# Impacts of Biological Additives, Part 1: Solids Accumulation in Septic Tanks

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**Abstract** **The efficacy of three septic tank additives and a control was assessed using a randomized complete-block design in a double-blind study described in this article. Sludge depth, scum thickness, and total solids were measured within 48 full-scale, functioning septic tanks. These tanks were distributed across three sites with low, intermediate, and high prior-maintenance levels. No significant, positive long-term additive treatment effects occurred across all maintenance levels at the $\alpha$ = .05 level. Separate analyses of variance, however, indicated that at the high prior-maintenance site, significant treatment effects occurred on sludge depth, scum thickness, and total solids. Sludge depths for the Liquid-Plumr and Rid-X additives were significantly reduced compared to the control at the high-maintenance site, but not at the low-maintenance site. Liquid-Plumr septic tank additive had significantly greater sludge depth at the intermediate-maintenance site, which is a negative impact. Sludge accumulation rates averaged 6.9 cm/yr. for 3,780-L (1,000 gallons) septic tanks.**

## Introduction

Twenty-five percent of existing housing and 33% of new development nationally use decentralized wastewater technologies such as on-site systems, also called septic systems (U.S. Environmental Protection Agency [U.S. EPA], 2005). The septic tank serves as a wastewater retention and solids digestion suboxic or anoxic chamber. Holding times are typically designed to be two to four days in septic tanks (Loudon, Bounds, Converse, Konsler, & Rock, 2005). Digestion of wastewater, sludge, and scum in septic tanks occurs naturally through various biological reactions via anaerobic and facultative anaerobic bacteria and larger organisms growing in the wastewater. The process of waste digestion is completed through various steps resulting in the formation of methane gas, carbon dioxide gas, hydrogen sulfide gas, and water. Up to 50% of the solids retained in a septic tank decompose over time (Iowa Department of Natural Resources, Onsite Wastewater Program, 2006). Although substantial digestion of waste occurs in septic tanks, the rate of digestion does not usually exceed the rate of solids delivery to the tanks from the household residents. Hence, these accumulated solids need to be pumped out from septic tanks on a periodic basis (Hoover & Konsler, 2004; Loudon et al., 2005).

Three basic categories of septic tank additives are available: chemical, physical, and biological. Most biological additives are designed to enhance the rate or efficiency of biological activity in the septic tank through the addition of organisms such as bacteria or enzymes. This article addresses only the efficacy of biological additives, specifically liquid biological additives. The objective of our study was to assess solids buildup and breakdown in a replicated and controlled field-scale experiment designed to measure the impacts of three bacterial additives. The accumulation of total solids in septic tanks in particular was assessed, including both sludge and scum accumulation.

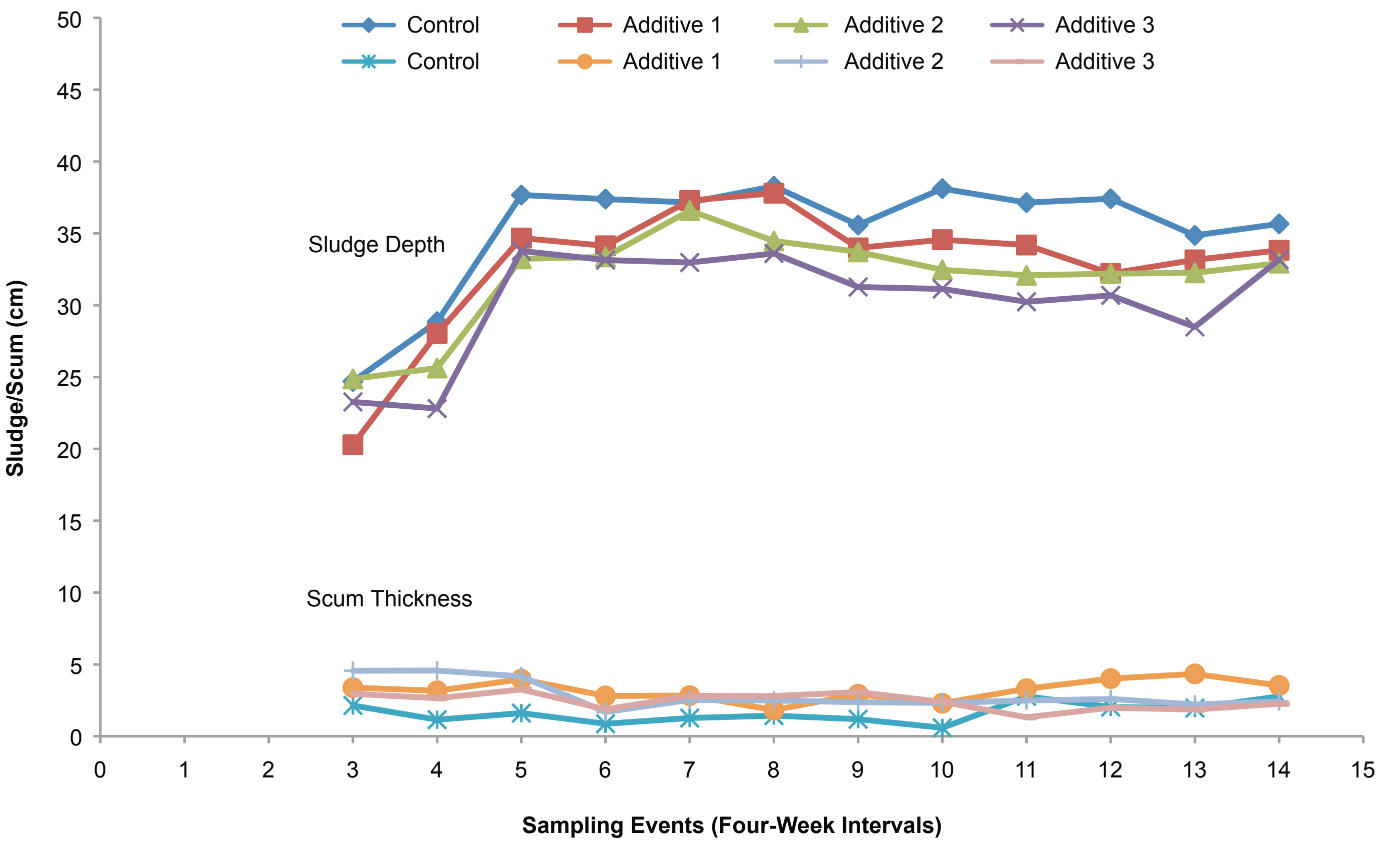
## Materials and Methods

The research locations included three sites (Pradhan et al., 2008). The three sites represented poorly maintained tanks (not pumped in 15–20 years), highly maintained tanks (pumped within 2–3 years prior to study), and septic tanks that received an intermediate level of maintenance. The initial solids contents of each tank (sludge depth and scum thickness) were classified into one of three relative maintenance levels prior to the study (low, intermediate, and high). These three maintenance levels were identified as the "site" parameter in the statistical model. Each site was divided into three to five blocks of four tanks, with a total of 12 blocks over all sites combined. The treatments were assigned randomly in such a way that each block contained all treatments (treatment 1 = control, treatment 2 = additive 1, treatment 3 = additive 2, and treatment 4 = additive 3) with no repetition (Pradhan et al., 2008).

Distribution of the additive treatments followed a double-blind approach (Pradhan et al., 2008). The treatments evaluated were a Drano septic tank additive (additive 1), a Liquid Plumr septic tank additive (additive 2), and a Rid-X septic tank additive (additive 3). The bacterial additives commenced after the first two sampling events so that each treatment had "before additive" data and "after additive" data. "Before additive" data were utilized to assess baseline conditions and to adjust for them as covariants.

FIGURE 1

**Least Squares Means for Sludge Depth and Scum Thickness Averaged Over All Three Sites***




*In treated and untreated septic tanks during the portion of the study period following initiation of additive application. Sludge treatment mean standard errors for control and each additive were the same (2.7). Scum treatment mean standard errors for additive 1 and additive 2 were 0.7, and scum treatment mean standard errors for additive 3 and control were 0.8. Treatment addition began following sampling event 2.

The experimental units were full-scale two-compartment septic tanks in which sludge depth and scum thickness were measured within the inlet (Clark, 1999). The multiple responses taken in sequence on the same tank, for sludge depth and scum thickness, were analyzed statistically using a linear mixed model implemented with the MIXED procedure (Littell, Henry, & Ammerman, 1998) using SAS. The model used for our study was as follows.

$Y = \beta_0 + \beta_1 X$ + site + block (site) + treatment + treatment*site + $\delta_t X$*treatment + time + time*site + time*treatment + time*treatment*site + within-tank error.

The variable "site" corresponded to the three different prior-maintenance levels (low, intermediate, and high). The variable "block (site)" evaluated the blocks within a site. "Treatment*site" evaluated how the treatments performed at the different maintenance levels that occurred in our study. The covariate for this analysis, X, was the average response from sampling periods one and two, the measurement periods prior to starting the monthly additions of additives to the experimental units. The block (site) and within-tank errors were random and all other terms were fixed effects. Two-sided Dunnett's *t*-test using the Hsu correction at an $\alpha = .05$ level was used to compare the effectiveness of treatments to the control.

## Results and Discussion

The 48 experimental units averaged 29.0 cm total solids (combined sludge and scum) prior to initiation of the additive experiment. These 48 full-scale septic tanks typically had working liquid depths of 122 cm. Hence they had reached 24% of their capacity, on average, but that capacity varied depending upon the level of maintenance provided prior to starting the experiment. Tanks at the high-, intermediate-, and low-maintenance sites were 20%, 22%, and 33% full, respectively. We interpreted these results to indicate that the rate of sludge accumulation is the greatest within the first few years following pumping, then solids accumulate at a slower rate in later stages in the solids accumulation life cycle of a septic tank. Others (Bounds, 1992, 1996; Moores, 2002; Weibel, Bendixen, & Coulter, 1949) also have reported this relationship.

## Sludge Depths

Sludge depth was measured to determine whether bacterial additives reduced sludge depths or sludge accumulation rates, thereby enhancing anaerobic digestion while also reducing the frequency necessary to pump solids from the septic tanks. Figure 1 depicts least squares means (LSM) of additive-treated tanks and control tanks over the period of time following initiation of additive applications.

While the *F*-test for the main sludge depth treatment effect was not significant, the effects of the covariate and the effects of time were statistically significant (Table 1). Even though the site by treatment effect was not significant, this effect had a lower *p*-value than the treatment main effect, so a separate analysis of variance (ANOVA) was conducted at the individual maintenance levels.

TABLE **1**

**Type 3 Effects for Fixed Effects on Sludge Depth, Scum Thickness, and Total Solids in Septic Tanks**

| Effects | *p*-Values | | |
|---|---|---|---|
| | Sludge | Scum | Total Solids |
| X | **<.0001**[a] | **<.0001** | **<.0001** |
| Site | .2243 | .4550 | .3470 |
| Treatment | .2245 | .7138 | **.0023** |
| Site*treatment | .1275 | .4971 | **.0471** |
| X*treatment | .1550 | **<.0001** | **.0005** |
| Time | **<.0001** | **.0044** | **<.0001** |
| Site*time | .2134 | **<.0001** | .1645 |
| Treatment*time | .6352 | .4437 | .6319 |
| Site*treatment*time | .6236 | **.0250** | .7807 |

[a]Numbers in bold are statistically significant at $\alpha = .05$.

*ANOVA for Site and Treatment Interactions for the Additives as a Group*

The *F*-test at each maintenance level (Table 2) showed that the treatment effect was significant at the highly maintained site (site 3) at a 95% confidence interval (*CI*). This approach tested for effects of treatments, when all additive treatments were considered as combined groups, at each specific maintenance level. Therefore, this analysis simply shows any effects of the additives, as groupings, at different sites. It does not reveal, however, which additives had positive effects at the high-maintenance site.

The graph of the estimated adjusted treatment means (LSM) for different sites indicated that the control sludge means were not consistently greater than the additive sludge means at all sites (Figure 2). This result illustrates that the additives, when considered as one combined group, were not having the desired reduction in sludge accumulation for the entire study sample. Further ANOVA was conducted to test effects of individual treatments (i.e., specific additives) at different maintenance levels since it was possible that one or more additives could be more effective than others.

TABLE **2**

**Test of Maintenance Level Effect (Treatment by Site)**

| Effect | Maintenance Levels | Treatments | *p*-Values | | |
|---|---|---|---|---|---|
| | | | Sludge | Scum | Total Solids |
| Site*treatment | Low (site 1) | Additives 1, 2, 3 | .8963 | .9476 | .4184 |
| | Medium (site 2) | Additives 1, 2, 3 | .1710 | .3747 | .1257 |
| | High (site 3) | Additives 1, 2, 3 | **.0156**[a] | **.0064** | **.0147** |

[a]Numbers in bold are statistically significant at $\alpha = .05$.

*ANOVA for Specific Site and Specific Treatment Interactions*

Following the *F*-test ANOVA to assess the interaction for combined treatments and sites by maintenance level, a separate ANOVA was further conducted for each septic tank maintenance level. The purpose here was to evaluate potential significant impacts of specific treatments on sludge accumulation at each of the three sites that had varying prior-maintenance levels.

At the highly maintained site (site 3), Dunnett's *t*-tests performed at an $\alpha = .05$ level indicated that additive 2 and additive 3 sludge depths were significantly different (i.e., less) than the control, which is a potentially positive result. Sludge level differences between additive 1 and the control were not large enough to be statistically significant.

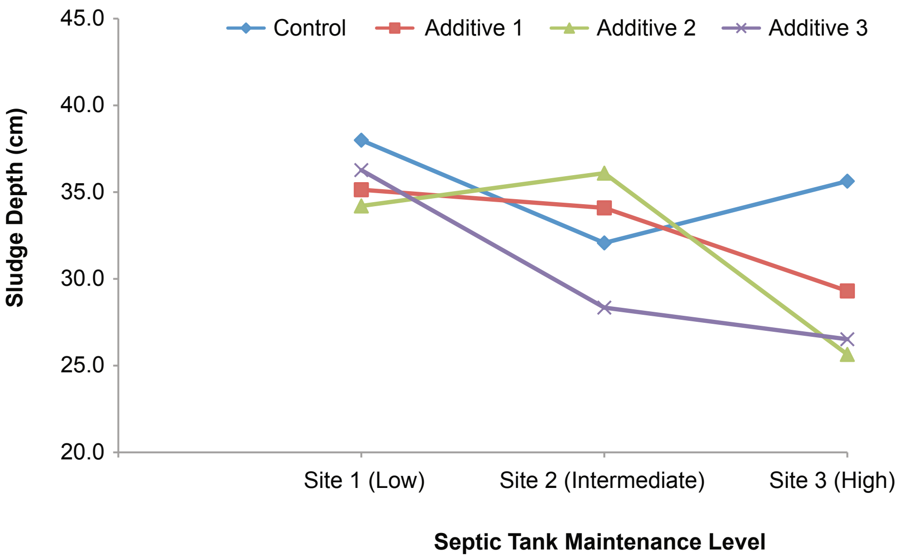
At the intermediate-maintenance site (site 2), the LSM indicated that sludge depths for the additive 2 tanks were greater (i.e., thicker depth) than for the control and significantly different from the control at an $\alpha = .05$ level. Hence, the use of additive 2 both increased sludge depths at site 2 (tanks with an intermediate-maintenance level), which is a potentially negative result, while this additive reduced sludge depths at site 3 (tanks with a high-maintenance level), which is a potentially positive effect. These results illustrate the complex effects that specific additives can have depending upon existing ambient conditions within septic tanks.

At the poorly maintained site (site 1), Dunnett's *t*-test at $\alpha = .05$ indicated that no significant differences existed between the control and any of the additives tested.

In summary, sludge depths were not consistently reduced due to additive usage when compared to the control. Some

FIGURE 2

**Sludge Depth Least Squares Means for Treatment by Site Averaged Over Sampling Events 3 to 14**




Standard error for treatment means for sites 1, 2, and 3 ranged from 3.8 to 4.6, 3.1 to 3.3, and 2.8 to 3.0, respectively. Variation in standard error was due to inclusion of covariance in the model and some missing data.

significant interactions occurred, however, between maintenance level and treatment effects. Yet no additive positively impacted sludge depth for all maintenance levels. Also, additives as a group did not positively impact (reduce) sludge levels in septic tanks compared to the control.

*Sludge Accumulation Rates*

The overall sludge accumulation throughout the study period ranged from –16.0 cm to +34.0 cm among the 48 tanks. Negative numbers indicate a reduction in sludge over time. The average increase in sludge depth was 8.0 cm during the study period with a standard deviation of 9.8 cm and a 122% coefficient of variation (CV). The equivalent annual (365 days) sludge accumulation rate was 6.9 cm/yr. averaged over all septic tanks. A 6.9 cm/yr. accumulation rate equates to a 4.4- to 5.8-year average pump-out frequency for these 3,780-L (1,000 gallons) septic tanks (with a working depth of 122 cm) assuming pump out is warranted when solids occupy 25% to 33% of the liquid working volume. This provides useful information for the environmental health specialist in the field who is helping people estimate needed pump-out frequencies. The extreme variability in sludge accumulation between tanks (CV = 122%), however, indicates that average estimates have limited usefulness for any one specific septic tank.

Hence, we recommend that periodic field measurement of actual sludge accumulation via a comprehensive management and monitoring program is a more accurate and valuable method than using rigid time-based pre-established pump-out frequencies (e.g., every three years, four years, etc.) based upon average accumulation rates. We believe this approach (i.e., routine monitoring to determine pump-out needs) is more environmentally sensible since it precludes unnecessary pump outs that can have undesirable environmental and economic impacts due to septage disposal requirements.

**Scum Thickness and Accumulation Rates**

By way of contrast to sludge accumulation, the average increase in scum thickness was only $4.1 \times 10^{-2}$ cm during the study period with a standard deviation of 3.8 cm. Hence, scum layer thickness only marginally increased overall for all 48 septic tanks during the study period. Also, the scum layer was quite variable from tank to tank with an extremely high CV: 9,407%. Scum accumulation rates, therefore, cannot be accurately predicted.

As in the case of sludge depth, the *F*-test for main treatment effect for scum thickness was not significant at an $\alpha$ = .05 level during the study period (Table 1). The initial value (X) and time effects were significant for scum thickness. Additional significant interactions for scum thickness were present, however, specifically X*treatment, site*time, and site*treatment*time.

*ANOVA for Site and Treatment Interactions for the Additives as a Group*

A detailed analysis (using *F*-test) was conducted to evaluate the efficacy of additives, as a combined group, for reducing scum thickness based on septic tank maintenance levels. The treatment means as a grouping were found to be significantly different (i.e., greater scum accumulation, a negative result) than the control at the highly maintained site (site 3) at a 95% *CI* (Table 2).

The scum thickness LSM values were also numerically greater in tanks treated with additives than the control at the intermediate-maintenance site, which is a potentially negative result, but these differences were not significantly different. No such specific pattern occurred, however, at the poorly maintained site. The additives as a combined group were not having the desired reduction in scum accumulation for the entire study sample, nor as a group at any maintenance level.

*ANOVA for Specific Site and Specific Treatment Interactions*

As in the case of sludge, ANOVA was further conducted separately at individual septic tank maintenance levels to evaluate potential significant impacts of specific additive treatments on scum accumulation at each maintenance level. Dunnett's *t*-tests performed at the intermediate- and low-maintenance sites at an $\alpha$ = .05 level, however, indicated that scum thickness in the additive 1, 2, and 3 tanks was not significantly different than the control at either maintenance level. The control LSM and additive 1 were not estimated at the high-maintenance site, because nearly all readings for the control and for additive 1 were zero.

*ANOVA for Site, Treatment, and Time Interaction*
Since the site, treatment, and time interaction for scum was significant at an α = .05 level, a separate ANOVA was conducted using *F*-tests for maintenance level and time (sampling events) interaction. This analysis revealed that treatment effects were only infrequently significant on a few dates at any maintenance level or additive. Hence these were short-term, transitory effects of little practical value. We concluded that scum thicknesses were not consistently reduced by additive usage when compared to the control.

### Total Solids (Combination of Sludge Depth and Scum Thickness)

Statistical analyses were also performed on the combined sludge depth and scum thickness data. *F*-tests for main treatment effects for the three additives as a combined group were significantly different than the control (Table 1) at a 95% *CI*. Dunnett's *t*-tests performed to evaluate each of the individual additives for total solids accumulation in tanks (α = .05), however, indicated that none of the specific additives tested (additive 1, additive 2, or additive 3, individually) was significantly different from the control. The initial total solids value (X), time, the site*treatment interaction, and the X*treatment interaction were significant for total solids in the septic tanks.

*ANOVA for Site and Treatment Interaction for the Additives as a Group*
As in the cases of sludge and scum, the treatment effects analyzed at individual maintenance levels indicated that the treatment effect was significant (Table 2) at the highly maintained site at a 95% *CI*.

The plot of the estimated LSM for treatment effects for different sites indicated that the control's mean was greater than the additives at low- and high-maintenance sites but not at the intermediate-maintenance site (Figure 3). This result illustrates that the additives were not having the desired reduction in solids accumulation rates. ANOVA was further conducted separately to evaluate potential significant impacts of specific treatments on total solids accumulation at specific maintenance levels.

*ANOVA for Specific Site and Specific Treatment Interactions*
As in the case of sludge and scum accumulation, ANOVA was further conducted separately at individual septic tank maintenance levels to evaluate potential significant impacts of specific treatments on solids accumulation at each maintenance level. Dunnett's *t*-tests at α = .05 indicated that none of the individual additives was significantly different than the control at any maintenance level.

In summary, total solid contents were not consistently reduced due to additives (as a collective group) when compared to the control. Treatment effects were also not significantly different for individual additives at any of the maintenance levels.

## Conclusion

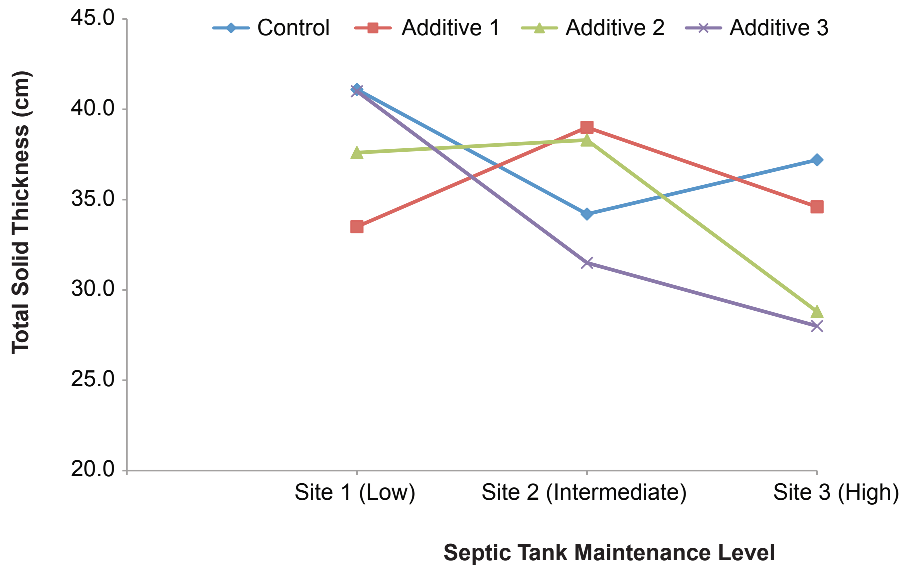
We conclude that our study does not indicate any long-term, statistically significant effects on solids digestion in septic tanks for additives as a collective group. Our study also does not support using bacterial septic tank additives as a substitute or to reduce septic tank pumping frequency. The effect of the initial (X) sludge, scum, and total solids contents prior to additive application was significant all the time. This result supports the importance of our experimental design that included both "before" and "after" data from each experimental unit (i.e., full-scale septic tank). In addition, the X*treatment effect was significant for scum and total solids.

Overall, additives were not statistically significant for the parameters and conditions tested. The *F*-test, however, showed some significant treatment effects at the highly maintained site at an α = .05 level for sludge depth, scum thickness, and total solids accumulation. Separate ANOVA for site 1, site 2, and site 3 indicated the following effects of additives:

1. Sludge depths were not significantly less for any of the additives compared to the control at site 1 (low prior maintenance).
2. Sludge depths were significantly greater for tanks treated with additive 2 compared to the control, which is a negative effect, at site 2 (intermediate prior maintenance).
3. Sludge depths were significantly less for tanks receiving additives 2 and 3 compared to the control, which is a potentially positive effect, at site 3 (high prior maintenance).
4. Scum thickness was not significantly less for any of the additives compared to the control at sites 1 and 2.

FIGURE **3**

**Total Solid Thickness Least Squares Means for Treatment by Site* Averaged Over Sampling Events 3 to 14**




*I.e., maintenance level. Standard error for treatment means for site 1, site 2, and site 3 ranged from 4.2 to 4.7, 3.3 to 3.7, and 3.0 to 3.3, respectively. Variation in standard error was due to inclusion of covariance in the model and some missing data.

5. Scum thickness could not be statistically assessed at the high-maintenance site (site 3) due to very thin discontinuous scum layers.
6. Total solids contents were not significantly less for any of the individual additives compared to the control tanks at any site.
7. Infrequent, short-term, transitory interactions were noted for total solids content for two sampling events at site 3 and also for scum thickness for six sampling events at site 1 and one sampling event at site 3. It was not determined, however, whether these were positive or negative effects.

In addition, the average overall sludge accumulation rate (for all 48 experimental units) was 6.9 cm/yr. with a CV for sludge depth of 122%. The average volumetric sludge accumulation rate was 75.7 L/yr. (20.0 gal/yr.) on an estimated per capita basis. This is approximately equivalent to a one-inch per-person per-year sludge accumulation rate for the typical 1,000-gallon rectangular septic tanks used in North Carolina. This rate of accumulation is equivalent to an average pump-out frequency interval of about four to six years for the 48 septic tanks studied here.

Solids accumulation rates vary substantially from home to home as indicated by the high CV for sludge accumulation rates (122%) and extremely high CV for scum thickness accumulation rates (9,407%). The large variation from septic tank to septic tank reveals that using a standardized pump-out frequency for all septic tanks is a poor choice. Instead, periodic field assessment of sludge depth and scum thickness is recommended to determine the ideal time from performance, environmental, and economic perspectives for pumping accumulated solids from individual septic tanks.

In general, septic tank additives as a collective group did not positively impact solids accumulation in the septic tanks studied here, but only three of over 1,200 septic tank additives on the market were studied. Furthermore, a very broad set of environmental and experimental conditions was analyzed. While no positive effects were noted for additives on the whole, some specific additives had potentially positive effects individually under a narrower range of conditions. Before concluding that additive 2 or 3 had positive effects at the high-maintenance site, the effluent five-day biochemical oxygen demand ($BOD_5$) and total suspended solids (TSS) concentrations discharged from well-maintained tanks treated with additives also need to be assessed. The potentially positive effects of additives 2 and 3 on recently pumped septic tanks can only be confirmed as resulting from enhanced and more complete digestion within these septic tanks if both $BOD_5$ and TSS effluent concentrations released from these septic tanks to the drain field portions of the systems are not negatively affected by the additives. That assessment is the objective of our additional research (“Impacts of Biological Additives, Part 2: Septic Tank Effluent Quality and Overall Additive Efficacy,” on page 22).

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