Soil Moisture Controlled Effluent Disposal by Subsurface Drip Irrigation in the Alabama Black Belt Soil Area

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ABSTRACT

Conventional onsite septic systems are not suitable for many soils of the Blackland Prairie in Alabama; however this rural wastewater treatment and disposal system has been widely applied in this region for decades. A soil survey of the Alabama Black Belt area indicates a wide spread environmental threat from conventional onsite septic systems. An alternative integrated sewage treatment system consisting of subsurface drip irrigation and crop uptake is proposed as a small community based decentralized system in this region. The system proposed uses volumetric soil moisture controlled subsurface drip irrigation (SDI) together with selected crops to dispose and treat pre-filtered septic tank effluent in a high clay drain field.

The goal of this study is to maximize the seasonal hydraulic dosing rates of a synthetic pre-treated septic tank effluent on a Houston clay in the Alabama Black Belt area, while maintaining a favorable soil aeration level for biological nutrient treatment. One and half years field data indicated three distinct dosing periods throughout a year, during which the field hydraulic loading rate ranged from a maximum 4 times the state's dosing recommendation in summer to zero disposal during winter. Grasses from controlled experiment plots showed significant yield differences due to the nutrient contribution from the synthetic wastewater. Initial field data suggest a promising strategy using field moisture controlled dosing system in high clay soil areas. The real-time SDI control system can prevent overdosing to a wastewater drain field during unfavorable (i.e. saturated) field conditions.

KEY WORDS

Black Belt; Decentralized; Hydraulic dosing rate; Onsite sewage disposal; Soil; Subsurface drip irrigation; Wastewater.

INTRODUCTION

Onsite wastewater treatment systems are a major component, in addition to municipal wastewater treatment plants, of the modern wastewater treatment industry. In the U.S., about thirty percent of households are using onsite septic systems, while in Alabama this number is 47 percent (AOWT 2005). Site conditions are critical for the success of onsite septic systems, and soil is the most important factor. The environmental challenge for conventional onsite septic systems comes from the system's almost complete reliance on soil properties (Oron 1996). The soil in a drain field should have a percolation rate that allows wastewater to penetrate into soil at an appropriate speed so that soil can absorb the wastewater and provide aerobic treatment of the nutrients and contaminants brought in with the wastewater. The requirement of an adequate soil percolation rate (not too fast or too slow) makes heavy clay soils and very sandy soils generally unsuitable for conventional onsite sewage systems.

Charles *et al.* (2005) did an extensive septic effluent field survey in Australia and compared the results with published regulations in U.S. and Australia. Charles concluded that 80th percentile of the effluent survey values (250 mg/L for TN, and 36 mg/L for TP) should be incorporated into new regulations in order to minimize the overloading which is associated with most onsite system failures. Lipp *et al.* (2001) demonstrated that the pathogen impact from onsite sewage systems to the coastal community was related to local onsite system density. Carroll and Goonetilleke (2005) confirmed that a high septic system density (290 systems/ km^2) significantly impacts shallow groundwater systems. Incidences of poor treatment performance from onsite systems, particular conventional septic systems, are quite common in U.S. and worldwide (U.S. EPA 2002; Carroll and Goonetilleke 2005), and are a significant source of water pollution (Beggs et al. 2004).

Conventional onsite septic systems have been used in the Alabama Black Belt area for decades. A preliminary soil survey (Figure 1) that rates the soils in the Alabama Black Belt area in terms of suitability for conventional onsite septic systems was conducted within a GIS using NRCS SSURGO digital soil data. The results indicated that although 78% of the Alabama Black Belt area is rated as unsuitable for conventional onsite septic systems, in fact conventional onsite septic systems are the most common and widespread system in this region (Dougherty 2006).

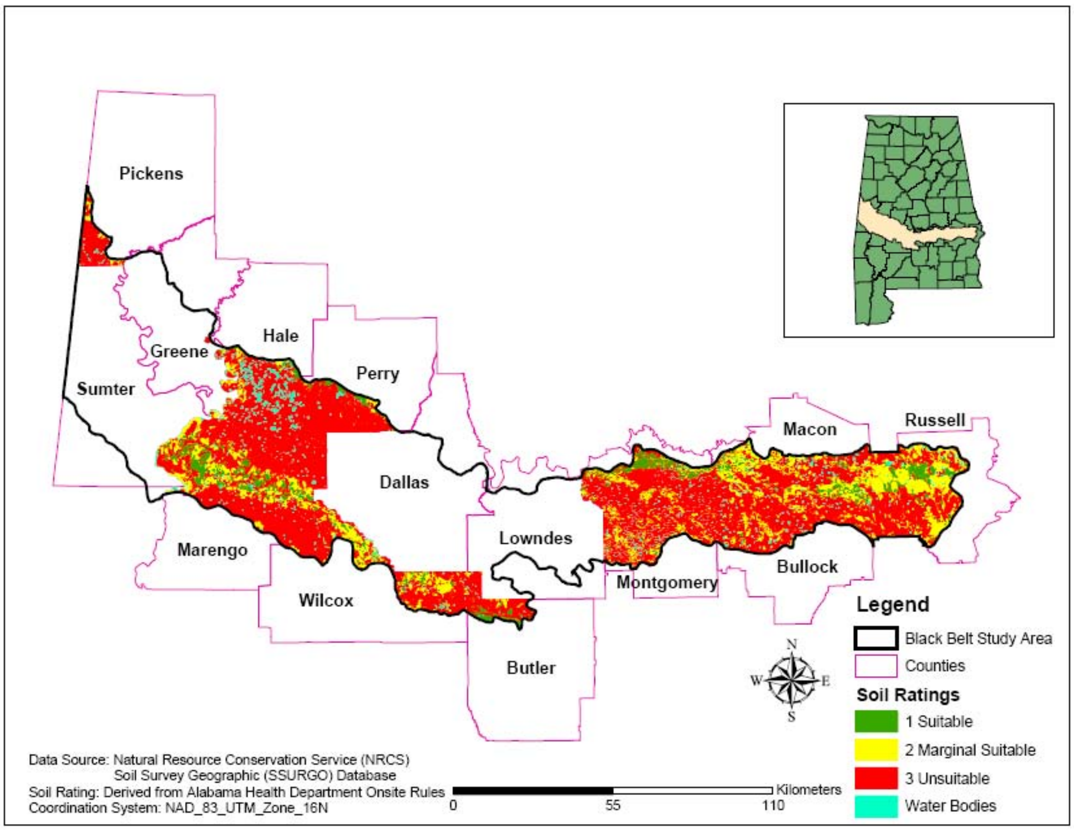

Figure 1. Soil ratings in Alabama Black Belt soil area.

The Alabama onsite sewage disposal rules (2005) exclude the use of conventional onsite septic systems in most Alabama Black Belt soils by regulating soil percolation rates for drain field design. Furthermore, all existing onsite systems installed after 2000 come under the influence of the new regulations. Those systems not meeting current regulations will not be allowed to renew their permits unless site conditions are improved or until disposal methods are upgraded. Therefore, the new regulations provide a strong incentive for alternative treatment and disposal systems in the Alabama Black Belt area.

An engineered wastewater dosing system is proposed uses a volumetric soil moisture controlled subsurface drip irrigation (SDI) system together with mixed grasses to dispose of pre-filtered septic tank effluent. Theoretically, a septic tank effluent is disposed into a drain field using SDI in series with engineered self-flushing filters (110 micrometers) to substantially remove septic tank effluent solids. The principal difference between the proposed SDI system and conventional septic systems is the self-regulated dosing and hydraulic control of the SDI system. The dosing of the septic tank effluent is controlled by soil moisture sensors buried in the drain field. Water disposal will be turned on when soil moisture content drops below 40% (v/v), and water disposal will be turned off when soil moisture content goes above 45% (v/v). In such dosing strategy, the real-time drain field moisture can prevent drain field overdose at or near field capacity. Selected grasses grown over the drain field provide additional uptake of water and nutrients thus providing more water and nutrient capacity in the drain field.

The objective of this study is to determine the hydraulic dosing rate of a pre-filtered septic tank effluent on a high clay soil (Houston clay) in Alabama Black Belt soil area, while maintaining nutrient levels in the drain field at an environmentally safe level.

EXPERIMENT METHOD

The testing site is at the Black Belt Research and Extension Station in Marion Junction, AL. The design drain field hydraulic loading rate is set to 0.05 gal/sq.ft./day and the design flow rate is 270 gal/day/household. The soil in the drain field is Houston clay which is rated as marginally suitable for conventional onsite septic system according to the new Alabama onsite rules. A 1000 gallon septic tank is used as a dosing reservoir. A 1/2 horse power pump with a capacity of 20 gpm supplies water from the tank to a $60' \times 90'$ drain field through subsurface drip irrigation tubing (Figure 2). The irrigation controller is installed onsite to datalog and control operating conditions and wastewater disposal in the drain field. Wheat (Jackson) and Ryegrass (Special effort) are grown during fall and winter, with hybrid Sorghum Sudangrass grown during spring and summer. During the first year, the SDI system was dosed using clean well water only, with the area surrounding the drain field used as a non-irrigated control. Nitrogen fertilizer at agronomic application rates was applied to both the irrigated and non-irrigated control plots. In the second year, the SDI drain field was divided into two plots, an irrigated nutrient plot and an irrigated non-nutrient plot. The area surrounding the drain field remained as a non-irrigated control. The irrigated nutrient plot received a synthetic wastewater with an N: P ratio similar to septic tank effluents. The irrigated non-nutrient plot received only clean water. Nitrogen fertilizer applied at agronomic application rates was applied to both the irrigated plot and non-irrigatedcontrol plot at the beginning of each plant season. Both the irrigated nutrient plot and the irrigated non-nutrient irrigated plot received the same amount of water each time the dosing pump operated. The collected field data, continuously logged at 15-minute interval includes soil moisture content, rain fall, soil temperature, pumping rate and volume, irrigation frequency and dosing time. Grasses nutrient content was analyzed by the soil lab in the Agronomy and Soil Department of Auburn University. Field suction lysimeters are placed in drain field with the sampling depths of 6", 12" and 18" to collect soil water samples periodically.

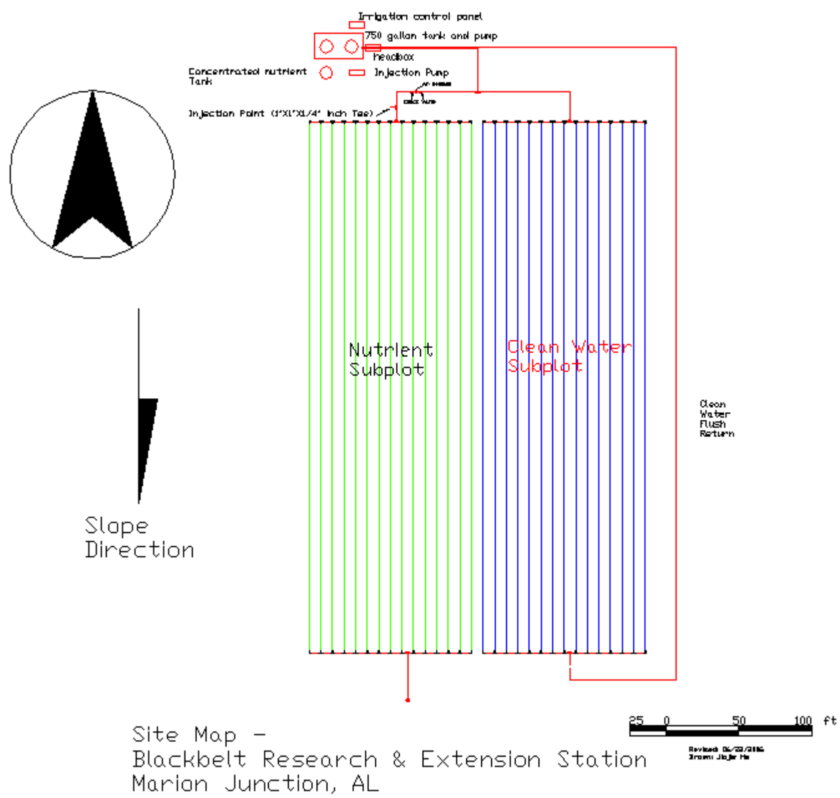

Figure 2. Field experiment sketch.

EXPERIMENT PROGRESS AND RESULTS

Clean water application (First year)

The field experiment was started on September 7, 2006. The drain field soil moisture went through a start up period before stabilizing (Figure 3). The total water applied to the drain field during the stabilized period was 15,618 gallons, approximately 1,115 gpd, four times higher than the design rate (270 gpd/household). During August and September, sufficient water in the irrigated drain field stimulated plant growth as expected. Evaluation of rainfall and flow data during August and September 2006 indicates SDI was the major contributor of the soil moisture. Due to an unexpected power outrage in the winter of 2006/2007, the dosing system was idle from October 6, 2006 untill January 09, 2007. Nevertheless, from soil moisture field data stored in the data logger, it is estimated that water disposal rate into the drain field would have been halted between October and September anyway due to naturally wet, rainfall-fed field conditions. In November, rain precipitation brought drain field volumetric moisture content above 45% (the set point to halt dosing) three times. Each time it took a longer time for the drain field volumetric moisture level to drop below 40% (the set point to begin irrigation after dosing is halted). In December 21, 2006, an intensive precipitation brought drain field moisture content above 45% again, and then the drain field moisture content stabilized above 45% with almost no variation till March 7, 2007.

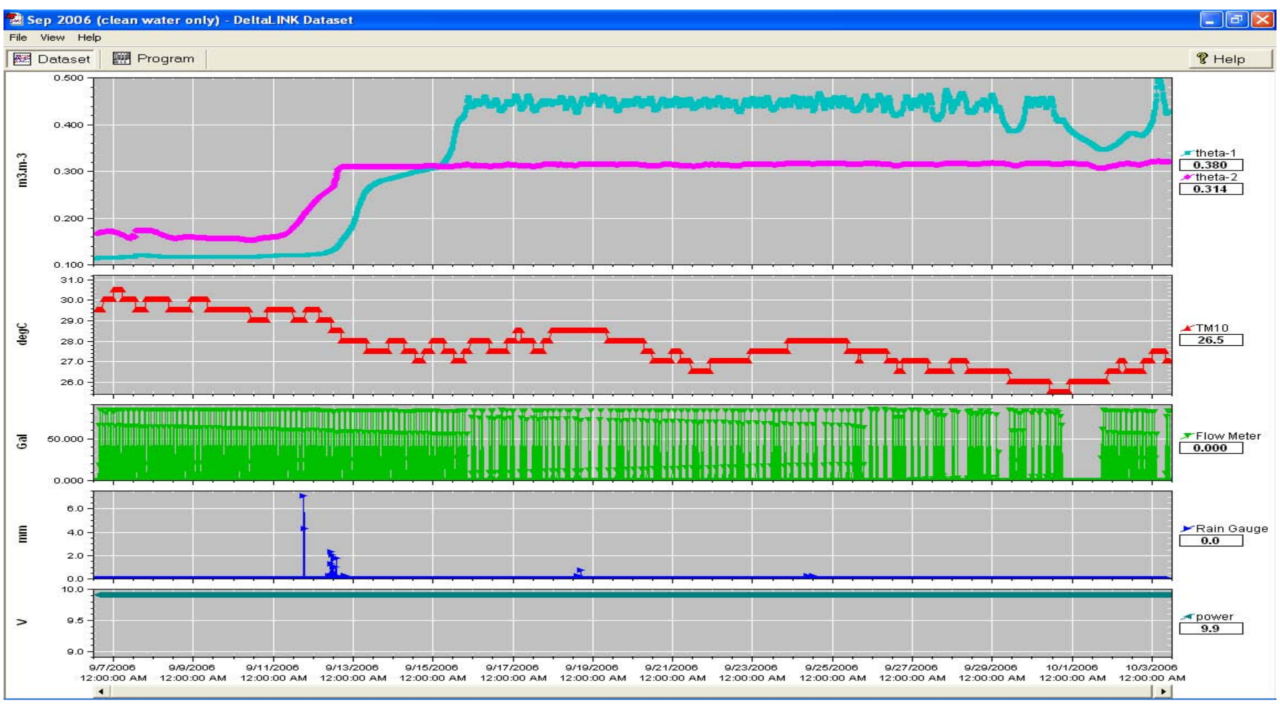

Figure 3. Field data from September 07,2006 ~ October 03,2006.

From late December 2006 to early March 2007, drain field moisture content stayed above 45%, which prevented SDI wastewater dosing. This indicats that there could be at least three months during which the drain field can not accept wastewater and a three month wastewater storage capacity would needed to store wastewater generated during those times when drain field moisture volumetric content exceeds 45%. After March 7, 2007, it was observed that the daily water dosing rate into the drain field was raised from 361 gallon per day in early March to 1056 gpd in late March due to dryer field conditions. The water disposal rate then stabilized untill early August at a rate between 1147~1223 gpd. After August 10, 2007, the daily water dosing rate stabilized at around 803~844 gpd.

Above results indicate a water dosing pattern that is comprised of a dormant season, two transition periods, and a growing season. The dormant season occurred when drain field volumetric moisture content maintained above 45%. The observed growing season between late March and early August is when the hydraulic dosing rate reached its peak value. Two transition periods lay between the dormant season and the growing season, one occurred between the dormant season to the growing season in March (less than one month), and a longer one occurred after the growing season but before the start of the dormant season (around 5 month).

The hybrid of Sorghum Sudangrass grown during the long transition period (August 03, 2006 ~ November 01, 2006) showed significant yield differences among the tested plots (Table 1). The irrigated plot had a field yield that was three fold that of the non-irrigated plot. Ryegrass and wheat grown during the dormant season (November 01,2006 ~April 20,2007) showed irrigated plot had a field yield 1.3 times higher than non-irrigated plot (Table 1). From the grasses elemental analysis, the N, P, K contents of different treatments were at fairly the same level with K has a 20% difference (Table 2).

In general, the soil moisture controlled dosing system operated in the drain field as designed. Seasonal moisture differences in the drain field influenced the effluent disposal rate as planned. Grasses yields in the drain field demonstrate the potential for grasses to increase water and nutrient uptake in the drain field.

Table 1. Grasses yield at different seasons

Grass Planted	Treatments	Date planted	Date harvested	pounds / acre	dry matter %	Dry matter lbs/acre
Sourghum/Sudan*	Irrigated plot	8/3/2006	11/1/2006	12,561	27.68	3477
	Non-irrigated plot	8/3/2006	11/1/2006	3862	28.36	1095
Wheat /Ryegrass**	Irrigated plot	11/1/2006	4/20/2007	22967	28.00	6431
	Non-irrigated plot	11/1/2006	4/20/2007	17522	27.50	4819
Sourghum/Sudan*	Irrigated nutrient plot	6/14/2007	8/9/2007	17494	30.14	5273
	Irrigated non-nutrient plot***	6/14/2007	8/9/2007	6594	31.00	2044
	Non-irrigated plot***	6/14/2007	8/9/2007	4073	35.47	1445

* Planted at 30 lbs seed /acre John Deere Drill 7" spacing, Fertilized 60# N 08/17/2006
**Fertilized 60# N 11/15/2006 &3/08/2007, Planted 60 LBS wheat & 20 lbs of ryegrass. John Deere drill 7" spacing
***Fertilized 60# N 07/20/2007

Table 2. Grasses element content

Grass Planted	Treatments	Date planted	Date harvested	N (%)	P (mg/kg)	K (mg/kg)
Sourghum/Sudan*	Irrigated plot	8/3/2006	11/1/2006	1.49	1732	5387
	Non-irrigated plot	8/3/2006	11/1/2006	1.91	1734	5007
Wheat /Ryegrass**	Irrigated plot	11/1/2006	4/20/2007	1.88	1534	10005
	Non-irrigated plot	11/1/2006	4/20/2007	1.90	1522	8869

Synthetic wastewater application (Second year)

A positive displacement injection pump (Neptune Inc.) was put in place on June 16, 2007 and started to inject synthesized, TSS fee, wastewater into the drain field. The simulated nutrient level was around 250 mg N/L and 36 mg P/L. As expected, the dosing record indicated a gradually reduced disposal rate after August 2007. This result confirms that this transition period will likely continue for a longer period than the March transition period. Grasses and soil nutrient levels are currently being analyzed. The most recent data for the hybrid Sorghum Sudangrass (June 14, 2006 ~August 09, 2007) show that the irrigated nutrient plot had a field yield 3.65 times higher than irrigated non-nutrient plot and 2.58 times higher than clean irrigated plot (Table 1). The grass elemental analysis is still under analyze.

CONCLUSION

The seasonal hydraulic dosing rates on a Houston clay soil in central Alabama were field observed through almost two years field study. During typical dry summer conditions, the hydraulic dosing rate can reach as much as four times the state's recommendation (0.05 gal/sq.ft./day). During fall and early spring, the hydraulic dosing rate dropped to around two times the state recommendation. During winter, the drain field was in a saturated state and could not safely accept any more wastewater. Field grasses harvested during each season indicate that grasses content was not influenced by the addition of synthetic wastewater. However, the yield in the soil moisture controlled drain field was five times as much as the non-irrigated control. It is expected that nutrient uptake results will show comparable increase in nutrients removal from the field. Soil water analyses taken from suction lysimeters 6", 12", and 18" (not yet available) will quantify the nutrient residence and balance in the drain field due to the synthetic wastewater application. HYDRUS-2D soil moisture modeling, developed by U.S. Salinity Laboratory, U.S. Department of Agriculture, will be incorporated to simulate the collected field data to better quantify and validate drain field water and nutrient conditions during each season.

BIBLIOGRAPHY

Alabama Health Department (2005). Administration Code, Chapter 420-3-1, Onsite Sewage Disposal.

AOWT (2005). Advanced Licensing Training Manual, Alabama Onsite Wastewater Traning Center.

Beggs, R. A., G. Tchobanoglous, Hills, D., Crites, R.W. (2004). Modeling subsurface drip application of onsite wastewater treatment system effluent. 8th International Drainage Symposium, Sacramento, CA (USA).

Carroll, S. and A. Goonetilleke (2005). "Assessment of high density of onsite wastewater treatment systems on a shallow groundwater coastal aquifer using PCA." Journal of Water and Health [J. Water Health] 3(2): 139-155.

Charles, K. J., N. J. Ashbolt, et al. (2005). "Effluent quality from 200 on-site sewage systems: Design values for guidelines." Water Science & Technology 51(10): 55-63.

Dougherty, M., Shaw, J., Wood, W., Fulton, J., Harper, W. F., He, J., Ducote, E. (2006) Innovative subsurface drip irrigation (SDI) alternatives for on-site wastewater disposal in the Alabama Black Belt, The 27th Annual International Irrigation Show, San Antonio, TX, November 2006.

Lipp, E. K., Farrah, S. A., Rose, J. B. (2001). "Assessment and Impact of Microbial Fecal Pollution and Human Enteric Pathogens in a Coastal Community." Marine Pollution Bulletin 42(4): 286-293.

Oron, G. (1996). "Soil as a complementary treatment component for simultaneous wastewater disposal and reuse." Water Science & Technology . 34(11).

U.S. EPA. (2002). Onsite Wastewater Treatment Systems Manual, Office of Water, Office of Research and Development and U.S. Environmental Protection Agency, EPA/625/R-00/008.