect 8-10 leaves from the middle two rows and analyze for total N and minerals.
Grain yield	Harvest the middle two rows of each plot with a small plot combine

All plant and soil samples were analyzed by the procedures of the UWEX Soil and Plant Analysis Laboratory. Data were analyzed with an analysis of variance program for the randomized complete block design within each crop. Means were separated with a Fisher=s LSD where significant differences were found. A probability level of 0.05 (Pr>F) was used to determine statistical significance.

Results and Discussion

The initial soil test for the field was pH 5.8, organic matter content 4.2 %, and 44 and 78 ppm P and K, respectively. An acidic field was selected to allow measurement of the liming effect of the material. The initial soil test P level is in the excessively high range for this soil; whereas the soil test K level is consider low for corn and soybean production.

The biosolids material was supplied and delivered by the Appleton Wastewater Facility. The nutrient and dry matter content of the biosolids applied in 2006 is presented in Table 2. These results show the biosolids had relatively low total and ammonium-N contents. It was high in Ca as would be expected and has appreciable levels of P, Mg, and Fe. The lime analysis showed a calcium carbonate equivalent of 15.8 (pure calcium carbonate = 100) and a neutralizing index of 20. Most agricultural limestone has a neutralizing index greater than 60, therefore while this material would not be considered a good lime source it would be expected to increase soil pH if applied at rates that would supply corn N need.

Table 2. Nutrient and dry matter content of the Appleton lime-amended biosolids used in the Arlington field study, 2006.

TKN	NH_4-N	Solids	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Al	Na
%	ppm	%	-- ppm --										
1.19	193	31.5	20,111	1,944	193,362	11,062	7,301	265	<3	1,039	32,271	8,911	4,447

Note: 10,000 ppm = 1 %.

The effect of treatment on the soil pH over the four seasons is shown in Table 3. Plots were rotated by crop between years, so they are identified as the north half and south half. Initially in 2006 the south half was planted to soybean and the north half to corn. It is apparent that the 10 t/a treatment in the south plot area were not made since all soil test values are similar to the control. The biosolids when applied at 20 or 40 tons/a increased the soil pH comparable to that observed with conventional aglime in the south half and the 40 t/a rate was the only treatment to approach the aglime pH in the north half.. The 2009 soil pH values would suggest that the soil pH has equilibrated in the study.

The effect of treatment on soil test P is shown in Table 4. Soil test P in the control was initially at about 42 ppm, and by the fourth season it had decreased in the range of 5 - 10 ppm. This decrease could be attributed to crop removal and further mixing with the soil. A 200 bu/a grain yield would be expected to remove approximately 76 lb P_2O_5/a (UWEX Pub. A2809). Assuming a buffer ratio of 18 lb P_2O_5:1 ppm soil test P the decrease is reasonable. Similarly the soil test P was elevated with the addition of the biosolids in 2006, but over time the values have decreased due to crop removal, and mixing and interaction with soil minerals that “fixed” some of the applied P. It should also be pointed out that approximately 35 lb P_2O_5/a was applied annually in the starter fertilizer.

Table 3. Soil pH trends following the application of a lime-amended biosolids to a silt loam soil, Arlington, Wis., 2006 – 2009.

Treatment	Soil pH			
	2006	2007	2008	2009
	North half			
Control	5.3	5.2	5.2	5.2
5 t/a	5.5	5.7	5.4	5.5
10 t/a	5.4	5.8	5.5	5.5
20 t/a	5.7	6.0	5.8	5.8
40 t/a	6.0	6.4	6.1	6.2
Aglime	5.7	6.1	5.8	6.0
Pr>F	<0.01	<0.01	<0.01	<0.01
LSD	0.3	0.3	0.3	0.2
	South half			
Control	5.5	5.4	5.5	5.4
5 t/a	6.0	6.0	6.0	5.8
10 t/a	5.6	5.6	5.6	5.6
20 t/a	6.1	6.2	6.2	6.0
40 t/a	6.1	6.4	6.4	6.6
Aglime	6.1	6.2	6.2	6.1
Pr>F	<0.01	<0.01	<0.01	<0.01
LSD	0.3	0.4	0.4	

Table 5 shows the effect of the treatments on soil test K. The biosolids contained 10 % the amount of K compared to P and therefore the effect on soil test K was minimal. Soil test K was not affected by treatment in any year with the exception of the north half in 2009 where the aglime treatment had the highest soil test K. Approximately 45 lb K_2O/a was supplied in the starter fertilizer each year, which supplied about two-thirds the estimated removal by the harvested grain. Similarly a lack of response of treatment on soil organic matter was observed as shown in Table 6 as there were no significant treatment effects in any year. Soil organic matter levels were somewhat lower in 2008 across all treatments compared to the measurements of previous years or in 2009, suggesting that there was a systematic effect either related to sampling or analysis that caused the lower values that year.

The effect of treatment on the final stand of corn and soybean for the term of the study is shown in Table 7. There was no effect of treatment on this measurement in any year. Corn stand was relatively constant over the four years, but soybean stand varied substantially between years; and was about 50 % lower than expected in 2008. Factors such as the heavy rains that were received in southern Wisconsin in early June at the time that soybean was emerging contributed to the reduced final stand. Fortunately soybean stands were consistent within years and this crop has a capacity to adjust to lower populations by developing greater branching and therefore yield was not substantially reduced in a year when stand was low.

Table 8 shows the measured corn and soybean grain yield for the four years of the study. Corn yield was affected by treatment in one year only (2006), but there was a strong trend for response to treatment in the other three years. Soybeans was similarly significantly affected in 2007 and 2009; and also showed strong trends for response to treatment in the other two years. It is difficult to partition all the possible reasons for the response (pH, organic addition, macro and/or micro nutritional, soil physical improvement) and in fact they may be additive. Response in corn followed increasing rate, suggesting that nutritional additions were important. It may have been a combined effect of several nutrients and was not solely due to pH improvement, since the lime alone treatment tended to yield less. The reason for the response in soybean is less obvious, as there is more yield variability related to treatment, but appears to be more of a pH response since the limed treatment tended to well especially in the second and third years when its neutralization would have been more complete.

Tables 9 - 12 show the effect of treatment on the corn ear leaf and soybean tri-foliate leaf nutrient concentration. These samples were taken at flowering when it is generally best to assess the nutrient status of these crops. There were few differences other than those that might be expected where the pH is substantially modified. Specifically the Ca concentration in the corn increased as pH increased and the concentration of some metals decreased as the pH increased. Sulfur in the leaf tissue of both crops either significantly increased or tended to increase as the biosolids rate increased. This response to biosolids application will become more important in future years as the contribution of S from atmospheric deposition has been reduced substantially leading to speculation that crop S needs will become more apparent in the coming years.

Summary

This report summarizes four years of research examining the response of corn and soybean to a one-time application of various rates of municipal biosolids co-mingled with water treatment plant lime residuals. Control treatments consisted of no material applied or standard aglime applied to adjust the soil pH to 6.6. Biosolids applied at a rate of 20 – 40 tons (as-is) per acre resulted in the optimal pH adjustment. The standard lime rate that was applied appeared to be lower than what would be necessary to reach the target pH of 6.6. Soil test P was increased substantially by the higher rates of biosolids addition, but decreased in succeeding years due to a combination of fixation and crop removal. Soil organic matter and soil test K were not affected by treatment. Plant stand of both crops were unaffected by treatment. Specific leaf nutrient concentrations were affected by treatment, but only to the extent that might be expected where the soil pH was adjusted and large amount of residual materials were applied. These differences were more frequent in the first two years of the study and were more common in corn. Nutritional benefits from nutrients such as P, Mg, S, and some micronutrients would be expected from standard treatment, as well as the reduction in plant Mn concentration due to soil pH adjustment. Grain yield of both crops was positively affected by treatment and never showed significance less than 0.13. This response appeared to be due to factors that were in addition to pH adjustment alone, including the addition of plant nutrients and perhaps improvement in soil physical condition. No direct soil physical measurements were made in the course of the study. The application of this biosolids, if managed to adjust soil pH, appears to be a sound agronomic practice. Caution is recommended to avoid the buildup of soil test P, which has been shown to increase the risk of P loss to surface water.

Table 4. Soil test P trends following the application of a lime-amended biosolids to a silt loam soil, Arlington, Wis., 2006 – 2009.

Treatment	Soil test P (ppm)			
	2006	2007	2008	2009
	North half			
Control	42	33	31	34
5 t/a	66	53	39	49
10 t/a	60	46	43	46
20 t/a	63	57	47	47
40 t/a	81	73	60	67
Aglime	46	43	35	40
Pr>F	0.14	0.05	0.08	0.08
LSD	NS	24	NS	NS
	South half			
Control	42	36	32	37
5 t/a	92	72	60	69
10 t/a	40	38	31	35
20 t/a	77	66	43	55
40 t/a	95	95	65	76
Aglime	69	57	48	54
Pr>F	0.05	0.06	0.16	0.09
LSD	41	NS	NS	NS

Table 5. Soil test K trends following the application of a lime-amended biosolids to a silt loam soil, Arlington, Wis., 2006 – 2009.

Treatment	Soil test K (ppm)			
	2006	2007	2008	2009
	North half			
Control	70	69	63	72
5 t/a	76	67	63	74
10 t/a	70	60	58	68
20 t/a	79	73	60	80
40 t/a	78	67	62	70
Aglime	87	72	61	85
Pr>F	0.07	0.35	0.60	0.02
LSD	NS	NS	NS	10
	South half			
Control	87	63	60	68
5 t/a	79	58	56	66
10 t/a	79	57	58	59
20 t/a	85	63	59	66
40 t/a	88	63	56	62
Aglime	79	58	56	63
Pr>F	0.67	0.76	0.36	0.67
LSD	NS	NS	NS	NS

Table 6. Soil organic matter trends following the application of a lime-amended biosolids to a silt loam soil, Arlington, Wis., 2006 – 2009.

Treatment	Soil organic matter (%)			
		2006	2007	2008
	North half			
Control	4.6	4.5	4.0	4.8
5 t/a	4.6	4.5	4.0	4.8
10 t/a	4.5	4.5	4.0	4.8
20 t/a	4.6	4.6	4.0	4.8
40 t/a	4.6	4.6	3.9	4.8
Aglime	4.4	4.6	3.9	4.9
Pr>F	0.41	0.76	0.73	0.77
LSD	NS	NS	NS	NS
	South half			
Control	3.8	3.9	3.5	4.2
5 t/a	4.1	4.1	3.7	4.4
10 t/a	3.7	3.7	3.5	4.1
20 t/a	3.9	3.8	3.4	4.1
40 t/a	4.1	4.0	3.6	4.2
Aglime	3.9	3.9	3.6	4.3
Pr>F	0.15	0.11	0.24	0.26
LSD	NS	NS	NS	NS

Table 7. Plant stand of corn and soybean following the application of a lime-amended biosolids to a silt loam soil, Arlington, Wis., 2006 – 2009.

Treatment	Plant stand (plants/a x 1000)			
	2006	2007	2008	2009
	Corn			
Control	33.4	35.5	35.5	36.8
5 t/a	35.5	35.7	36.9	36.2
10 t/a	35.0	35.9	36.6	36.1
20 t/a	34.5	36.7	36.4	36.8
40 t/a	34.4	36.4	35.9	35.8
Aglime	34.7	36.2	36.7	34.9
Pr>F	0.43	0.52	0.22	0.38
LSD	NS	NS	NS	NS
	Soybean			
Control	119.8	171.3	73.3	100.6
5 t/a	103.5	159.7	72.6	114.8
10 t/a	111.8	171.3	67.9	105.3
20 t/a	112.5	165.9	75.1	110.0
40 t/a	105.6	171.3	79.1	111.4
Aglime	109.3	165.2	75.5	100.6
Pr>F	0.86	0.80	0.56	0.65
LSD	NS	NS	NS	NS

Table 8. Corn and soybean grain yield following the application of a lime-amended biosolids to a silt loam soil, Arlington, Wis., 2006 – 2009.

Treatment	Grain yield (bu/a)			
	2006	2007	2008	2009
	Corn			
Control	181	188	220	227
5 t/a	210	193	227	232
10 t/a	191	197	225	232
20 t/a	213	200	227	238
40 t/a	210	200	235	243
Aglime	192	195	228	229
Pr>F	<0.01	0.06	0.13	0.13
LSD	18	NS	NS	NS
	Soybean			
Control	55	67	52	39
5 t/a	60	66	62	44
10 t/a	58	63	56	46
20 t/a	62	67	62	48
40 t/a	68	67	56	52
Aglime	56	69	62	51
Pr>F	0.07	0.05	0.11	0.05
LSD	NS	4	NS	8

Table 9. Effect of the Appleton lime-amended biosolid on the nutrient concentration of corn ear leaf and soybean trifoliate at flowering, Arlington, Wis., 2006.

Treatment	P	K	Ca	Mg	S	B	Zn	Mn	Cu	Fe	Al
	------------------ % ------------------					-------------------- ppm --------------------					
	Corn										
Control	0.25	1.25	0.57	0.41	0.16	4.9	29	86	12	126	53
5 t/a	0.27	1.28	0.60	0.42	0.17	6.1	40	78	12	98	41
10 t/a	0.28	1.01	0.65	0.50	0.17	11.7	41	86	13	103	51
20 t/a	0.29	1.30	0.61	0.41	0.18	10.3	42	80	14	110	46
40 t/a	0.30	1.31	0.64	0.42	0.19	5.6	54	81	14	100	48
Aglime	0.26	1.23	0.57	0.43	0.16	4.4	32	69	12	94	50
Pr>F	<0.01	0.15	0.03	0.05	<0.01	0.53	0.03	0.45	<0.01	0.4	0.92
LSD	0.02	NS	0.06	0.06	0.01	NS	15	NS	1	19	NS
	Soybean										
Control	0.36	1.47	1.14	0.50	0.29	46	73	95	16	108	44
5 t/a	0.38	1.30	1.18	0.54	0.31	44	78	74	15	113	40
10 t/a	0.38	1.37	1.15	0.52	0.31	43	56	94	16	113	43
20 t/a	0.37	1.48	1.22	0.52	0.32	38	63	84	17	114	39
40 t/a	0.37	1.41	1.33	0.57	0.33	41	66	94	18	129	63
Aglime	0.39	1.36	1.08	0.51	0.30	42	67	71	14	125	59
Pr>F	0.26	0.33	<0.01	0.15	<0.01	0.21	0.31	0.31	0.09	0.62	0.38
LSD	NS	NS	0.10	NS	0.01	NS	NS	NS	NS	NS	NS

Table 10. Effect of the Appleton lime-amended biosolid on the mineral nutrient content of corn and soybean leaves, Arlington, Wis., 2007.

Treatment	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu
	------------------------------ % -----------------------------					------------------------------ ppm -----------------------------				
					Corn Study					
Control	0.29	1.28	0.85	0.50	0.19	59	9	129	75	14
5 t/a	0.32	1.02	0.98	0.65	0.20	69	11	83	68	14
10 t/a	0.31	1.15	0.92	0.56	0.20	53	11	118	72	14
20 t/a	0.32	1.23	0.92	0.55	0.20	55	12	84	71	14
40 t/a	0.35	1.05	1.03	0.64	0.22	60	12	96	76	15
Aglime	0.30	1.09	0.96	0.66	0.20	61	11	86	71	15
Pr>F	<0.01	0.20	<0.01	0.03	<0.01	0.29	0.18	0.04	0.09	0.94
LSD	0.02	NS	0.08	0.10	0.01	NS	NS	34	NS	NS
					Soybean Study					
Control	0.32	1.33	1.43	0.48	0.27	72	51	125	81	13
5 t/a	0.35	1.33	1.48	0.50	0.30	77	74	107	91	14
10 t/a	0.36	1.26	1.44	0.50	0.32	68	65	103	92	14
20 t/a	0.35	1.26	1.55	0.49	0.32	63	39	98	95	14
40 t/a	0.37	1.39	1.49	0.48	0.33	60	42	82	93	14
Aglime	0.35	1.35	1.44	0.51	0.32	67	45	89	93	14
Pr>F	0.28	0.65	0.51	0.96	0.03	0.46	0.32	0.02	0.09	0.43
LSD	NS	NS	NS	NS	0.03	NS	NS	24	NS	NS

Table 11. Effect of the Appleton lime-amended biosolids on the mineral nutrient content of corn and soybean leaves, Arlington, Wis., 2008.

	N	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu
	---------- % ----------						---------- ppm ----------				
					Corn Study						
Control	2.49	0.27	1.21	0.63	0.33	0.17	28.6	4.4	82.8	91.2	12.5
5 t/a	2.52	0.28	1.17	0.66	0.32	0.18	32.0	4.5	72.4	84.8	12.2
10 t/a	2.54	0.29	1.05	0.69	0.35	0.18	29.5	4.8	72.0	88.4	12.0
20 t/a	2.53	0.28	1.13	0.68	0.33	0.18	26.4	4.2	62.0	91.8	11.4
40 t/a	2.60	0.29	1.15	0.77	0.37	0.20	30.3	4.3	56.2	88.7	12.6
Aglime	2.63	0.28	1.15	0.69	0.39	0.18	31.7	4.3	58.0	90.7	12.8
Pr>F	0.59	0.50	0.31	0.02	0.07	<0.01	0.63	0.81	<0.01	0.61	0.35
LSD	NS	NS	NS	0.07	NS	0.01	NS	NS	12.3	NS	NS
					Soybean Study						
Control	4.32	0.35	1.66	0.80	0.39	0.24	58.2	41.9	76.0	106.4	12.0
5 t/a	4.69	0.35	1.34	0.81	0.41	0.26	65.4	42.7	59.5	110.4	11.4
10 t/a	4.58	0.34	1.48	0.82	0.39	0.25	44.7	42.0	63.6	91.3	12.2
20 t/a	4.62	0.39	1.19	0.69	0.31	0.21	38.0	32.8	47.7	73.7	10.5
40 t/a	4.22	0.33	1.31	0.88	0.42	0.26	43.5	38.7	53.0	101.4	12.3
Aglime	4.62	0.34	1.37	0.79	0.44	0.25	48.4	44.1	55.2	88.7	11.8
Pr>F	0.20	0.47	0.15	0.35	0.13	0.42	0.02	0.34	<0.01	0.10	0.79
LSD	NS	NS	NS	NS	NS	NS	16.0	NS	13.3	NS	NS

Table 12. Effect of the Appleton lime-amended biosolids on the mineral nutrient content of corn and soybean leaves, Arlington, Wis., 2009.

	N	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu
	%						ppm				
					Corn Study						
Control	2.74	0.26	1.32	0.96	0.59	0.16	49.4	6.6	104.8	76.3	10.6
5 t/a	2.70	0.28	1.10	1.06	0.68	0.16	54.8	7.7	76.3	72.9	10.8
10 t/a	2.68	0.28	1.29	1.03	0.64	0.17	43.6	7.2	106.9	75.9	10.8
20 t/a	2.83	0.27	1.25	1.05	0.62	0.16	43.9	6.4	76.1	72.4	10.2
40 t/a	2.88	0.29	1.21	1.12	0.63	0.17	46.3	7.3	74.0	77.0	10.6
Aglime	2.85	0.28	1.08	1.05	0.73	0.16	47.8	7.3	78.2	72.2	10.5
Pr>F	0.28	0.29	0.05	0.01	<0.01	0.38	0.51	0.38	0.02	0.54	0.82
LSD	NS	NS	0.18	0.08	0.06	NS	NS	NS	24.0	NS	NS
					Soybean Study						
Control	3.77	0.40	2.08	1.66	0.77	0.24	64.9	48.2	75.1	74.4	11.1
5 t/a	4.05	0.49	2.15	1.69	0.70	0.27	69.2	46.9	67.7	79.3	11.9
10 t/a	4.05	0.39	1.48	1.38	0.65	0.25	68.6	39.6	58.7	72.4	10.4
20 t/a	4.29	0.48	2.01	1.71	0.71	0.32	66.5	45.0	69.1	95.0	13.0
40 t/a	4.66	0.51	1.88	1.65	0.71	0.33	47.5	39.5	61.9	99.0	11.9
Aglime	4.41	0.46	2.02	1.63	0.77	0.30	53.5	41.4	66.2	110.5	13.9
Pr>F	0.07	0.22	0.23	0.35	0.63	0.06	0.32	0.50	0.39	0.02	0.08
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	22.9	NS