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# Amendment Effects on Soil Test Phosphorus

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## ABSTRACT

**Applications of animal manures have increased soil test P values in many parts of the USA and thus increased the risk that soil P will be transferred to surface water and decrease water quality. To continue farming these areas, landowners need tools to reduce the risk of P losses. A field experiment was conducted near Kurten, TX, on a Zulch fine sandy loam (thermic Udertic Paleustalfs) with Bray-1 P values exceeding 3000 mg P kg$^{-1}$ soil (dry wt.) in the $A_p$ horizon to evaluate the effectiveness of soil amendments for reducing soil test P values. Soils were amended annually from 1999 to 2001 with 1.5 and 5.0 Mg gypsum ha$^{-1}$, 1.4 Mg alum ha$^{-1}$, or 24.4 Mg ha$^{-1}$ of waste paper product high in Al alone or in combination with 1.5 Mg gypsum ha$^{-1}$ and/or 1.4 Mg alum ha$^{-1}$. These treatments supplied a maximum of 225 and 1163 kg ha$^{-1}$ yr$^{-1}$ of Al and Ca, respectively. Soil Bray-1 P and dissolved reactive P levels were monitored from 1999 to 2004. None of the soil amendment treatments affected Bray-1 P values. Only annual additions of 5.0 Mg gypsum ha$^{-1}$ from 1999 to 2001 significantly reduced soil dissolved reactive P. Dissolved reactive P levels reached minimal levels after two applications of 5.0 Mg gypsum ha$^{-1}$ but increased in 2003 and 2004. These results indicate that soil dissolved reactive P levels can be reduced if sufficient amounts of gypsum were added to supply Ca in amounts similar to the soil test P values.**


Environmental concerns associated with the land application of manures are leaching and runoff losses of P to ground and surface water (Sims et al., 1998). Concentrated animal feeding operations are a major source of animal manure in the USA. Applications of P from fertilizers or animal manures to agricultural land have resulted in high soil test P (STP) levels. In the northeastern USA, much of the soil analyzed for plant-available P exceeded levels needed for agricultural production (Sims, 1992; Sharpley et al., 1994; Stout et al., 1998). In Arkansas, Mehlich III extractant soil tests in 1999 showed that >60% of soil samples from counties with high intensity poultry production had high STP and >30% were very high (DeLong et al., 2000).

New technologies are needed to minimize the risk of soil P being transported from soils testing high to ground and surface water. It may be possible to reduce the loss of P from soils with high STP through the use of amendments. In certain instances, the addition of gypsum has been effective in reducing the loss of reactive P in runoff from fields with high STP (Stout et al., 1998). The chief mechanism by which gypsum reduces P losses is by decreasing the disaggregation of soil particles, thus reducing the amount of P carried along with sediment (McCray and Sumner, 1990). It is possible that reduction in P losses also arises from the formation of relatively insoluble Ca phosphate complexes when Ca in gypsum reacts with soluble phosphate.

Another soil amendment that has been found to reduce soluble P losses from fields with high STP is alum (Moore et al., 1999). The chief mechanism by which alum is effective in reducing P losses is by immobilization of readily soluble P by the formation of relatively insoluble complexes between soil P and the added Al. Alum can be added to the litter or as a soil amendment to reduce the soluble forms of soil P and thus reduce the likelihood that soil P will be transported from agricultural land to surface water. Despite decreases in soluble soil P, STP of fields tended to increase with the application of alum-treated litter (Moore et al., 1999).

It may be possible to add Al to soils to complex readily soluble P by adding a waste paper product. Waste paper contains significant quantities of Al with levels routinely exceeding 3 g kg$^{-1}$ dry weight (Edwards et al., 1995). When an amendment produced from waste paper and anhydrous ammonia to adjust the C/N ratio to 30:1 was added to soil, Al was released into the soil solution (Edwards et al., 1995; Edwards, 1997; Lu et al., 1995, 1997). Addition of the waste paper to soils resulted in N, Ca, Mg, and P foliar deficiency symptoms of corn seedlings (Lu et al., 1995). It was hypothesized that plants growing in amended soils were P deficient as a result of the precipitation of P from the soil solution by Al. To overcome this problem, P is currently being added to a weed control mulch product developed from recycled paper to reduce the toxic effects of Al (Smith et al., 1997, 1998). Therefore, it may be possible to use a soil amendment made from waste paper as a source of Al to complex readily soluble soil P. The objective of this research was to compare the effects of a soil amendment made from waste paper on STP to that of alum and gypsum on a site in which STP is very high.

## MATERIALS AND METHODS

### Characteristics of Experimental Site

Plots were established near Kurten, TX (approximately 25 km northeast of College Station, TX), on a Zulch fine sandy loam (thermic Udertic Paleustalfs) formed from weathered shale with a slope of 1 to 3%. The soil is moderately deep to weathered shale (76–102 cm), moderately well-drained, low natural fertility, and is very slowly permeable. Annual rainfall in Kurten, TX, is <90 cm with most of the rain occurring during the

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**Abbreviations:** DRP, dissolved reactive phosphorus; STP, soil test phosphorus.

**Table 1. Amounts of added Ca and Al for the seven amendment treatments, on an annual basis and total after 3 yr of applications.**

| Treatment description (abbreviation for figure legends) | Amount added annually | | Total amount added | |
|---|---|---|---|---|
| | Ca | Al | Ca | Al |
| | kg ha$^{-1}$ | | | |
| 1.5 Mg gypsum ha$^{-1}$ (low Ca) | 349 | 0 | 1047 | 0 |
| 5.0 Mg gypsum ha$^{-1}$ (high Ca) | 1163 | 0 | 3489 | 0 |
| 1.4 Mg alum ha$^{-1}$ (Al) | 0 | 127 | 0 | 382 |
| 24.4 Mg waste paper ha$^{-1}$ (paper) | 24 | 98 | 73 | 293 |
| 24.4 Mg paper ha$^{-1}$ paper + 1.4 Mg alum ha$^{-1}$ (paper + Al) | 24 | 225 | 73 | 675 |
| 24.4 Mg paper ha$^{-1}$ + 1.5 Mg gypsum ha$^{-1}$ (paper + Ca) | 373 | 98 | 1120 | 294 |
| 24.4 Mg paper ha$^{-1}$ + 1.5 Mg gypsum ha$^{-1}$ + 1.4 Mg alum ha$^{-1}$ (paper + Al + Ca) | 373 | 225 | 1120 | 675 |

winter and spring months. Average annual temperature is about 20°C. The $A_p$ horizon is typically 12.5 cm deep. The site's vegetation had been a common bermudagrass (*Cynodon dactylon* L.) sod for several years before establishment of the experiment. Bermudagrass was allowed to reestablish after the soil amendments were incorporated. Bermudagrass hay was harvested when forage height exceeded 25 to 30 cm, usually two or three times a year depending on rainfall. Each plot was 7.6 by 7.6 m.

## Soil Amendment Treatments and Soil Sampling Protocols

The soil amendment treatments were: (i) unamended control; (ii) 1.5 Mg gypsum [$CaSO_4{\cdot}2(H_2O)$] ha$^{-1}$; (iii) 5.0 Mg gypsum ha$^{-1}$; (iv) 1.4 Mg alum [$Al_2(SO_4)_3{\cdot}14(H_20)$] ha$^{-1}$; (v) 24.4 Mg ha$^{-1}$ waste paper; (vi) 24.4 Mg ha$^{-1}$ waste paper + 1.4 Mg alum ha$^{-1}$; (vii) 24.4 Mg ha$^{-1}$ waste paper + 1.5 Mg gypsum ha$^{-1}$; and (viii) 24.4 Mg ha$^{-1}$ waste paper + 1.5 Mg gypsum ha$^{-1}$ + 1.4 Mg alum ha$^{-1}$. The waste paper soil amendments were manufactured from ground waste paper and $(NH_4)_2SO_4$ by Tascon (Houston, TX). The C/N ratio was 30:1. The content of Al and Ca in the waste paper product averaged 0.4 and 0.1% (dry wt. basis), respectively. All soil amendments were incorporated into the top 10 cm of soil with a vertical action tiller. Amendments were applied in March of 1999, 2000, and 2001. The amounts of Ca and Al added per treatment annually and the total over the 3 yr are presented in Table 1.

Initially, four soil samples were collected from the experimental area to establish initial chemical and physical properties before application of amendments. These soil samples were collected in increments to a depth of 90 cm. Soil samples from the 0- to 7.5- and 7.5- to 15-cm depths were collected from all plots in July or August of 1999, 2000, and 2001, approximately 4 mo after soil amendments were applied. Soil samples from each of the 3 yr were analyzed for dissolved reactive phosphorus (DRP) and samples from 1999 and 2001 were analyzed for Bray-1 P levels as described below. Samples from the 0- to 7.5-cm depth were collected in June 2002, 2003, and 2004. Samples from 2002 through 2004 were analyzed for both Bray-1 P and DRP as described below.

## Soil Testing Protocols

Soil pH was determined in a 1:1 water–soil suspension (Peech, 1965). Plant-available P was determined by the Bray-1 P method (Olsen and Sommers, 1982). Bray-1 P assay was used because the soils in this study are naturally acidic. Dissolved reactive P was extracted with a 25:1 ratio of distilled water

**Table 2. Selected chemical characteristics of the Zulch fine sandy loam soil before establishment of experimental plots by depth. Data are the average of four samples.**

| Soil depth | Horizon | pH | Bray-1 P | DRP | Mehlich III extractable K | Mehlich III extractable Ca |
|---|---|---|---|---|---|---|
| cm | | mg kg$^{-1}$ soil (dry wt.) | | | | |
| 0–6.5 | Ap | 7.8 | 3990 | 45.9 | 894 | 6030 |
| 6.5–15 | Ap | 8.0 | 2940 | 51.3 | 681 | 5090 |
| 15–30 | Bt | 8.2 | nd† | 37.5 | 992 | 3998 |
| 30–45 | Bt | 8.2 | nd | 3.1 | 550 | 3608 |
| 45–60 | Bt | 8.2 | nd | 1.0 | 228 | 3641 |
| 60–90 | Bt | 8.4 | nd | 0.5 | 114 | 5209 |

† nd, not determined.

(mL)/soil (g) (Self-Davis et al., 2000). An extractant to soil volume of 25:1 was chosen because Pote et al. (1996) demonstrated that these values were most closely correlated with DRP in runoff. Phosphorus concentrations in Bray-1 P and water extracts were determined colorimetrically (Murphy and Riley, 1962). Extractable Ca and K were measured by ICP after extraction with Mehlich III (Mehlich, 1984). Water-soluble soil Ca levels were measured by ICP in extracts prepared for DRP. All soil test values are reported on a dry weight basis.

## Statistical Analyses

The experimental design was a randomized complete block of eight soil amendment treatments with four replications. Analysis of variance was performed using ProcGLM (SAS Institute, 1999). Data collected from 1999 to 2001 were analyzed separately from data collected from 2002 to 2004. Mean comparisons were made by the use of standard errors of the mean (SE) in those cases where the source of variation in the analysis of variance had a *F* test significant at $P < 0.05$.

# RESULTS

Before establishment of the experiment, the top 30 cm of soil had very high values for STP, soil pH, and extractable K and Ca (Table 2). Bray-1 P values approached 4000 mg P kg$^{-1}$ soil in the top 6.5 cm of soil. Dissolved reactive P values exceeded 35 mg P kg$^{-1}$ soil at depths down to 30 cm. Soil pH and soil Ca values were high throughout the soil's profile, especially for a soil that is naturally acidic. Extractable levels of Ca exceeded 3000 mg Ca kg$^{-1}$ soil and soil pH exceeded 7.8 throughout the profile.

Bray-1 P values of soil samples collected in 1999–2001, years in which amendments were applied, were affected by depth, but not by years or soil amendment treatments (Table 3). The mean Bray-1 P values were 3990 ± 61

**Table 3. Summary of the analysis of variance describing experimental effects on soil tests levels for Bray-1 P and dissolved reactive P (DRP) during the 3 yr that soil amendments were applied (1999–2001).**

| Source of variation | Bray-1 P df† | Bray-1 P *F*-test | Soil DRP df† | Soil DRP *F*-test |
|---|---|---|---|---|
| Years | 1 | 0.22 | 2 | 43.70*** |
| Soil amendments (SA) | 7 | 0.61 | 7 | 8.06*** |
| Depths | 1 | 36.35*** | 1 | 1.35 |
| Years × SA | 7 | 0.71 | 14 | 1.42 |
| Years × depths | 1 | 0.01 | 2 | 1.41 |
| SA × depths | 7 | 0.20 | 7 | 1.72 |
| Years × SA × depths | 7 | 0.36 | 14 | 0.80 |

*** Significant at the 0.001 probability level.
† df, degrees of freedom.

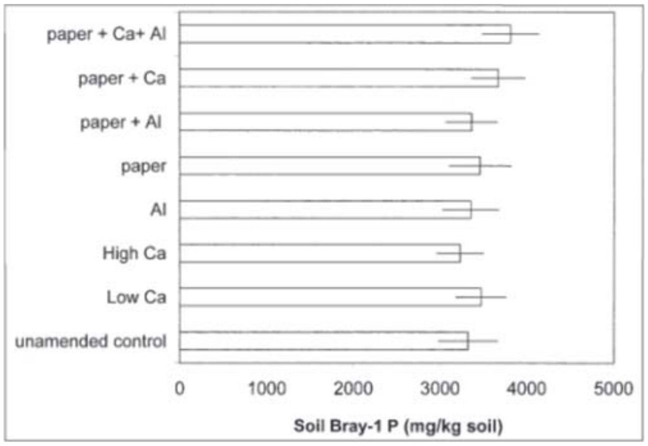


**Fig. 1. Effects of soil amendment treatments on Bray-1 P levels. Data are averages across depths, years and replications. Bars represent SE. Treatment legend is in figure.**

(SE) and 2940 ± 103 (SE) mg P $kg^{-1}$ soil for samples taken from 0 to 7.5 cm and 7.5- to 15-cm depths, respectively, when averaged across treatments and years. Bray-1 P values (averaged across years, depths, and replications) varied among soil amendment treatments from 3200 to 3800 mg P $kg^{-1}$ soil (Fig. 1), but these differences were not statistically significant.

Dissolved reactive P values varied significantly with years (Table 3). Dissolved reactive P values for samples collected in 2001 tended to be significantly greater than those for samples collected in 1999 and 2000. Soil DRP was 55.4 ± 2.8 (SE) mg P kg soil in 2001 when averaged across depths, soil amendments, and replications, as compared with 45.0 ± 1.6 (SE) and 42.3 ± 1.3 (SE) mg P $kg^{-1}$ soil in 1999 and 2000, respectively. Environmental factors, like conditions that promote soil drying, can alter STP (Pote et al., 1999), and thus is a possible explanation for the higher values in 2001.

The significant effect of soil amendment treatments on DRP (Table 3) was associated with significantly lower means for the high gypsum treatment (Fig. 2). Across replications, years, and depths, soil DRP was about 36 mg P $kg^{-1}$ soil with the 5.0 Mg gypsum $ha^{-1}$ treatment. This mean is significantly lower than the means of 46 to 50 mg P $ha^{-1}$ for the other six soil amendment treatments and unamended soil.

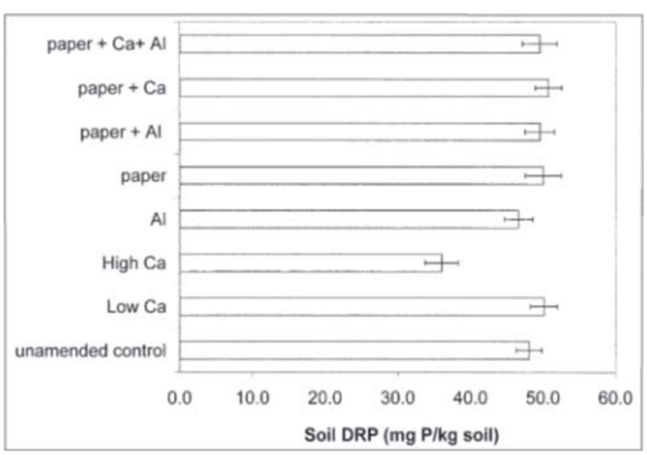


**Fig. 2. Effects of soil amendment treatments on dissolved reactive P (DRP) levels. Data are averages across depths, years, and replications. Bars represent SE. Treatment legend is in figure.**

**Table 4. Summary of the analysis of variance describing experimental effects on soil tests levels for Bray-1 P and dissolved reactive P (DRP) during the 3 yr after soil amendments were applied (2002–2004).**

| | Bray-1 P | | Soil DRP | |
|---|---|---|---|---|
| Source of variation | df† | *F*-test | df | *F*-test |
| Years | 2 | 4.06* | 2 | 19.52*** |
| Soil amendments (SA) | 7 | 0.50 | 7 | 18.46*** |
| Years × SA | 14 | 0.17 | 14 | 1.42 |

* Significant at the 0.05 probability level.
*** Significant at the 0.001 probability level.
† df, degrees of freedom.

Soil samples collected the 3 yr (2002–2004) following the last amendment application (2001) were analyzed for Bray-1 P and DRP to assess the residual effects of the soil amendment treatments. Bray-1 P values for soils collected in 2002–2004 were affected by years only (Table 4). Bray-1 P values for the 2002 samples averaged 4038 ± 143 mg P $kg^{-1}$ soil and were significantly greater than the means for samples collected in 2003 and 2004, which averaged 3499 ± 156 (SE) and 3596 ± 146 (SE) mg P $kg^{-1}$ soil, respectively.

Dissolved reactive P values from 2002 to 2004 were affected by years and soil amendment treatments (Table 4). Means for DRP from each of the 3 yr were significantly different from each other, 57.4 ± 1.7 (SE), 50.6 ± 1.7 (SE), and 65. 3 ± 1.6 (SE) mg P $kg^{-1}$ soil, for 2002, 2003, and 2004, respectively. Dissolved reactive P values for soil collected 2002–2004 from the high gypsum treatment were significantly less than the means for the other six soil amendment treatments and the unamended soils. Across years (2002–2004) and replications, DRP averaged 36.1 ± 2.7 (SE) mg P $kg^{-1}$ soil for the high gypsum treatment as compared with means of 51 to 71 mg P $kg^{-1}$ soil for the other seven treatments.

Soil DRP values for the high gypsum soil amendment treatments and unamended control are compared in Fig. 3. Soil DRP values for the high gypsum treatment

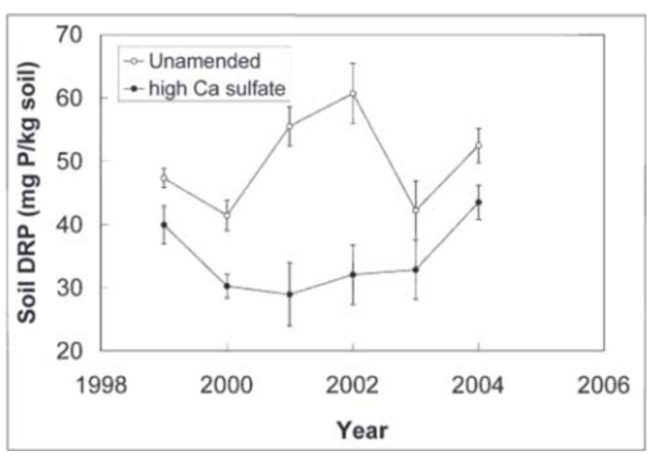


**Fig. 3. Changes in soil dissolved reactive P (DRP) levels with time for the 5.0 Mg gypsum $ha^{-1}$ soil amendment treatment (closed symbols) and unamended control (open symbols). SE are presented as bars.**

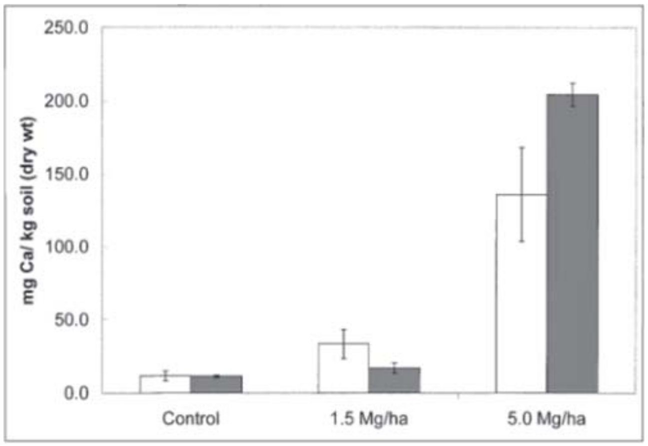


**Fig. 4. Water-soluble Ca levels in soil samples from the 0-7.5 cm depth in 1999 (open bars) and 2001 (solid bars). Data from soils receiving 1.5 Mg and 5.0 Mg gypsum $ha^{-1}$ are presented along with those from control plots. SE are presented as bars.**

in 1999 tended to be less than those for the control samples collected. Soil DRP values for soil from the high gypsum treatment declined between 1999 and 2000, and then held nearly constant in 2001 and 2002. Soil DRP values increased in the control in 2001 and 2002 as compared with those from 2000. Therefore, the difference in DRP between the high gypsum and the control was greatest in 2002. Soil DRP values for soil from the high gypsum treatment tended to increase in 2003 and 2004. By 2004, the difference in soil DRP between the control and the high gypsum treatment was barely significant.

In 1999 and 2001, soils collected from the 0- to 7.5-cm depth in control plots and those receiving the two gypsum treatments were analyzed for water-soluble Ca. Analysis of variance indicated that soil amendment treatments and soil amendment treatments × year interaction had significant effects on water-soluble soil Ca (data not shown). Annual applications of 5.0 Mg gypsum $ha^{-1}$ increased water-soluble soil Ca almost 10 times that in the control plots in 2001 (Fig. 4). Water-soluble soil Ca was greater in soils receiving annual applications of 1.5 Mg gypsum $ha^{-1}$ as compared with that found in control plots. Water-soluble soil Ca was unchanged in control soils between 1999 and 2001. Water-soluble soil Ca tended to increase from 1999 to 2001 for soils receiving 5.0 Mg gypsum $ha^{-1}$, whereas levels tended to decrease from 1999 to 2001 for soils receiving 1.5 Mg $ha^{-1}$.

## DISCUSSION

The objective of this study was to determine the effectiveness of different types of soil amendments to reduce STP values with a soil with very high values. Bray-1 P values for the topsoil at the experimental site exceeded 3000 mg P $kg^{-1}$ soil. None of the soil amendment treatments had an effect on Bray-1 P levels (Table 3 and 4, and Fig. 1). Out of the seven soil amendment treatments in this study, only one, the higher application rate of gypsum, 5 Mg $ha^{-1}$, affected DRP (Table 3 and 4, and Fig. 2 and 3). The high gypsum amendment provided at least three times more Ca than any of the other treatments (Table 1) and the amount of added Ca approached that of the Bray-1 P values. Calcium additions from the waste paper product were relatively small. These results indicate that reduction in DRP was associated with additions of Ca in amounts similar to Bray-1 P values. Reductions in DRP appeared to be dependent on continual applications of gypsum (Fig. 4).

Additions of Al by the seven soil amendment treatments were less than that of Ca (Table 1). The alum soil amendment treatment provided only 127 kg Al $ha^{-1}$ $yr^{-1}$ and the waste paper product supplied slightly less Al, 98 kg $ha^{-1}$ (Table 1). The maximum amount of Al supplied over the 3 yr was 675 kg Al $ha^{-1}$ by the waste paper plus alum with or without gypsum treatments. None of the treatments provided Al in amounts that approached the Bray-1 P values. Soil amendments supplying Al in this study were ineffective in reducing DRP and Bray-1 P test values (Table 3 and 4, Fig. 1 and 2). These results indicate that additions of Al in amounts less than that of STP did not reduce DRP values. The amounts of Ca plus Al provided by the waste paper + alum + gypsum soil amendment treatment approached the Bray-1 P values, i.e., the addition of about 1800 kg of Ca plus Al $ha^{-1}$ after 3 yr compared to Bray-1 P values of 3000 kg P $ha^{-1}$. However, this treatment did not alter DRP values. Two applications of 5.0 Mg gypsum $ha^{-1}$ supplied about 2300 kg Ca $ha^{-1}$ and resulted in decreased DRP. This lack of an effect of the waste paper + alum + gypsum treatment suggests that the effects of Ca and Al were not additive in this soil system.

Additions of greater amounts of waste paper to supply more Al were not practical. The waste paper product covered the surface area of the plot to a height exceeding 30 cm at an application rate of 22.4 Mg $ha^{-1}$. Incorporation of higher levels with the machinery used in this study would have been problematic.

Differences between the low and high gypsum soil amendment treatment in reducing DRP suggests a dosage × time interaction for the response. The Ca additions during the 3 yr by the lower gypsum treatment were only slightly less than the Ca supplied annually by the higher rate, 1047 vs. 1163 kg Ca $ha^{-1}$. Three annual applications of the lower rate of gypsum did not affect DRP values, whereas DRP was lower after the first application of gypsum at the higher rate. Higher rates of gypsum additions were also associated with increasing water-soluble Ca levels, whereas the lower rate had little or no effect (Fig. 4).

In 2000, simulated rainfall/runoff experiments were conducted at Kurten, TX, on soils that had received either gypsum or the waste paper soil amendment and a preliminary report has been published (Livingston et al., 2002). Simulated rainfall/runoff studies were conducted about a month after soil amendments were incorporated. The amounts of total and soluble P in the runoff from a simulated rainfall were significantly less for soils receiving either gypsum or the waste paper, as compared with untreated soils. Although application of the waste paper decreased the P in runoff in the previous study (Livingston et al., 2002), there were no indications in this report that the addition of the waste paper product decreased DRP or Bray-1 P values (Fig. 1 and Table 3). Although the mechanism responsible for reduced runoff P in the previous study is not known, changes in the degree of aggregation of soil particles, or reaction of soil P with organic constituents, are potential explanation for the results from these two studies. Experiments are being conducted currently to examine the effects of amending soils with the waste paper product on soil aggregation and to test the feasibility of reducing STP with the waste paper product in a situation in which STP values are less.

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