Impact of ENCAP's *Fast Acting Lime Plus AST*^{TM} Compared to Traditional Lime

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Introduction

Transport of soil particles, fertilizers, and other nutrients throughout the landscape as a result of erosion and surface runoff poses significant economic costs and environmental concerns to society. Surface application of lime ($CaCO_3$), has primarly been used to overcome soil acidity by raising soil pH (Kelling and Schulte, 2004), however it has been suggested that lime enhances soil structural stability (Chan and Heenan, 1999), thereby enhancing infiltration and reducing runoff and sediment loss.

Water soluble anionic polyacrylamides (WSPAM) are used to enhance aggregate stability, promote infiltration and reduce runoff and erosion. This practice has been widely accepted in irrigated agriculture where low application rates effectively increase infiltration and decrease sediment loss. The combined application of WSPAM with lime to soil can be advantageous in that lime provides divalent cations in the form of Ca^{2+}, that enhance cation bridging and the sorption of WSPAM to soil particles (Laird, 1997; Green et al., 2000). ENCAP's Advanced Soil Technology (*AST*^{TM}) impregnates and/or coats soil conditioning and/or fertilizer products such as Traditional Lime with the intent of making them more effective by keeping them in place, overcoming soil and nutrient losses due to runoff, infiltration/leaching, and erosion. ENCAP LLC's (Green Bay, WI) patented carrier and delivery technology is utilized in one of their products called *Fast Acting Lime Plus AST*^{TM}.

The objective of this study was to evaluate the impact of ENCAP LLC's (Green Bay, WI) *Fast Acting Lime Plus AST*^{TM} product on sediment and nutrient transport with respect to the performance of Traditional Lime.

Methods and Materials

Rainfall Simulations

Infiltration, runoff, erosion and nutrient transport were studied using a laboratory rainfall simulator based on the design used in previous WSPAM tests by Petersen et al., 2007. The drip-type simulator consisted of an enclosed PVC chamber with approximately 700 hypodermic needles protruding from the base of the chamber in a 25 mm by 25 mm grid spacing. Water was pumped from a holding tank through a 19 mm (0.75 in) hose using a 1.5 HP submersible pump. A pressure regulator maintained a constant water pressure in the enclosed chamber and a ball valve allows flow to the simulator to be turned on or off. The enclosed chamber was positioned 1.5 m (5 feet) above a sloped platform (10%) on four support legs. Small oscillating fans positioned on the support columns of the simulator induced spatially random drop distributions on the test area below the simulator. Average droplet diameter was 3.5 mm, determined volumetrically by collecting 50 drops from twenty randomly selected needles. The 1.5 m (5 feet) drop height produced drops with a fall velocity of 4.94 $m \cdot s^{-1}$ according to Epema and Riezebos (1983).

Plano silt loam soil obtained from agricultural fields at Arlington Agricultural Research Station (Arlington, WI) was used in all experiments. Soil was taken from the upper 10 cm (4 inches) of the soil surface, air-dried, crushed and passed through a 4.0 mm sieve to maintain soil uniformity throughout the tests. The soil was spread evenly in two lifts over a pea gravel base layer in soil boxes measuring 0.457 m long by 0.203 m wide by 0.089 m deep. Dionized (DI) water was applied to each soil lift using a hand sprayer to achieve an overall moisture content of 20% by volume. The soil was compacted to a bulk density of 1.2 g cm^{-3} by pressing the soil with a flat piece of PVC to a known depth. Treatments were then spread on the soil surface, covered, and allowed to rest for 24 hours before rainfall simulations were performed.

Three soil boxes were positioned side-by-side on the sloped platform to allow simultaneous testing of three treatments. Rainfall was simulated at approximately 65 mm/hr for 60 minutes. Each soil box had a fixed gutter along the downslope edge with a PVC pipe outlet from which runoff was collected, and an infiltration outlet positioned at the underside of each soil box from which leachate was collected. Runoff was collected in 20 minute intervals throughout the 60 minute rainfall simulation. Leachate was collected for the entire 60 minute simulation. After samples were collected they were weighed and approximately 60 mL runoff samples were filtered (.45 micron) and analyzed by the Soil and Plant Analysis Lab (SPAL) at the University of Wisconsin-Madison for dissolved reactive phosphorus (DRP), soluble ammonium (NH_4-N), soluble nitrate (NO_3-N), soluble calcium (Ca), and soluble sulfur (S). The remaining runoff sample was oven dried. Dried runoff sediment was weighed, collected, and sent to SPAL for analysis of total phosphorus (TP) and NH_4-N.

Two treatments were tested in addition to a bare soil control: 1) soil conditioner, where Traditional Lime was applied to the soil surface at an application rate of 280 kg/ha (250 lb/acre); and 2) *Fast Acting Lime Plus AST*™, where WSPAM coated lime, provided by ENCAP LLC. (Green Bay, WI), was applied at 280 kg/ha (250 lb/acre) [WSPAM application rate of 5.6 kg/ha (5.0 lb/acre)]. All treatments were replicated four times.

Data Analysis

Sediment loads, nutrient loads, mineral loads, runoff volumes, and leachate volumes were accumulated over the duration of the rainfall simulation for each replicate, averaged and the percent reduction in each variable was determined as

$$\%\ Reduction = \frac{A_c - A_t}{A_c} \times 100 \qquad (1)$$

where A_c is the average accumulated sediment load, nutrient load, mineral load, runoff volume or leachate volume from the control and A_t is the average sediment load, nutrient load, mineral load, runoff volume or leachate volume from the treatment.

Data obtained from the rainfall simulations were analyzed with SYSTAT using a multi-variable analysis of variance (ANOVA) and utilized a Bonferroni method Post hoc test to obtain critical levels of significance ($P<0.05$).

Results and Discussion

Sediment and sediment bound P and NH_4

Traditional Lime and *Fast Acting Lime Plus AST*™ treatment decreased cumulative sediment loads throughout 60 minutes of simulated rainfall (Fig. 1A). *Fast Acting Lime Plus AST*™ was more effective than Traditional Lime alone. When compared directly to Bare Soil, the percent reduction of sediment load after 20 minutes of simulated rainfall (21 mm of applied rain) was 54, and 94% for Traditional Lime and *Fast Acting Lime Plus AST*™, respectively (Fig. 1B). After 40 minutes (43 mm of applied rain) the percent sediment load reductions had fallen to 34 and 91% and after 60 minutes (65 mm of applied rain) they were 30 and 83%. The results after 60 minutes are shown in Table 1. The consistent order of cumulative load among treatments is Bare Soil > Traditional Lime > *Fast Acting Lime Plus AST*™. The apparent separation of slopes in Fig. 1 into two groups ((1) bare soil and lime and (2) *Fast Acting Lime Plus AST*™) likely reflects the significant differences in how *Fast Acting Lime Plus AST*™ and Traditional Lime alone contribute to soil consolidation and stability. Table 1 also shows a 75 percent cumulative sediment load reduction when comparing the *Fast Acting Lime Plus AST*™ to lime treated soil.

The results for sediment bound P and NH_4 show similar trends to those of sediment load (Tables 1-2 and Fig. 2A-D). The one exception is that mean cumulative NH_4 loads were not significantly different for Traditional Lime compared to Bare Soil or *Fast Acting Lime Plus AST*™ (Table 2).

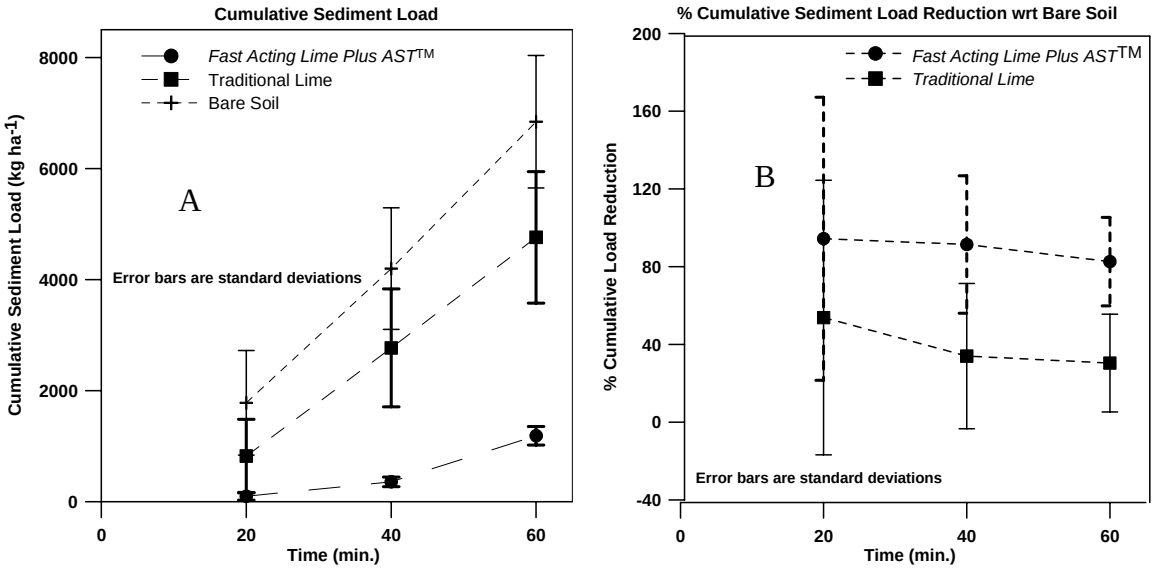

Figure 1. (A) Cumulative sediment load during 60 minutes of simulated rainfall (total precip ~ 65 mm) for Bare Soil, Traditional Lime treated soil and *Fast Acting Lime Plus AST*™ treated soil. (B) Percent reduction in cumulative sediment load wrt Bare Soil for soils treated with Traditional Lime and *Fast Acting Lime Plus AST*™

Table 1. Percent reduction in 60 minute cumulative sediment load and sediment bound and dissolved runoff constituent loads. Comparisons are made between both experimental treatments and Bare Soil as well as between Traditional Lime and *Fast Acting Lime Plus AST*™ (ns= means were not significantly different based on ANOVA).

	Runoff Sediment			Runoff Solution				
	Percent Reduction compared to bare soil							
	Sediment	P	NH4	DRP	NH4	NO3	Ca	S
Traditional Lime	30	31	ns	37	ns	ns	-211	ns
Fast Acting Lime Plus AST™	83	82	74	67	ns	ns	ns	ns
	Percent Reduction compared to Traditional Lime							
	Sediment	P	NH4	DRP	NH4	NO3	Ca	S
Fast Acting Lime Plus AST™	75	74	ns	47	ns	ns	57	ns

Table 2. Runoff sediment and sediment bound P and NH_4 (kg ha^{-1}) and standard deviations for 0-60 minutes of simulated rainfall.

	Runoff Sediment (all units are kg ha-1)		
	Sediment	P	NH4
Bare Soil	6.8E+03 ± 1.2E+03 **a**	4.7E+00 ± 7.8E-01 **a**	2.8E-01 ± 8.7E-02 **a**
Traditional Lime	4.8E+03 ± 1.2E+03 **b**	3.3E+00 ± 7.5E-01 **b**	1.7E-01 ± 5.3E-02 **ab**
Fast Acting Lime Plus AST™	1.2E+03 ± 3.4E+02 **c**	8.4E-01 ± 2.5E-01 **c**	7.1E-02 ± 4.3E-02 **b**

Means followed by the same letter are not significantly different by ANOVA ($P < 0.05$)

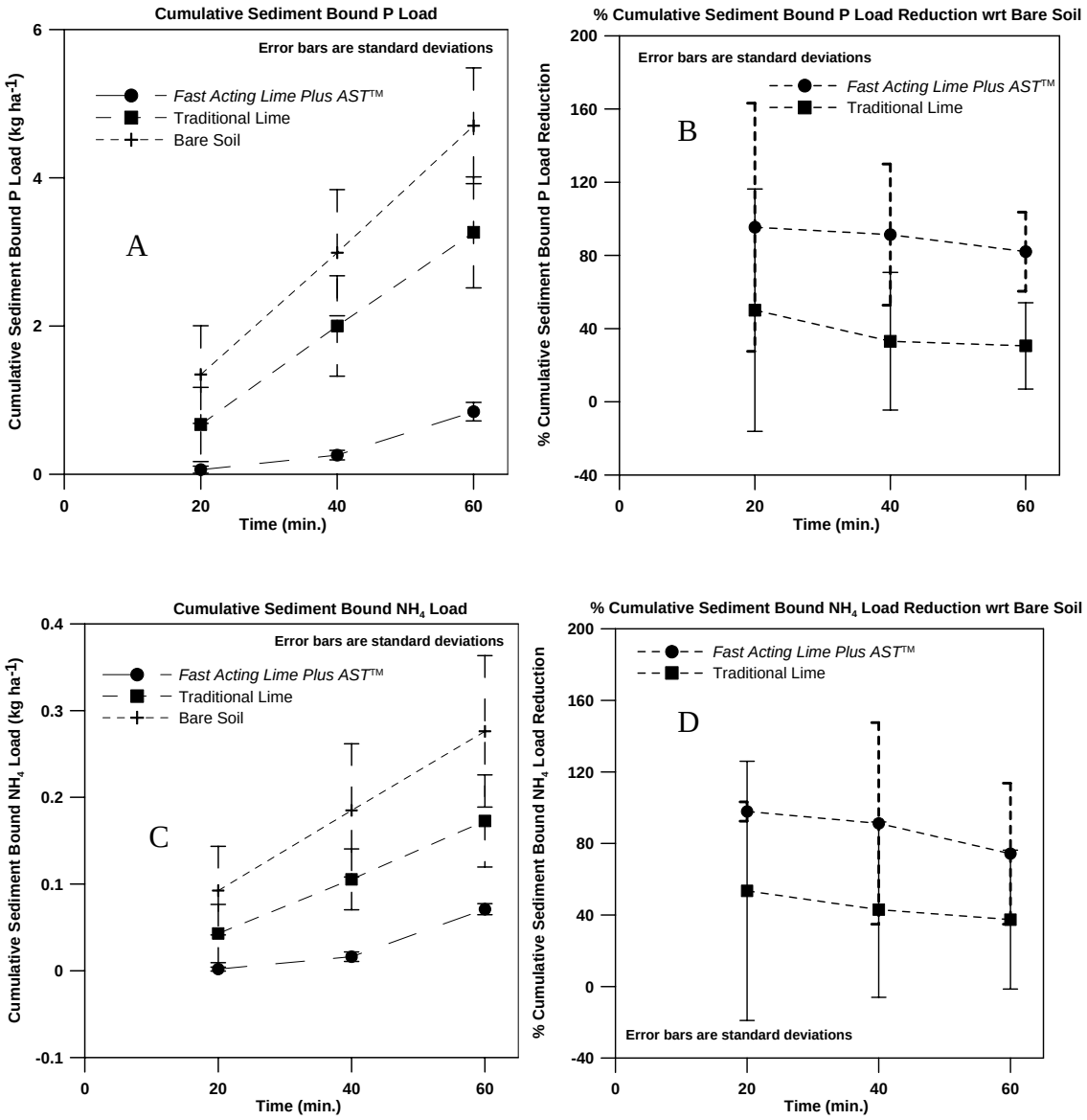

Figure 2. (A) Cumulative sediment bound P load during 60 minutes of simulated rainfall (total precip ~ 65 mm) for Bare Soil, Traditional Lime and *Fast Acting Lime Plus AST*™ treated soils. (B) Percent reduction in cumulative sediment bound P load wrt bare soil for soils treated with the two different conditioners. (C) Cumulative sediment bound NH_4 load during 60 minutes of simulated rainfall (total precip ~ 65 mm) for Bare Soil, Traditional Lime treated and *Fast Acting Lime Plus AST*™ treated soils. (D) Percent reduction in cumulative sediment bound NH_4 load wrt bare soil for soils treated with the two different conditioners.

Dissolved Runoff Constituents

Table 3 lists the cumulative loads of dissolved runoff constituents dissolved reactive phosphorus (DRP), NH_4, NO_3, Ca and S. Only Ca and DRP have significant differences between treatment means. It is expected that Ca runoff would increase because it is added in significant quantities with the lime. For Ca, the treatment results fall into two statistical groups: 1) Bare Soil and *Fast Acting Lime Plus AST*™, and 2) Traditional Lime (Table 3). For DRP, the cumulative loads follow the statistical order of Bare Soil > Traditional Lime > *Fast Acting Lime Plus AST*™. Because DRP also can be correlated to sediment yield, it is difficult to assess the reason for DRP load reduction.

Table 3. Runoff solution constituent loads (kg ha^{-1}) for 0-60 minutes of simulated rainfall. The NO_3 value for Bare Soil (highlighted in grey) is influence by an outlier.

	Runoff Solution (all units are kg ha-1)				
	DRP	NH4	NO3	Ca	S
Bare Soil	4.0E-02 ± 5.1E-03 a	6.9E-03 ± 4.9E-03 a	2.5E-01 ± 3.6E-01 a	5.3E-01 ± 1.2E-01 a	6.2E-02 ± 3.1E-02 a
Traditional Lime	2.5E-02 ± 6.8E-03 b	5.3E-03 ± 1.3E-03 a	6.0E-02 ± 2.0E-02 a	1.7E+00 ± 2.3E-01 b	4.7E-02 ± 4.3E-03 a
Fast Acting Lime Plus AST™	1.3E-02 ± 4.7E-03 c	6.4E-03 ± 5.2E-03 a	3.6E-02 ± 1.7E-02 a	7.2E-01 ± 7.3E-02 a	3.2E-02 ± 1.4E-02 a

Means followed by the same letter are not significantly different by ANOVA ($P < 0.05$)

Comparisons between 0-40 and 0-60 min.

The decrease in percent load reduction over time (Fig. 1B) motivated ANOVA of results of the first 40 minutes of simulated rainfall. Table 4 contains percent load reduction for all runoff constituents for 0-40 minutes. The reduction, with respect to bare soil, in sediment load and sediment P for the Traditional Lime treated soil were not significant for 0-40 minutes, as they were for 0-60 minutes.

For sediment load and sediment bound P load reductions from *Fast Acting Lime Plus AST*™, which were statistically significant for 0-60 minutes, there is an increase in percent reduction for 0-40 minutes. Table 5 lists the increase in percent reduction for 0-40 minutes when compared to 0-60 minutes. The increases (*i.e.*, 9 % for sediment load and P when comparing *Fast Acting Lime Plus AST*™ to Bare Soil) likely reflect the decrease in effectiveness of PAM over time as cumulative rainfall increases.

For both time periods *Fast Acting Lime Plus AST*™ DRP load reduction was significantly higher than Traditional Lime with respect to Bare Soil.

Table 4. Percent reduction in 0-40 minute cumulative sediment, sediment bound and dissolved runoff constituent loads. Comparisons are made between the two experimental treatments and bare soil as well as between *Fast Acting Lime Plus AST*™ and Traditional Lime (ns= means were not significantly different based on ANOVA).

	Runoff Sediment			Runoff Solution				
	Percent Reduction compared to bare soil							
	Sediment	P	NH4	DRP	NH4	NO3	Ca	S
Traditional Lime	ns	ns	ns	ns	ns	ns	-235	ns
Fast Acting Lime Plus AST™	91	91	ns	62	ns	ns	ns	ns
	Percent Reduction compared to Traditional Lime							
	Sediment	P	NH4	DRP	NH4	NO3	Ca	S
Fast Acting Lime Plus AST™	87	87	ns	ns	ns	ns	64	ns

Table 5. Difference (%) between 0-40 (Table 4) and 0-60 (Table 1) minute percent reduction of RO constituent loads. "ns" indicates value from at least one time period was statistically insignificant.

	Runoff Sediment			Runoff Solution				
	Percent Reduction compared to bare soil							
	Sediment	**P**	**NH4**	**DRP**	**NH4**	**NO3**	**Ca**	**S**
Traditional Lime	ns	ns	ns	**ns**	ns	ns	**-24**	ns
Fast Acting Lime Plus AST™	**9**	**9**	**ns**	**-5**	ns	ns	ns	ns
	Percent Reduction compared to Traditional Lime							
	Sediment	**P**	**NH4**	**DRP**	**NH4**	**NO3**	**Ca**	**S**
Fast Acting Lime Plus AST™	**12**	**13**	**ns**	**ns**	**ns**	**ns**	**7**	**ns**

Leachate

Leachate volume for *Fast Acting Lime Plus AST*™ was significantly greater compared to Bare Soil indicating enhanced infiltration (Table 6). There were no other significant differences in leachate volumes between treatments or between leachate solution constituents (Tables 6 and 7).

Table 6. Averages and standard deviations of leachate volumes (L).

	Bare Soil	Traditional Lime	*Fast Acting Lime Plus AST*™
Average:	0.04 a	0.12 ab	0.65 b
Std. Dev:	0.05	0.12	0.44

Table 7. Leachate solution loads (kg ha^{-1}).

	NH4	NO3	DRP	Ca	S
Bare Soil	6.92E-04 **a**	4.32E-02 **a**	3.78E-04 **a**	1.18E-01 **a**	1.61E-02 **a**
Traditional Lime	7.61E-05 **a**	1.59E-02 **a**	1.13E-03 **a**	1.27E-01 **a**	1.47E-02 **a**
Fast Acting Lime Plus AST™	5.12E-03 **a**	4.25E-02 **a**	5.89E-03 **a**	3.45E-01 **a**	2.75E-02 **a**

Means followed by the same letter are not significantly different by ANOVA ($P < 0.05$)

Significant Findings

- *Fast Acting Lime Plus AST*™ reduced sediment in runoff by 75% over a 60 minute period compared to Traditional Lime.
- *Fast Acting Lime Plus AST*™ reduced sediment-bound phosphorus in runoff by 74% over a 60 minute period compared to Traditional Lime.
- *Fast Acting Lime Plus AST*™ reduced dissolved reactive phosphorus in runoff by 47% over a 60 minute period compared to Traditional Lime.
- *Fast Acting Lime Plus AST*™ reduced calcium in runoff by 57% over a 60 minute period compared to Traditional Lime.
- Although a significant amount of Ca was added to the soil with the lime, Ca in runoff from *Fast Acting Lime Plus AST*™ was not significantly different from Bare Soil.

Summary

The significant reduction of sediment and sediment bound nutrient loss from *Fast Acting Lime Plus AST*™ treated soils was likely due to reduced chemical and physical dispersal of soil particles. Similarly, Smith et al. (1990) found WSPAM treated soils were more effective in reducing soil erosion, irrespective of raindrop kinetic energy. The addition of *Fast Acting Lime Plus AST*™ likely guarded against raindrop impact and helped preserve aggregate stability throughout the rainfall duration. The increased Ca content supplied by the lime (approximately 103% increase with the addition of lime) likely increased WSPAM sorption to soil particles through cation bridging while simultaneously reducing chemical dispersal of soil particles.

The lack of significant reduction in dissolved runoff constituents may partly be explained by WSPAM's primary function of binding soil particles together and maintaining aggregate stability. The ability of WSPAM in combination with lime to "entrap" soluble nutrient forms is less understood and may only be linked to reducing runoff volumes. Predictably the amount of Ca in runoff was increased with the addition of lime however Ca loads in runoff from the *Fast Acting Lime Plus AST*™ treatment were similar to those from bare soil.

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