# EFFECT OF ALUM WATER TREATMENT RESIDUALS ON SOILS WITH VERY HIGH BRAY P1 SOIL TEST LEVELS

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## Abstract

As point discharges of phosphorus (P) and other pollutants to surface waters from industrial and municipal wastewater systems have been reduced, nonpoint sources of P are now contributing a greater portion of P inputs into freshwater resources. Agricultural runoff and/or erosion can be a main contributor to this nonpoint source pollution. Continued inputs of fertilizer and manure P in excess of crop requirements have led to a build-up of soil P levels which are of environmental, rather than agronomic concern, particularly in areas of intensive crop and livestock production. Six sites with soils having very high Bray P1 test levels were selected for field evaluation of utilizing water treatment residuals (WTR) to reduce these high levels. Two sites were established each year for amendment with WTR in 1998, 1999 and 2000. The six sites had Bray P1 test levels of about 600, 1200, 1100, 1100, 800 and 500 lb P/acre. Alum WTR were applied to the 1998 sites at rates of 17 and 51 dry ton/acre and to the 1999 sites at rates of approximately 20 and 60 dry ton/acre. In 2000, a different source of alum WTR was used at rates of 33 and 99 dry ton/acre. Soils were disked twice at each site following WTR application to mix the WTR with soil. Subsequent tillage for additional mixing and seedbed preparation prior to planting varied from site to site. All six sites were rototilled in April/May, 2000 prior to planting. Field corn (*Zea mays L.*) was planted at each site in all three years, except one of the sites established in 1999 was planted to soybeans (*Glycine max L.*) in 2000. Diagnostic leaf tissue samples and yield measurements of corn and soybeans were taken during each growing season. Soils were periodically sampled to evaluate changes in Bray P1 test levels with time. Bray P1 soil test levels declined at the two sites established in 1998 from spring, 1998 to fall, 1999, but alum WTR amendments did not contribute to this decrease. At the 1999 sites, some decline in Bray P1 soil test levels was observed during 1999, and alum WTR appeared to contribute to this decrease at the high application rate. The decrease in Bray P1 soil test that was expected may be delayed, due to inadequate mixing of alum WTR and/or the amount of active aluminum added by the WTR.

## Introduction

As water pollution regulations have reduced point discharges of P to surface waters, nonpoint source losses of P from watersheds have received greater attention. Agricultural land is often a main contributor to this pollution. Sharpley et al (1994) recently noted "Although P management is an integral part of profitable agrisystems, continued inputs of fertilizer and manure P in excess of crop requirements have led to a build-up of soil P levels, which are of environmental rather than agronomic concern, particularly in areas of intensive crop and livestock production." When soil test P levels become very high, the risk of losing P from the landscape as particulate P and dissolved P increases.

Sharpley et al (1993) explained that soil test P levels are influenced by (1) the quantities of manure P, crop residue P and fertilizer P added to the soil-plant system and (2) the capability of the soil to make P unavailable as organic and inorganic forms. As P additions to soils become larger and in excess of what crop harvest can remove, the "pools" of unavailable inorganic and organic P increase. As the quantities of unavailable P increase, the bioavailable and soil test P level can, in turn, also gradually increase.

Sharpley et al (1994) further indicated that the soil test P level provides a good measure of plant-available P and solubility (or mobility) of P in the soil. When soil test levels are low to medium, crop yields can be increased by adding P to the soil. However, when soil test levels become high to very high, potential environmental problems become more important than any agronomic benefits that can be obtained by further inputs of P to the soil-plant system. After high levels of soil test P are attained, considerable time is required to significantly reduce these levels, particularly if P is being removed from the soil only by crop harvest.

Recent laboratory and greenhouse studies (Bugbee and Frink, 1985; Elliott and Singer, 1988; Elliott et al, 1990; Heil and Barbarick, 1989; Ippolito et al, 1999; Rengasamy et al, 1980) have evaluated land application of alum and ferric chloride WTR and found that WTR can safely be used on cropland. While some beneficial soil physical conditioning and plant nutrient availabilities were found, one effect that was noted with each investigation is the associated reduction in availability of P for plant growth.

However, these and later studies (Geertsema et al, 1994; Lucas et al, 1994; Novak et al, 1995) determined that addition of P fertilizer can be used to offset any reduced bioavailability of P, so crop yields would not be reduced. While some of the laboratory phases of these investigations suggested that application of WTR could reduce bioavailable P in soils, the focus of these research studies was to evaluate low application rates that would not significantly reduce bioavailable P below levels necessary to support optimum crop yields. The potential of utilizing WTR to reduce P mobility in soils that test very high in plant-available P was not discussed or investigated.

Only limited research focusing on the ability of alum or alum WTR to reduce soluble P has been published, but more studies are currently underway. Moore and Miller (1994) and Shreve et al (1995) have shown that treating poultry litter with alum and other amendments, prior to spreading on fescue pastures, will significantly reduce soluble P lost during runoff events. In a laboratory incubation of two soils, Peters and Basta (1996) found alum WTR to be effective in reducing excess bioavailable P, i.e., that P described by Sharply et al (1994) as "very high" soil test P levels and a potential environmental problem. Current ongoing laboratory incubation and greenhouse studies reported at the 1998 American Society of Agronomy (ASA) annual meetings (Alvisyahrin et al, 1998a,b; Codling et al, 1998; Morris and Hyde, 1998; Zupancic and Basta, 1998) and the 1999 ASA annual meetings (Chardon and Koopmans, 1999; Eaton and Sims, 1999; Isensee and Codling, 1999; Jacobs and Teppen, 1999; Lynch et al, 1999; Maguire and Sims, 1999) further demonstrate the ability of WTR to reduce soil test P levels.

The next logical step that would build on the current knowledge base regarding this potential "water pollution prevention practice" is to conduct field investigations. Laboratory and greenhouse experiments evaluating WTR amendments to soils, and field application of alum-treated poultry litter to pastures as a practice to reduce nonpoint source losses of P, strongly suggest that WTR amendments will reduce soil P availability and mobility. Field studies to determine the optimum rates for applying WTR to high and excessive P testing soils are now needed, before a database can be developed that will provide the necessary guidelines for producers to implement this practice.

The author is aware of only two studies where applications of WTR to soils in the field have been reported. DeWolfe and Brandt (1997) showed that 11.5 dry tons WTR/acre increased soil pH, decreased extractable cadmium and manganese, caused a slight increase in extractable aluminum, and significantly decreased soil test P levels. Lang et al (1997) applied 2, 5, and 10 dry tons WTR/acre in combination with 5 dry tons/acre of biosolids, but no data was provided regarding effects on soil properties. In addition to determining optimum rates of WTR for controlled reduction of soil test P levels, further evaluation is needed to ensure that no deleterious effects on soil chemical reactions that control nutrient availability for plant growth will occur from a one-time or periodically-repeated applications of WTR.

In MI, the Bray-Kurtz P1 (Bray P1) extractant is used as part of the soil fertility test to determine plant-available P levels. When Bray P1 soil test levels reach 75-100 lb P/acre, the $P_2O_5$ fertilizer recommendations will usually be zero for most crops and yield levels grown in MI. When Bray P1 levels exceed 300 lb P/acre, MI Right To Farm "Generally Accepted and Agricultural Management Practices for Manure Management and Utilization" suggest that no additional manure or fertilizer P be applied until the Bray P1 level drops below 300 lb P/acre.

Significantly decreasing the Bray P1 test level strictly by crop removal is expected to take many years. However, previous and ongoing studies (discussed above) have shown that alum WTR can be effective in reducing plant-available P levels in soils over much shorter time periods. Therefore, this field investigation was initiated to (1) determine the effectiveness of alum WTR in reducing high Bray P1 test levels in coarse-textured soils under field conditions and (2) begin accumulating the database needed to establish what rates of WTR would be needed to reduce very high soil test P levels to more optimum agronomic levels on different soil types. We have previously reported on the progress of this field study (Jacobs and Teppen, 2000).

## Methodology

Six field sites located on the west side of Michigan were selected for this study. These sites were within short transportation distances of water treatment plants operated by the Cities of Grand Rapids, Holland and Wyoming, each of which generates alum WTR. All fields had received high rates of poultry litter for many years. The first site (WTR1) had a Granby fine sandy loam soil with Bray P1 test levels of about 600 lb P/acre (300 mg P/kg soil) and the second site (WTR2) had a Granby loamy sand soil with Bray P1 test levels of about 1,200 lb P/acre (600 mg P/kg soil). These two sites were established in 1998. The third site (WTR3) had a Granby loamy sand soil with Bray P1 test of about 1,100 lb P/acre (550 mg P/kg soil) and the fourth site (WTR4) had a Croswell sand with Bray P1 test of about 1,100 lb P/acre (550 mg P/kg soil) and were established in 1999. Two additional sites were established in 2000, both located on a Granby loamy sand soil. The WTR5 soil had a Bray P1 test of about 800 lb P/acre (400 mg P/kg soil) and WTR6 soil had a Bray P1 test of about 500 lb P/acre (250 mg P/kg soil).

A randomized, complete block design was established at each site with four replications per treatment and a plot size of 45 ft x 100 ft. At the WTR1 site, treatments were 0, 17 and 51 dry ton WTR/acre. At the WTR2 site, four treatments were used -- 0, 17 and 51 dry ton WTR/acre plus liquid alum applied at 12.8 wet ton/acre, or 6.4 dry ton/acre of alum solids. At the WTR3 and WTR4 sites, treatments were 0, 20 and 60 dry ton WTR/acre, and at WTR5 and WTR6 treatments were 0, 33 and 99 dry ton WTR/acre. Alum WTR that had been removed from lagoon storage and stockpiled for drying at the Holland, MI water treatment plant were utilized in 1998 and 1999. These WTR contained 57% solids in 1998 and 50% solids in 1999. In 2000, alum WTR were removed from the Grand Rapids, MI water treatment plant storage lagoon in the fall, 1999 and contained 43% solids when applied.

WTR were applied to plots using a Knight ProTwin Slinger, Model 8030 V-box spreader. The low rates (17, 20 and 33 dry ton/acre) were applied by making one round trip for each plot, spreading WTR across the 45 ft width of each plot from one side and then from the opposite side. The high rates (51, 60 and 99 dry ton/acre) were applied by making three passes on each side of the plot, or three round trips. The liquid alum was applied at WTR2 to the soil surface using a Big A tank truck applicator fitted with a splash plate and making two passes through the center of each plot, with the second pass being made in the opposite direction of the first pass.

All plots, including the untreated controls, were disked twice following WTR applications. The WTR1 site was chisel plowed and field cultivated prior to planting corn on May 5, 1998 and the WTR2 site was moldboard plowed before planting corn on May 4, 1998. In 1999, WTR1 was moldboard plowed before planting corn on May 4, 1999, and WTR2 was moldboard plowed and field cultivated before planting corn on May 7, 1999. The WTR3 site was moldboard plowed before planting corn on May 20, 1999 and the WTR4 site was chisel plowed and field cultivated before planting corn on May 28, 1999.

In 2000, all plots were rototilled prior to planting in an attempt to get a more thorough mixing of WTR and soil. This more intensive tillage was done to determine whether reaction of alum WTR with available P in soils could be enhanced. At WTR1, WTR2 and WTR5, soils were moldboard plowed before planting corn on May 3, May 2 and May 2, 2000, respectively. At WTR3, soils were chisel plowed and field cultivated before planting corn on May 26, 2000, and at WTR4, soils were chisel plowed and disked before planting soybeans on June 11, 2000. At WTR6, soils were only rototilled prior to planting corn on May 10, 2000, but then corn had to be replanted on June 10, 2000 due to excess rain and flooded soil conditions. Herbicides and insecticides for weed and pest control typically used by the cooperating farmers were applied at planting. Fertilizer nitrogen and potash were applied as needed.

Final plant populations of corn at WTR1 and WTR2 were measured on May 27 and July 9 in 1998, June 10 in 1999, and June 28 in 2000 by counting the number of corn plants in two 50 ft rows within each plot. Similar measurements was made at WTR3 on June 23, 1999 and July 21, 2000 and at WTR4 on June 17, 1999. Soybean populations at WTR4 in 2000 were done by counting the number of soybean plants in two 50 ft rows on July 12, 2000. Corn populations were measured at WTR5 on June 28, 2000, but no stand counts were taken at WTR6 due to the flooded conditions and poor stand after replanting the corn. Diagnostic leaf samples were collected on July 21, 1998 (WTR1 and WTR2), July 28, 1999 (WTR1, WTR2, WTR3, WTR4), and August 6, 2000 (all sites) by taking 20 ear leaves or 20 trifoliate leaves per plot. For determining yields, corn ears were harvested from two 25 ft rows each year at WTR1 and WTR2 on 10/8/98, 10/5/99 and 10/10/00, at WTR3 and WTR4 on 10/12/99 and at WTR3 and WTR5 on 10/10/00. No corn was harvested at WTR6 due to the poor stand, and soybeans at WTR4 were not yet harvested at the time of this paper. Following each corn ear harvest, grain was removed from the cob and weighed, grain moisture measured, weights of harvested grain adjusted to a 15.5% moisture basis, and adjusted weights converted to bushels/acre.

Surface soils were sampled from each plot prior to WTR application by compositing 20 one-inch cores from the top eight-inch depth. Initial sampling at WTR1 and WTR2 was done on April 20, 1998, at WTR3 and WTR4 on May 4, 1999, at WTR5 on April 24, 2000, and at WTR6 on May 4, 2000 prior to WTR application. Subsequent soil sampling was done at the WTR1 and WTR2 sites on 10/30/98, 6/10/99, 11/9/99 and 4/27/00. Subsequent soil sampling for WTR3 and WTR4 was done on 11/9/99 and 5/4/00. All sites will be resampled in fall, 2000. Soils were analyzed by the MSU Soil and Plant Nutrition Lab for routine soil fertility tests (Brown, 1998) which included pH, buffer pH, Bray P1 extractable P, and ammonium acetate extractable K, Ca and Mg, and 0.01 *M* calcium chloride ($CaCl_2$) extractable P (Kuo, 1996) were measured in soils collected each spring and fall.

## Results and Discussion

Plant populations were not significantly different for field corn or soybeans grown on untreated soils versus alum WTR-treated soils at any of the sites in 1998, 1999, and 2000. Diagnostic leaf tissue analyses of samples collected from sites in 1998 and 1999 have not shown any significant and consistant differences in essential plant nutrient concentrations. Analytical results for diagnostic tissue samples from 2000 are not yet available. Yield measurements for corn grain and statistics for 1998 and 1999 are shown in Table 1, but yield determinations for 2000 have not yet been completed. Yield results indicate that all treatments significantly increased corn grain yields at the WTR1 and WTR2 sites compared to the untreated control soils in 1998; however, no significant differences in grain yields were obtained at any of the four sites in 1999. We did not expect and cannot explain the reason for the significant yield increase at the WTR1 and WTR2 sites in 1998.

Bray P1 soil tests completed for samples collected in 1998 and 1999 are shown in Table 2. Test levels at the WTR1 and WTR2 sites did not decrease much in 1998, but by the fall of 1999 showed some significant decrease. However, this decrease does not yet appear to have been affected by the alum WTR treatments. At the WTR3 and WTR4 sites, some decrease in Bray P1 levels seems to have occurred during 1999 and the high WTR treatment has contributed to a greater decrease. $CaCl_2$ extractable P concentrations (Table 3) generally reflect the Bray P1 levels. Soil pH's were not changed by alum WTR applications at WTR1 (pH 6.3 - 6.7), WTR2 (pH 6.8 - 7.0), WTR3 (pH 7.1 - 7.5), or WTR4 (pH 6.8 - 7.1), except for the liquid alum application at WTR2, where soil pH's were decreased to a range of pH 6.0 - 6.3.

## Conclusions

Although applications of WTR at rates of 17 and 51 dry tons/acre and liquid alum at 6.4 dry tons/acre significantly increased corn grain yields at the WTR1 and WTR2 sites in 1998, similar yield increases were not obtained in 1999 at these two sites nor at the WTR3 and WTR4 sites that were established in 1999. Alum WTR amendments did not significantly change population stands of field corn nor diagnostic ear leaf composition in 1998 or 1999. Alum WTR amendments to P-enriched soils in the field have not yet significantly decreased the Bray P1 soil test levels at the WTR1 and WTR2 sites. However, some decrease in Bray P1 levels was obtained for all treatments by the fall, 1999 sampling. We are currently attributing this decrease to P leaching from surface to subsurface soils during this time. At the WTR3 and WTR4 sites, some decrease in Bray P1 levels were obtained between spring and fall of 1999, and some additional decrease occurred at the high WTR application rate. We hypothesize that the expected decrease in Bray P1 test levels by alum WTR may be delayed due to inadequate mixing of alum WTR and soil since the WTR were applied. Therefore, plots at all sites were more thoroughly mixed by rototilling in the spring of 2000 prior to planting.

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Table 1. Corn grain yields in 1998 and 1999.

| Treatment | 1998 WTR1 | 1998 WTR2 | 1999 WTR1 | 1999 WTR2 |
|---|---|---|---|---|
| | - - - - - - - - | bushels/acre | - - - - - - - - | |
| Control | 164±11 | 151±7 | 196±19 | 174±11 |
| 17 ton/ac | 190±4 | 170±13 | 193±17 | 166±15 |
| 51 ton/ac | 181±13 | 183±19 | 170±22 | 170±9 |
| 6.4 ton/ac (liquid alum) | ----[a] | 188±15 | ---- | 162±6 |
| LSD (0.05) | 12 | 18 | ns | ns |
| | | | WTR3 | WTR4 |
| Control | | | 164±9 | 145±5 |
| 20 ton/ac | | | 151±8 | 136±15 |
| 60 ton/ac | | | 162±14 | 136±9 |
| LSD (0.05) | | | ns | ns |

[a] The WTR1 site did not have a liquid alum treatment.

Table 2. Bray P1 soil test levels for WTR1, WTR2, WTR3 and WTR4 sites with time.

| Treatment | Spring '98 | Fall '98 | Spring '99 | Fall '99 |
|---|---|---|---|---|
| | lb P/acre | | | |
| | | **WTR1** | | |
| Control | 600 | 580 | 530 | 470 |
| 17 ton/acre | 600 | 550 | 530 | 480 |
| 51 ton/acre | 640 | 570 | 550 | 500 |
| | | **WTR2** | | |
| Control | 1,190 | 1,050 | 790 | 780 |
| 17 ton/acre | 1,140 | 1,090 | 840 | 820 |
| 51 ton/acre | 1,140 | 1,080 | 820 | 770 |
| 6.4 ton/acre (alum) | 1,140 | 1,140 | 860 | 810 |
| | | **WTR3** | | |
| Control | | | 1,050 | 950 |
| 20 ton/acre | | | 1,180 | 910 |
| 60 ton/acre | | | 1,020 | 610 |
| | | **WTR4** | | |
| Control | | | 1,100 | 880 |
| 20 ton/acre | | | 1,050 | 770 |
| 60 ton/acre | | | 1,140 | 650 |

Table 3. Calcium chloride extractable P concentrations for WTR1, WTR2, WTR3 and WTR4 sites with time.

| Treatment | Spring '98 | Fall '98 | Spring '99 | Fall '99 |
|---|---|---|---|---|
| | lb P/acre | | | |
| | | WTR1[a] | | |
| Control | 0.8 | 1.0 | 1.1 | 1.4 |
| 17 ton/acre | 0.8 | 1.0 | 1.0 | 1.1 |
| 51 ton/acre | 0.8 | 0.9 | 1.0 | 1.3 |
| | | WTR2 | | |
| Control | 21.9 | 23.8 | 13.4 | 12.9 |
| 17 ton/acre | 19.9 | 16.5 | 9.6 | 8.6 |
| 51 ton/acre | 19.8 | 10.8 | 7.0 | 6.6 |
| 6.4 ton/acre (alum) | 21.4 | 13.4 | 4.6 | 7.3 |
| | | WTR3 | | |
| Control | | | 26.0 | 17.1 |
| 20 ton/acre | | | 30.2 | 16.7 |
| 60 ton/acre | | | 24.2 | 5.0 |
| | | WTR4 | | |
| Control | | | 13.4 | 9.3 |
| 20 ton/acre | | | 13.8 | 3.9 |
| 60 ton/acre | | | 18.0 | 4.2 |

[a] All concentrations obtained for the WTR1 site were at the detection limit and were highly variable for all replicates.

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