August 2020

Rendering Co-Products as Electron Donors for Subsurface Remediation

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RENDERING CO-PRODUCTS AS ELECTRON DONORS FOR SUBSURFACE REMEDIATION

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Environmental Engineering and Earth Sciences

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by
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August 2020

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ABSTRACT

Chlorinated solvents are a widespread groundwater contaminant across the United States and worldwide. Bioremediation strategies for chlorinated solvents in groundwater environments often involve electron donor amendments to stimulate reductive dechlorination.

Electron donor amendment technologies have evolved over time, utilizing varying lipid or carbohydrate based compounds. Several popular electron donor amendments contain soybean based emulsified vegetable oil (EVO), or low molecular mass organic acid compounds including acetate and formate. This project seeks to develop a group of novel electron donor amendments based on animal co-products to outperform conventional products. These co-products are comprised of waste generated in the animal rendering process such as feathers or bone. The now patented technology will lead to considerably lower cost electron donor amendments compared to commonly used substrates.

Experiments were conducted in a batch setting on a laboratory scale. Serum bottles were assembled with 50 grams of sediment collected from a local site contaminated with trichloroethylene (TCE). The bottles were dosed with various animal co-products at different concentrations (3.2mg/L – 1g/L). Additionally, 20 ml of aquifer water and 20 μMols of TCE were added to each bottle. Bottles were then sealed and headspace was replaced with nitrogen. Control bottles were assembled with no electron donor, Lactate, and EOS. Headspace samples were taken on a weekly basis, and dechlorination was measured using gas chromatography-mass spectrometry. Measurements continued until stoichiometric ethene generation was observed (our operationally defined point of "success").

Further batch experiments were then conducted based on results of feasibility experiments. These experiments focused on optimization of co-product concentration, utilizing mixtures of different co-products, and replicating feasibility with diverse soil samples.

The data collected in this project highlight the potential for animal co-products to be utilized as a novel electron donor for in-situ chlorinated solvent remediation. Many co-products rendered for this study display comparable dechlorination rates to lactate and EOS controls. Mixtures of co-products also display similar dechlorination rates compared to controls.

Further research of these co-products could lead to significantly lower cost electron donor amendment strategies. Traditional soybean based electron donors cost between $0.25-3.00 per pound, while animal co-products based electron donors cost between $0.005-0.225 per pound. Considering many sites may require thousands of pounds of electron donor amendment, the savings potential is significant. Furthermore, by lowering the cost of the electron donor substrate, many more sites could potentially benefit from access to this technology.

ACKNOWLEDGMENTS

I would like to acknowledge Dr. Finneran for providing the opportunity to work on a great project, and serving as my advisor during my graduate program. I would also like to acknowledge all the EES professors who teach in the department with a special thanks to Dr. Freedman, Dr. Popat, and Dr. Ladner for allowing me to run the EES undergraduate laboratory.

Furthermore, I would like to thank my parents and other family members for providing the backbone of my education and all the continued support.

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INTRODUCTION

Groundwater contamination across the US is a substantial problem due to the increasing reliance on the resource as a drinking water source. Between 1950-2000 the US population dependent on groundwater increased, and withdrawal has increased around 5 fold.[1] This proposal focuses on electron donor amendment strategies for subsurface bioremediation of groundwater contamination. These amendments can be effective in treating several different classes of groundwater contaminants including chlorinated solvents, metals, explosives, metalloids, and more.[2]

Specifically, this proposal focuses on trichloroethene (TCE) as it is the primary risk driver at the majority of US contaminated groundwater sites. Around 250 million pounds of TCE were used by the US every year for a variety of degreasing applications.[3] TCE is classified by the EPA as carcinogenic to humans, and also carries acute hazard risks.[4] Removal of TCE or its derivatives by dumping or air stripping has been mostly disallowed and subsequently cleanup focus has shifted to biological methods of remediation.[5] The anaerobic biotransformation of TCE in aquifers is achieved via reductive dechlorination to ethene; the pathway is shown in Figure 1. This pathway is of particular concern due to the elevated toxicity of vinyl chloride (VC) in the intermediate step of reductive dechlorination.[2] For this reason, achieving the complete reduction of TCE to ethene is imperative when developing new remediation technology.

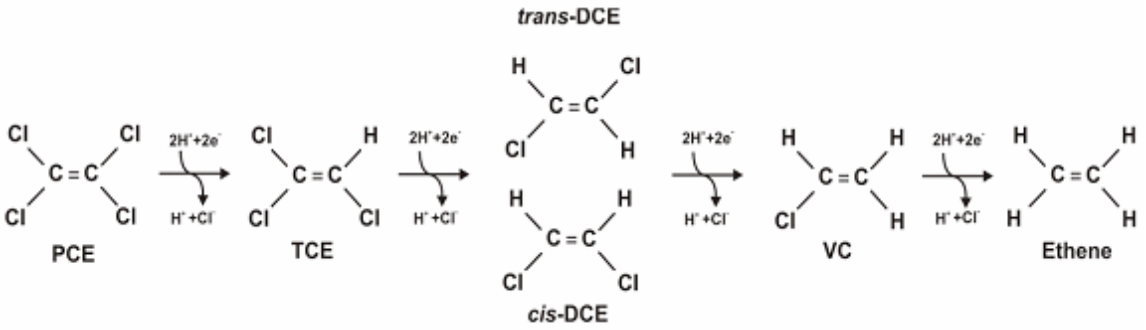


Figure 1. Pathway of TCE hydrogenolysis[6]

In-situ biotransformation of TCE is achieved via very specific enzymes (TCEa, VCRa, BVCa) by *Dehalococcoides* like bacteria. These enzymatic reactions require two electrons per step as seen in Figure 1. The only known electron donor to support the growth *Dehalococcoides* like bacteria is hydrogen, however this is difficult to provide in-situ. Therefore, to provide the required electrons for these reduction steps in-situ, an electron donor amendment is added to the subsurface. These electron donors stimulate fermentation reactions that produce hydrogen.[7]

Traditional electron donor amendments include soybean based emulsified vegetable oil (EVO) and lactate or other low molecular mass organic acids. These amendments are generally effective at achieving complete dichlorination but can also be expensive. Soybean substrates such as EVO cost between $0.25 to $3.00 per pound. This research aims to look at alternatives to popular soybean substrates by tapping into animal co-products as an electron donor resource. These co-products consist of non-edible tissue generated during production of animal based products such as eggs and milk. A list of co-products used in this study are seen in Table 1. In the rendering process heat is applied to these tissues in order to kill any microbial populations and remove moisture. Around 55 billion pounds of animal co-products are generated in the US on a yearly basis. The abundant supply of animal co-products which cost between $0.005-$0.225 per pound and their high electron donor density make them attractive options to replace more expensive soybean substrates.

Table 1. Select Rendered Animal Co-products used as Electron Donors. Compositional data was provided by vendors and does not always add to 100%.

Co-Product Name	Protein : Lipid %
Feather Meal	86 : 4
DAF	0 : 0
Brown Grease	0 : 61.8
Poultry Byproducts	63 : 10.5
PNM	61.63 : 3.96
TEVB	0 : 90
LoPro1	46.49 : 0
PBM+E	0 : 0
Bone Meal	57 : 10
Tallow	0 : 38
TE 80/20	0 : 90

Objectives of this research were to better understand the feasibility of using animal co-products for this application, and find as well as optimize the best preforming products:

- Determine feasibility of utilizing animal co-products as electron donors for groundwater remediation.
- Conduct optimization experiments to maximize dechlorination rates with animal co-products amendments at lower concentrations.
- Determine if there is a relationship between dechlorination rates using co-products as electron donors and their protein, chemical oxygen demand (COD), and total organic carbon content.

One of the main goals of this research was to further demonstrate the feasibility of using animal co-products as effective electron donors for groundwater remediation. Previous research indicated promising results using animal co-products on local soil samples from a site contaminated with TCE. By showing this initial success was repeatable, and utilizing additional soil samples from alternative site locations the feasibility of this method is improved.

In addition to cementing the feasibility of these animal co-products, one of the goal of this research was to optimize the experiments. This optimization occurred in several arenas: Concentration, Mixture of Co-products, Ratio of Mixture. The overall goal of this optimization was to show the maximum the dechlorination rate, at the minimum the co-product concentration. This was important, because lower concentrations of electron donor lead to lower overall cost of remediation.

Another goal of this research was to explore the composition of animals co-products and determine any relationship between composition and dichlorination rates. A better understanding of these relationships could lead to improved optimization of co-product mixtures.

EXPERIMENTAL DESIGN

Feasibility experiments were conducted in a batch setting. Soil was collected from a site contaminated with TCE in Easley, South Carolina. Additional soil was obtained from a chlorinated solvent contaminated site located in California. Batches were setup with 50 g of saturated soil and 20 ml of groundwater collected from Lake Hartwell. Porosity of all soil was assumed to be 0.3 with a density of 1.3 g/cm^3. Batches were amended with an animal co-product electron donor. Feasibility experiments dosed rendered co-products seen in Table 1 as received at 100 mg/L and 1 g/L. After amending, batches were capped with a blue butyl rubber stopper and the headspace replaced with nitrogen. Lastly, bottles were dosed with 20μM of TCE. Bottles were stored in an incubator set to room temperature to simulate aquifer conditions. After a 48-hour equilibration period a time zero measurement was taken. Each feasibility experiment also incorporated several controls, including unamended controls, EOS controls, and lactate controls. TCE transformation in these batches was measured using GC-FID analysis and sampling continued until complete dechlorination is observed. If complete dechlorination was not

observed measurements continued until activity was longer detected. GC-FID analysis was conducted using a 2014 Shimadzu Gas Chromatography, which has a flame ionization detector. The column used for chlorinated solvent separation was a 30 m GS-Q.

Optimization experiments sought to find optimal concentrations and mixtures of co-products shown in Table 2 that reach the highest dechlorination rates. The experimental design of these experiments mirrored the feasibility experiments. All soil used for optimization experiments was from a site contaminated with TCE in Easley, South Carolina. Batches each contained 50 g of saturated soil and 20 ml of groundwater collected from Lake Hartwell. Porosity of all soil was assumed to be 0.3 with a density of 1.3 g/cm^3. Amendments in these optimization experiments varied. Concentrations of co-product dose varied in single co-product amendments between 3 mg/L to 1 g/L. Batches to investigate mixtures of co-products contained two different co-products. Experiments exploring mixtures used varying ratios of co-products corresponding to their value. A 9:1 ratio of low value to high value co-products was utilized for these batch experiments, however other mixture experiments will used a 50:50 ratio. All mixture experiments followed the concentration range of 3 mg/L to 1 g/L. After amending, batches were capped with a blue butyl rubber stopper and the headspace was replaced with nitrogen. Lastly, bottles were dosed with 20μM of TCE. Bottles were stored in an incubator set to room temperature to simulate aquifer conditions. After a 48-hour equilibration period a time zero measurement was taken. Each optimization experiment also incorporated several controls, including unamended controls, EOS controls, and lactate controls. TCE transformation in these batches was measured using GC-FID analysis and sampling continued until complete dechlorination is observed. GC-FID analysis was conducted using a 2014 Shimadzu Gas

Chromatography, which has a flame ionization detector. The column used for chlorinated solvent separation was a 30 m GS-Q.

Protein content analysis was determined using a Modified Lowery Protein Assaykit. Co-products were digested using 6M HCL for 24 hours prior to analysis. Diluted albumin samples were used for the standard curve formation. The Modified Lowery Protein Assaykit uses cupric sulfate as the reagent and is measured using a spectrophotometer at 750nm.

The COD of the co-products was determined using an ultra-high range TNT 823 HACH COD kit. The TNT 823 kit records between 250-15000 mg/L COD. Total organic carbon analysis was achieved using catalytic combustion in a TOC-L machine.

In addition to these experiments, a column study was designed for this research project. The construction of columns was nearly complete, but the experiment was cut short due to COVID-19.

Table 2. Mixtures of co-products used for optimization experiments. 9:1 represents the concentration ratio between the two co-products.

Mixture Concentration and Name of Co-product
(100 mg/l) 9:1 DAF:TEVB
(100 mg/l) 9:1 DAF:TE 80/20
(100 mg/l) 9:1 DAF:LoPro 2
(100 mg/l) 9:1 DAF:PBM+E
(100 mg/l) 9:1 DAF: Wapak Bone Meal
(100 mg/L) 9:1 Brown Grease:TEVB
(100 mg/L) 9:1 Brown Grease:TE 80/20
(100 mg/L) 9:1 Brown Grease:LoPro 2
(100 mg/L) 9:1 Brown Grease:PBM+E
(100 mg/L) 9:1 Brown Grease:Wapack Bone Meal
(100 mg/L) 9:1 Tallow:TEVB
(100 mg/L) 9:1 Tallow:TE 80/20
(100 mg/L) 9:1 Tallow:LoPro 2
(100 mg/L) 9:1 Tallow:PBM+E
(100 mg/L) 9:1 Tallow:Wapcak Bone Meal
(100 mg/l) 9:1 DAF:TEVB
(100 mg/l) 9:1 DAF:TE 80/20
(100 mg/l) 9:1 DAF:LoPro 2
(100 mg/l) 9:1 DAF:PBM+E
(100 mg/l) 9:1 DAF: Wapak Bone Meal

RESULTS AND DISSCUSSION

FEASABILITY

Several types of feasibility experiments were conducted as part of this research. The repeatability of prior experiments using soil collected from Easley, South Carolina was confirmed using new soil samples. Soil collected from a chlorinated solvent contaminated site located in California was also used to show feasibility in alternative soil types.

Starting with the new contaminated sediment from Easley, South Carolina select co-products were dosed at 3.2 (mg/L), 32 (mg/L), and 1 (g/L). The results of this experiment further confirmed viability of these co-products as effective electron donors. The co-product Feather Meal seen in Figure 2 preformed equally to the control of 10 mM Lactate seen in Figure 3.

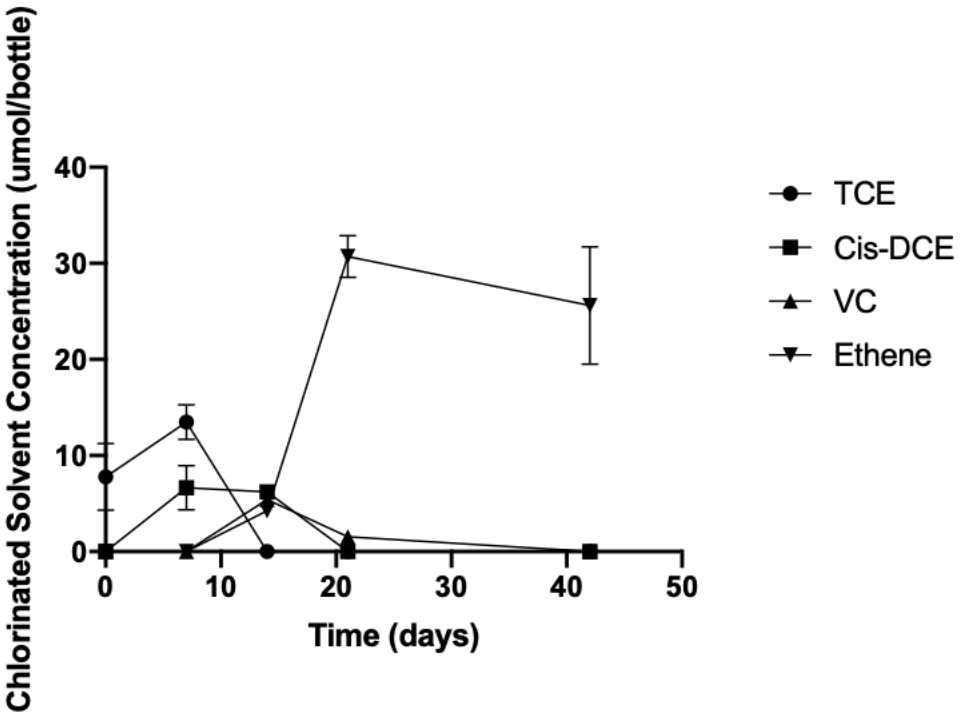


Figure 2. 1 (g/L) Feather Meal dosed bottles. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina. Values are an average of 3 bottles, error bars represent 1 standard deviation.

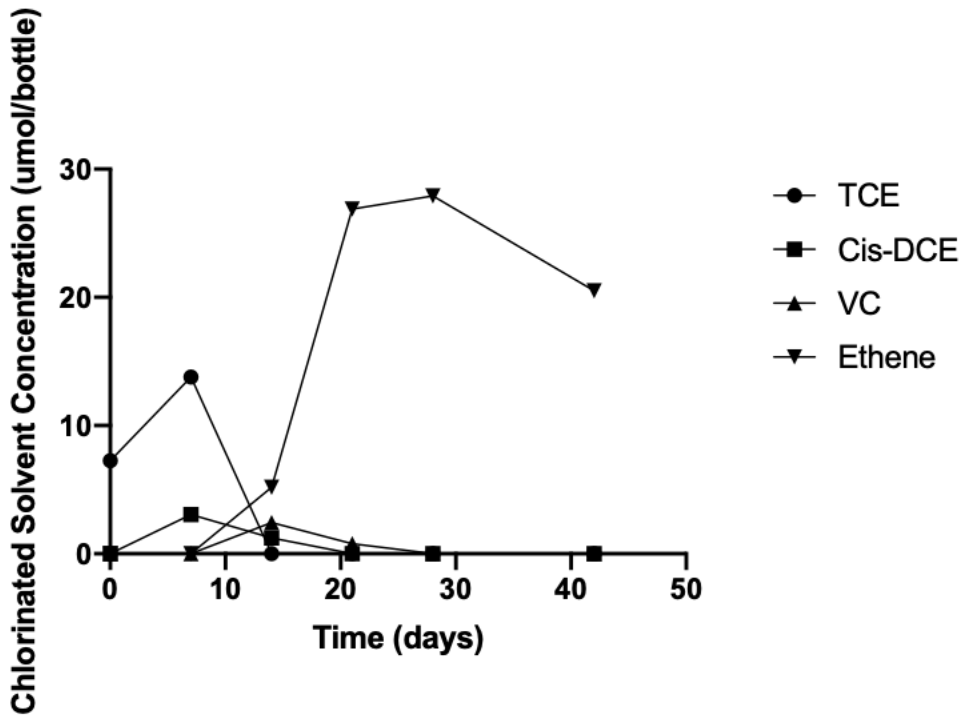


Figure 3. 10 mM Lactate dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.

All of the co-products in this experiment indicated completed dechlorination to ethene at rates comparable to controls. The highest preforming co-products were Feather Meal, DAF, and Tallow. A complete list of time to complete dechlorination is shown in Table 3. All Figures for this experiment are seen in the Appendix (1-45).

Table 3. Time to complete dechlorination for all co-products and controls in feasibility experiment with soil collected from Easley, South Carolina. Values were average of 3 bottles rounded to the nearest day.

Concentration and Name of Co-product	Time to complete dechlorination (Days)	1 Standard deviation of dechlorination (Days)
3.2 mg/L Brown Grease	95	16.6
32 mg/L Brown Grease	75	11.9
1 g/L Brown Grease	51	3.3
3.2 mg/L Tallow	61	6.6
32 mg/L Tallow	80	33.4
1 g/L Tallow	42	0
3.2 mg/L DAF	80	3.3
32 mg/L DAF	77	15.1
1 g/L DAF	42	0
3.2 mg/L Feather Meal	65	6.6
32 mg/L Feather Meal	95	19.3
1 g/L Feather Meal	**42**	**0**
Control: Unamended	119	19.8
Control: 10 mM Lactate	72	42.9
Control: 3.2 mg/L EOS	133	0

The next feasibility experiment used alternative soil samples collected from a chlorinated solvent contaminated site in California. The co-product concentration used for this experiment

varied: 100 mg/L, 500 mg/L, and 1 g/L. The results of this study were mixed, with significantly lower activity soil compared to the Easley Site. In this case, no co-product or control reached complete dechlorination after 288 days. The only bottles to show activity were 10 mM Lactate controls, 1 g/L Feather Meal, 500 mg/L Brown Grease, and 1 g/L Brown Grease. The Lactate control bottle is seen in Figure 4. These bottles displayed reduction of TCE to cis-DCE. There are several explanations that could account for this observation. The bottles simply may not have had the required enzymes needed to catalyze the reduction step of cis-DCE to VC. In this case the bottles would never show complete dechlorination. This observation could also be explained simply by lack of electron donor in low concentration bottles. To account for this, the bottles were all re-dosed on day 260. The soil conditions also may have played a role in slow activity by inhibiting growth of DHC like bacteria. In any case there are still important conclusions to be drawn from the data, as many co-products never achieved conversion to cis-DCE. This would suggest the co-products that did see conversion to cis-DCE are more effective electron donors than their counterparts. All Figures for this experiment are seen in the Appendix (46-81).

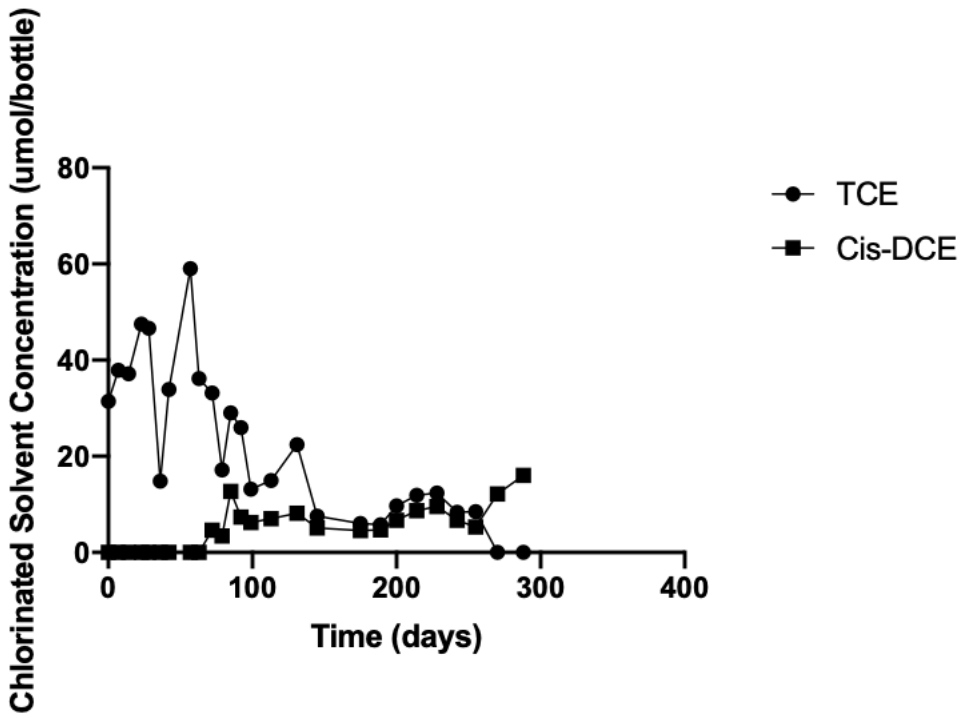


Figure 4. 10 mM Lactate dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.

OPTIMIZATION

There are several parameters that this project sought to optimize, focusing on co-product concentration, co-product mixtures, and co-product ratio. Considering co-product concentration, the goal was to find the lowest concentration with the highest dechlorination rate. All of these experiments were conducted using the Easley soil sediment. The first optimization was done simultaneously with the feasibility study seen in Appendix (1-45). This experiment coincided with another study looking only at low dose co-product amendments (3.2 – 32 mg/L). These concentrations proved too low to reach complete dechlorination at a rapid rate, even with the highest preforming co-products seen in Figure 5. All Figures for this experiment are seen in the Appendix (82-114).

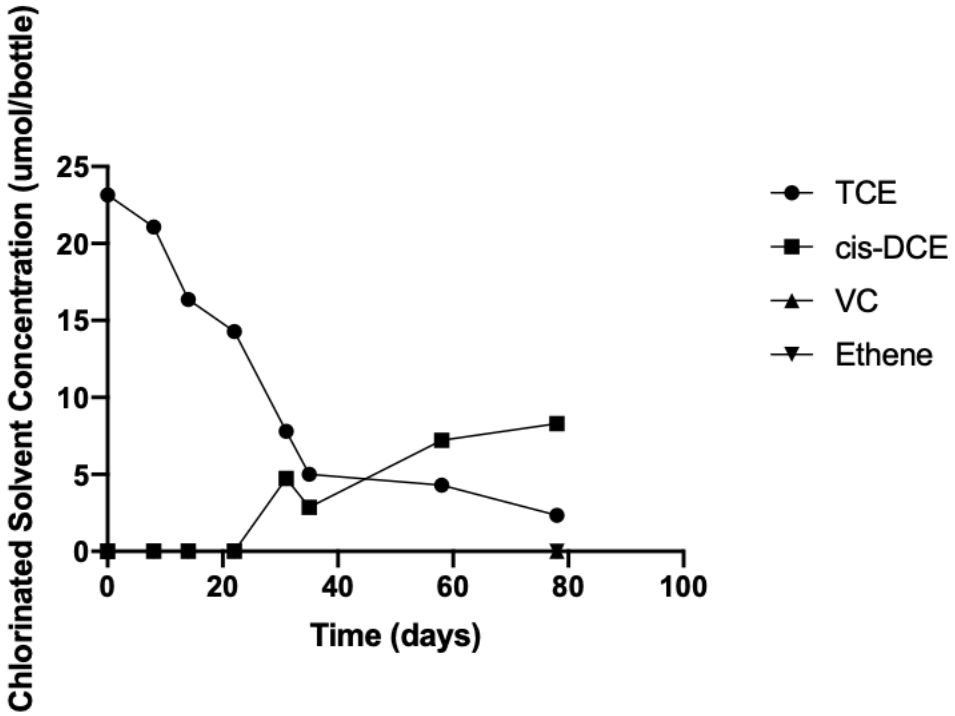


Figure 5. 3.2 mg/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.

Continuing with dose optimization experiments, another study was conducted with slightly higher co-product dose amendments (100 mg/L). These co-product concentrations were significantly more effective than lower dose (3.2- 32 mg/L). One of the highest preforming co-products (Feather Meal) is seen in Figure 6, compared to the Lactate Control, EOS Control, and Unamended Control in Figure 7, 8, and 9. These results (summarized in Table 4) show that co-product concentration of 100 mg/L is an effective concentration for complete reduction of TCE to ethene for these soil conditions. The most effective co-products in this experiment were Tallow, Feather Meal, and Brown Grease. All Figures for this experiment are seen in the Appendix (115-141).

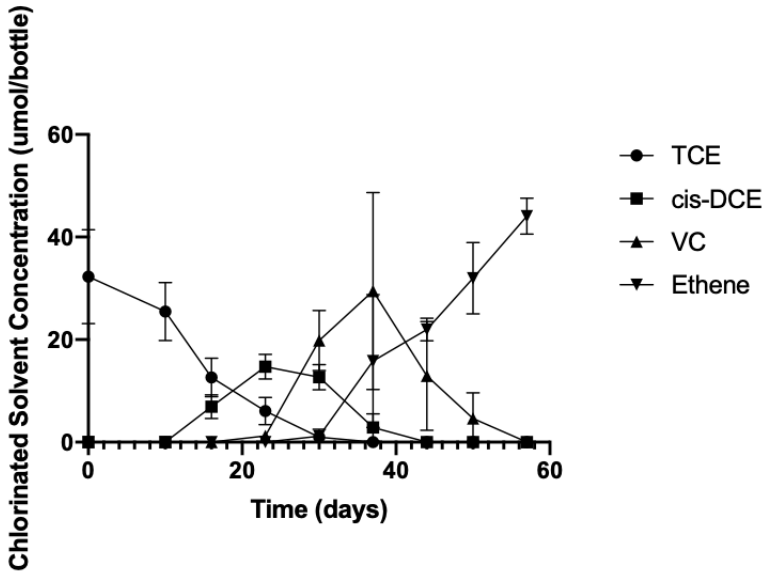


Figure 6. 100 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina. Values are an average of 3 bottles, error bars represent 1 standard deviation.

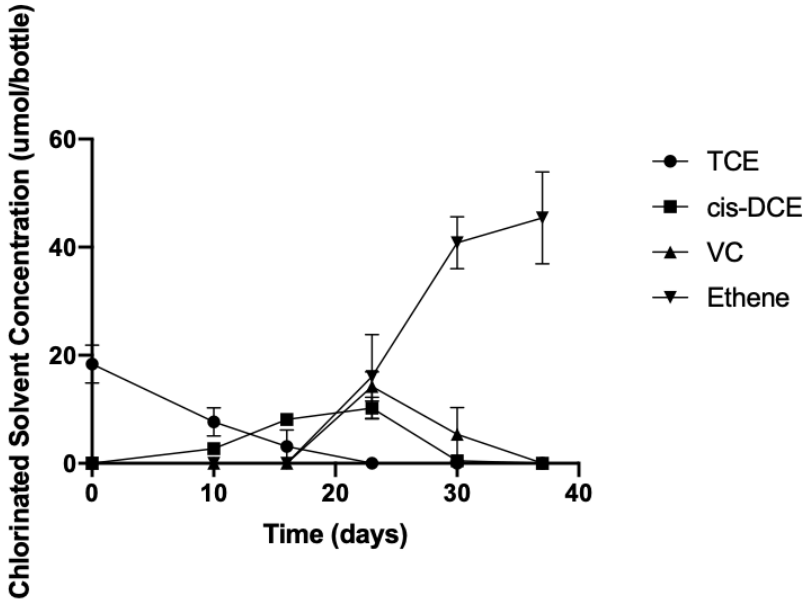


Figure 7. 10 mM Lactate dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina. Values are an average of 3 bottles, error bars represent 1 standard deviation.

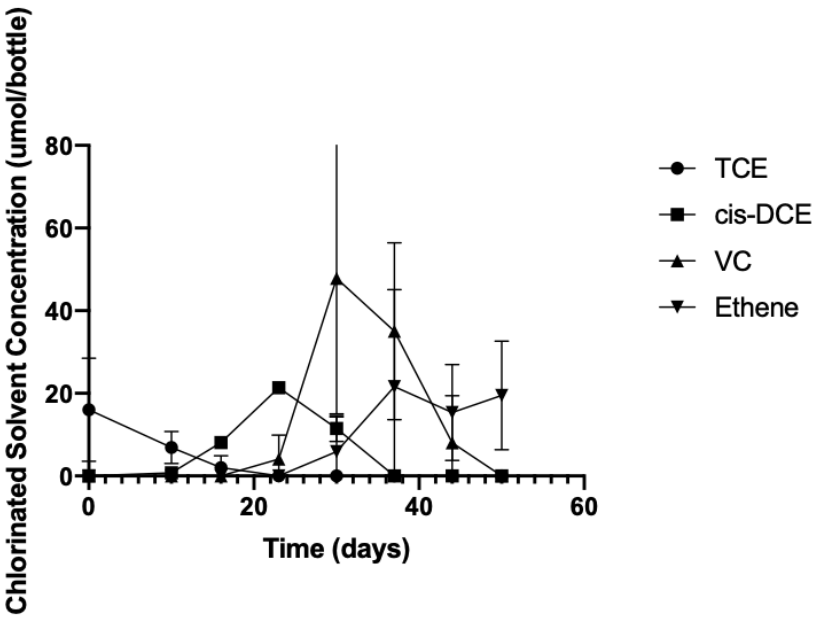


Figure 8. 100 mg/L EOS dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina. Values are an average of 2 bottles, error bars represent 1 standard deviation.

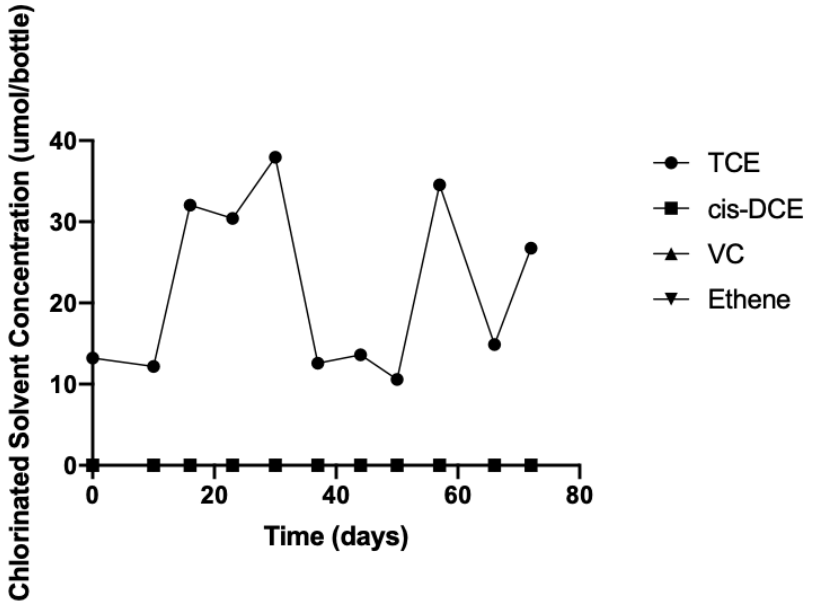


Figure 9. Unamended control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.

Table 4. Time to complete dechlorination for all co-products and controls in optimization experiment with soil collected from Easley, South Carolina. Values were average of 3 bottles rounded to the nearest day.

Concentration and Name of Co-product	Time to complete dechlorination (Days)	1 Standard deviation of dechlorination (Days)
100 mg/L DAF	72	0
100 mg/L Brown Grease	57	0
100 mg/L Feather Meal	57	0
100 mg/L Poultry Byproducts	63	4.2
100 mg/L NB Bloodmeal	60	4.2
100 mg/L Tallow	57	0
Control: Unamended	Not reached after 72 days	-
Control: 10 mM Lactate	37	0
Control: 3.2 mg/L EOS	50	0

The second main focus of optimization research revolves around using mixtures of high preforming co-products to potentially increase the novelty and dechlorination rate beyond the original co-products. These experiments were conducted at varying concentrations of co-product (100, 250, 500 mg/L) to further investigate co-product concentrations. For this study the co-products were dosed at a 50:50 ratio, for example if the total concentration was 100 mg/L this would indicate 50 mg/L co-product A and 50 mg/L co-product B. In this experiment no bottles reached complete dechlorination, only conversion to cis-DCE. Again there are a variety of explanations for this behavior such as lack of key enzymes or unfavorable soil conditions. The

results of this experiment are summarized in Table 5. Very effective co-product mixtures were 50 mg/L Poultry Byprodcuts + 50 mg/L PNM as well as 125 mg/L DAF + 125 mg/L PNM each reaching conversion to cis-DCE in 28 days. The most effective co-product mixture was 250 mg/L Poultry Byproducts + 250 mg/L PNM reaching conversion in 15 days. These data indicate mixtures of co-products may have an advantage in increased dichlorination rates compared to pure co-product doses. All Figures for this experiment are seen in the Appendix (142-204).

Table 5. Time to complete dechlorination for all co-product mixtures and controls in optimization experiment with soil collected from Easley, South Carolina. Values were average of 3 bottles rounded to the nearest day.

Concentration and Name of Co-product	Time to complete conversion to cis-DCE (Days)	1 Standard deviation of cis-DCE conversion (Days)
50 mg/L DAF + 50 mg/L PNM	45	15.2
50 mg/L DAF + 50 mg/L Tallow	33	6.6
50 mg/L Poultry Byproducts + 50 mg/L PNM	28	0
125 mg/L DAF + 125 mg/L PNM	28	0
125 mg/L DAF + 125 mg/L Tallow	33	6.6
125mg/L Poultry Byproducts + 125mg/L PNM	28	0
250 m/L DAF + 250 mg/L PNM	28	0
250 mg/L DAF + 250 mg/L Tallow	28	0
250mg/L Poultry Byproducts + 250mg/L PNM	15	0
Control: 100 mg/L Tallow	71	36.0
Control: 100 mg/L DAF	38	0
Control: 100 mg/L PNM	No conversion after 134 Days	-
Control: 100 mg/L Poultry Byproducts	38	0

Control: 250 mg/L Tallow	33	6.6
Control: 250 mg/L DAF	41	3.8
Control: 250 mg/L PNM	65	19
Control: 250 mg/L Poultry Byproducts	22	0
Control: 500 mg/L Tallow	15	0
Control: 500 mg/L DAF	22	22
Control: 500 mg/L PNM	33	7.5
Control: 500 mg/L Poultry Byproducts	15	0

The last optimization considered for this study looked at the ratio of co-products in a mixture. When evaluating co-product effectiveness, it is also important to consider cost. As mentioned in the introduction these co-products are cost effective but there is a large price range per pound of co-product (0.005$ - 0.225$ per pound). Some of these co-products are considered "High Value" and others are considered "Low Value". With that in mind, this study looked at using mixtures of co-products at a 9:1 ratio of (low value : high value) co-product amendments. All of the mixtures used in this experiment are seen in Table 2. All of these mixtures were dosed at 500 mg/L and performed exceptionally well. The best preforming mixture of 9:1 DAF to PBM+E is seen in Figure 10. The 10 mM Lactate control, as well as 500 mg/L EOS control are seen in Figure 11, and 12 respectively. The soil in this experiment was so highly active, it was somewhat difficult to distinguish between the mixtures. This activity led the unamended control to see complete dechlorination in only 48 days. This study indicated that co-product mixtures can serve as effective electron donors for dechlorination compared to Lactate and EOS controls, and

using a 9:1 co-product ratio can further improve the cost effectiveness of these low cost alternatives. All Figures for this experiment are seen in the Appendix (205-258).

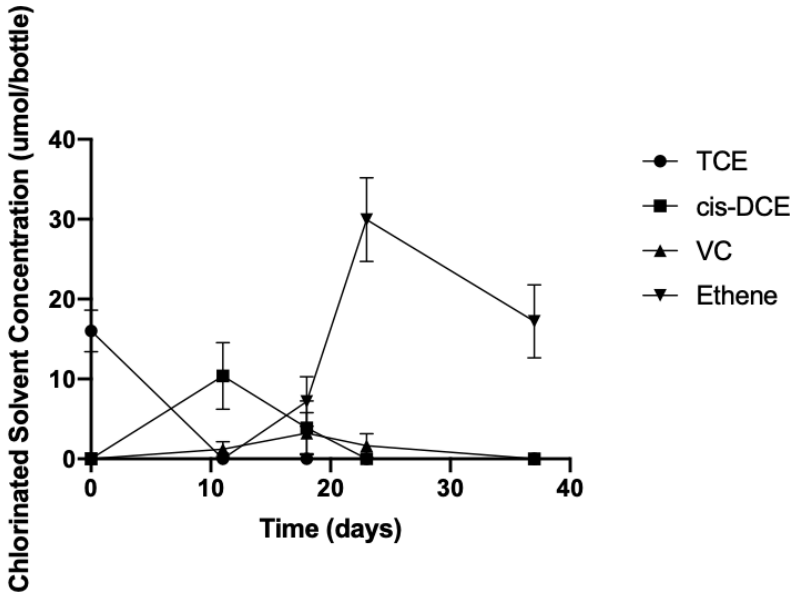


Figure 10. 9:1 DAF: PBM+E 500 mg/L dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina. Values are an average of 3 bottles, error bars represent 1 standard deviation.

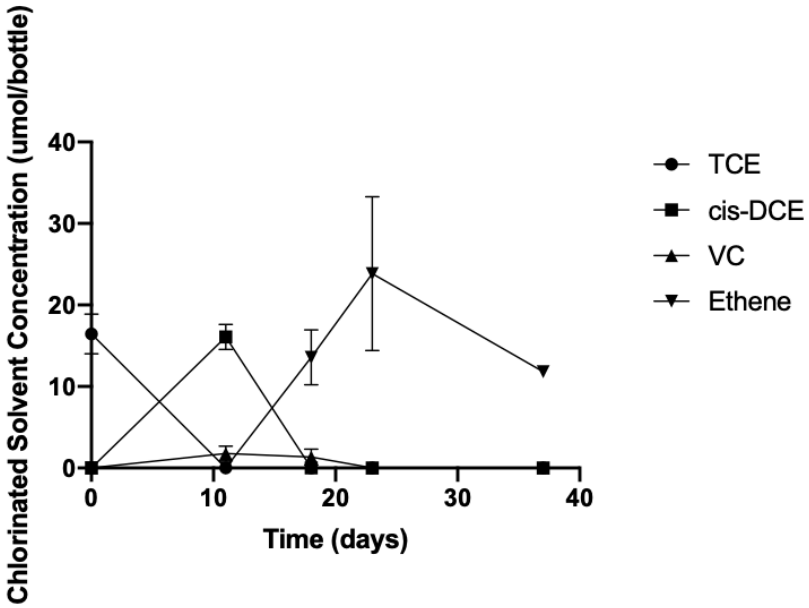


Figure 11. 10 mM Lactate dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina. Values are an average of 3 bottles, error bars represent 1 standard deviation.

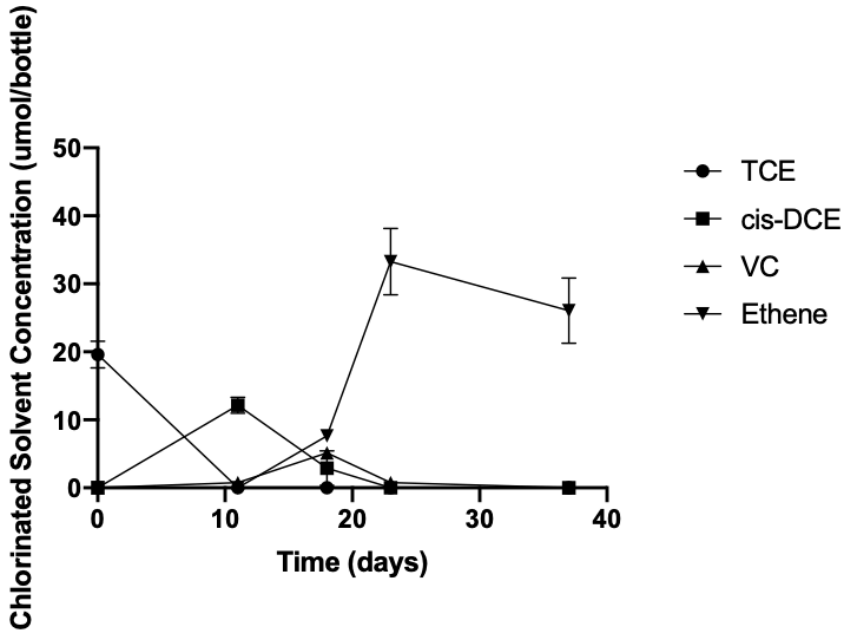


Figure 12. 500 mg/L EOS dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina. Values are an average of 3 bottles, error bars represent 1 standard deviation.

COMPOSITIONAL ANALYSIS

The last objective of this research study was to investigate the relationship between composition of co-product and dechlorination rate. The compositional analysis preformed were COD, protein content, and soluble TOC. The results of these analysis are seen in Tables 6, 7, and 8. These results give important context to co-products as electron donors, and in the case of COD can provide an estimate of the electron donating potential per unit mass. The COD measurement accounts for all oxidizable compounds in these co-products and may not necessarily reflect the biologically available electrons, however it does still provide insight on what may be the upper

limit of the electron donating capacity. Knowing this information is vital when designing remediation strategies in order to calculate mass of donor required. Looking at three of the consistently highest preforming co-products (Feather Meal, Brown Grease, and DAF) it is no surprise that they possess high % COD values by mass seen in Table 6. One of the advantages of using animal co-products for reductive dechlorination are they generally have high electron density. The protein content measurement provides another window into the composition of these co-products. However, considering the consistently highest preforming co-products (Feather Meal, Brown Grease, and DAF), and comparing the protein content seen in Table 7 we see no obvious trend. Feather Meal possessed 95% protein by mass, while Brown Grease and DAF possess 34 and 35% respectively. Taking a look at the TOC data yields similar conflicting results. The TOC of Feather Meal, Brown Grease, and DAF were found to be 3, 94, and 3% by mass. It is important to note that all of these measurements suffer from significant error as we observed values of over 100% by mass for some of the co-products. Further compounding these measurement errors, many of these co-products are heterogenous in nature and may vary significantly from sample to sample. Even considering the issues related to these measurements, having a general idea of the composition provides data to improve decision making regarding which co-products should be used in a mixture, and the relative electrons donated per unit mas vital for remediation strategies.

Table 6. Compositional properties of Animal Co-products. Chemical Oxygen Demand (COD) of animal co-products, obtained by using an ultra-high range TNT 823 HACH COD kit. Protein content of animal co-products using a Modified Lowery Protein Assaykit. Co-products were digested using 6M HCL for 24 hours prior to analysis. Diluted albumin samples were used for the standard curve formation. Total organic carbon content of co-products achieved using catalytic combustion in a TOC-L machine. The co-products were dissolved in water prior to analysis resulting in soluble TOC measurement.

Name of Co-product	% Mass COD of co-product	% Mass Protein of co-product	% Soluble mass TOC of co-product
LoPro1	54	54	12
LoPro 2	54	93	9
PBM + E	95	61	12
LoPro3	41	25	8
Feather Meal	76	95	3
WAPAE Bone Meal	56	88	6
PNM	93	57	7
Poultry Byproducts	99	47	-
Brown Grease	105	34	94
Tallow	85	30	88
TEHB	85	44	95
PL	99	49	112
PNG	92	36	108
DAF	46	35	3

LoPro4	75	59	6
Centrysis	71	47	1
TEVB	19	30	-
TE 80/20	43	42	93
TEFA	42	32	92
CWG	17	3	100
Kerman MBM	71	88	12

Table 7. Total Organic Carbon content of select animal co-products. The co-products were dried in an oven at 105 C for 48 hours prior to analysis. Ignition in a furnace occurred at 550 C for 4 hours.

Name of Co-product	TOC Content % by Mass
Feather Meal	98.7
LoPro1	63.0
DAF	89.9
Poultry Byproducts	82.1
Bone Meal	80.3
LoPro2	59.6
LoPro3	52.8
PBM+E	78.1
LoPro4	64.4

CONCLUSIONS

The application of this research could lead to much lower cost electron donors compared to commonly used substrates. As mentioned previously traditional soybean based products cost $0.25 – $3.00 per pound, while co-products cost $0.005 - $0.225 per pound. When considering that large sites could require upwards of 50,000 pounds, the saving are significant. These experiments have shown that not only are these co-products viable alternatives to low molecular mass organic acids or EOS as electron donors, but can perform on par with these industry staples at a significantly lower price point. By lowering the cost of the electron donor substrate, many more sites could potentially benefit from access to this technology.

FUTURE WORK

Our understanding of animal co-product electron donor technology has progressed significantly over the past few years, however there is still substantial work to be done for these co-products to see real world application.

While batch studies of the co-products have been successful at showing complete dechlorination, these batch systems are not fully representative of real world aquifer systems. In the future column studies of these co-products will be necessary to better simulate real world conditions of flowing aquifer systems and should provide additional insights that batch systems are not capable of showing. These insights could include pH monitoring, HPLC analysis of volatile fatty acid (VFA) formation, dissolved hydrogen monitoring, delivery methods including permeable reactive barrier, and more.

Another important aspect that would improve our understanding of co-product technology are biological analyses. In future experiments, quantitative polymerase chain reaction (qPCR) could be used to monitor the biological community of systems that use co-products for

dichlorination. This method could be used to track the growth of DHC like bacteria in these studies as well as the general eukaryotic bacterial community. This data could be used to better understand experimental data, and show that the co-products promote conditions favorable to the growth of DHC like bacteria.

This research could also be applied in a variety of other contaminant remediation applications. While reductive dechlorination is one of the prominent applications of electron donor technology, there are many other compounds that can be biologically reduced. Specifically, it would be important to show that these co-products could be effective at reducing hexavalent chromium which is a prominent groundwater contaminant in the US and around the globe.

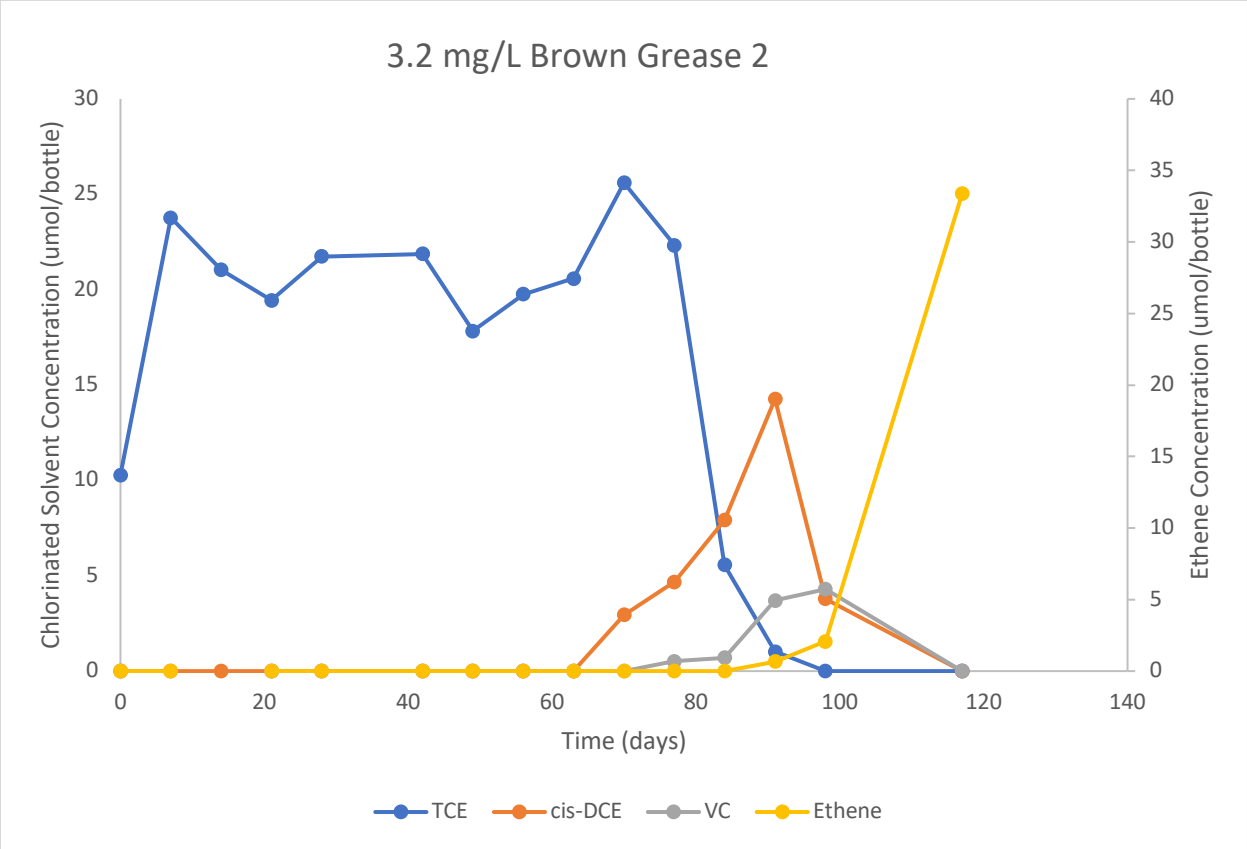
There are still holes in understanding of these co-products regarding exact electron donating capacity. Future research should be done to measure the electron donating capacity of all the co-products. There are many methods that could be used to determine this, including finding a representative biomolecule, reducing iron in a controlled batch study, or other alternatives.

Lastly, the most crucial test of this technology would come via a field study. Showing these co-products work in the lab or in column studies are important, but delivering them in a real field experiment could cement this technology as a true market ready alternative to other amendment substrates.

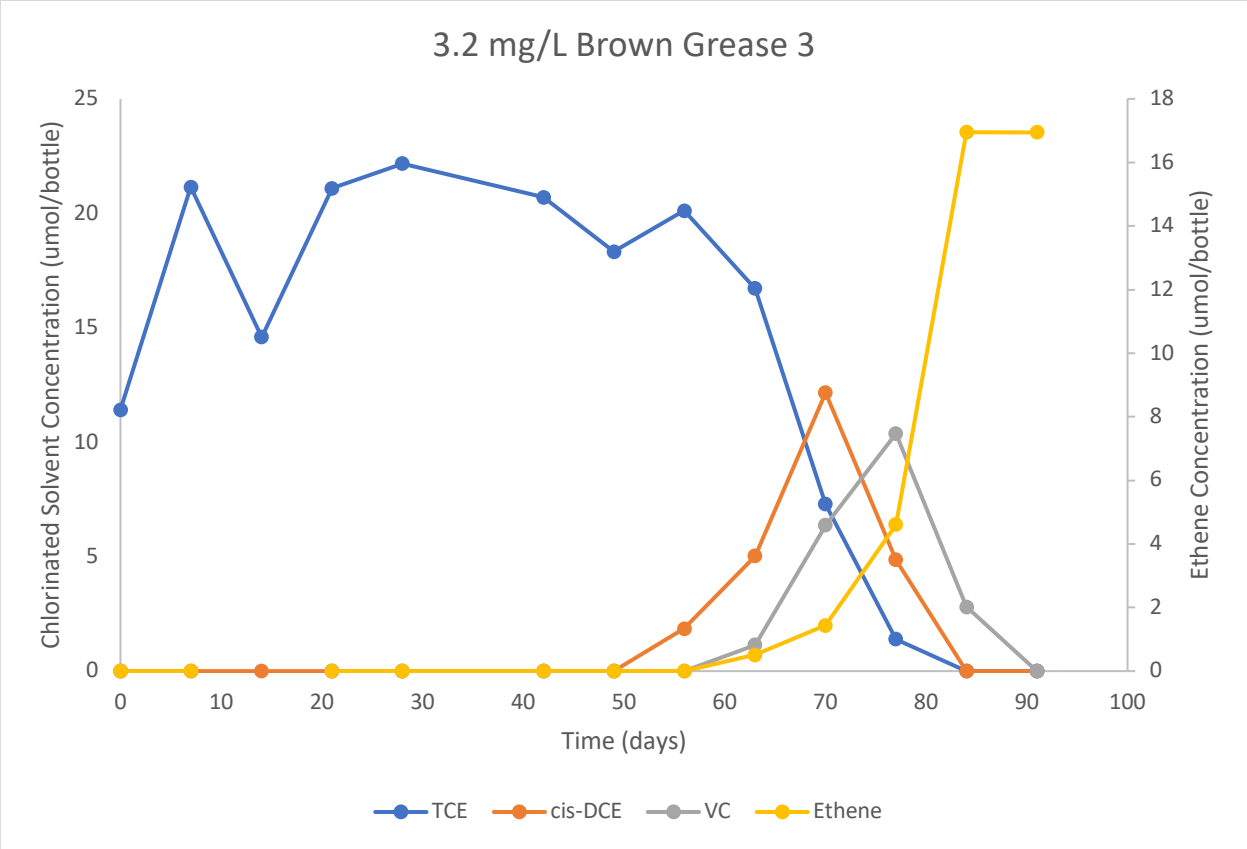
APPENDIX

FEASIBILITY EXPERIMENT

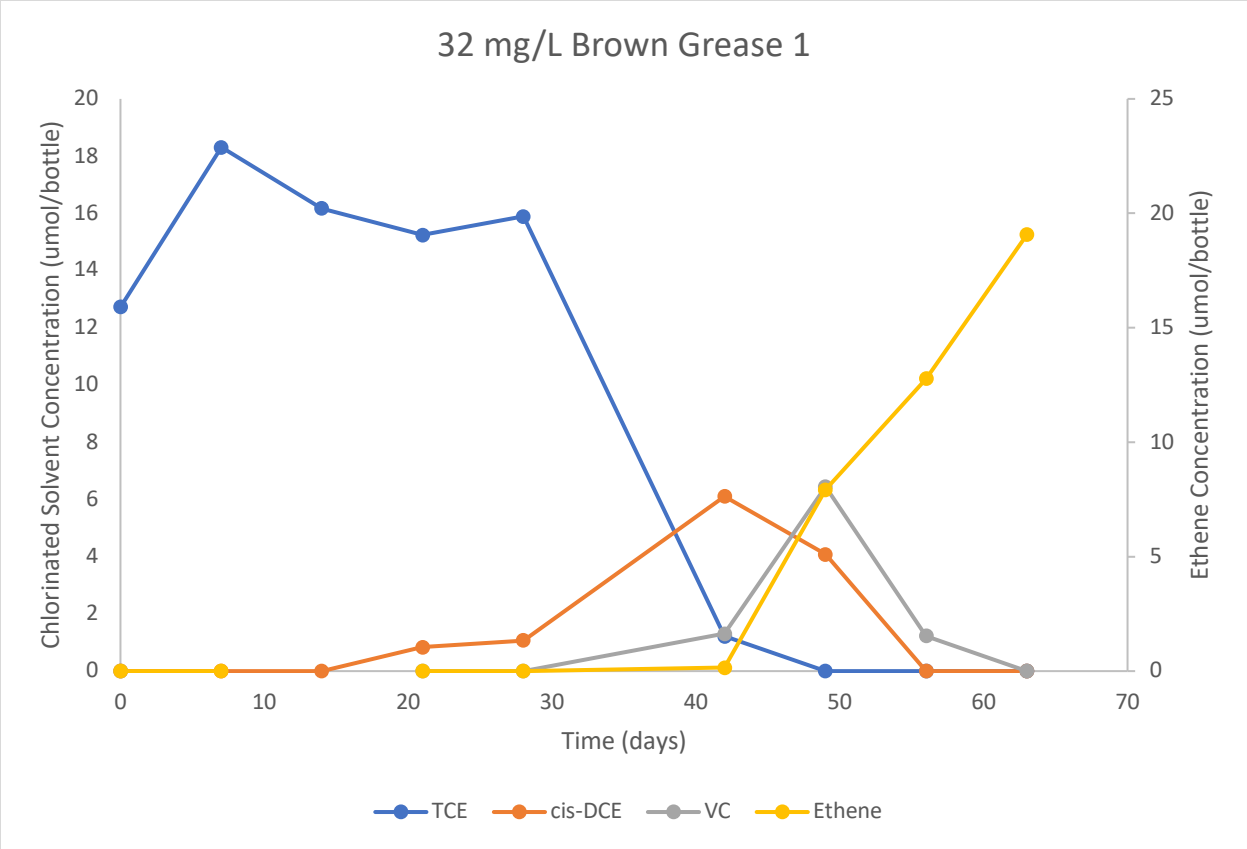
Appendix Figure 1. 3.2 mg/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



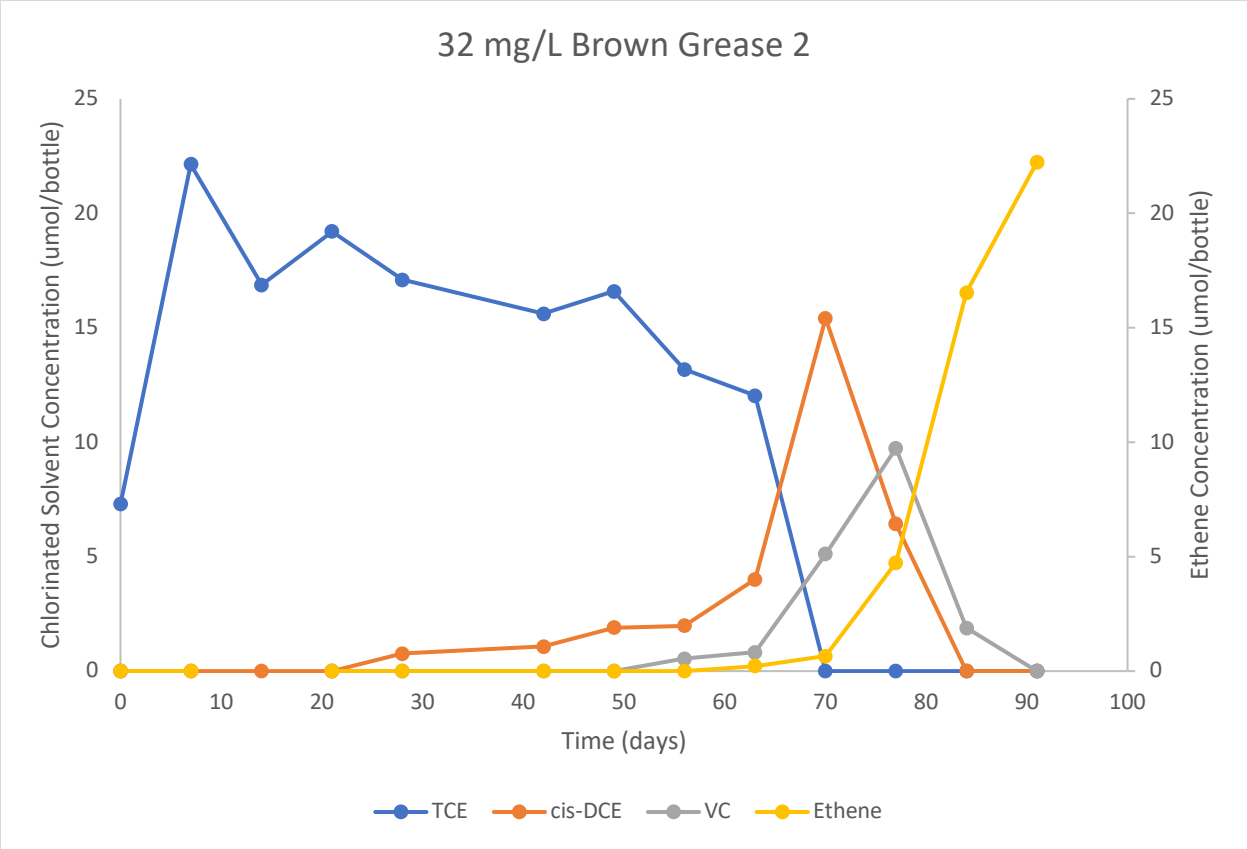
Appendix Figure 2. 3.2 mg/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



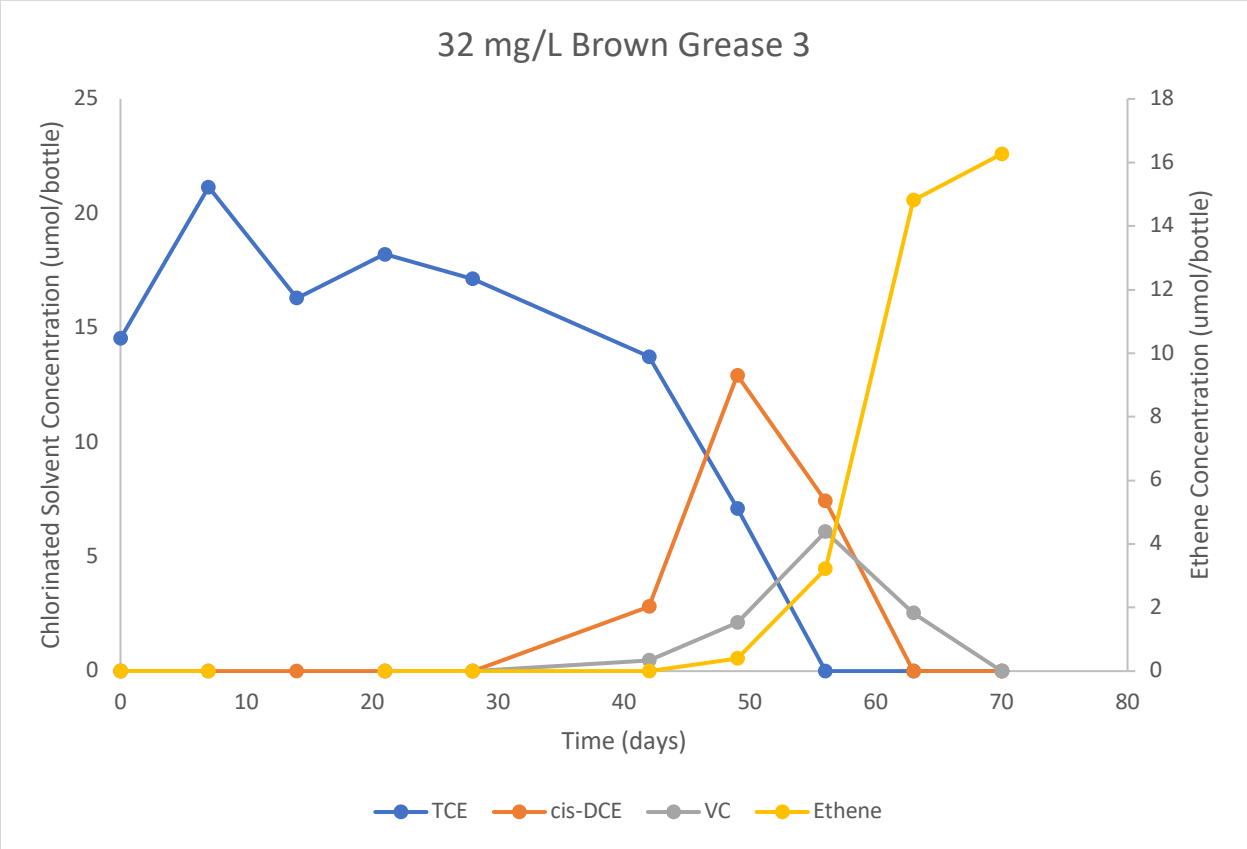
Appendix Figure 3. 3.2 mg/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



Appendix Figure 4. 32 mg/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



Appendix Figure 5. 32 mg/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.

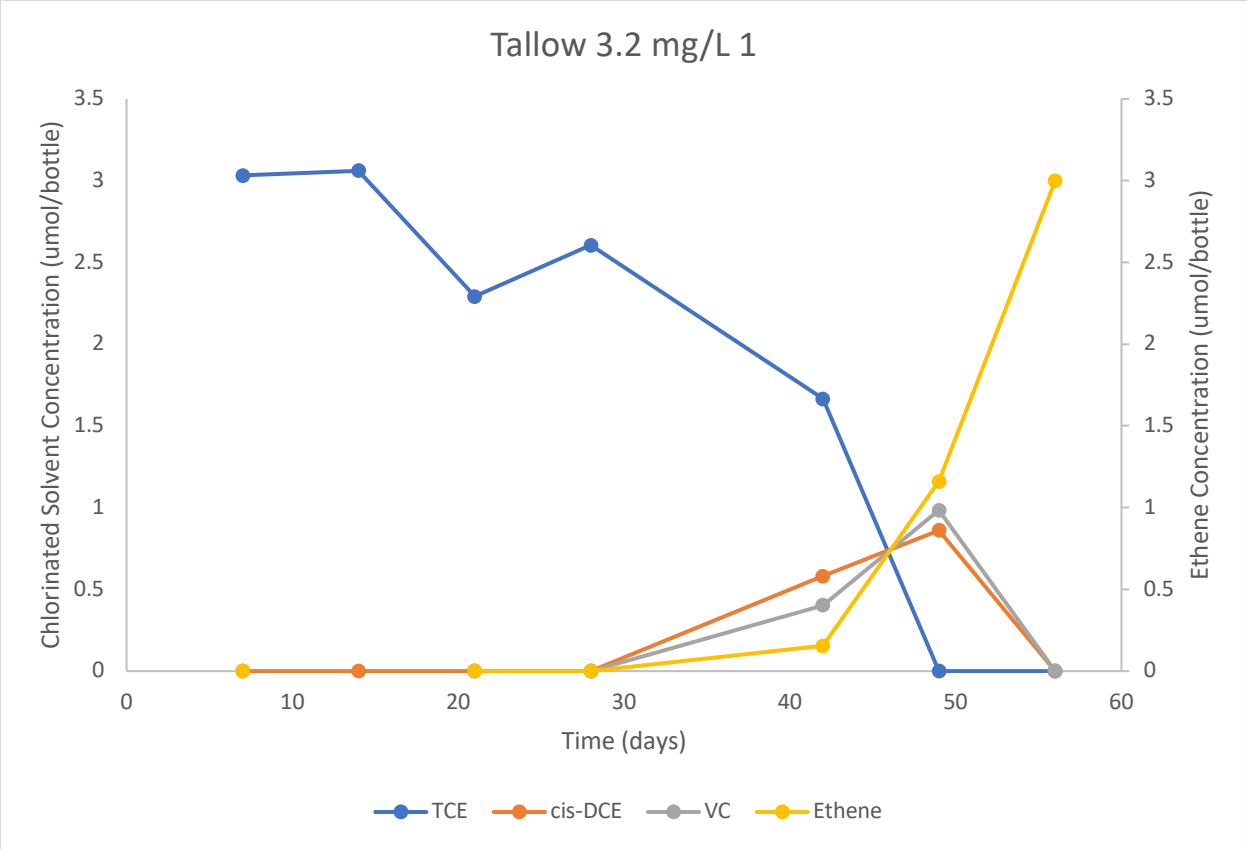


Appendix Figure 6. 32 mg/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.

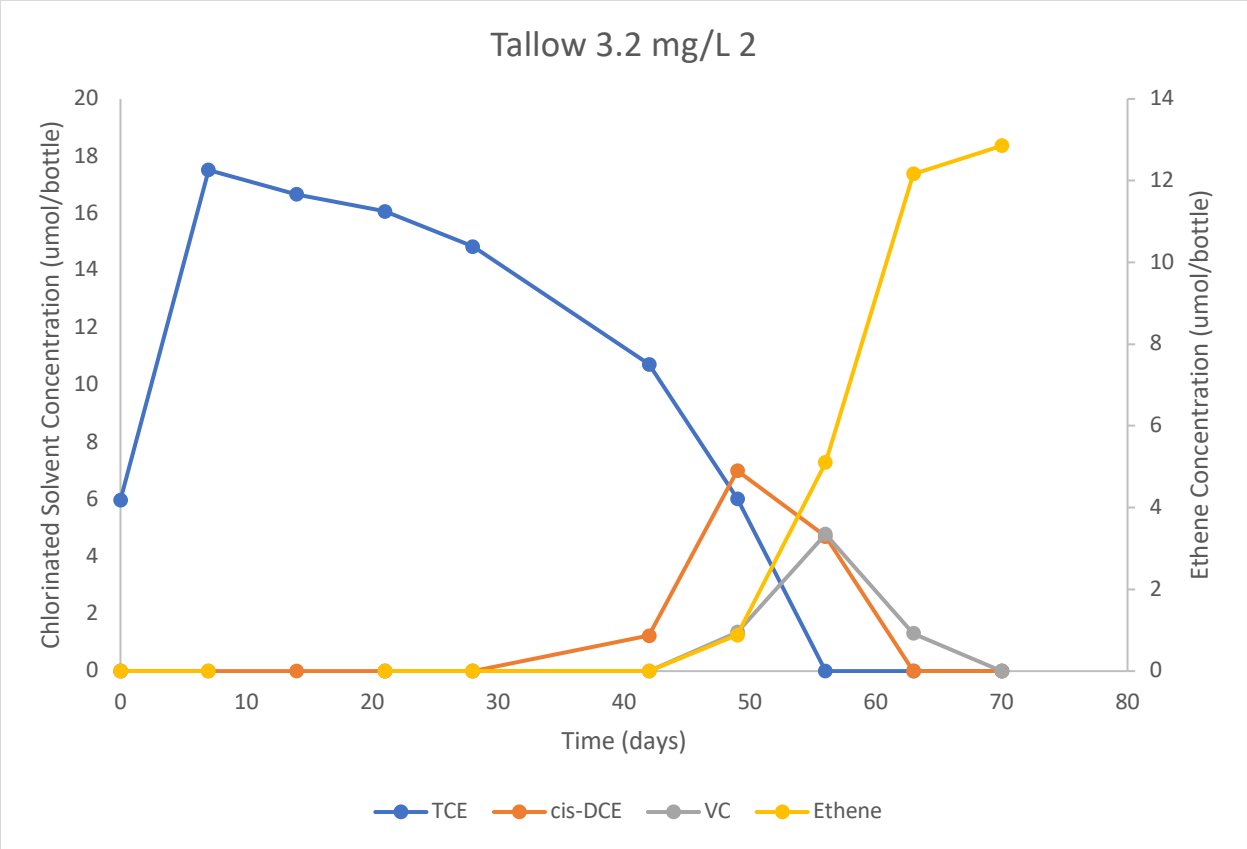
Appendix Figure 7. 1 g/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.

Appendix Figure 8. 1 g/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.

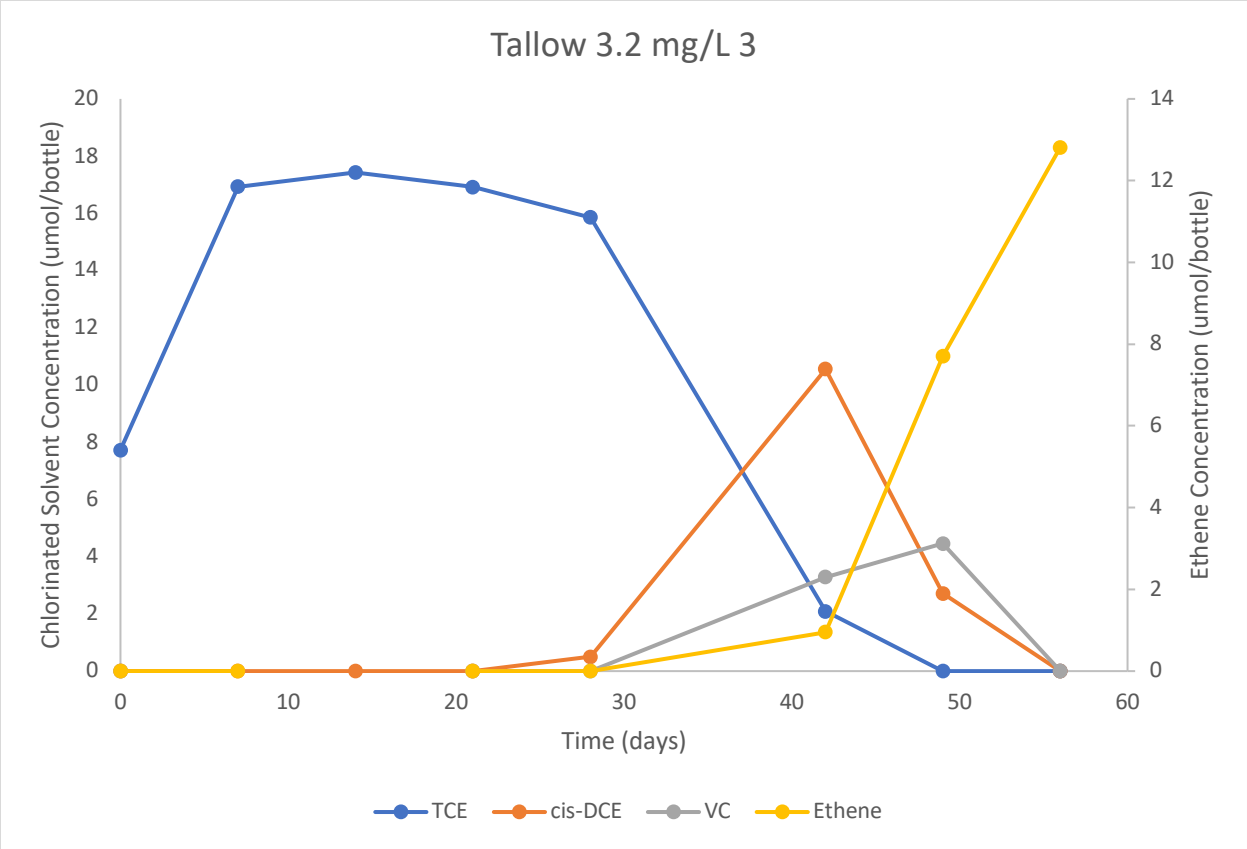
Appendix Figure 9. 1 g/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



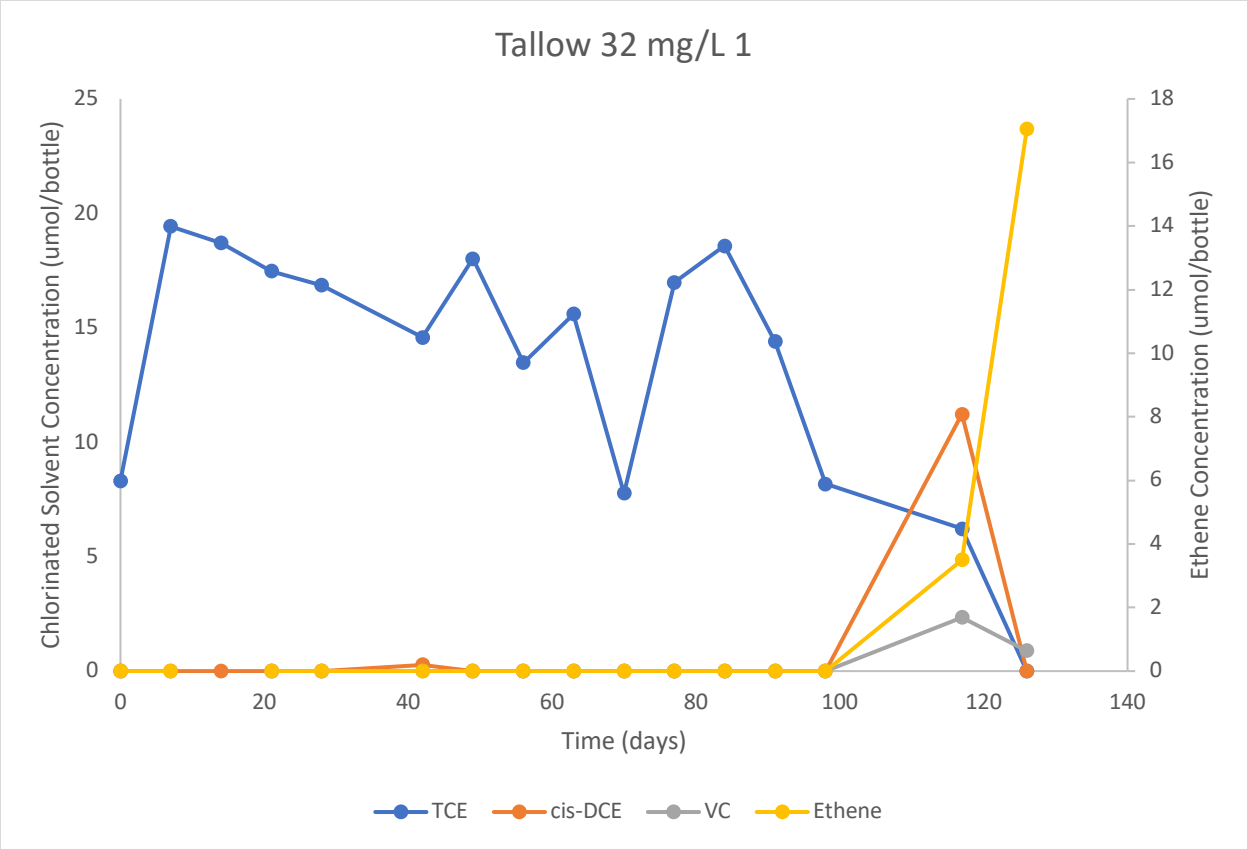
Appendix Figure 10. 3.2 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



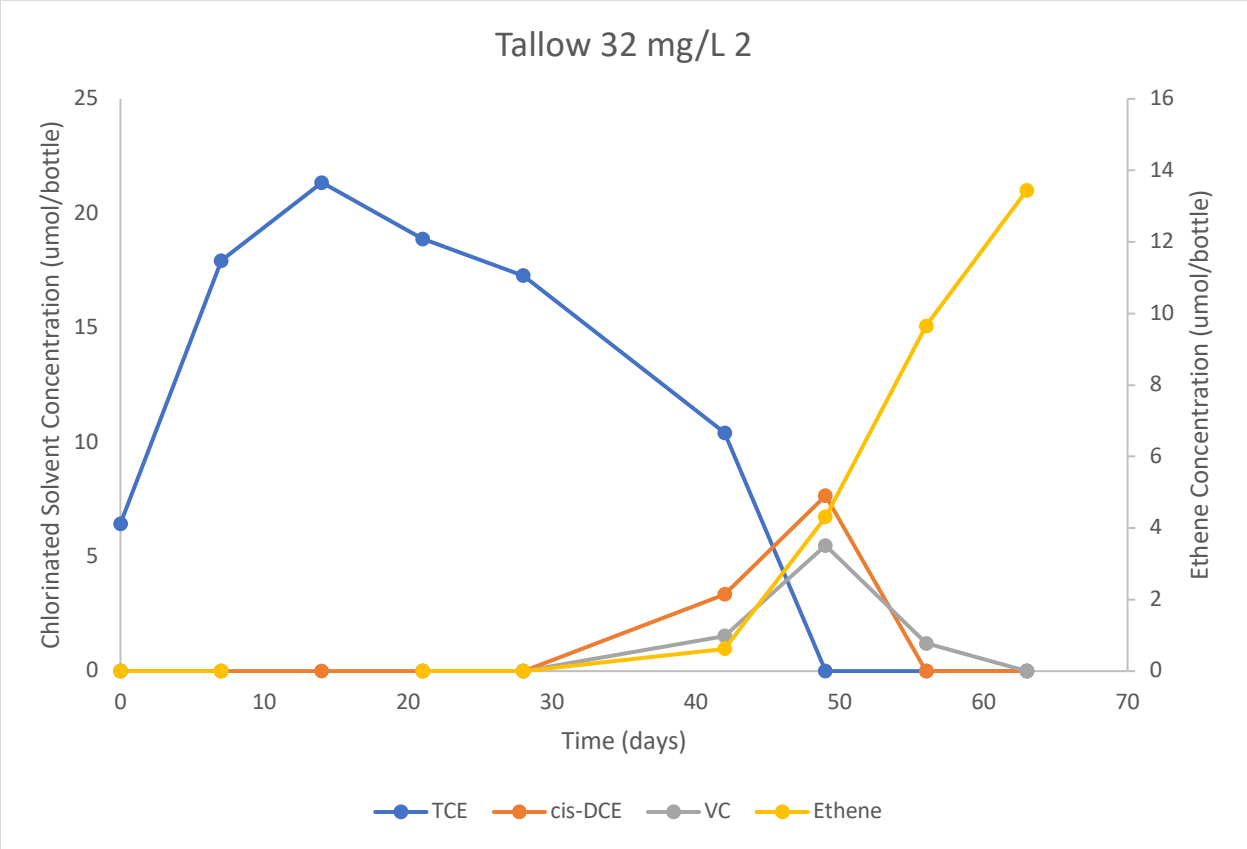
Appendix Figure 11. 3.2 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



Appendix Figure 12. 3.2 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.

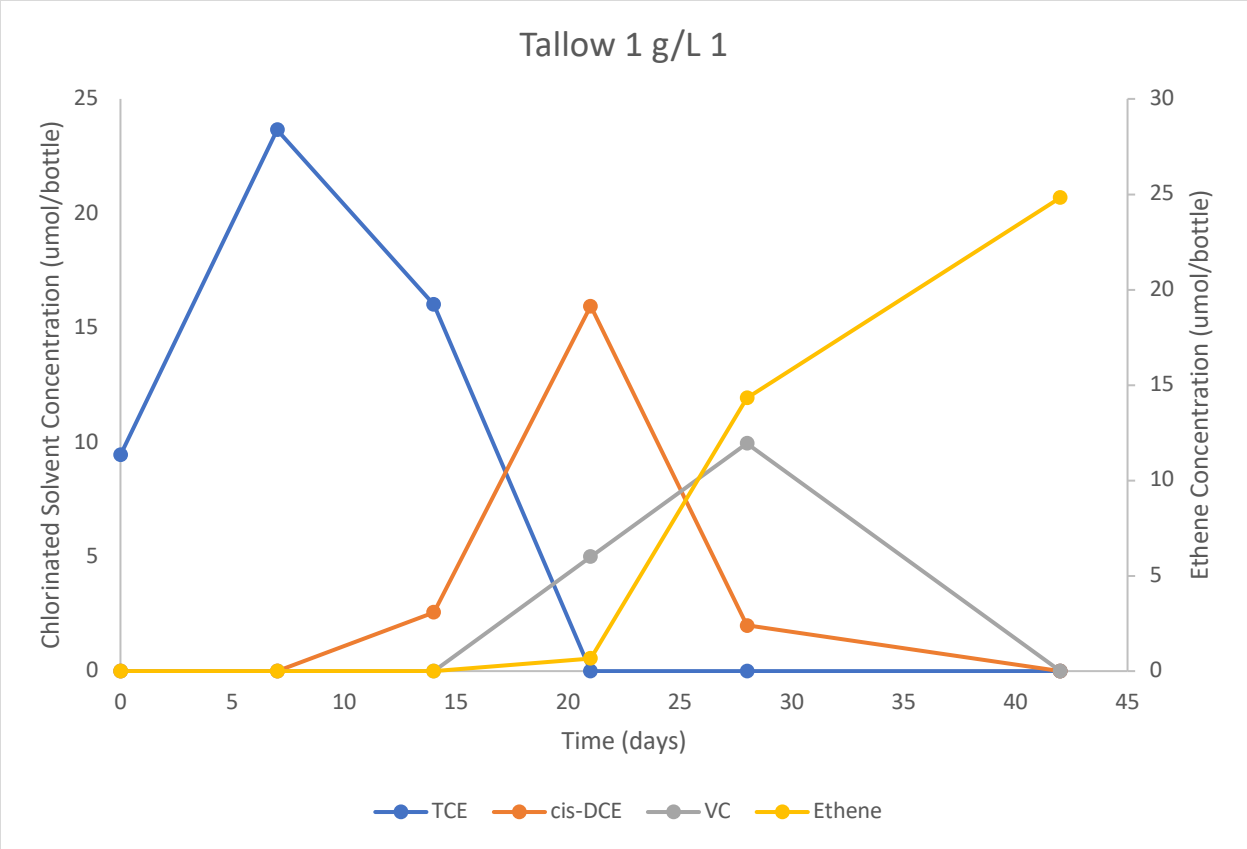


Appendix Figure 13. 32 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.

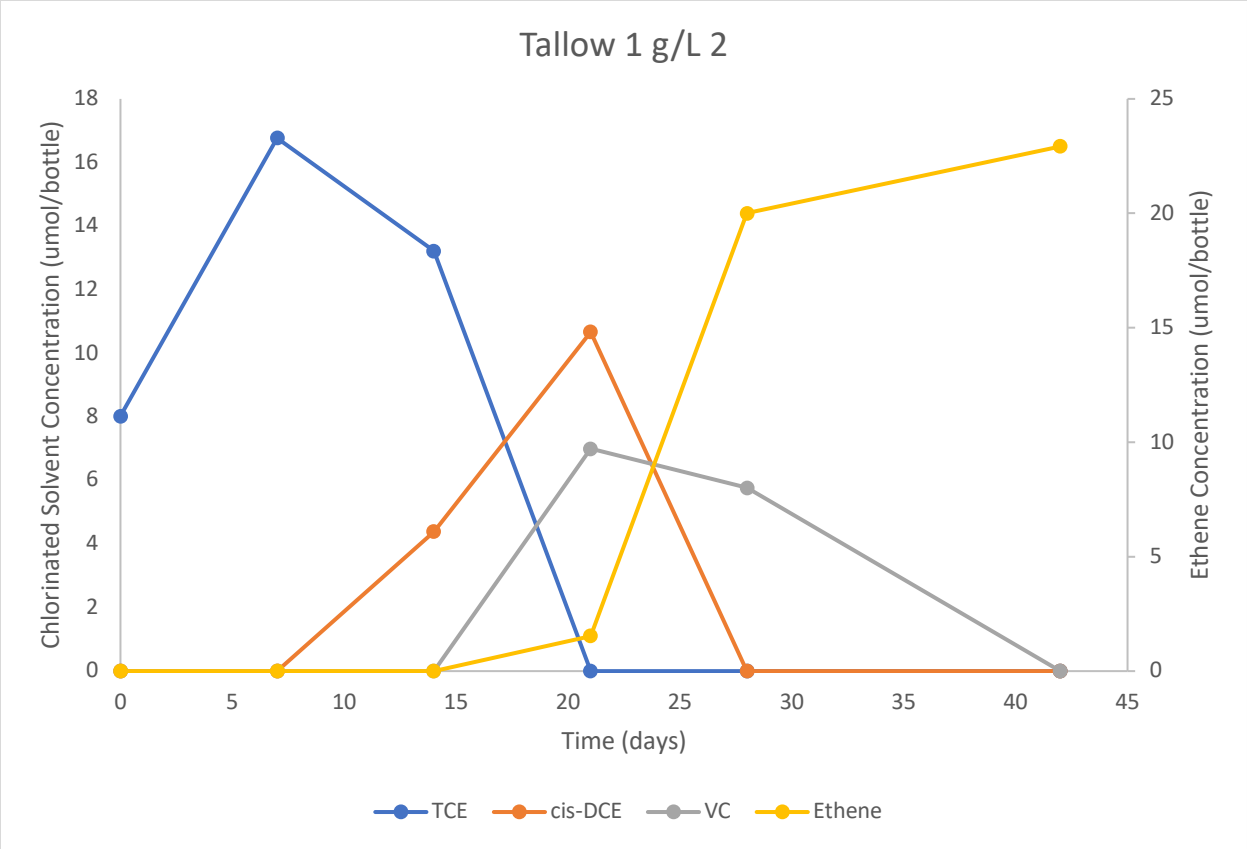


Appendix Figure 14. 32 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.

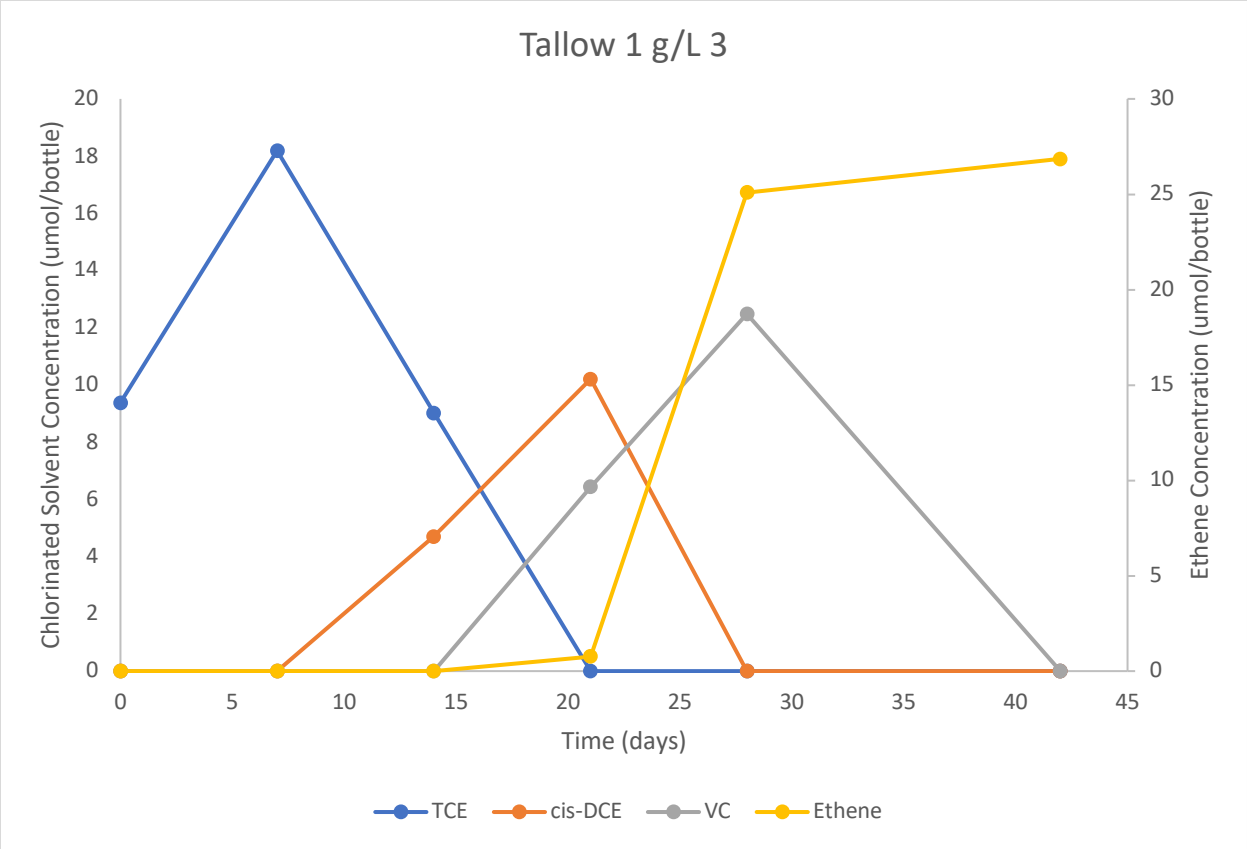
Appendix Figure 15. 32 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



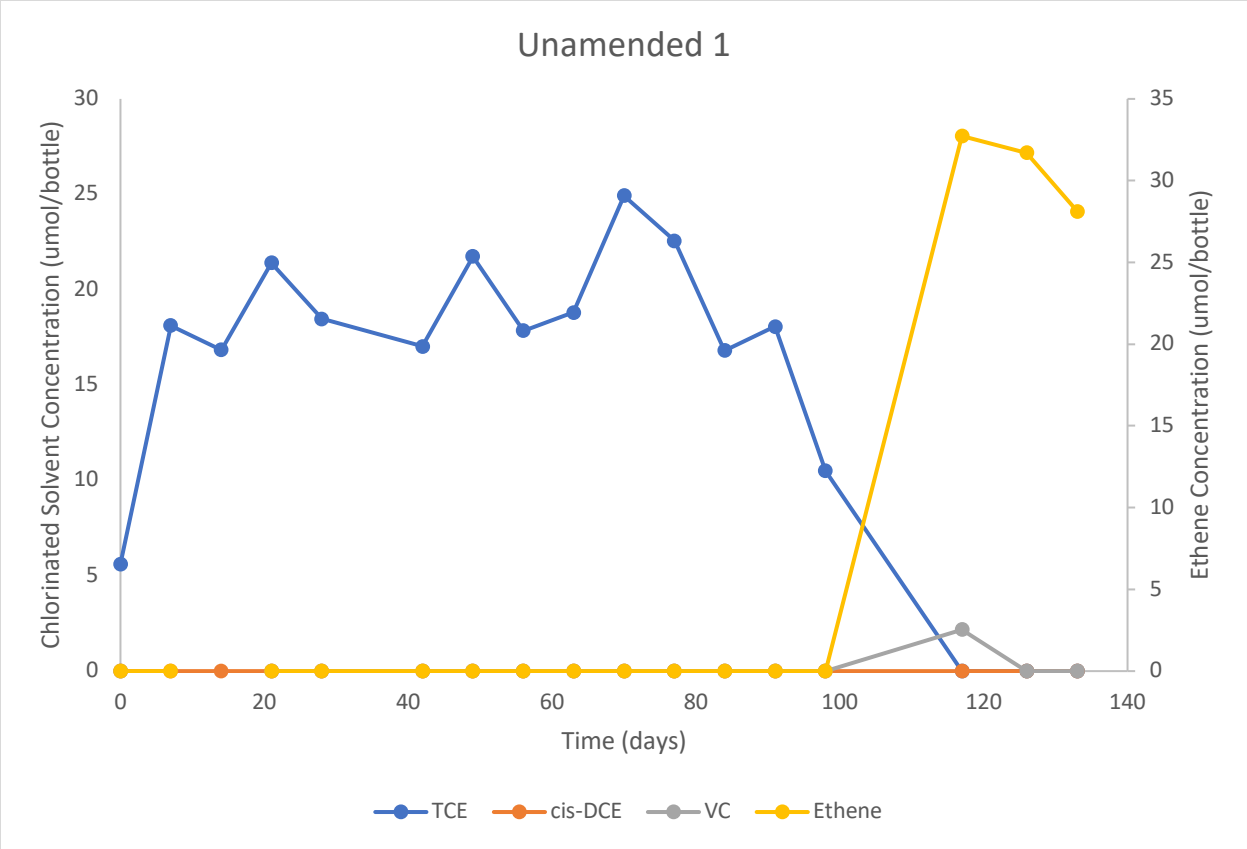
Appendix Figure 16. 1 g/L Tallow dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



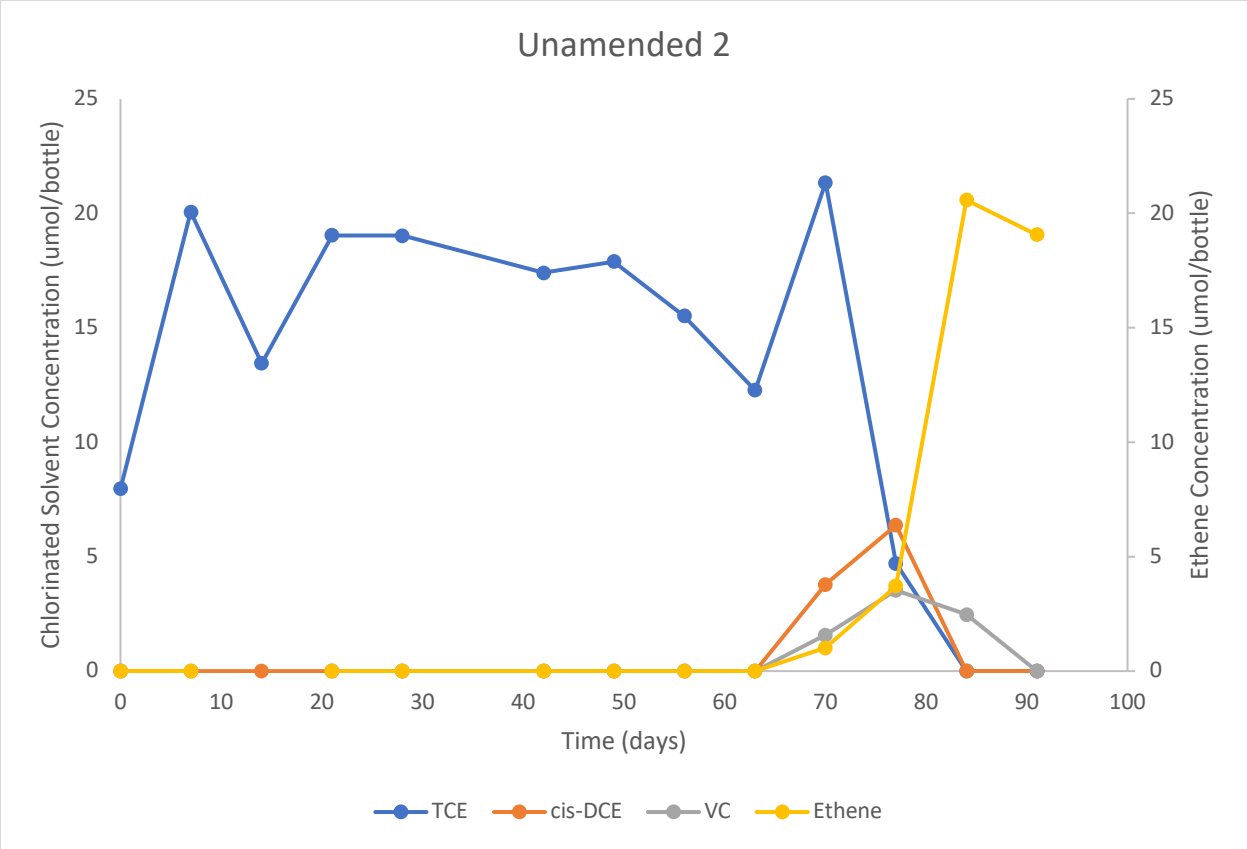
Appendix Figure 17. 1 g/L Tallow dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



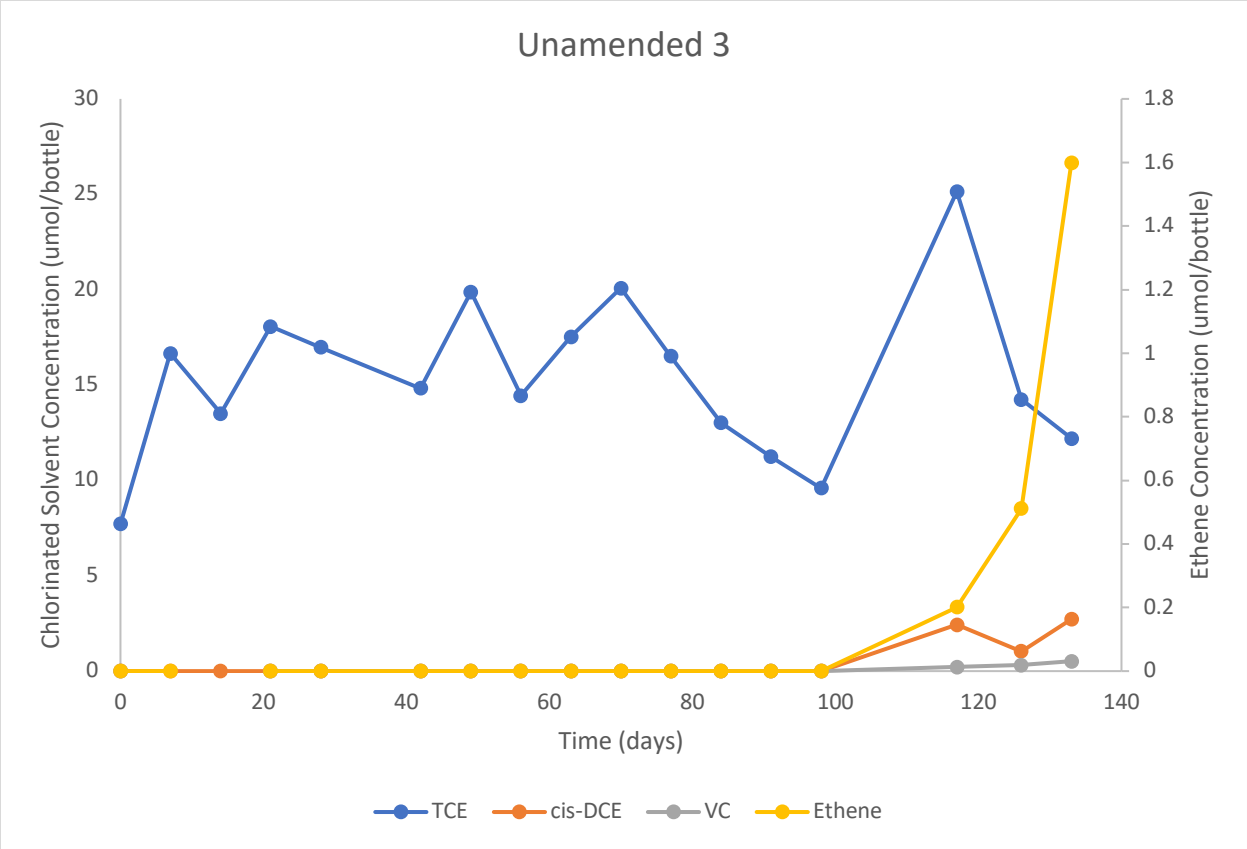
Appendix Figure 18. 1 g/L Tallow dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



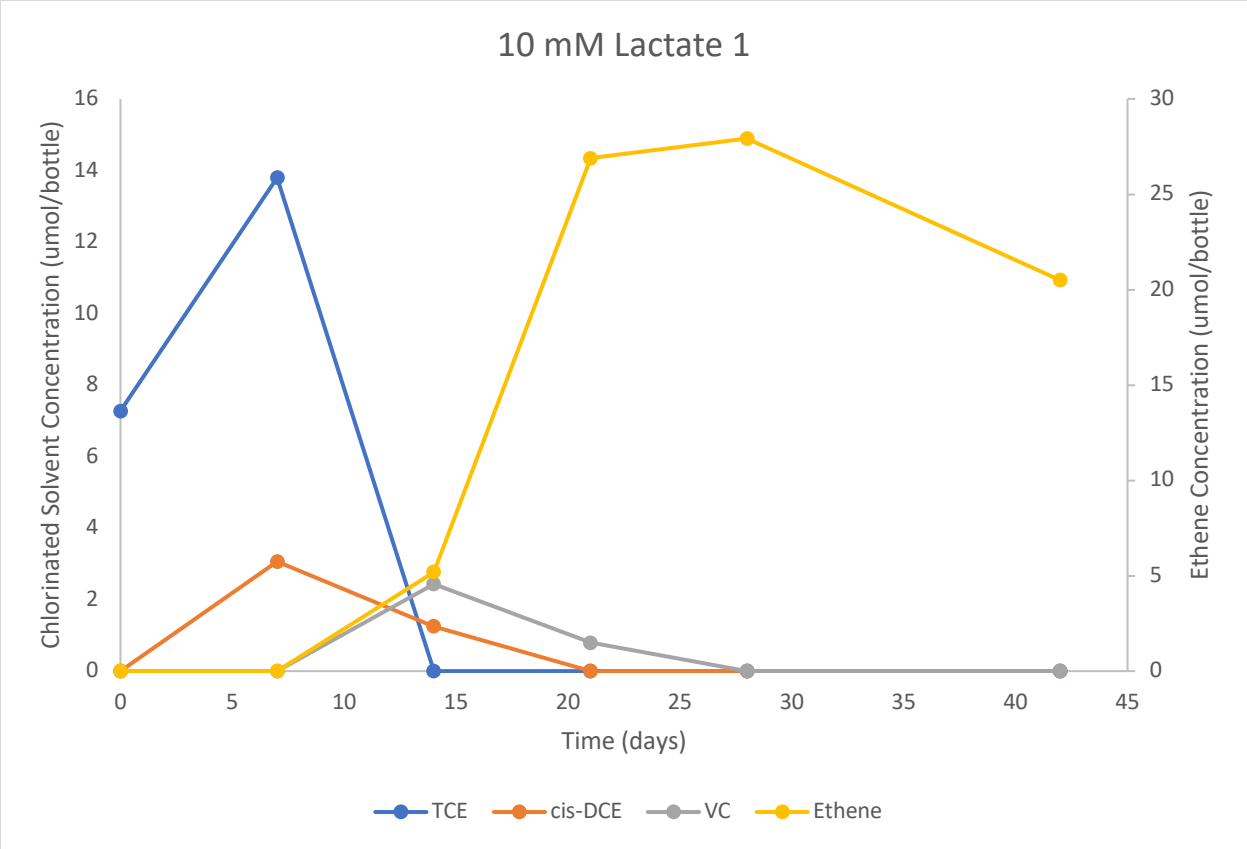
Appendix Figure 19. Unamended bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



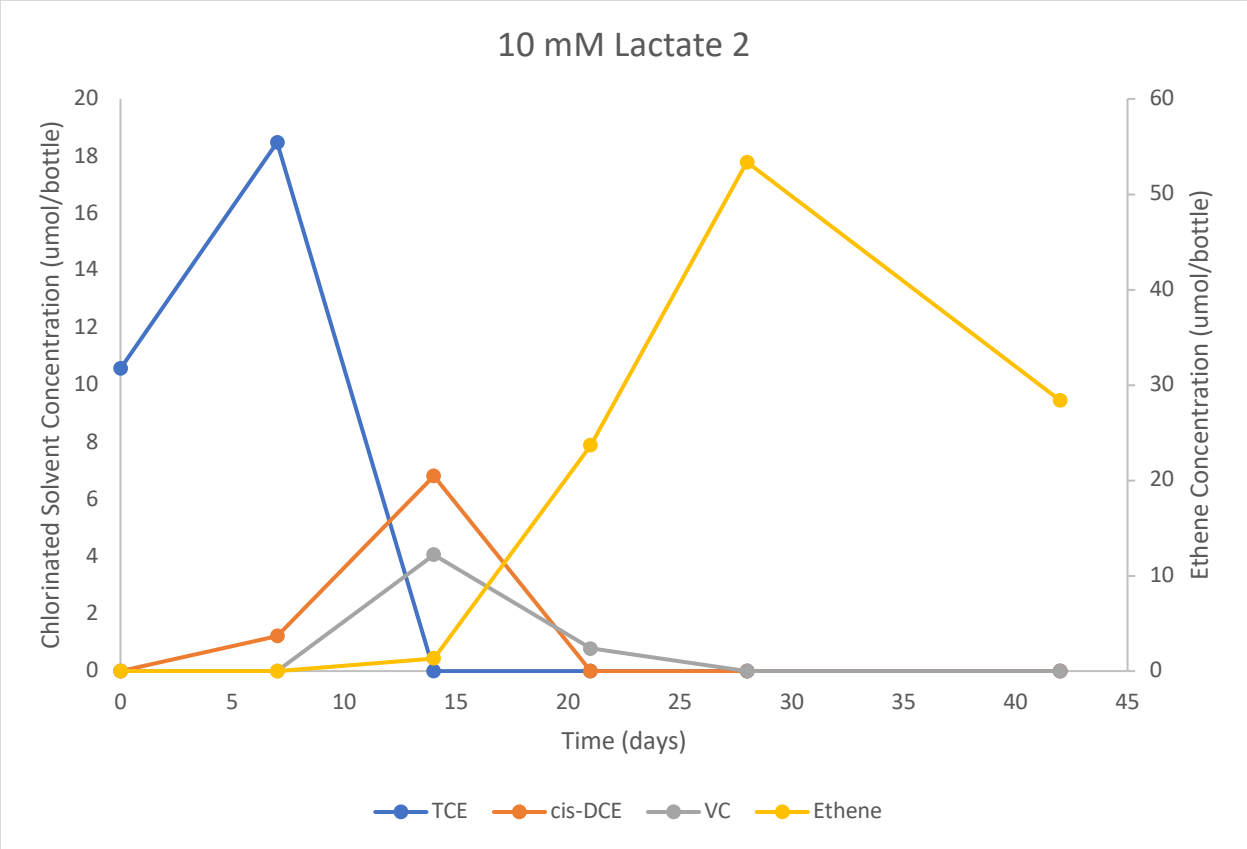
Appendix Figure 20. Unamended bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



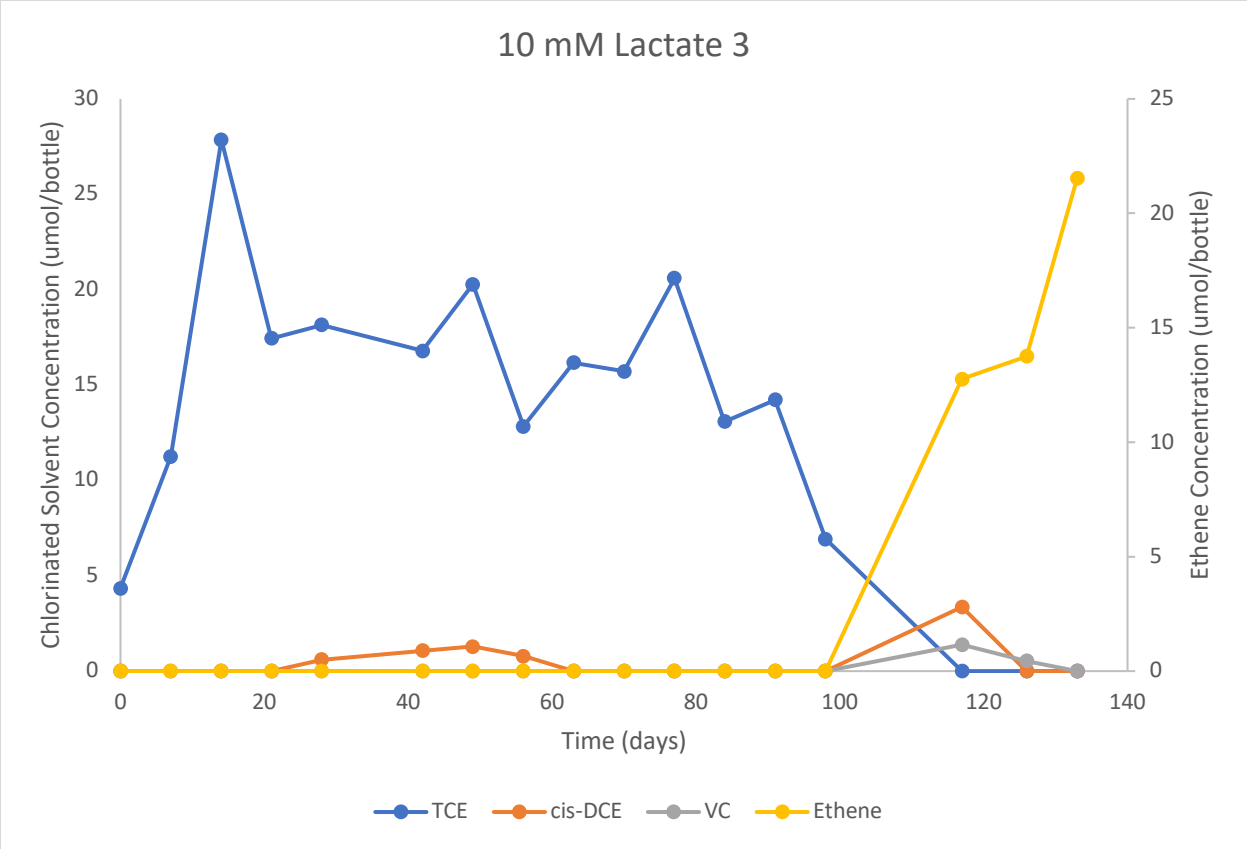
Appendix Figure 21. Unamended bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



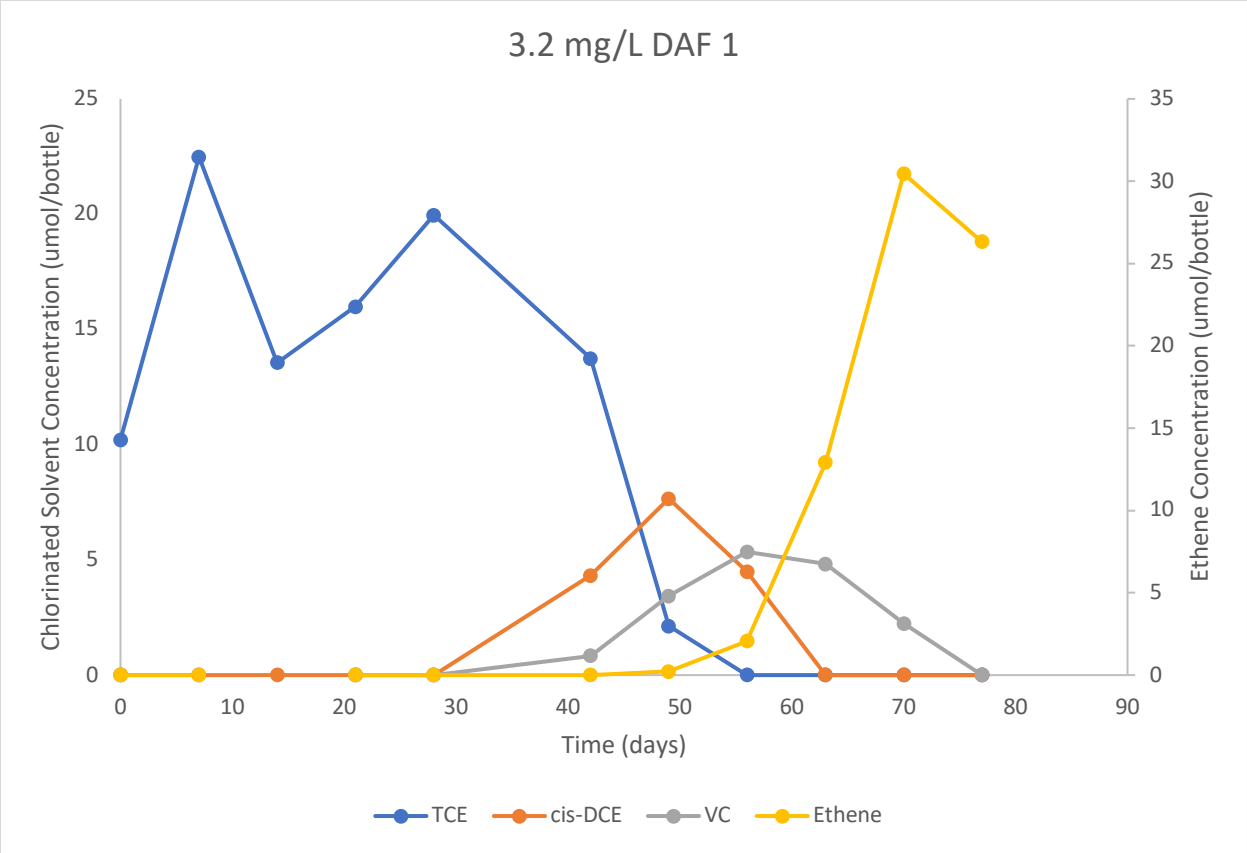
Appendix Figure 22. 10 mM Lactate bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



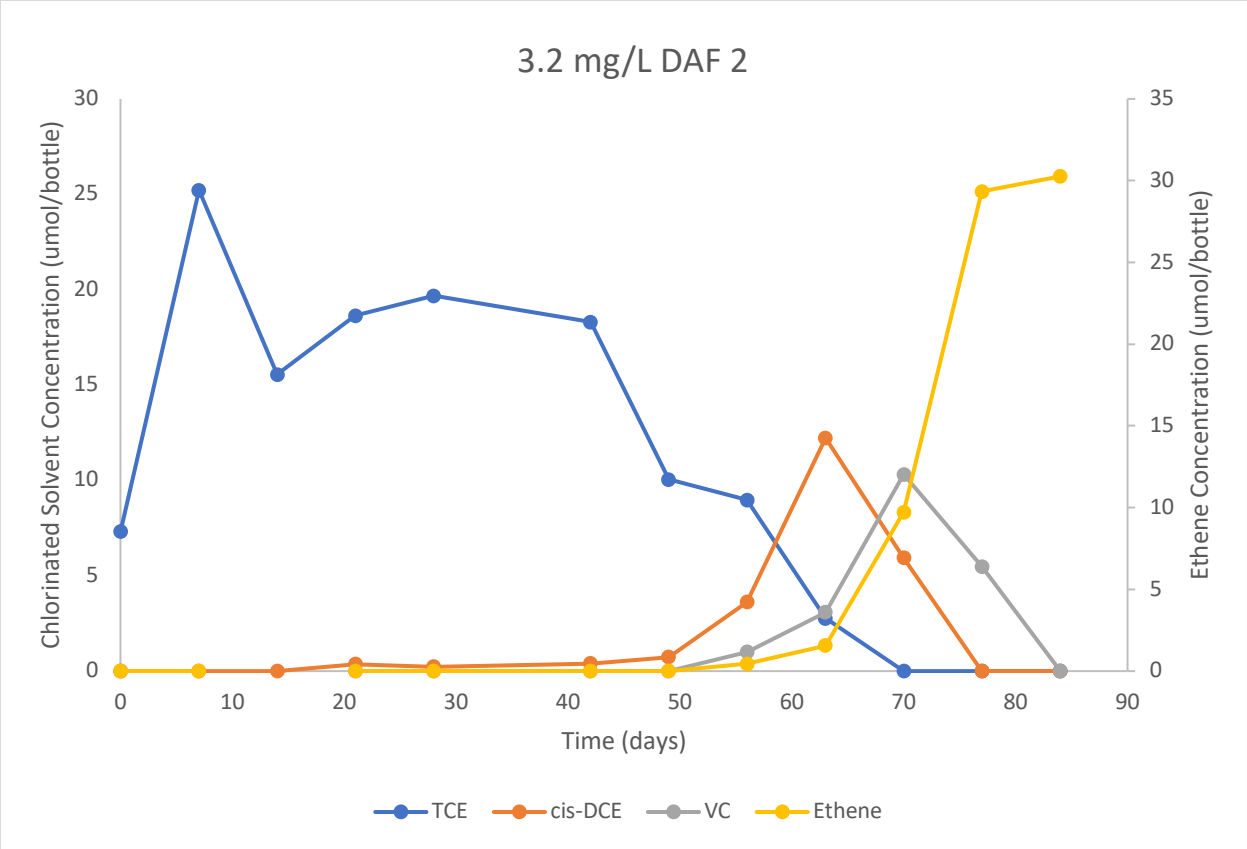
Appendix Figure 23. 10 mM Lactate bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



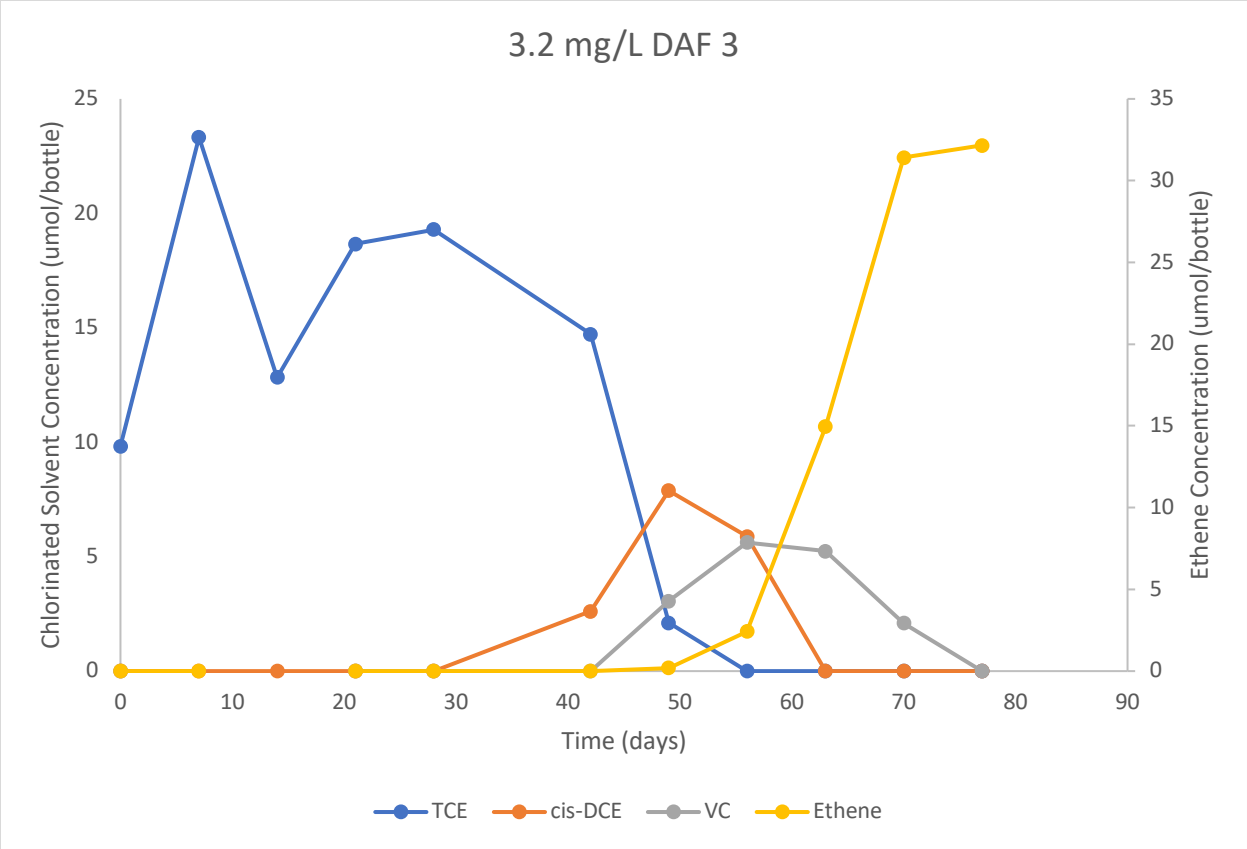
Appendix Figure 24. 10 mM Lactate bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



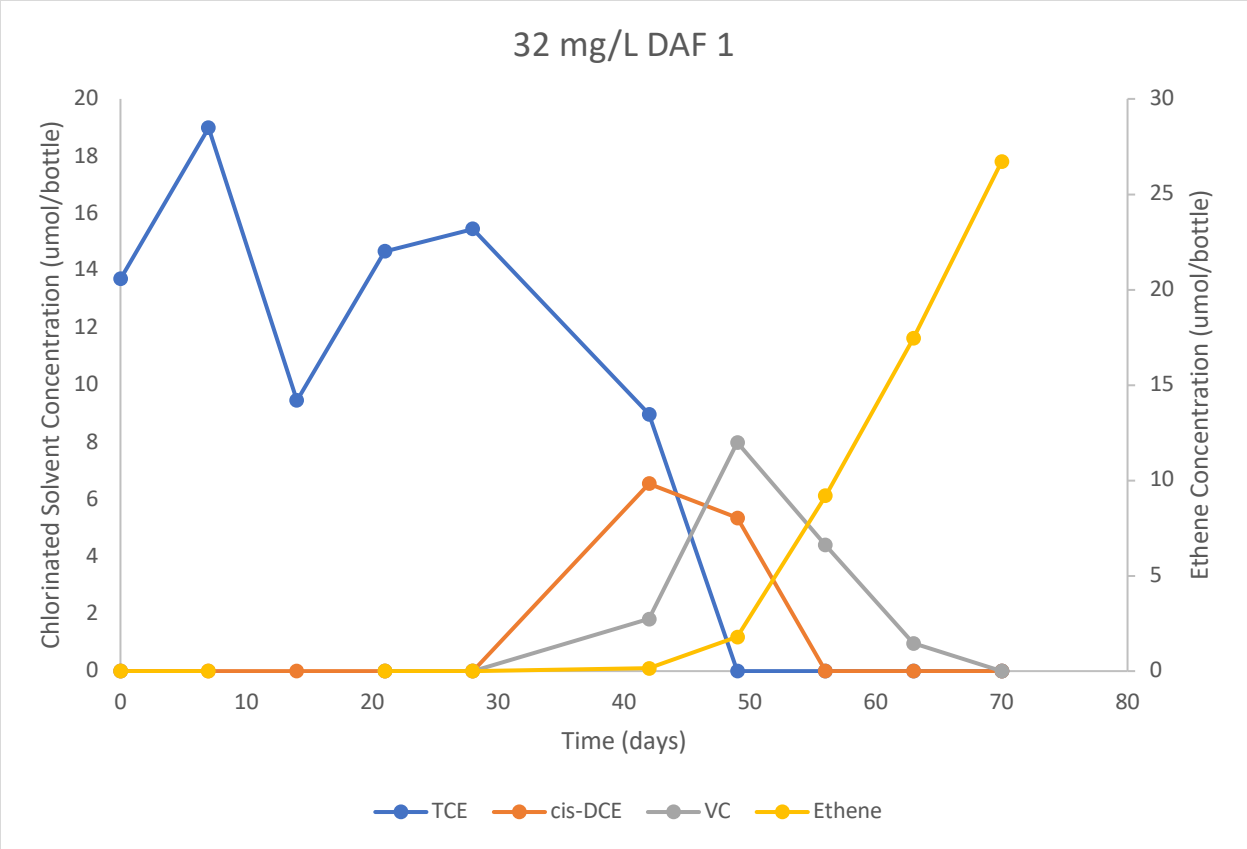
Appendix Figure 25. 3.2 mg/L DAF dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



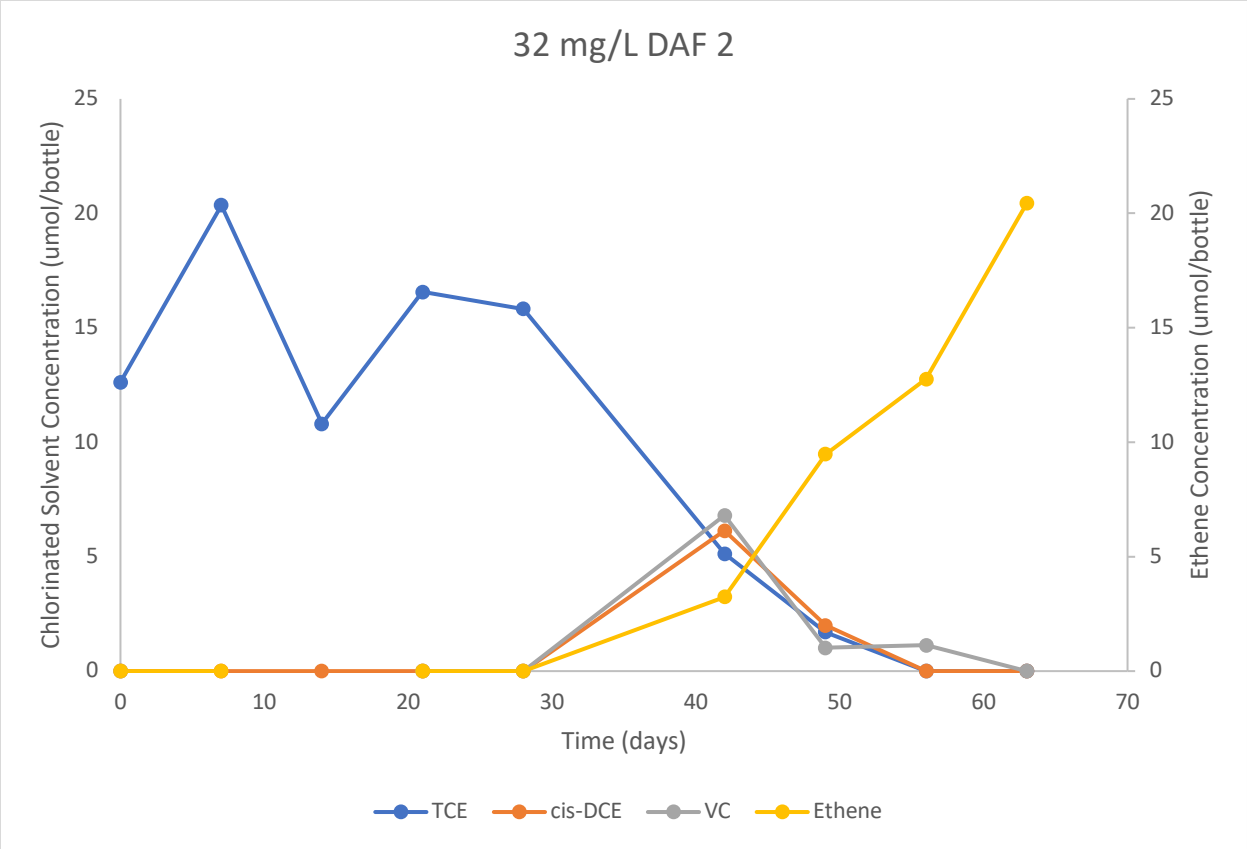
Appendix Figure 26. 3.2 mg/L DAF dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



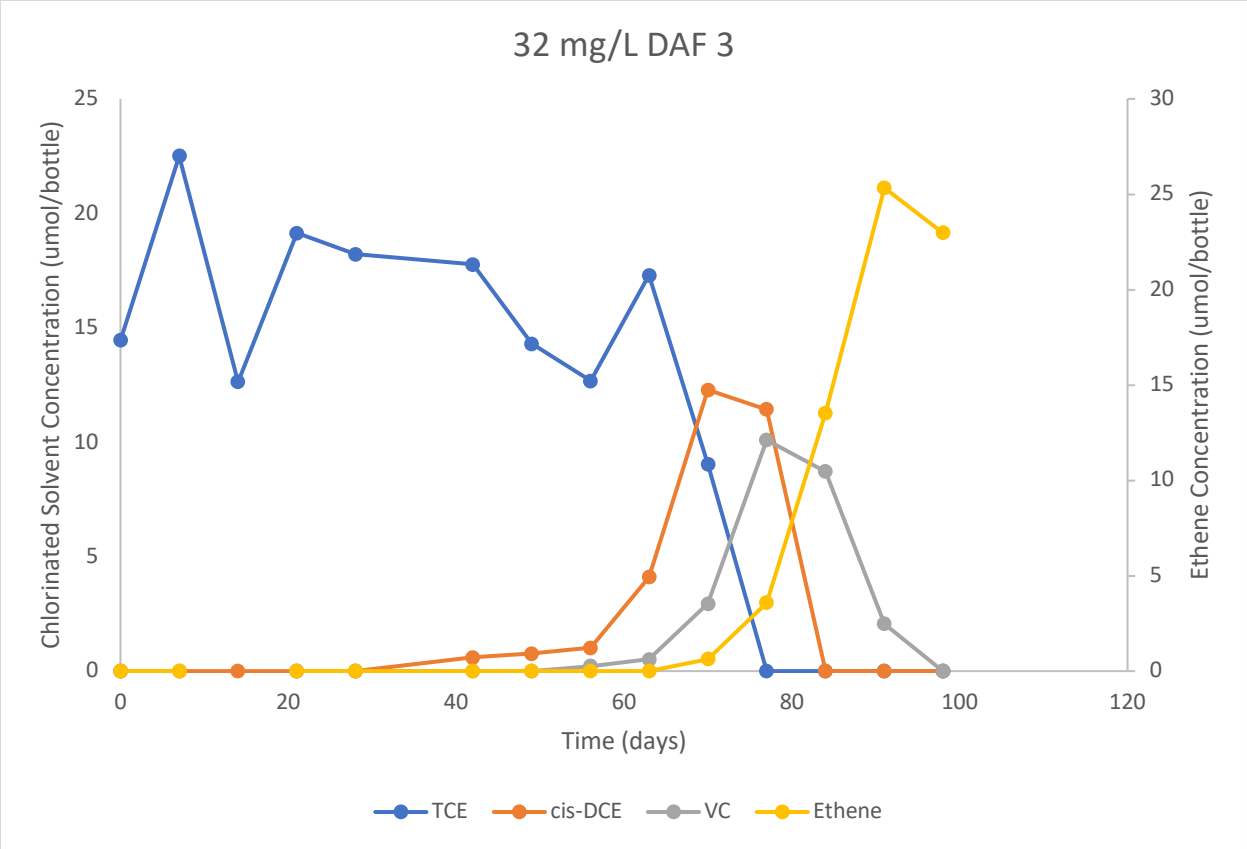
Appendix Figure 27. 3.2 mg/L DAF dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



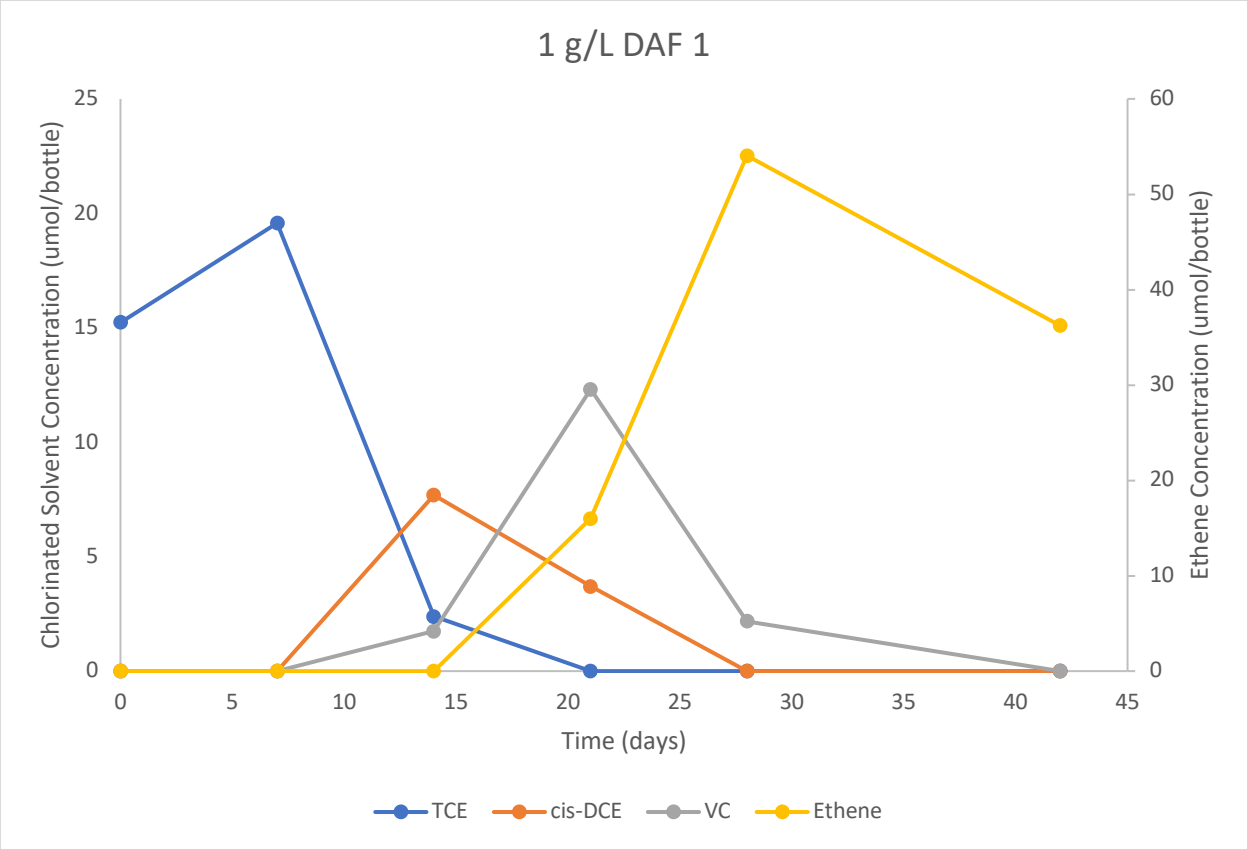
Appendix Figure 28. 32 mg/L DAF dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



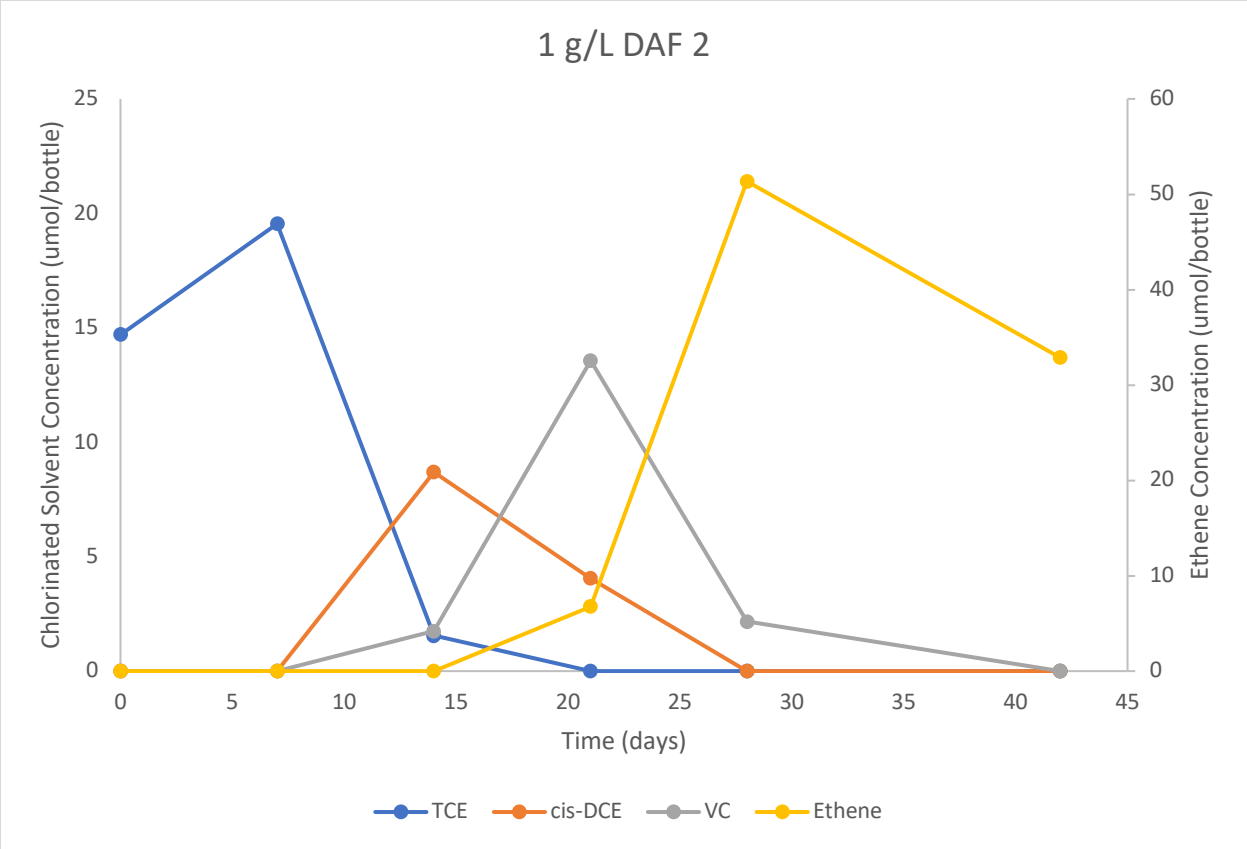
Appendix Figure 29. 32 mg/L DAF dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



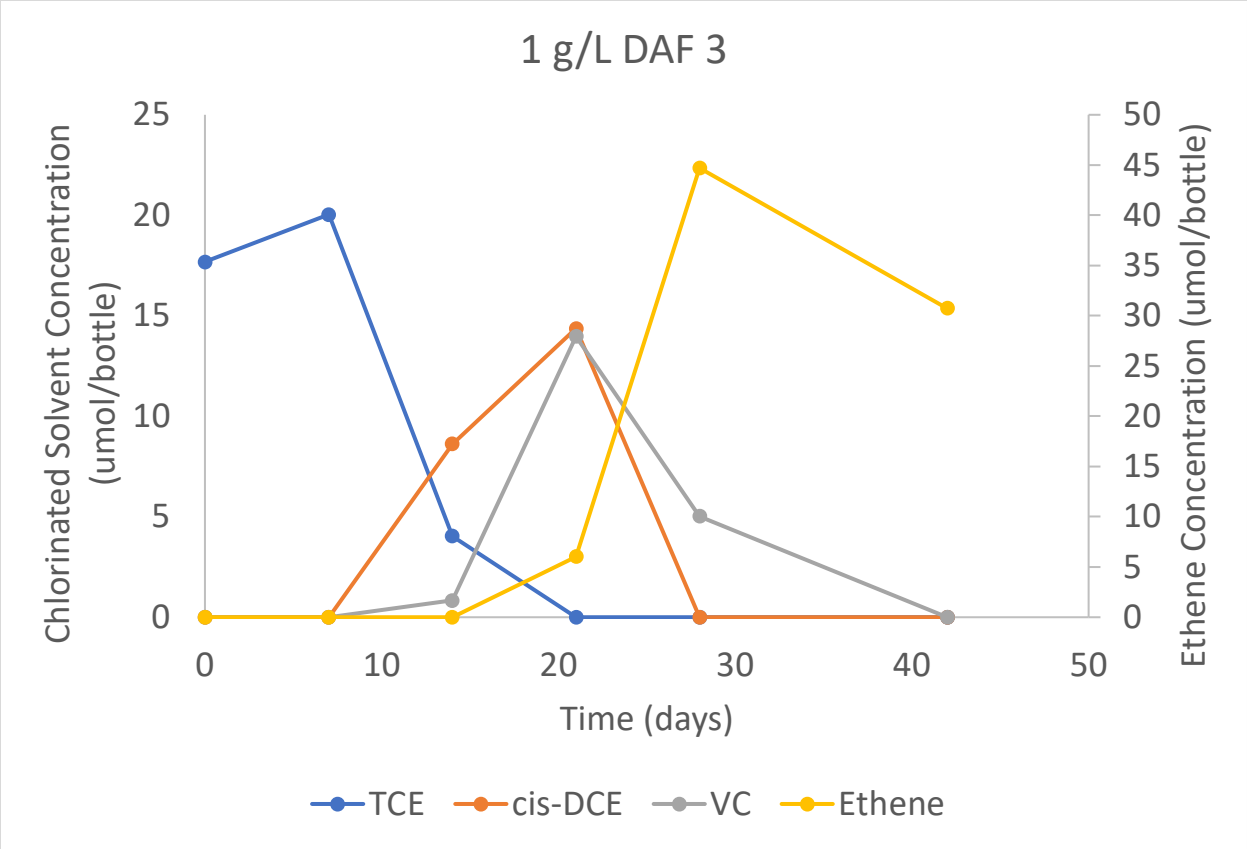
Appendix Figure 30. 32 mg/L DAF dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



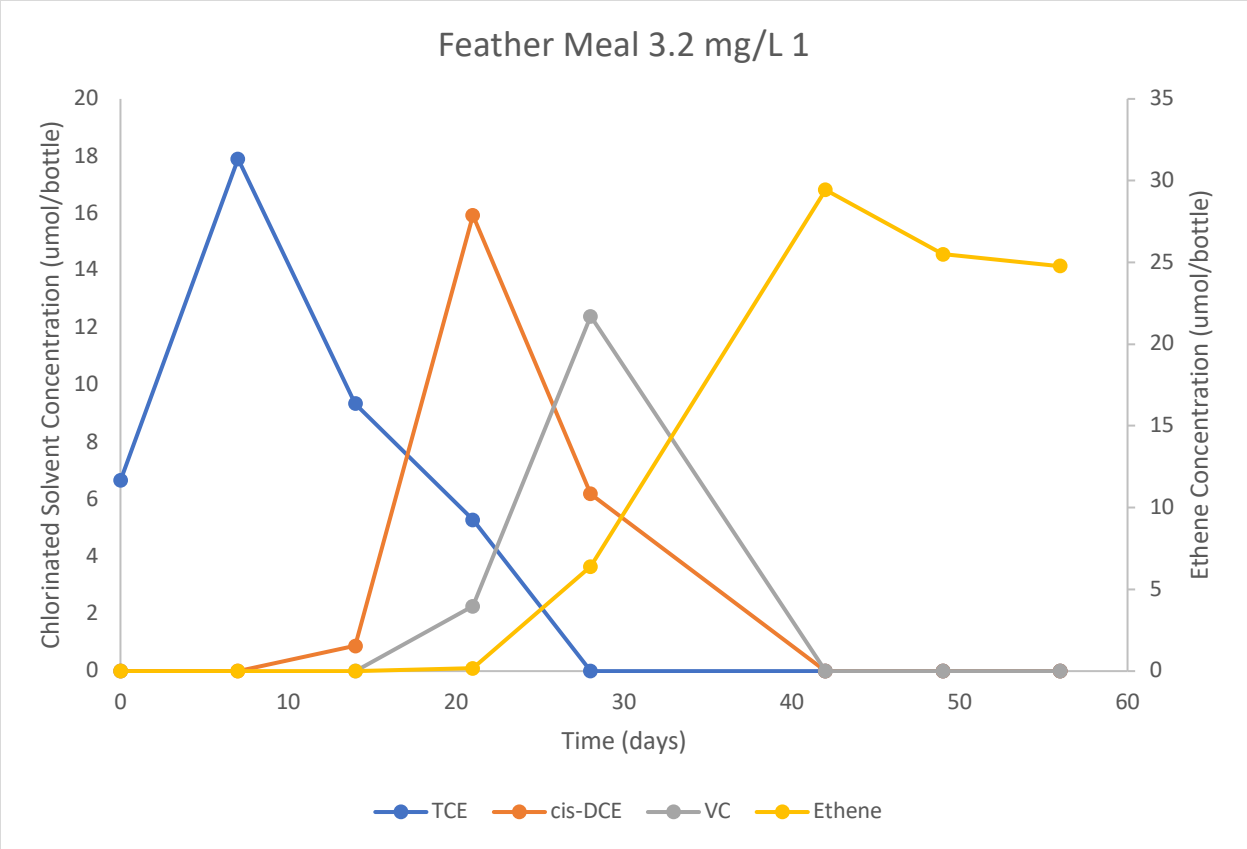
Appendix Figure 31. 1 g/L DAF dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



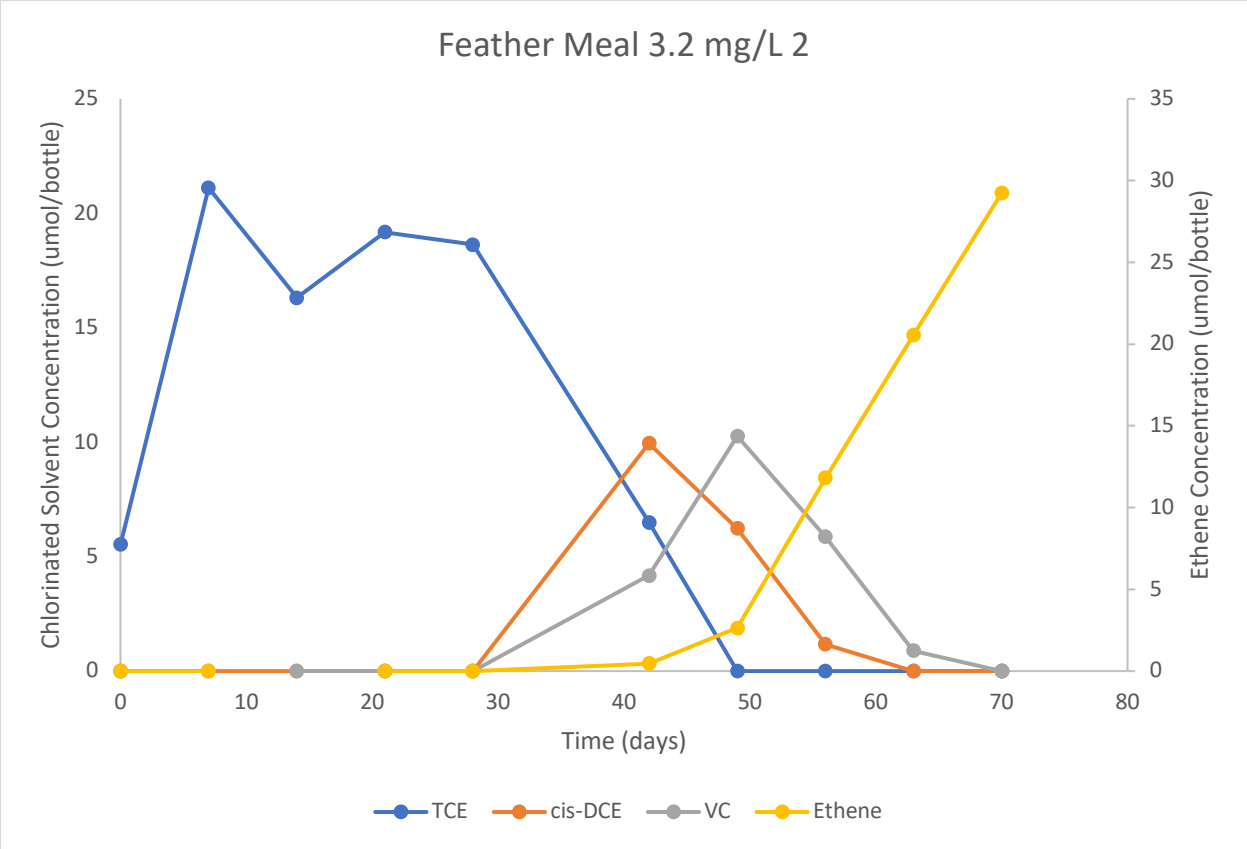
Appendix Figure 32. 1 g/L DAF dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



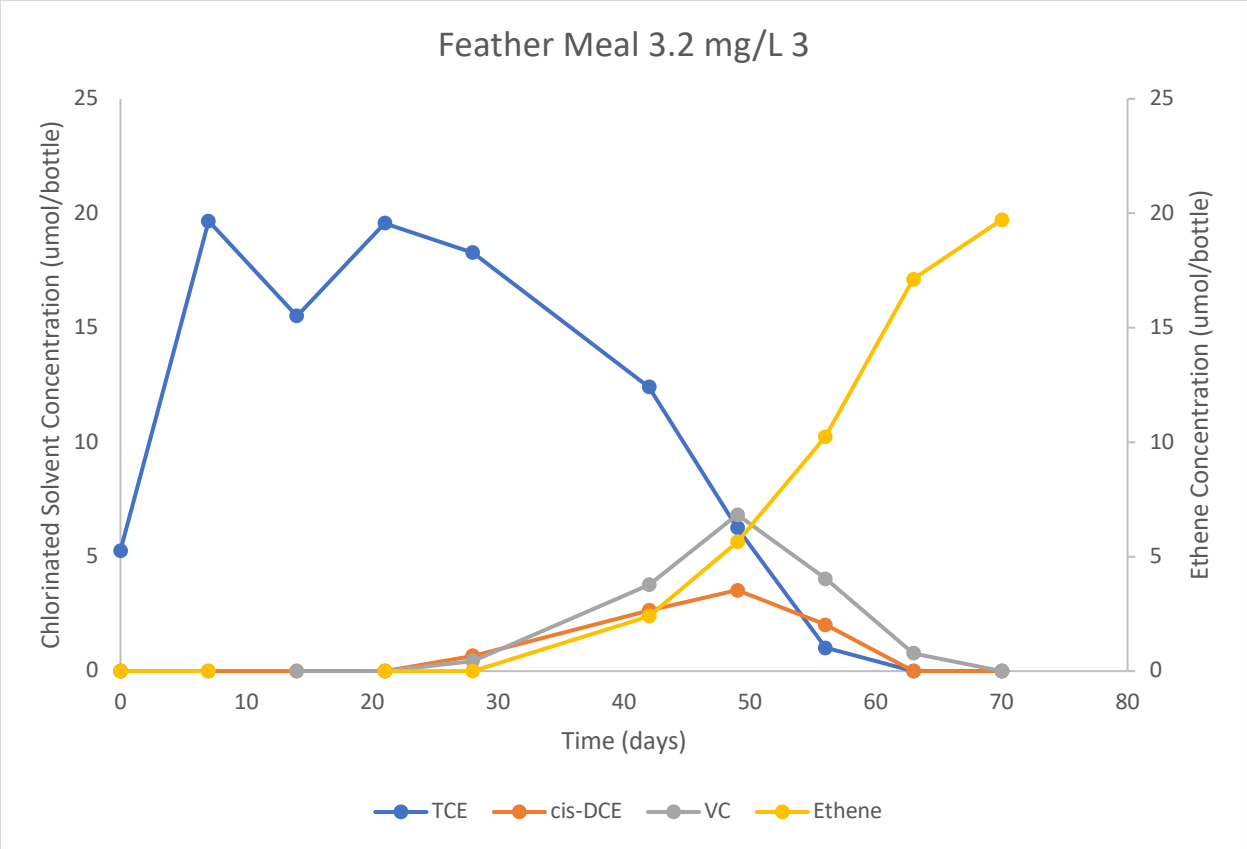
Appendix Figure 33. 1 g/L DAF dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



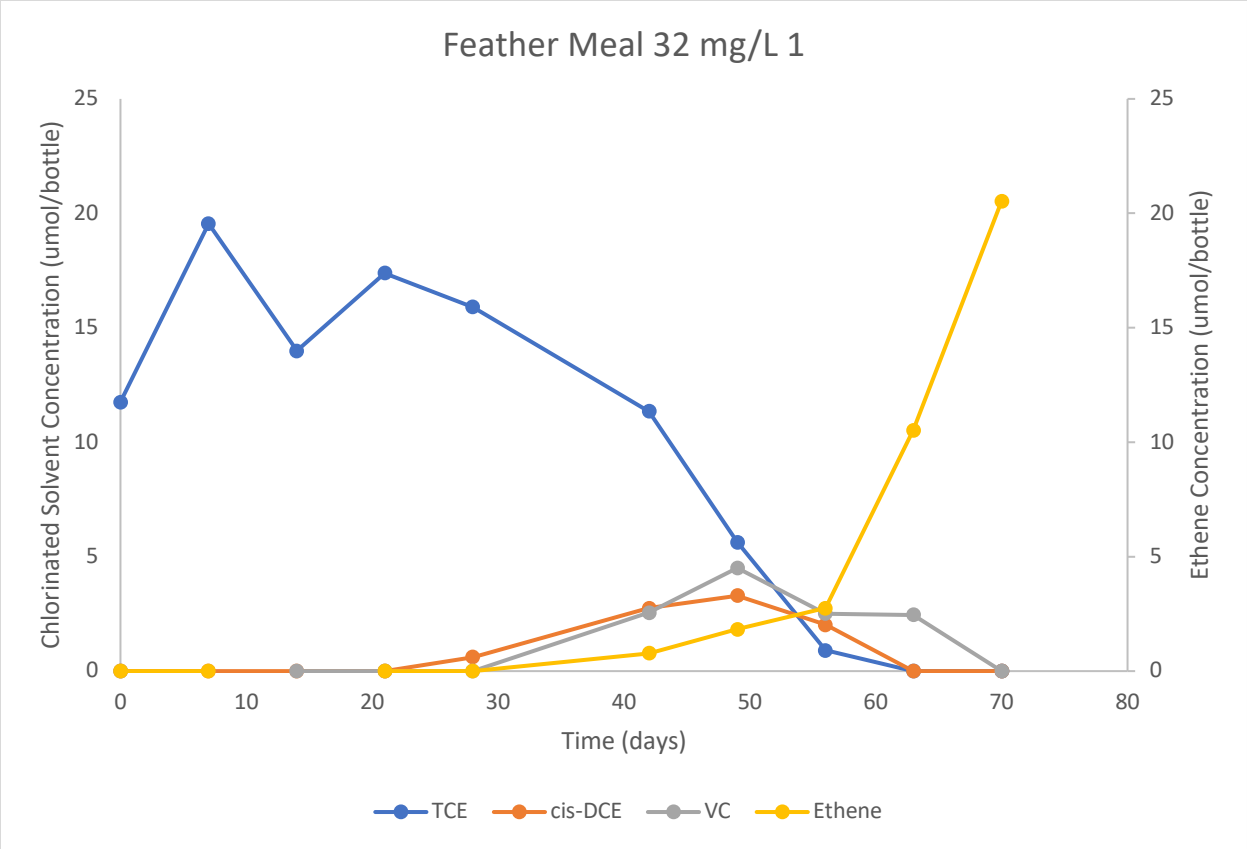
Appendix Figure 34. 3.2 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



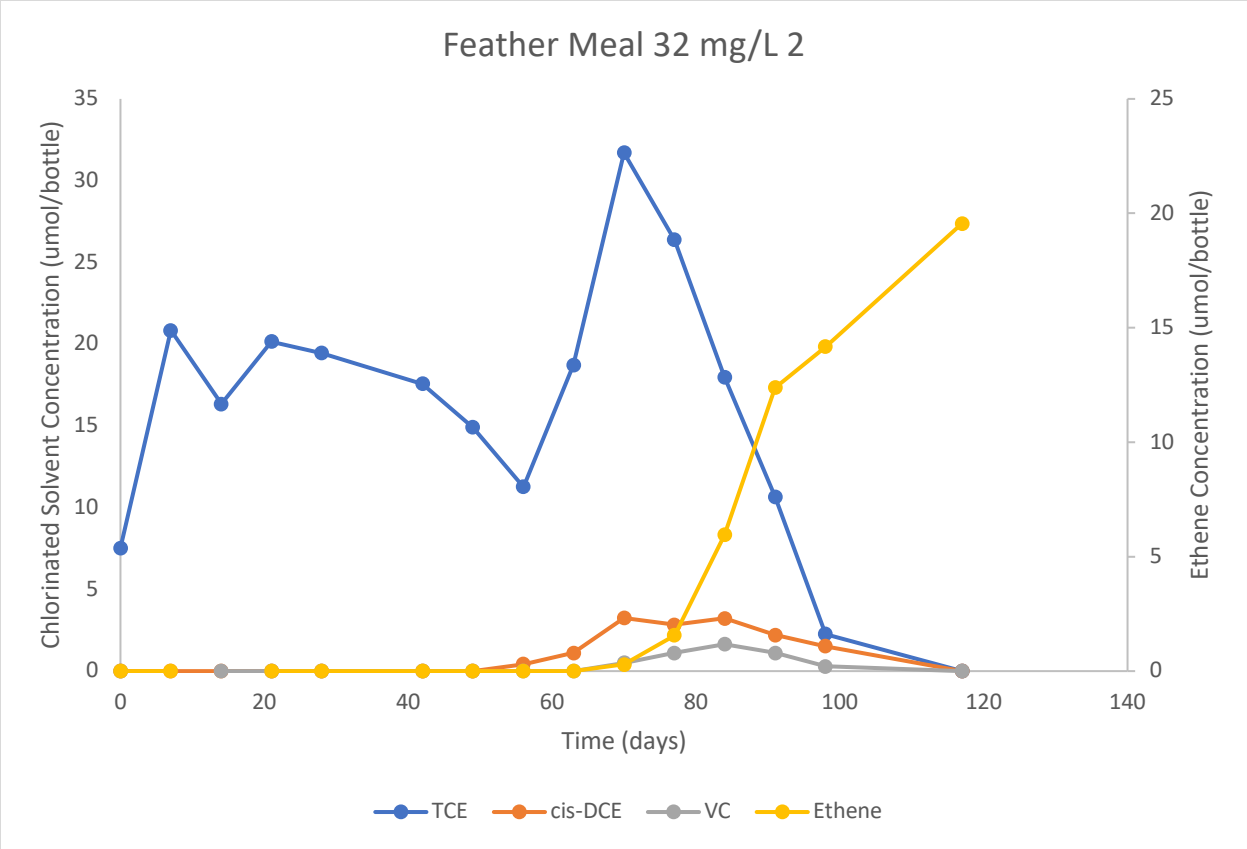
Appendix Figure 35. 3.2 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



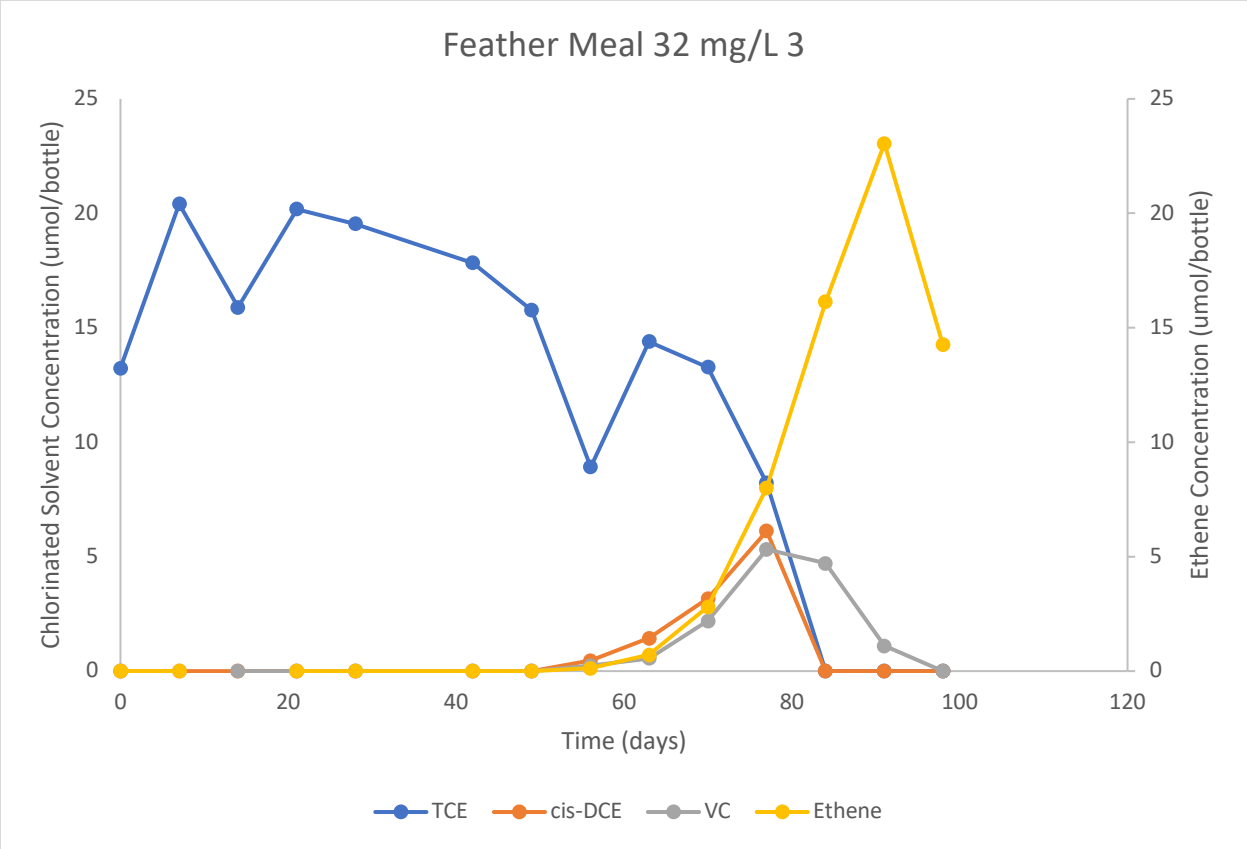
Appendix Figure 36. 3.2 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



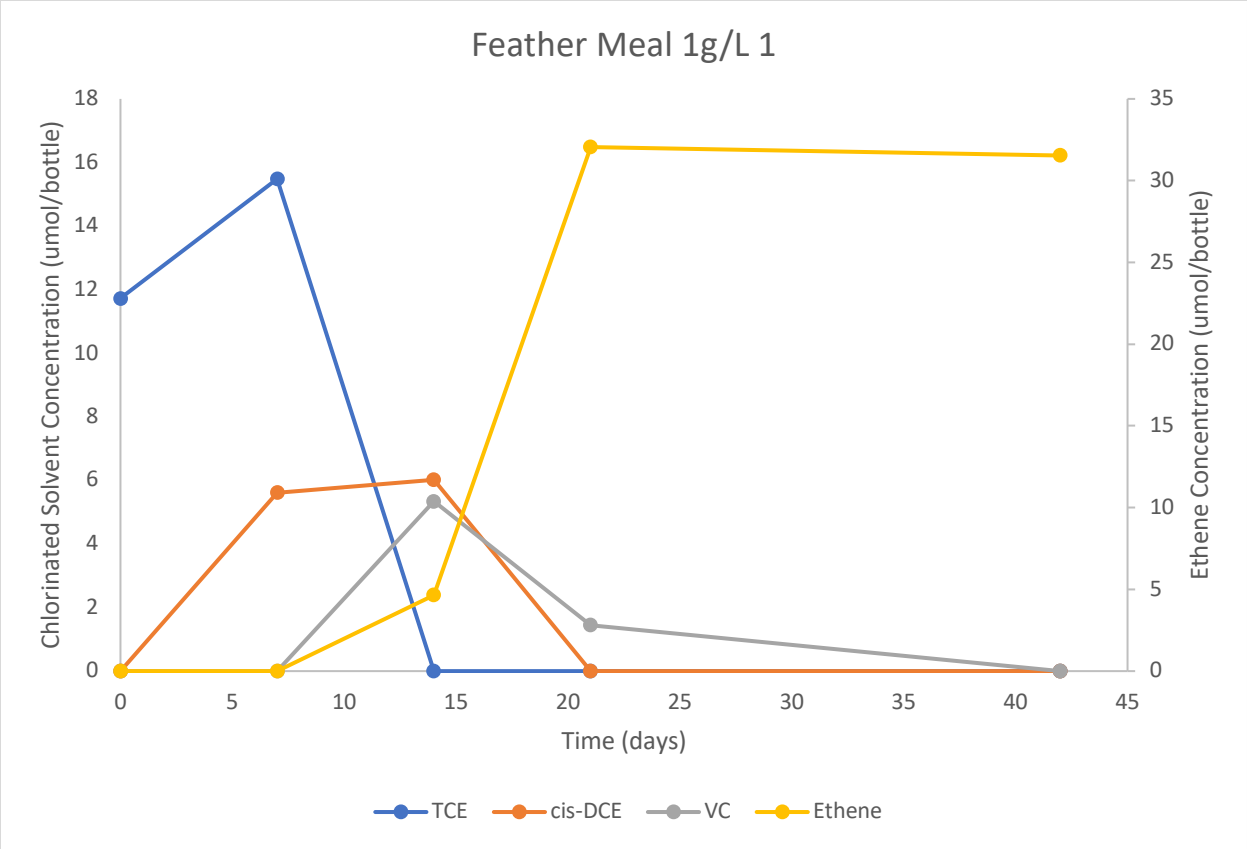
Appendix Figure 37. 32 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



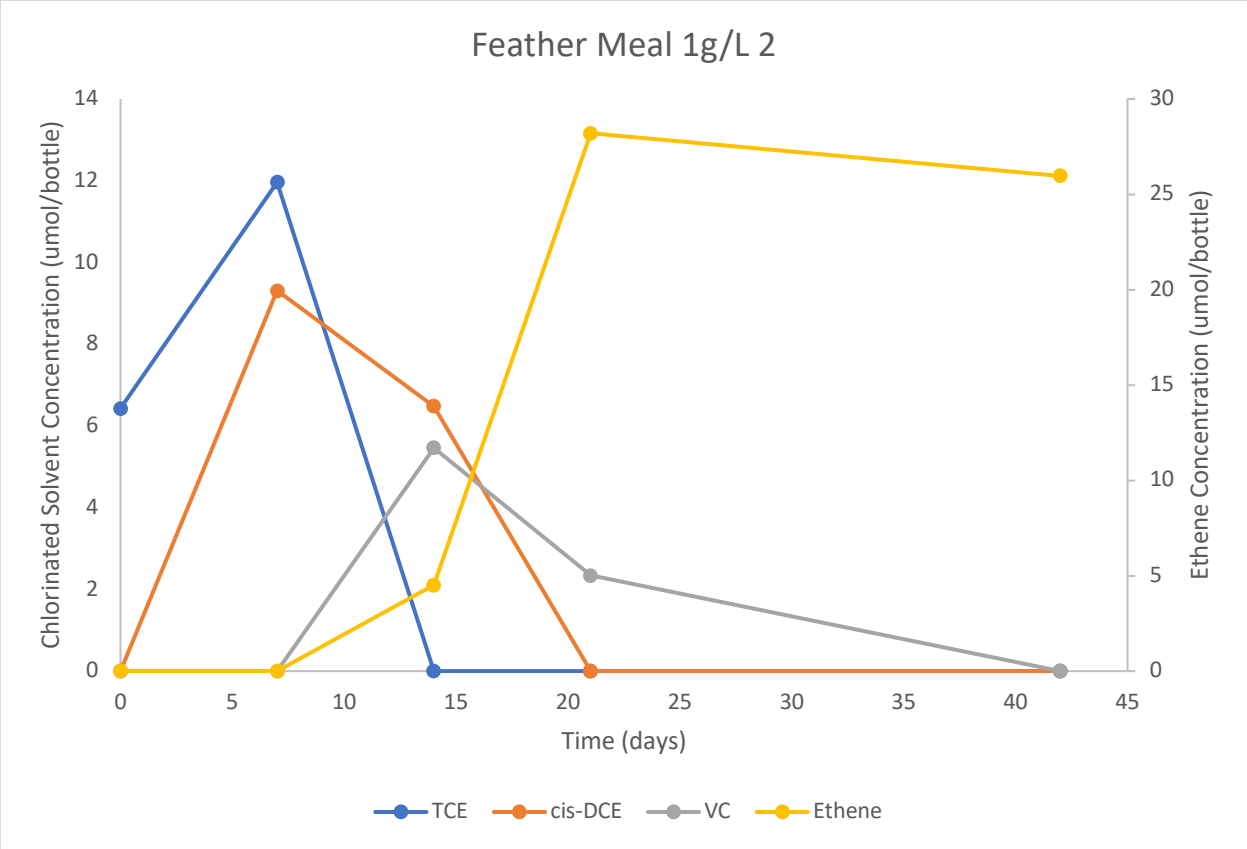
Appendix Figure 38. 32 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



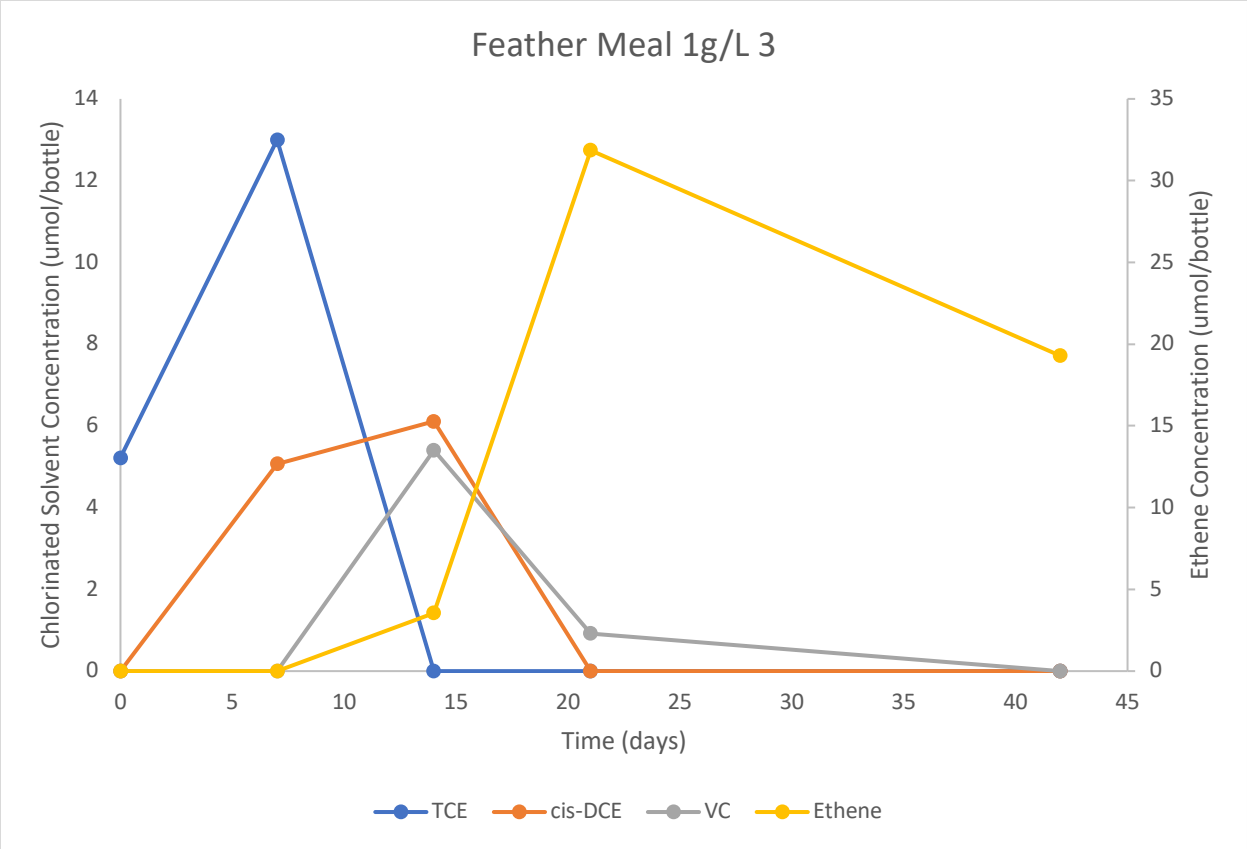
Appendix Figure 39. 32 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



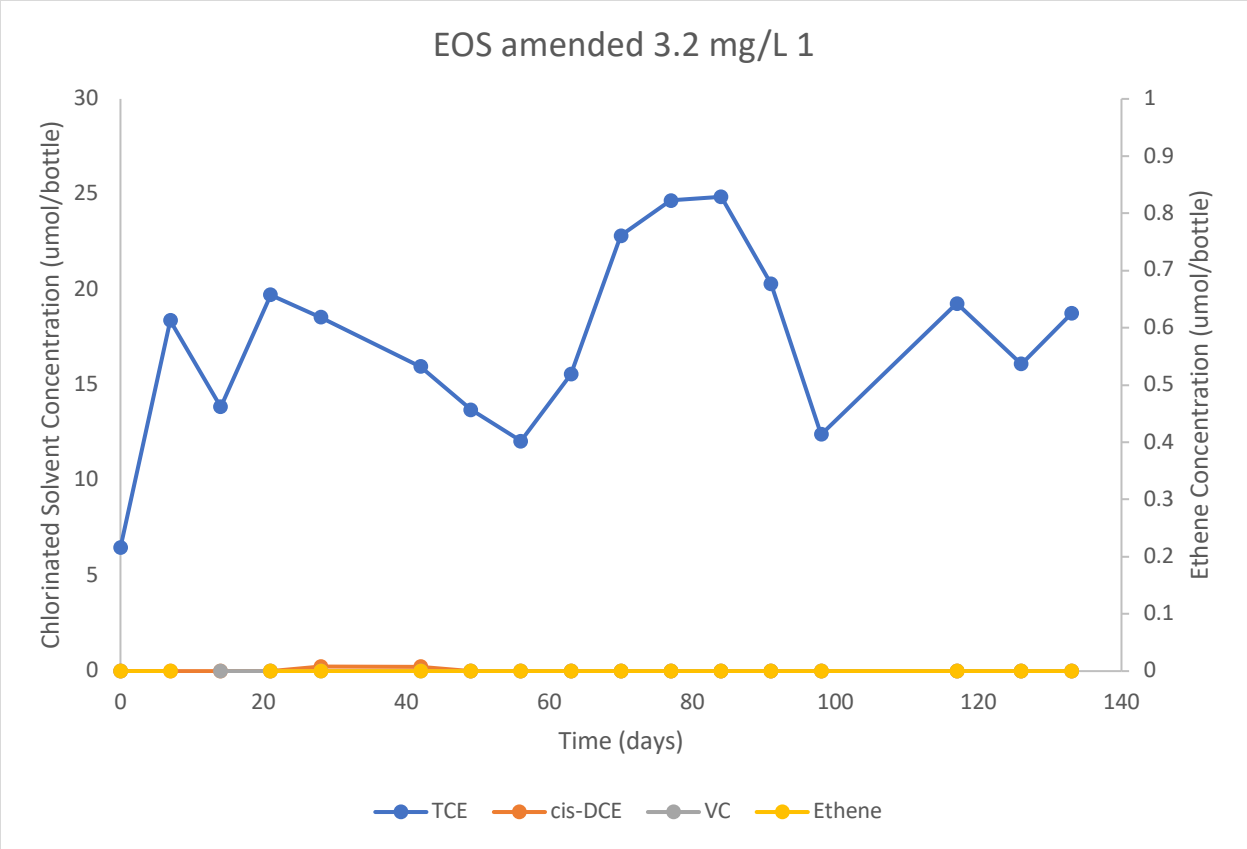
Appendix Figure 40. 1 g/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



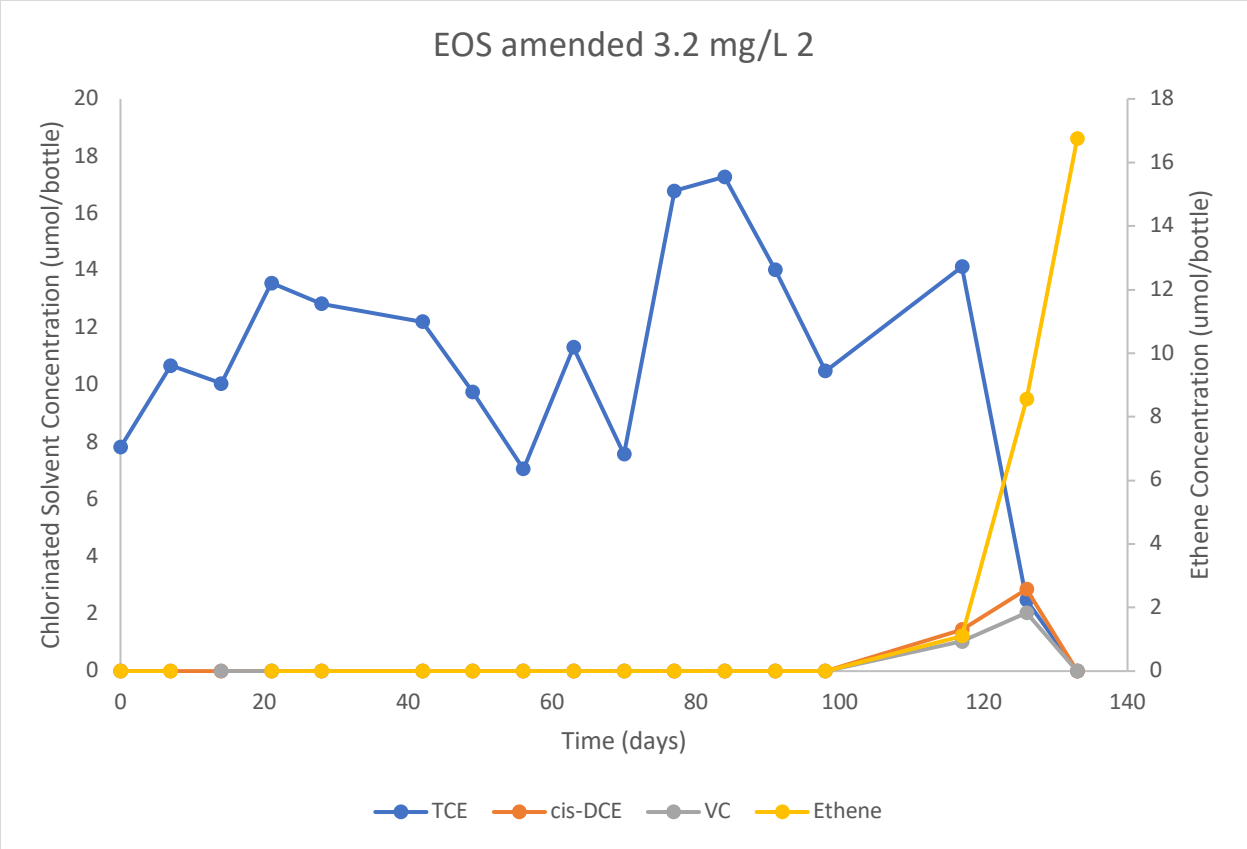
Appendix Figure 41. 1 g/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



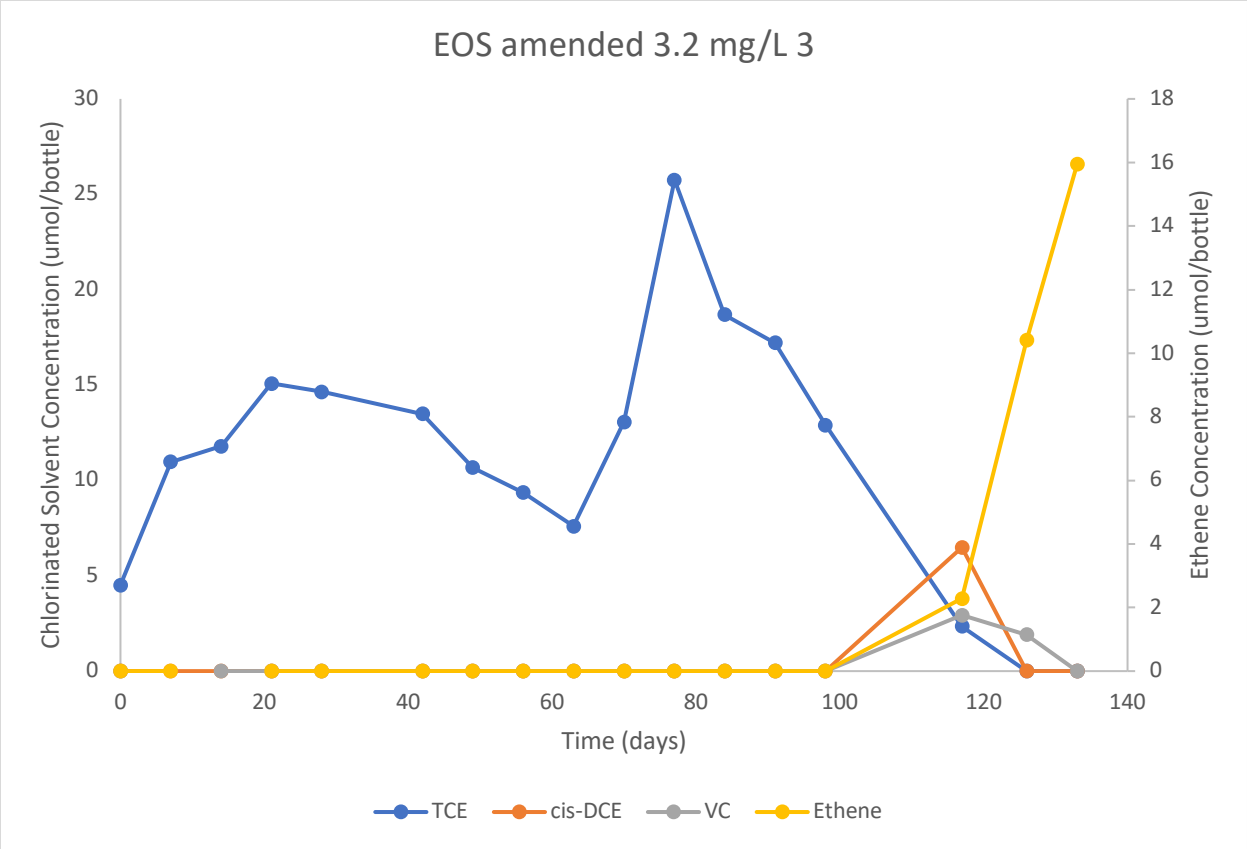
Appendix Figure 42. 1 g/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



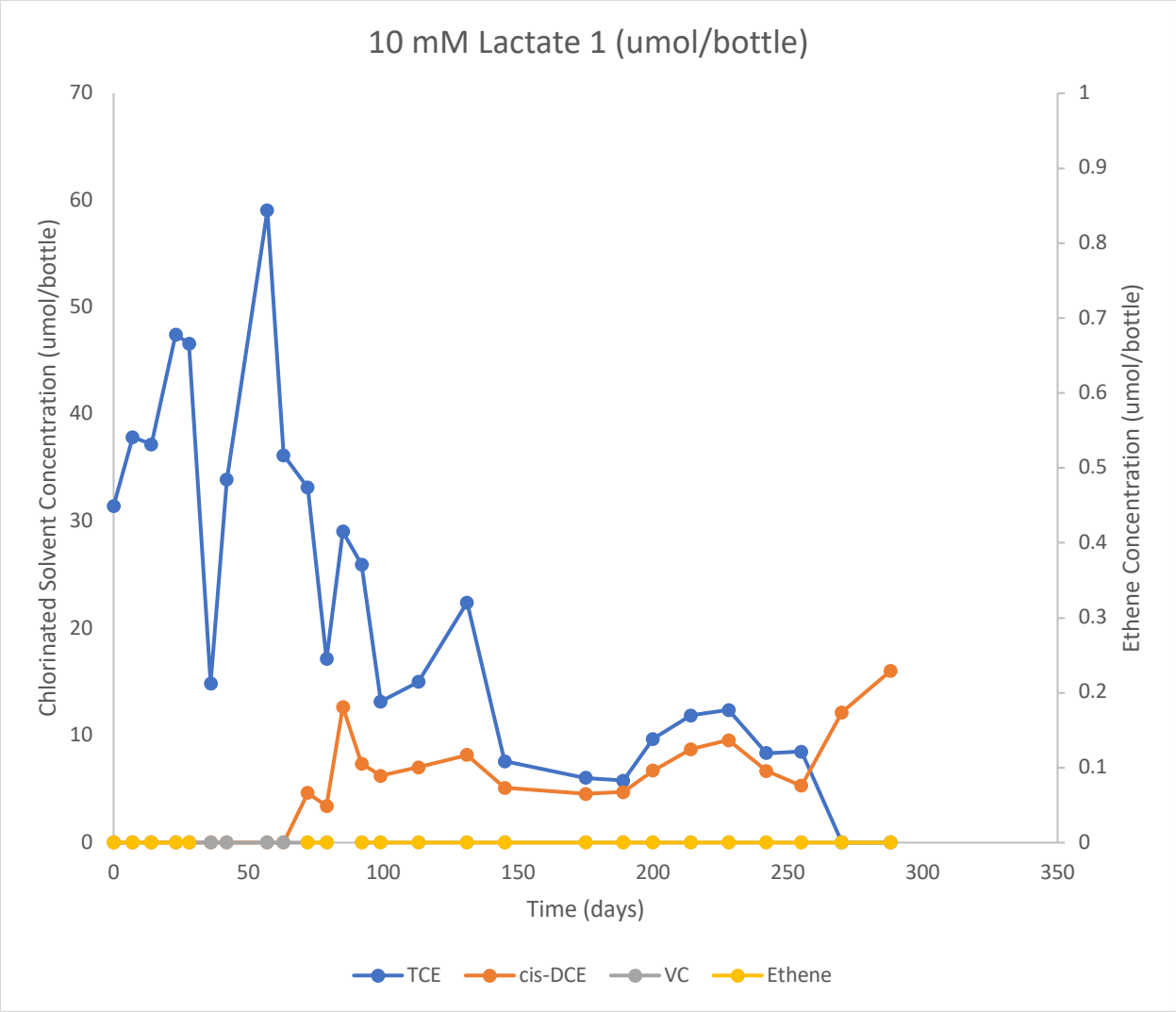
Appendix Figure 43. 3.2 mg/L EOS amended control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



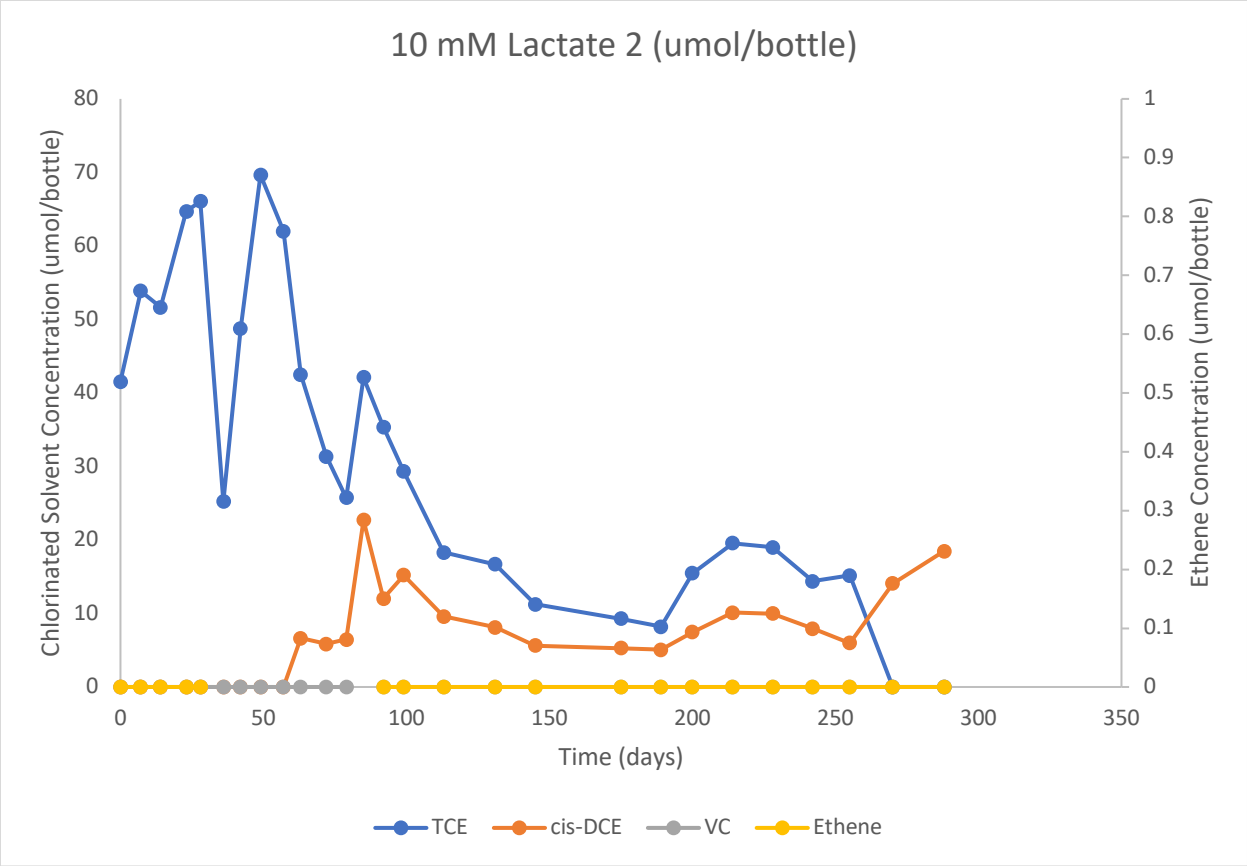
Appendix Figure 44. 3.2 mg/L EOS amended control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



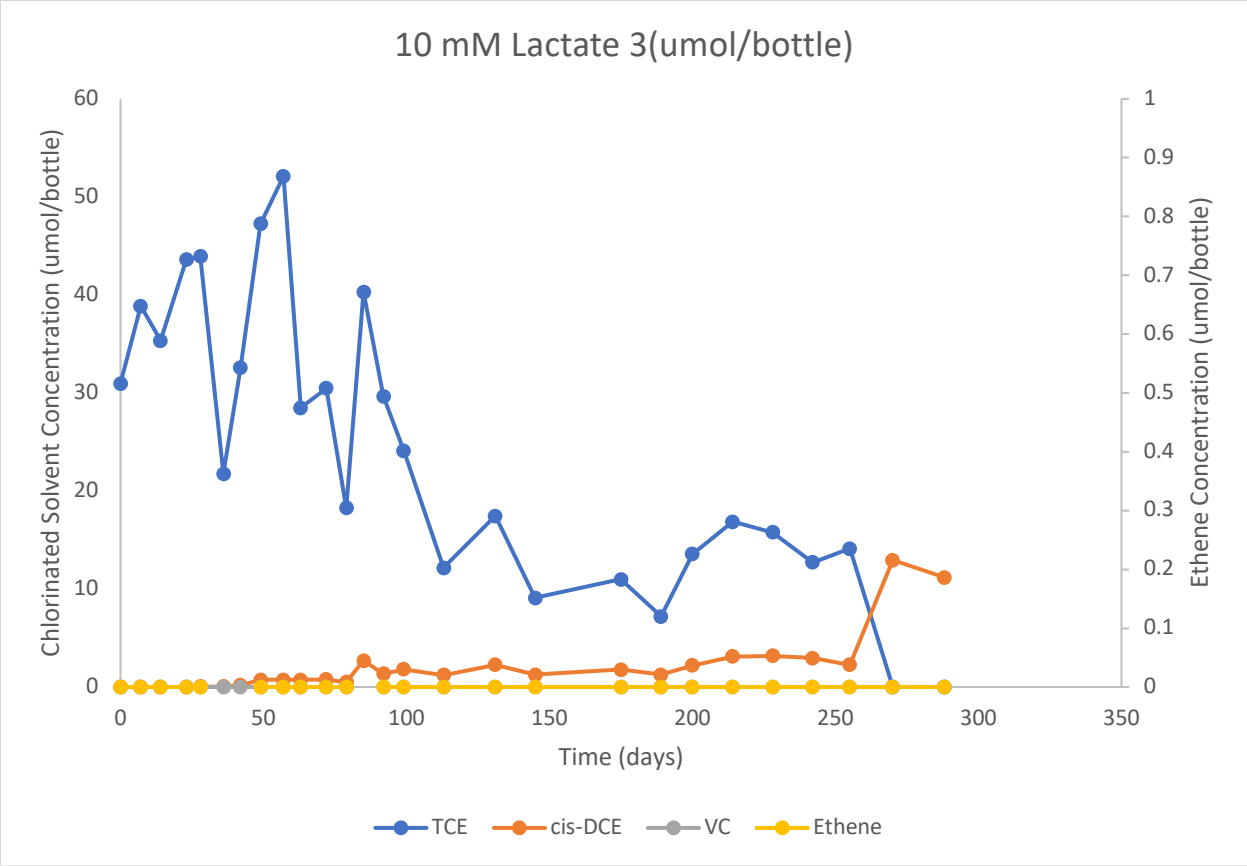
Appendix Figure 45. 3.2 mg/L EOS amended control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from Easley, South Carolina.



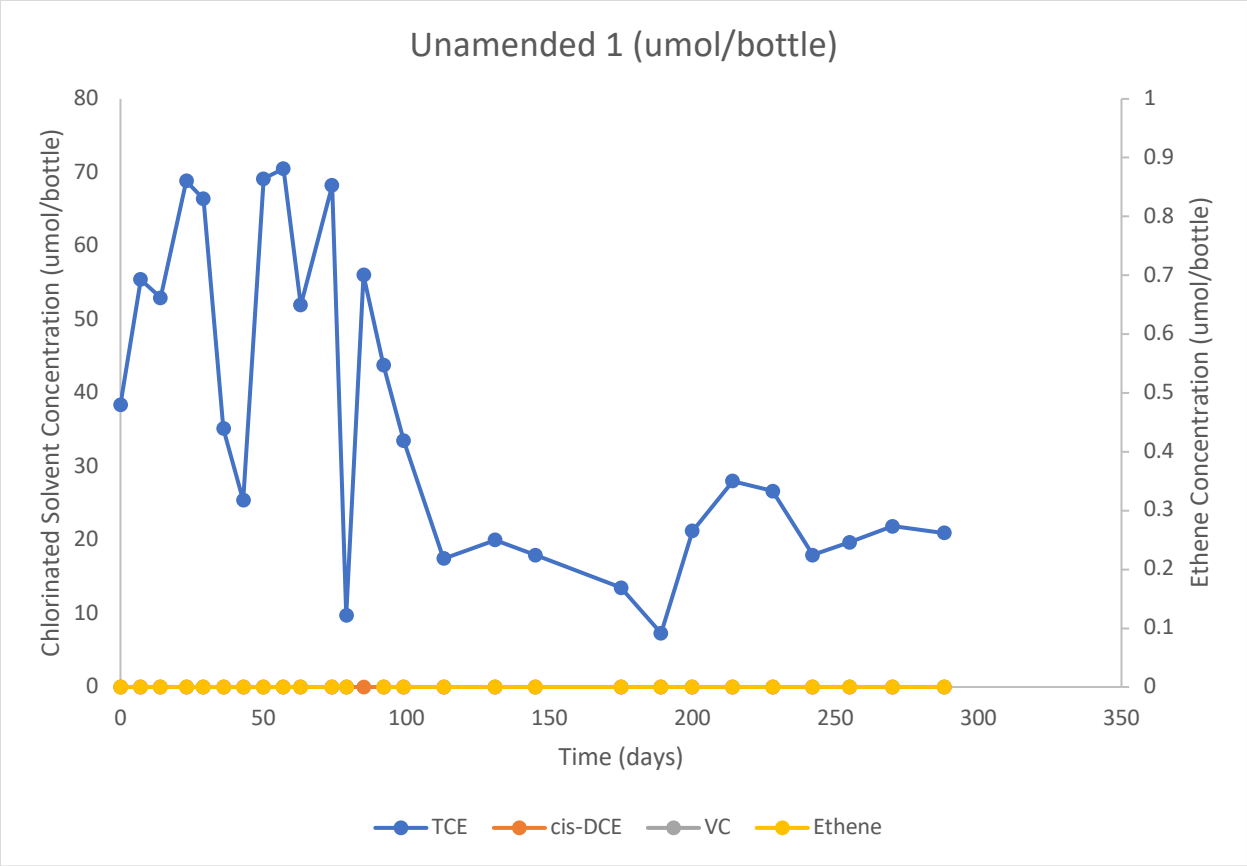
Appendix Figure 46. 10 mM Lactate amended control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



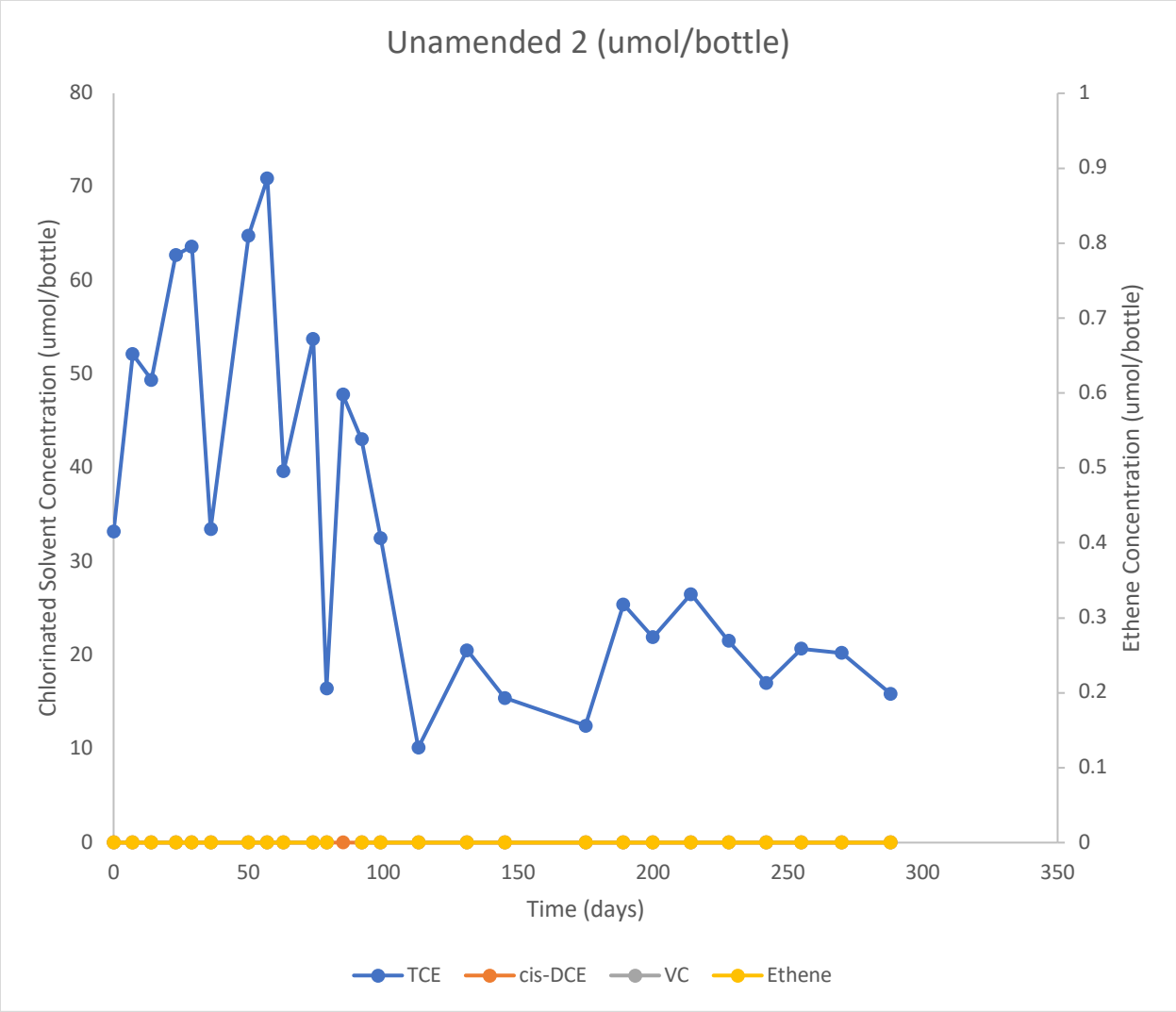
Appendix Figure 47. 10 mM Lactate amended control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



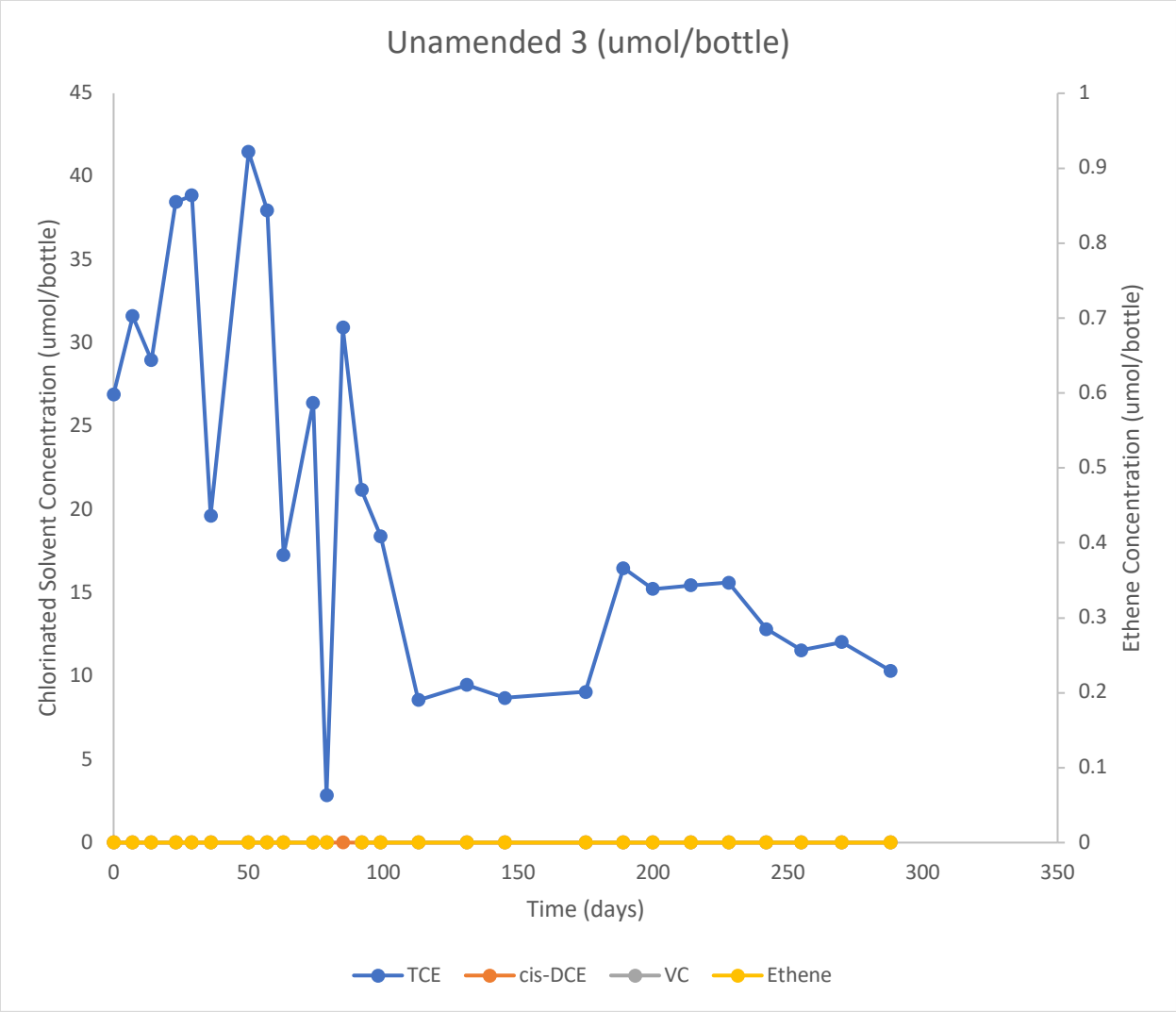
Appendix Figure 48. 10 mM Lactate amended control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



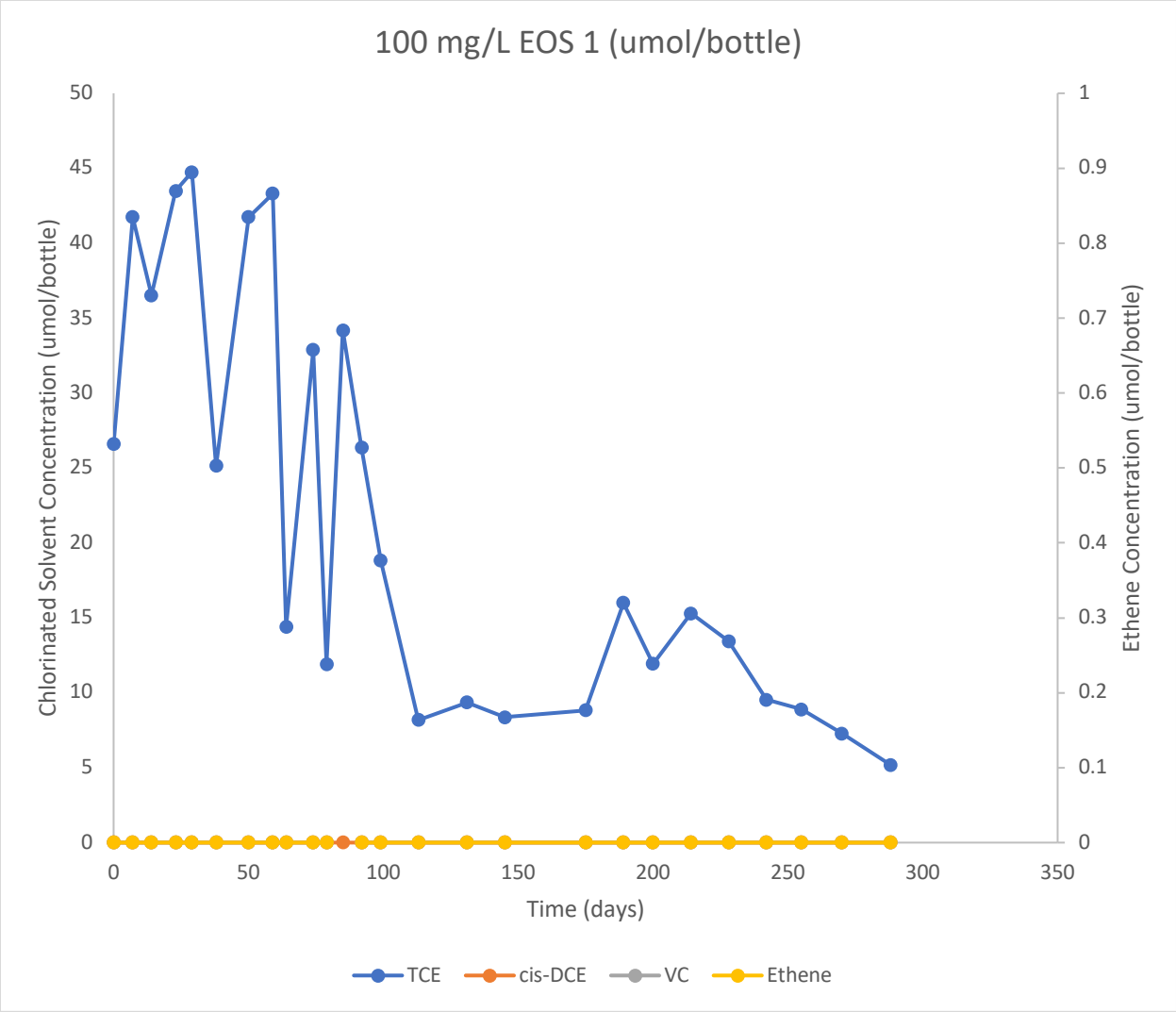
Appendix Figure 49. Unamended control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



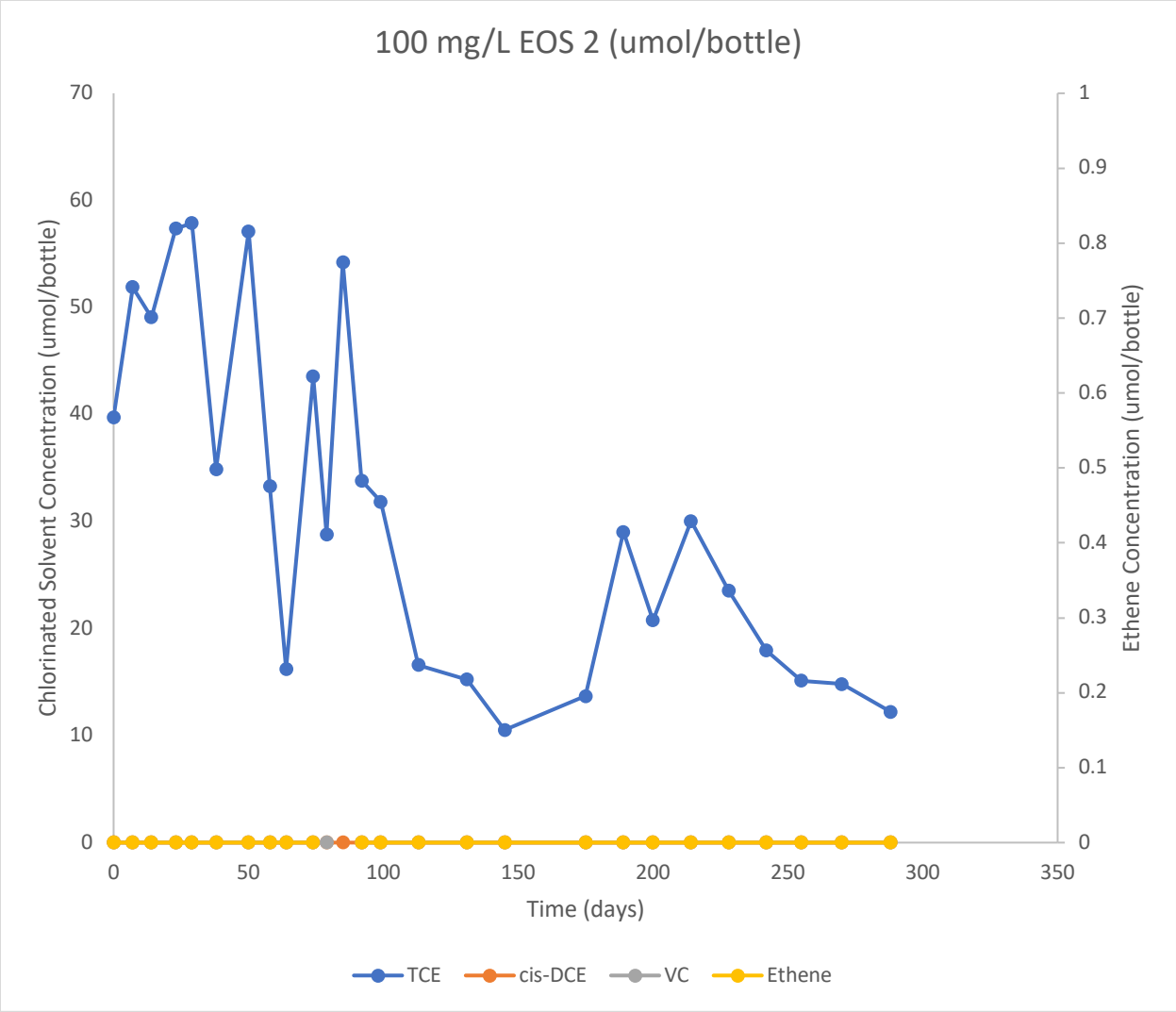
Appendix Figure 50. Unamended control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



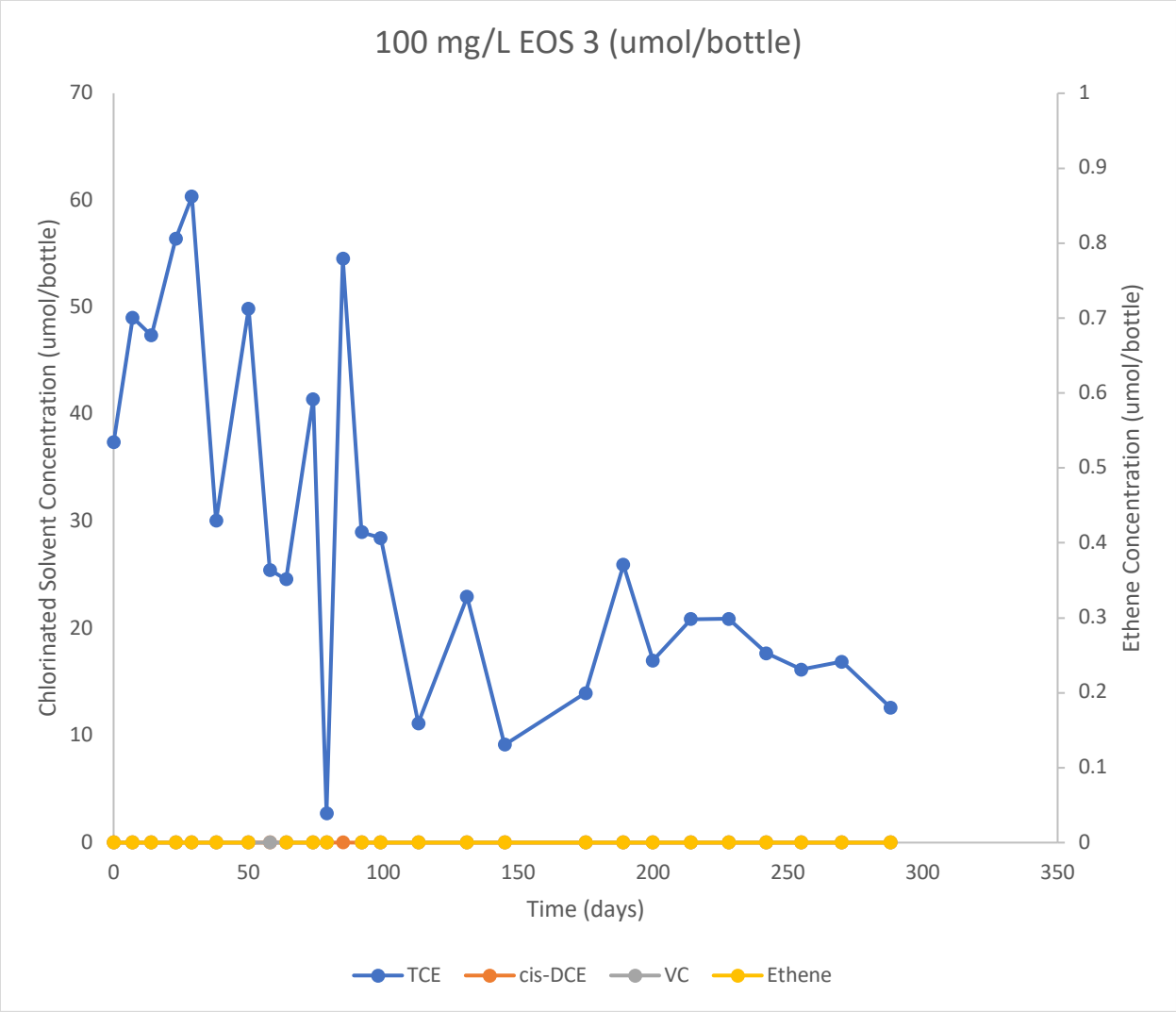
Appendix Figure 51. Unamended control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



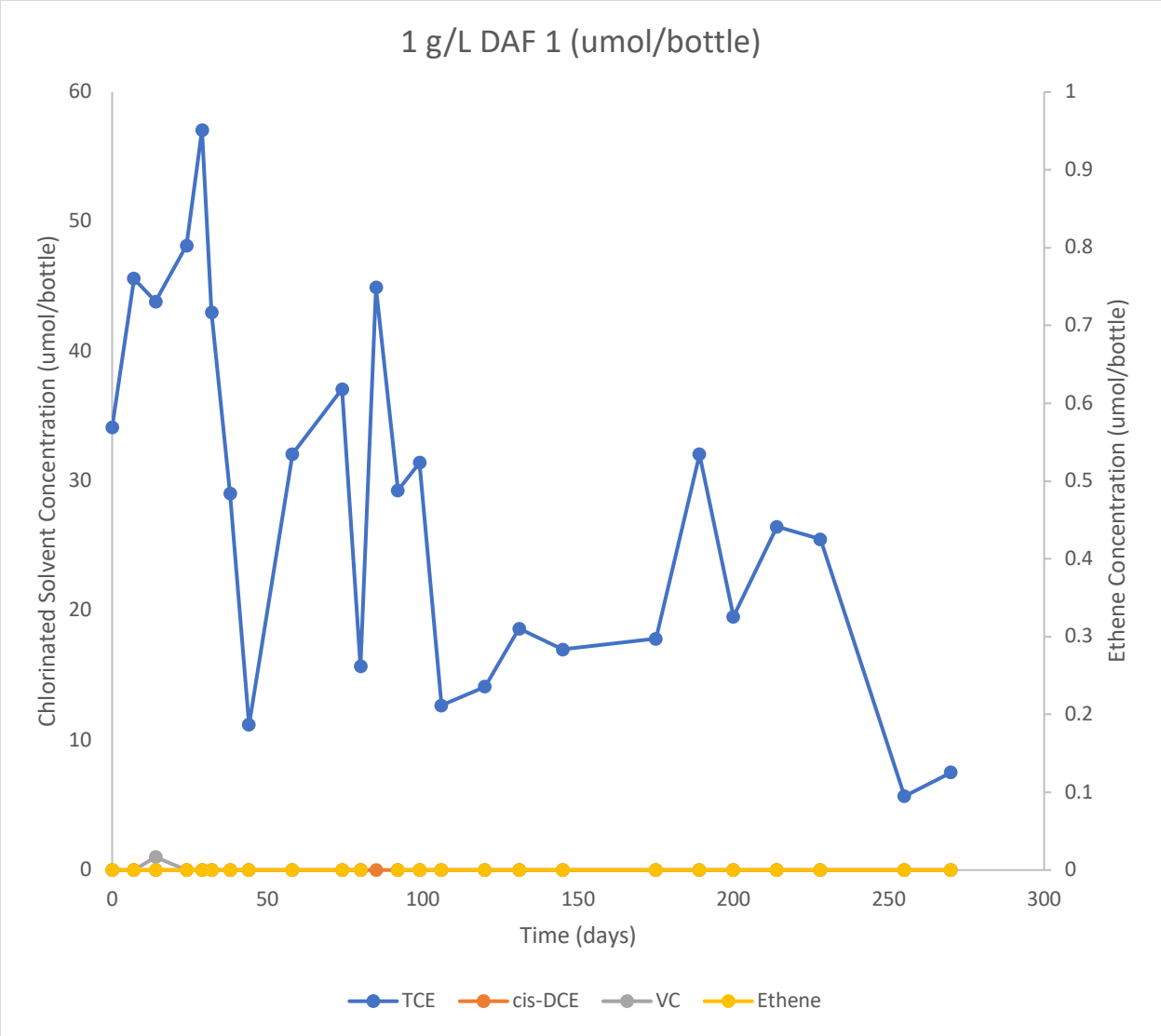
Appendix Figure 52. 100 mg/L EOS dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



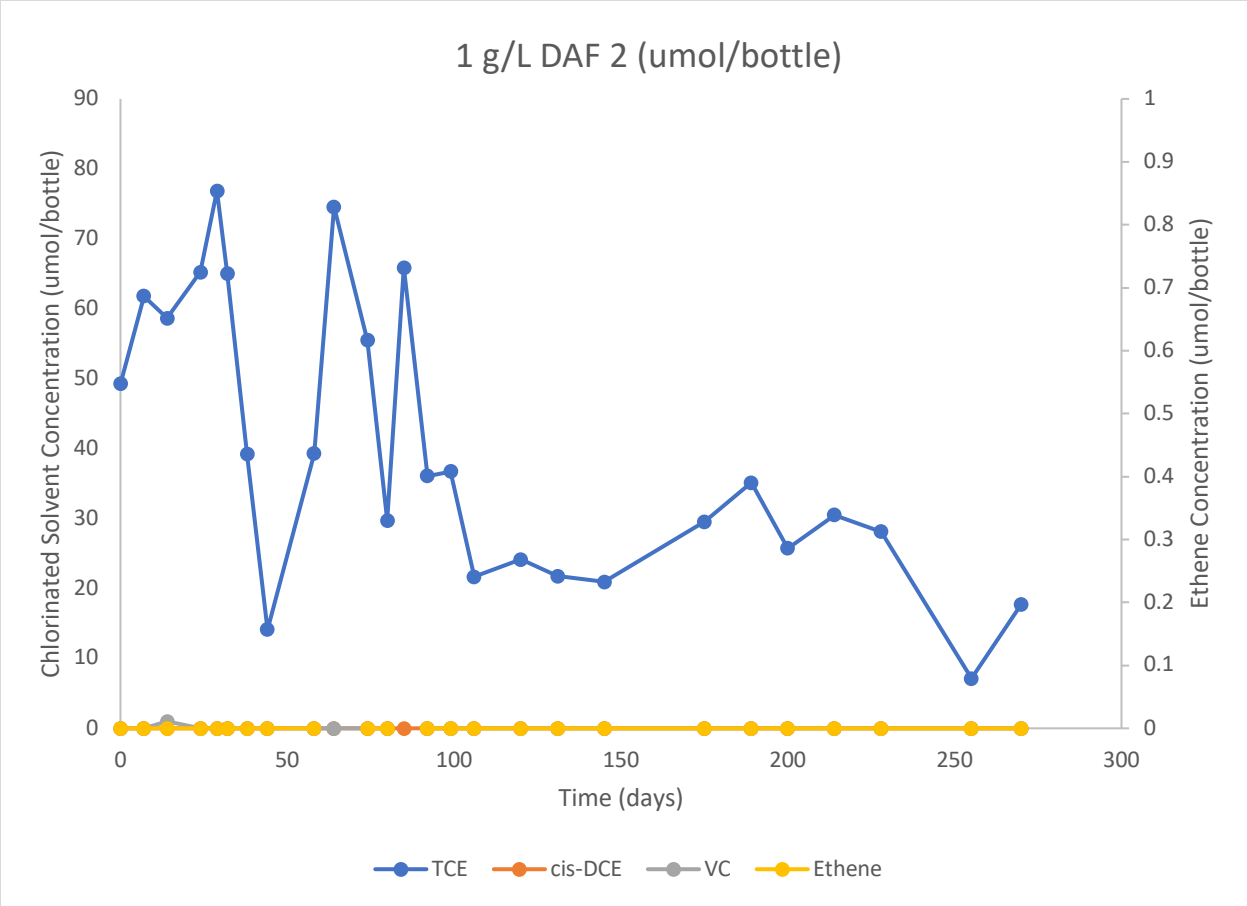
Appendix Figure 53. 100 mg/L EOS dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



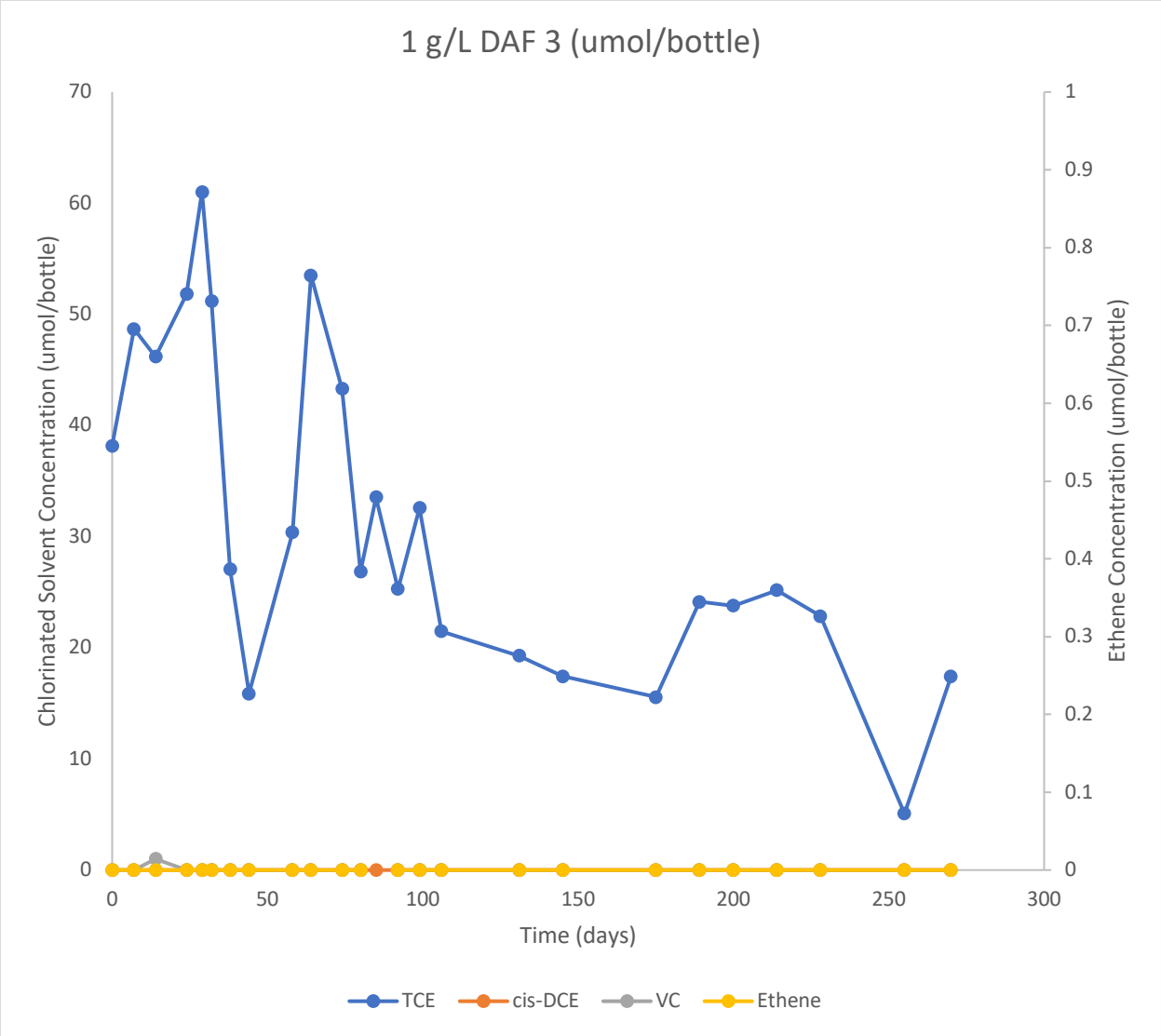
Appendix Figure 54. 100 mg/L EOS dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



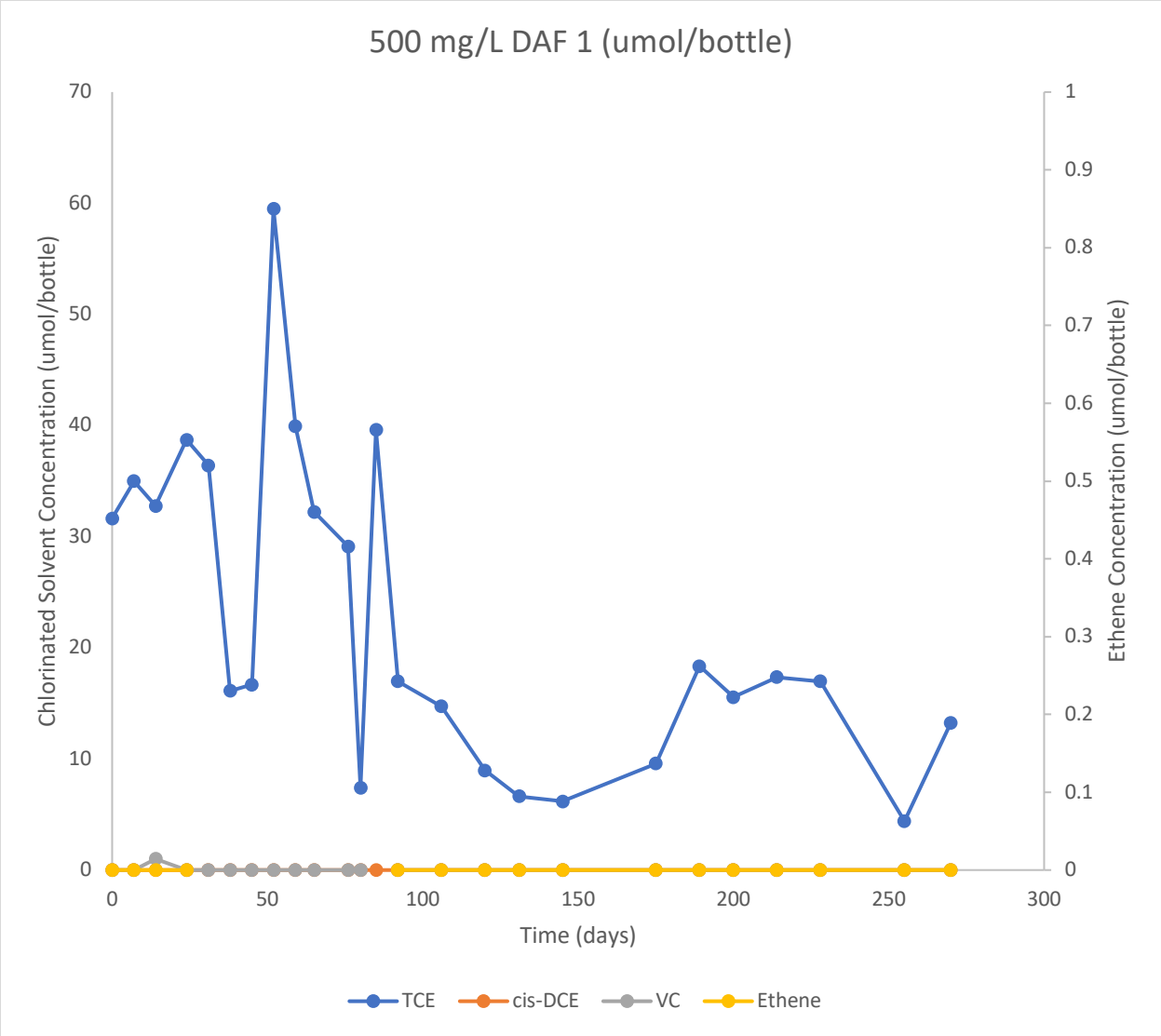
Appendix Figure 55. 1 g/L DAF dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



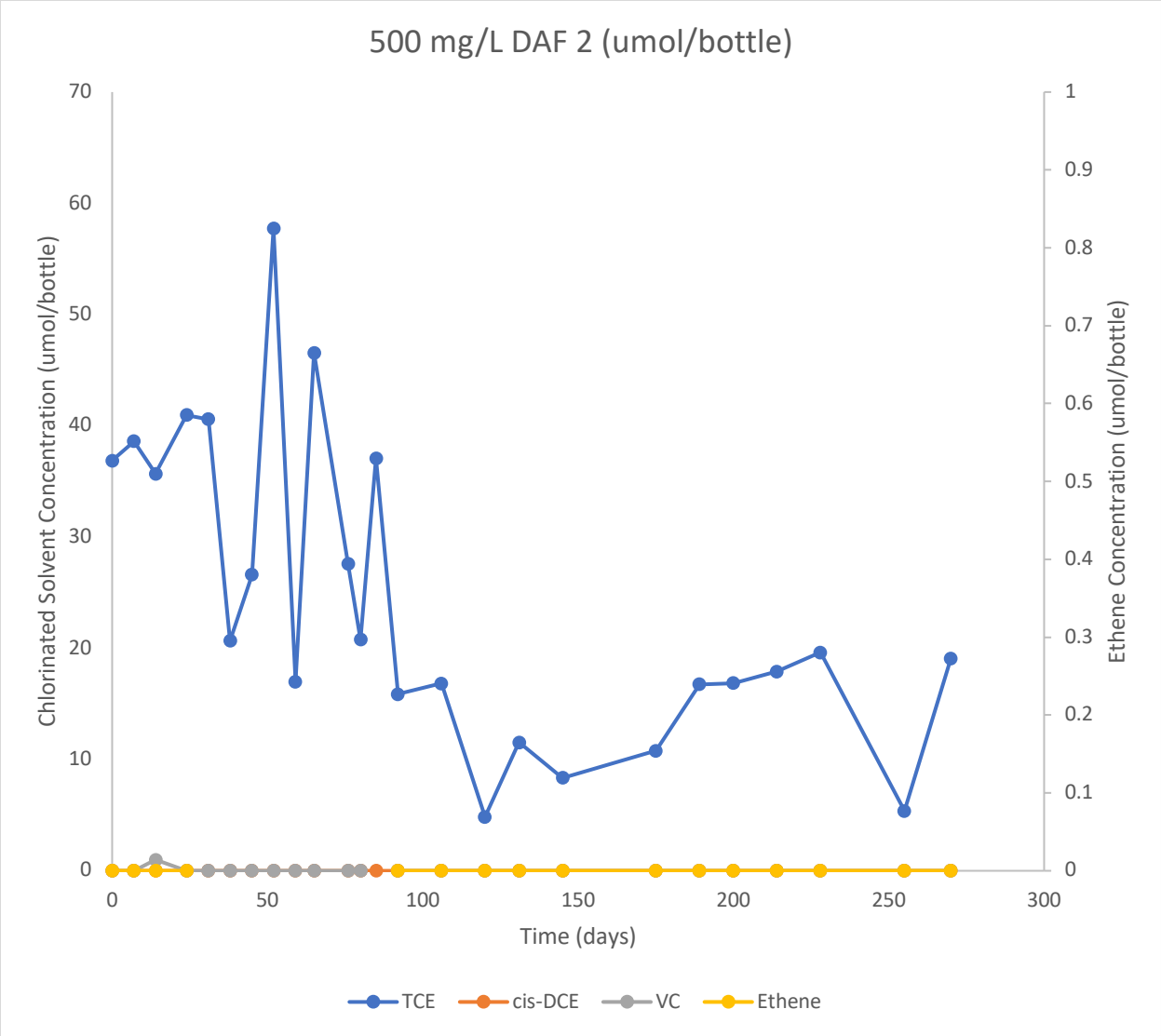
Appendix Figure 56. 1 g/L DAF dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



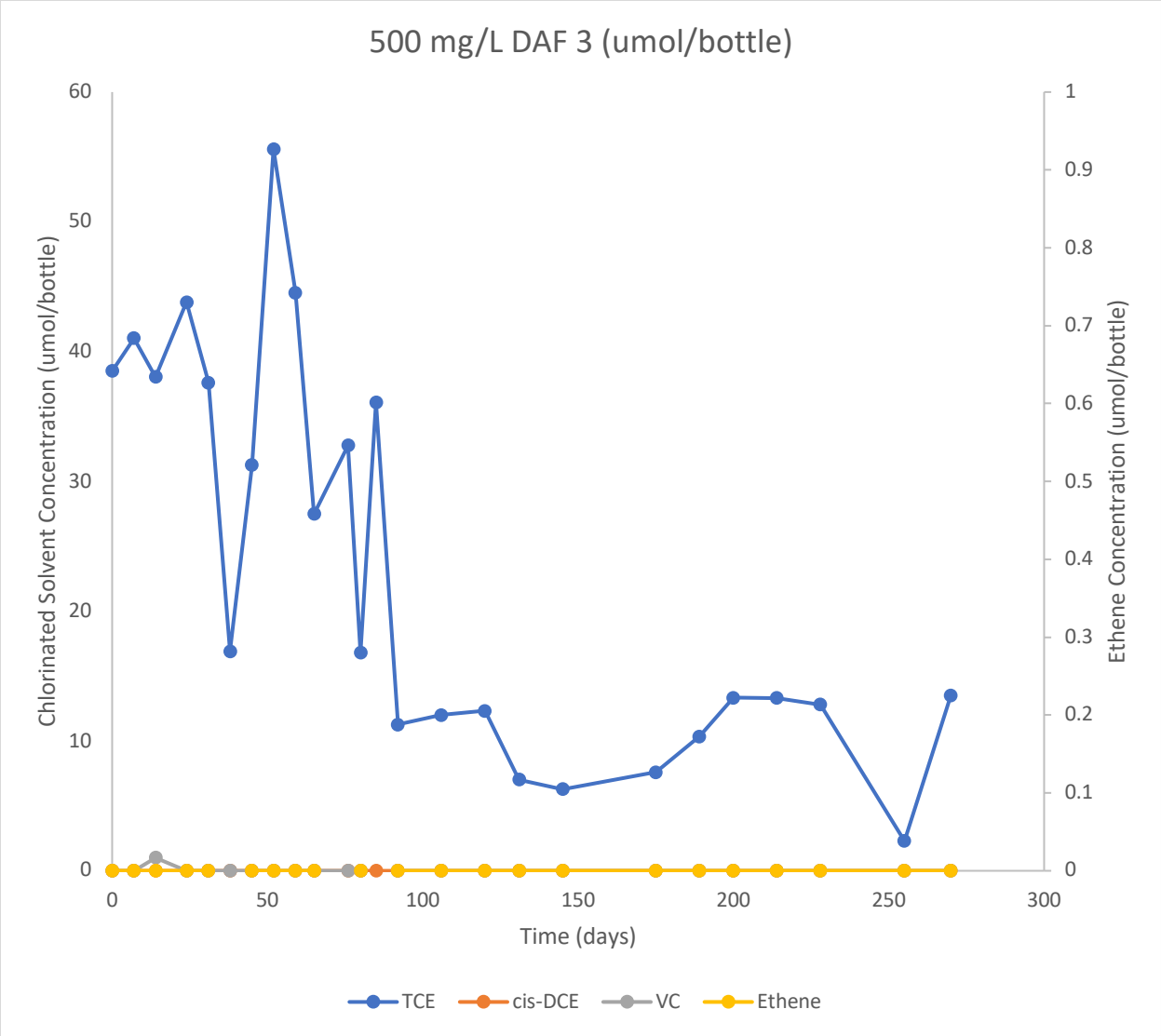
Appendix Figure 57. 1 g/L DAF dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



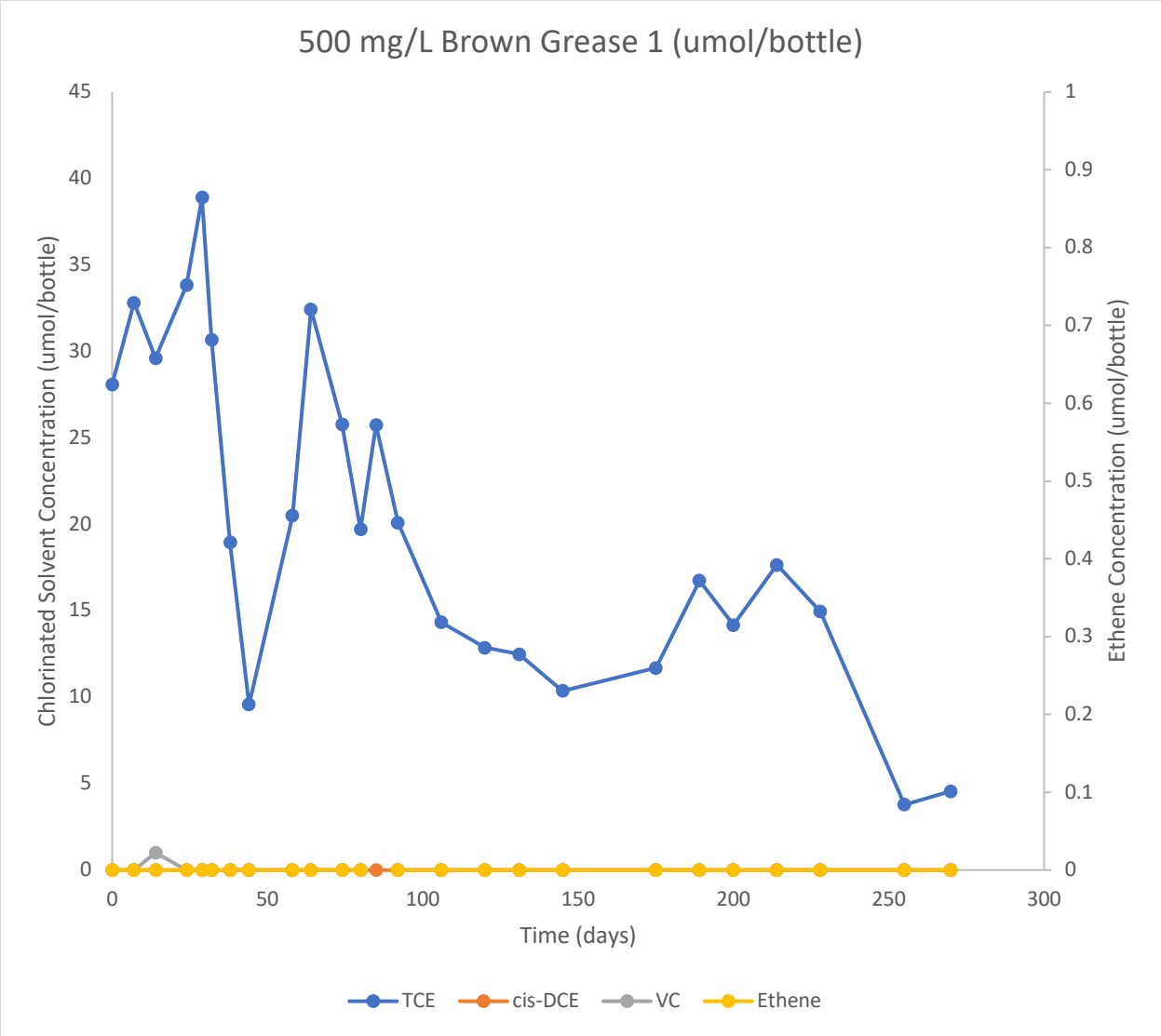
Appendix Figure 58. 500 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



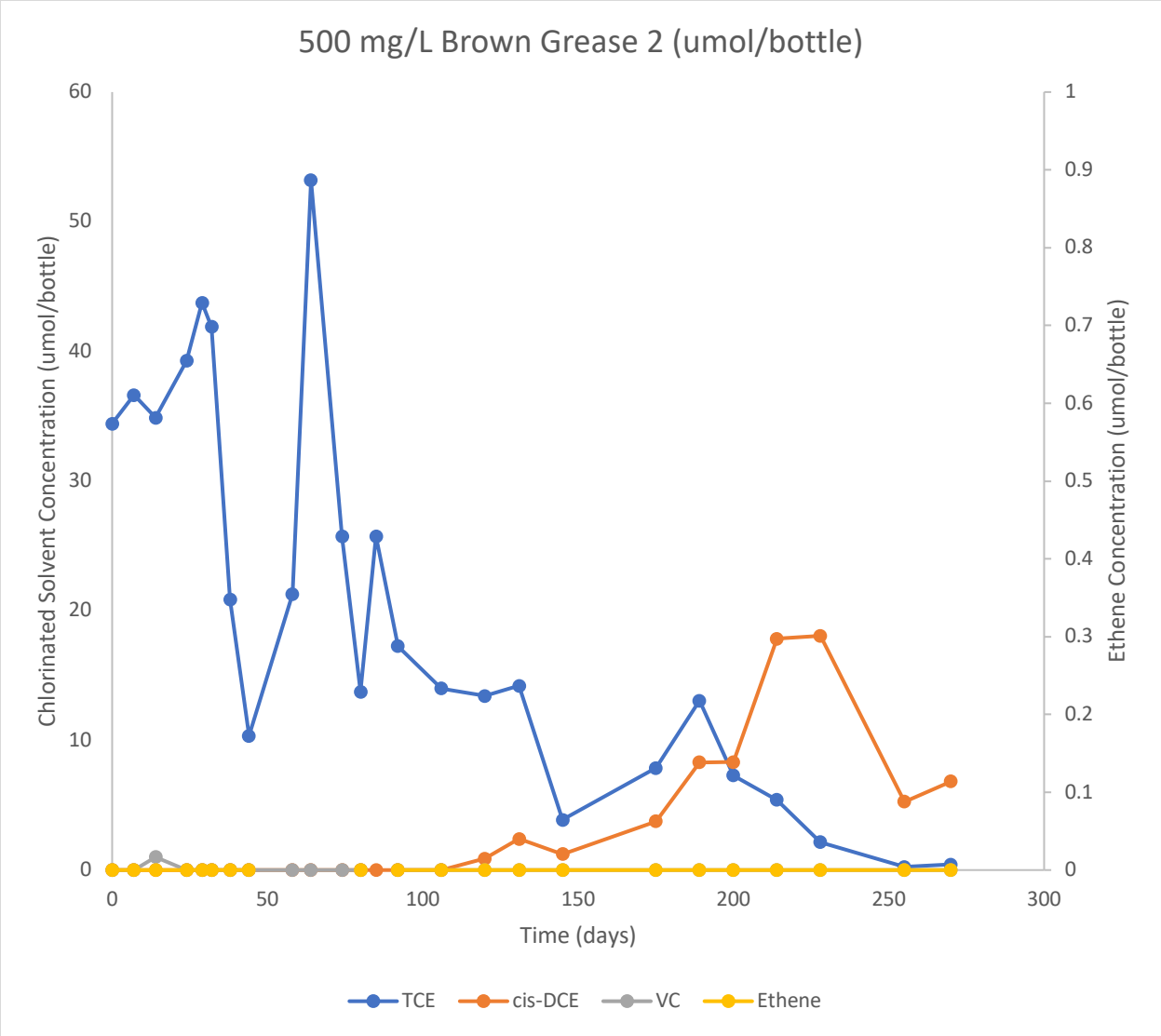
Appendix Figure 59. 500 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



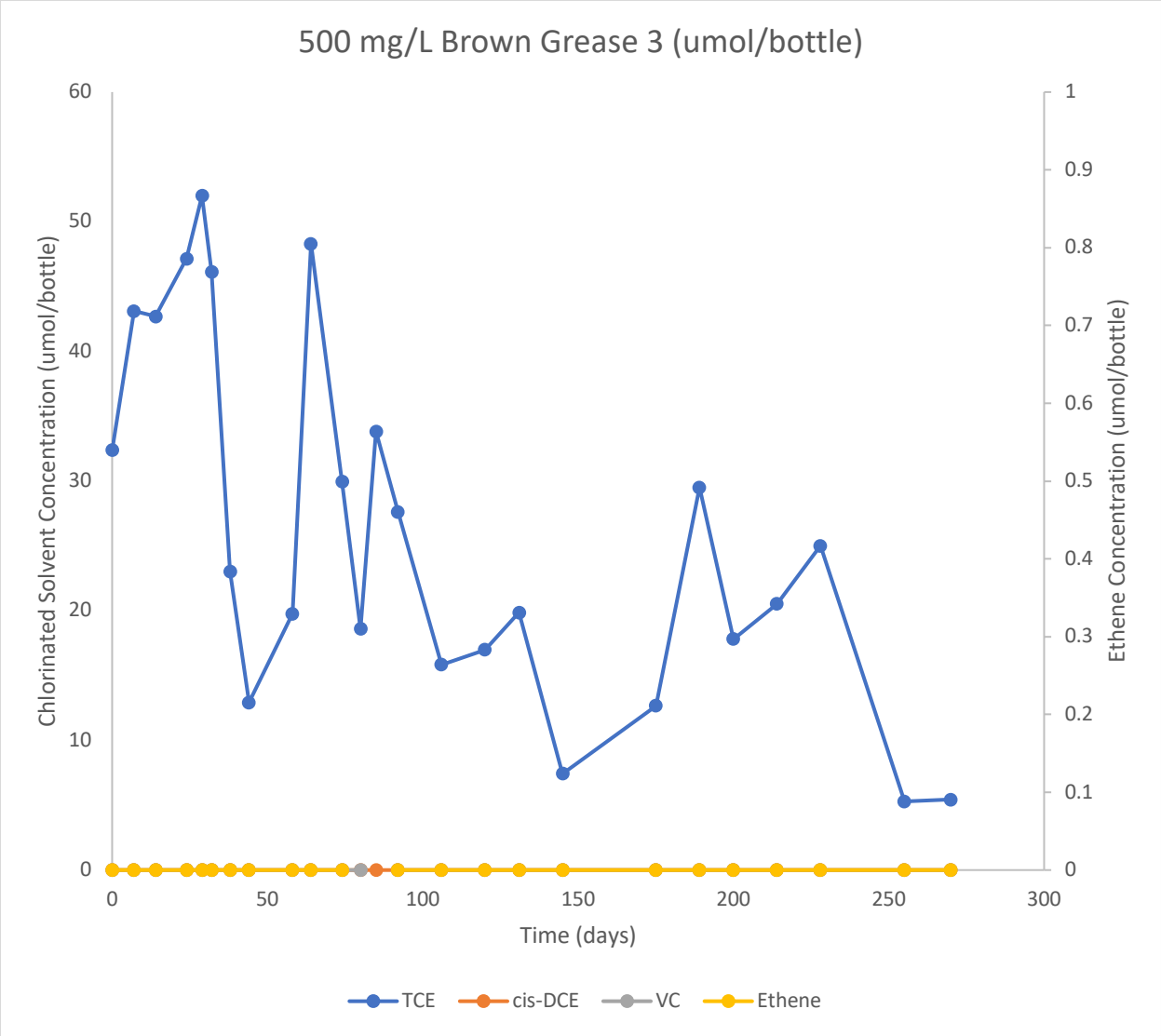
Appendix Figure 60. 500 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



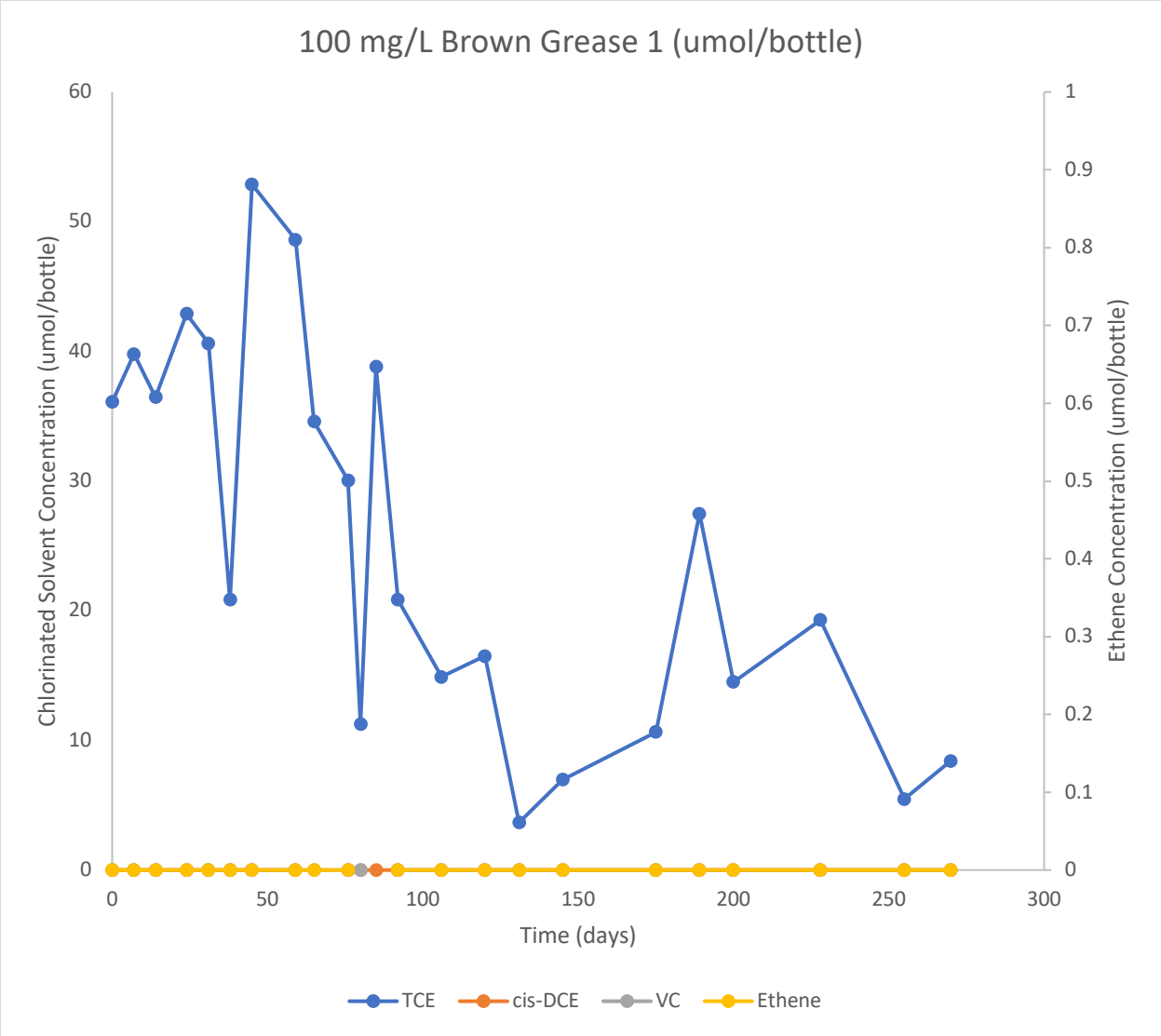
Appendix Figure 61. 500 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



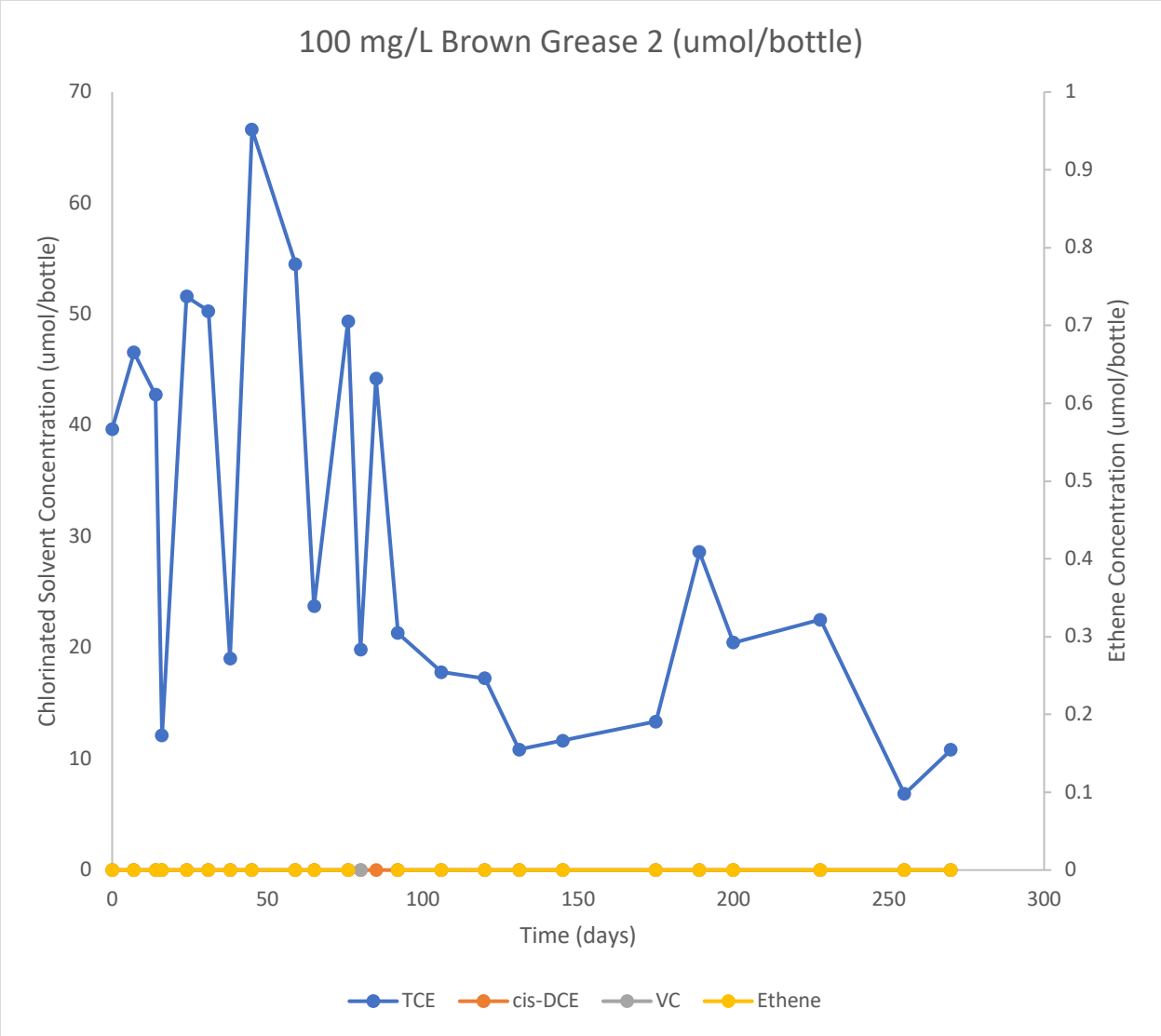
Appendix Figure 62. 500 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



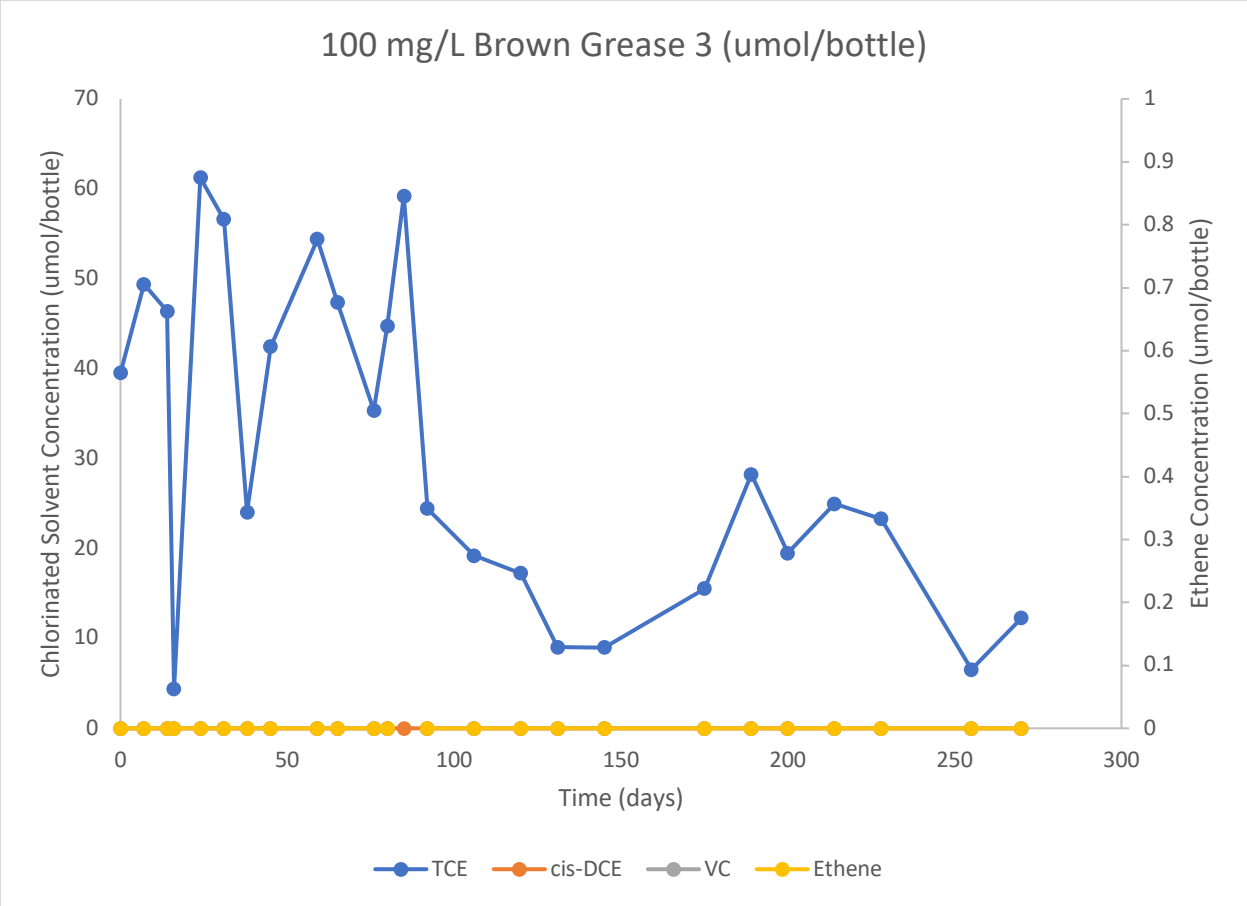
Appendix Figure 63. 500 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



Appendix Figure 64. 100 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.

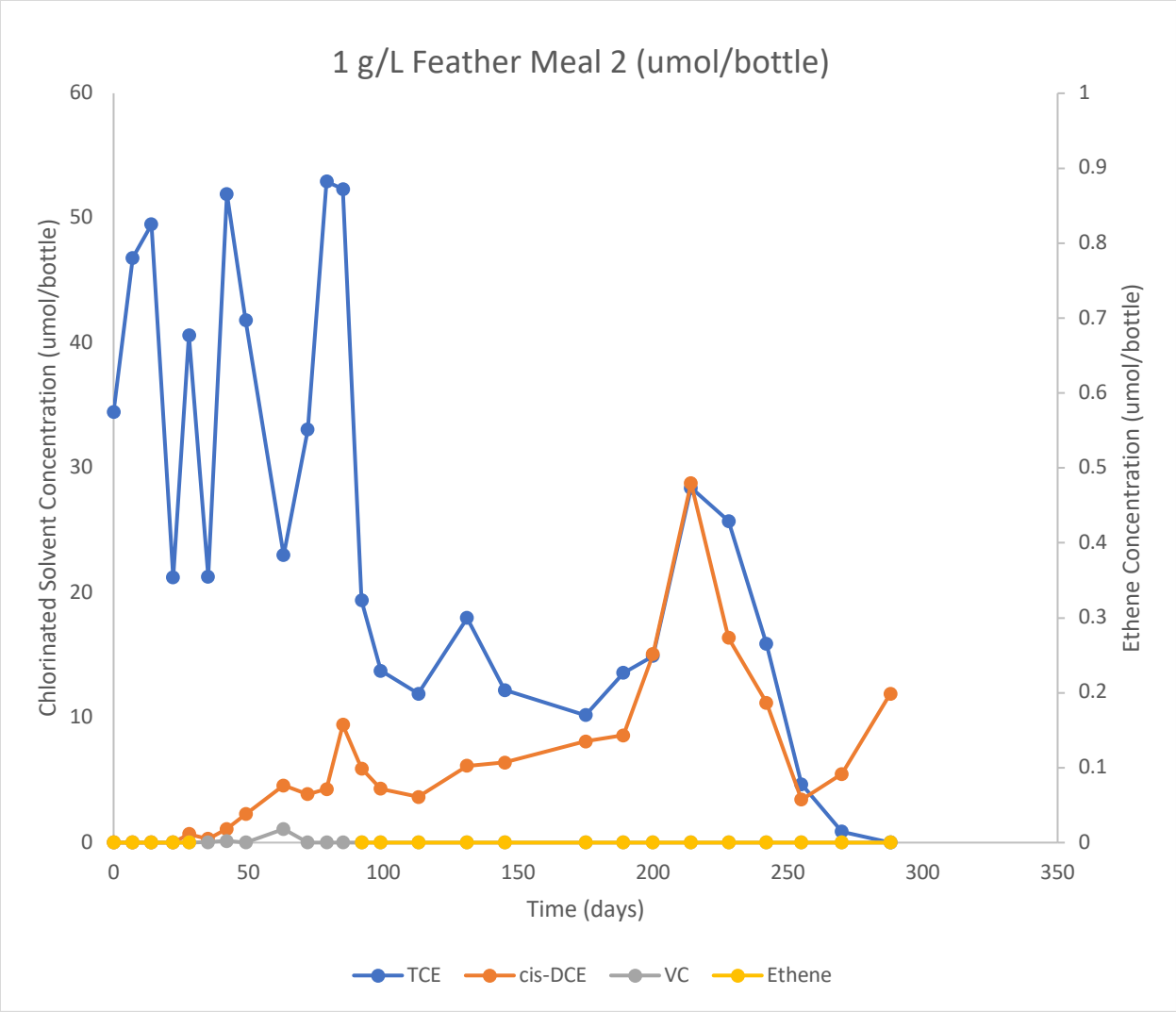


Appendix Figure 65. 100 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.

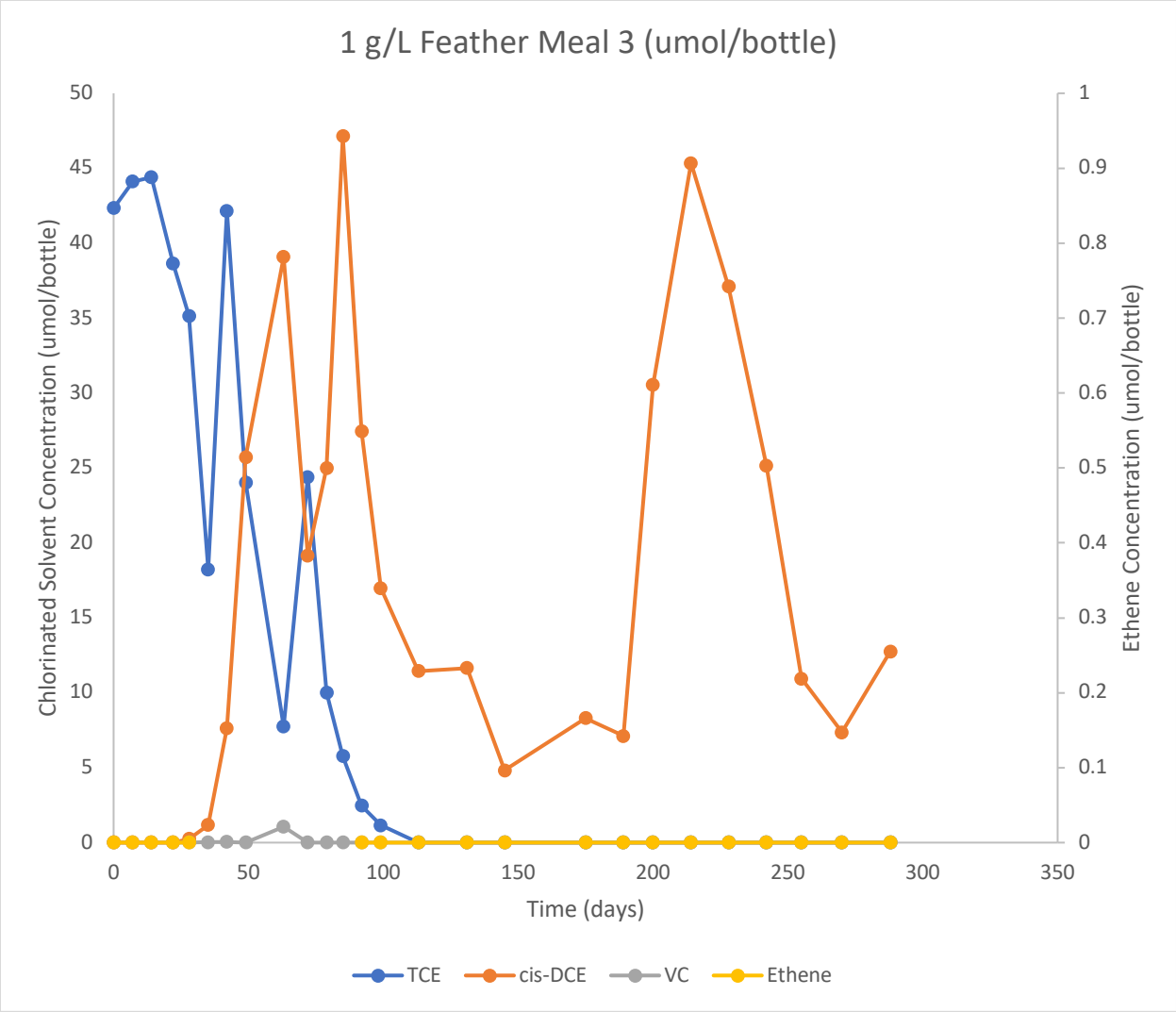


Appendix Figure 66. 100 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.

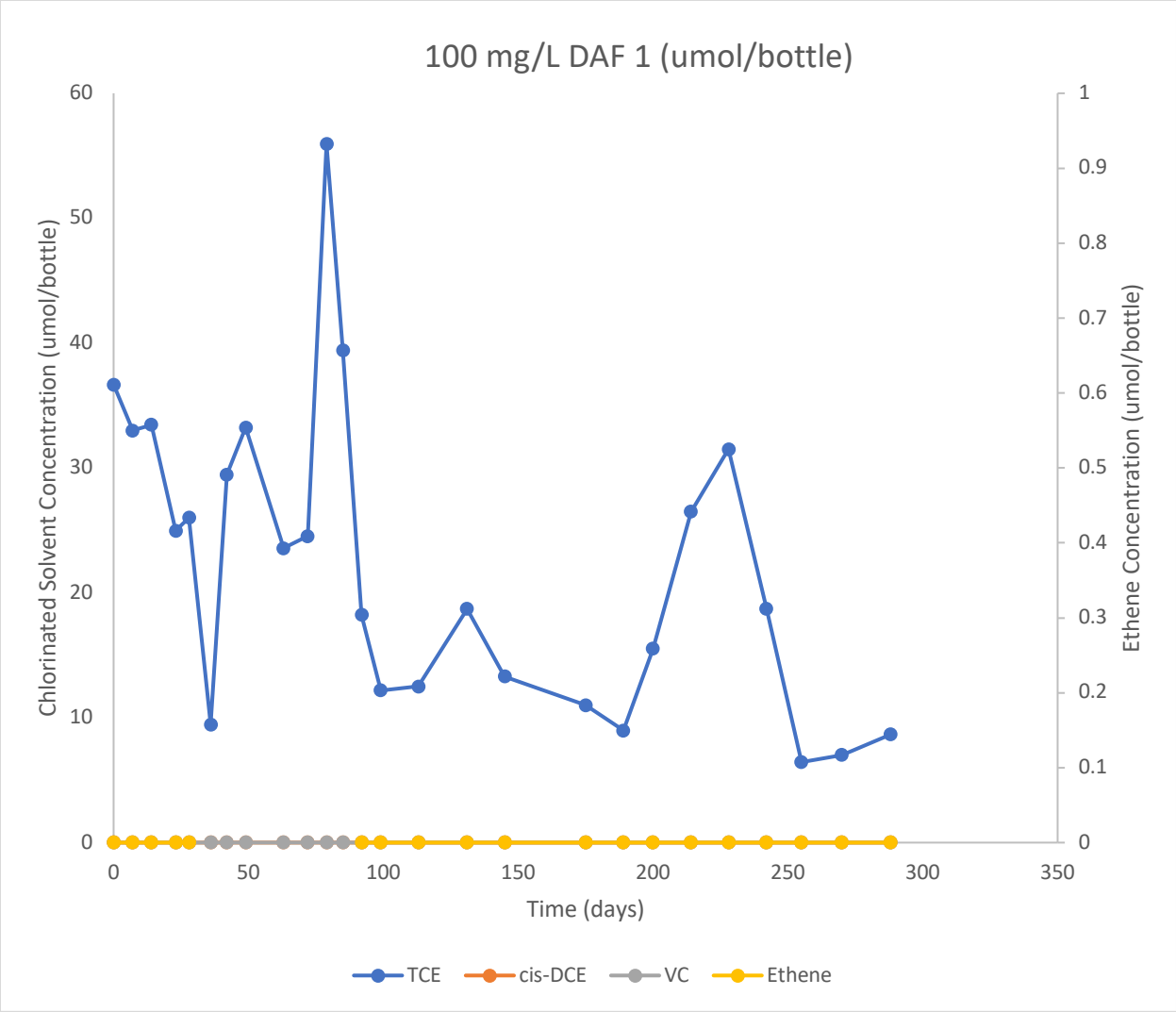
Appendix Figure 67. 1 g/L Feather Meal dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



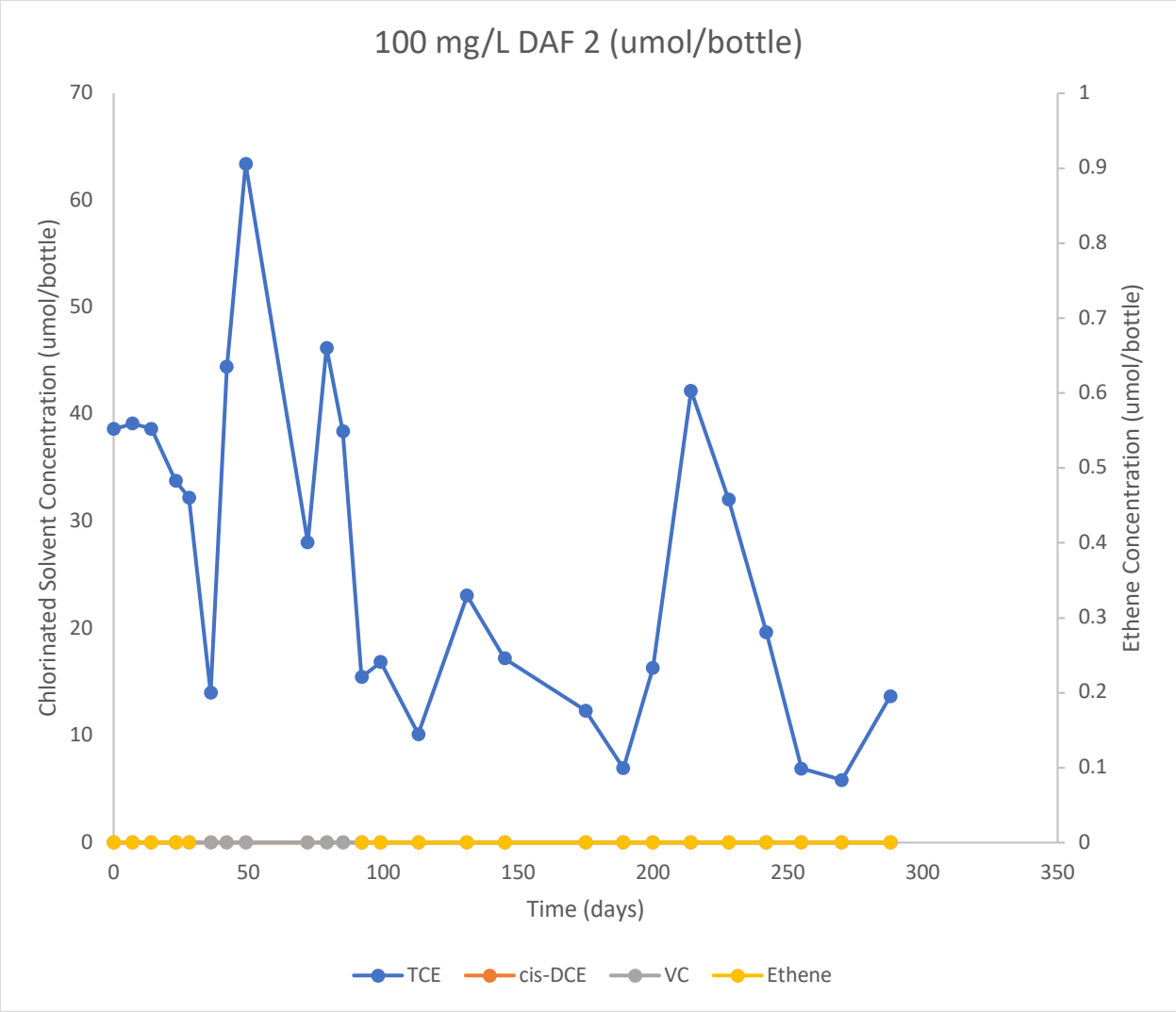
Appendix Figure 68. 1 g/L Feather Meal dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



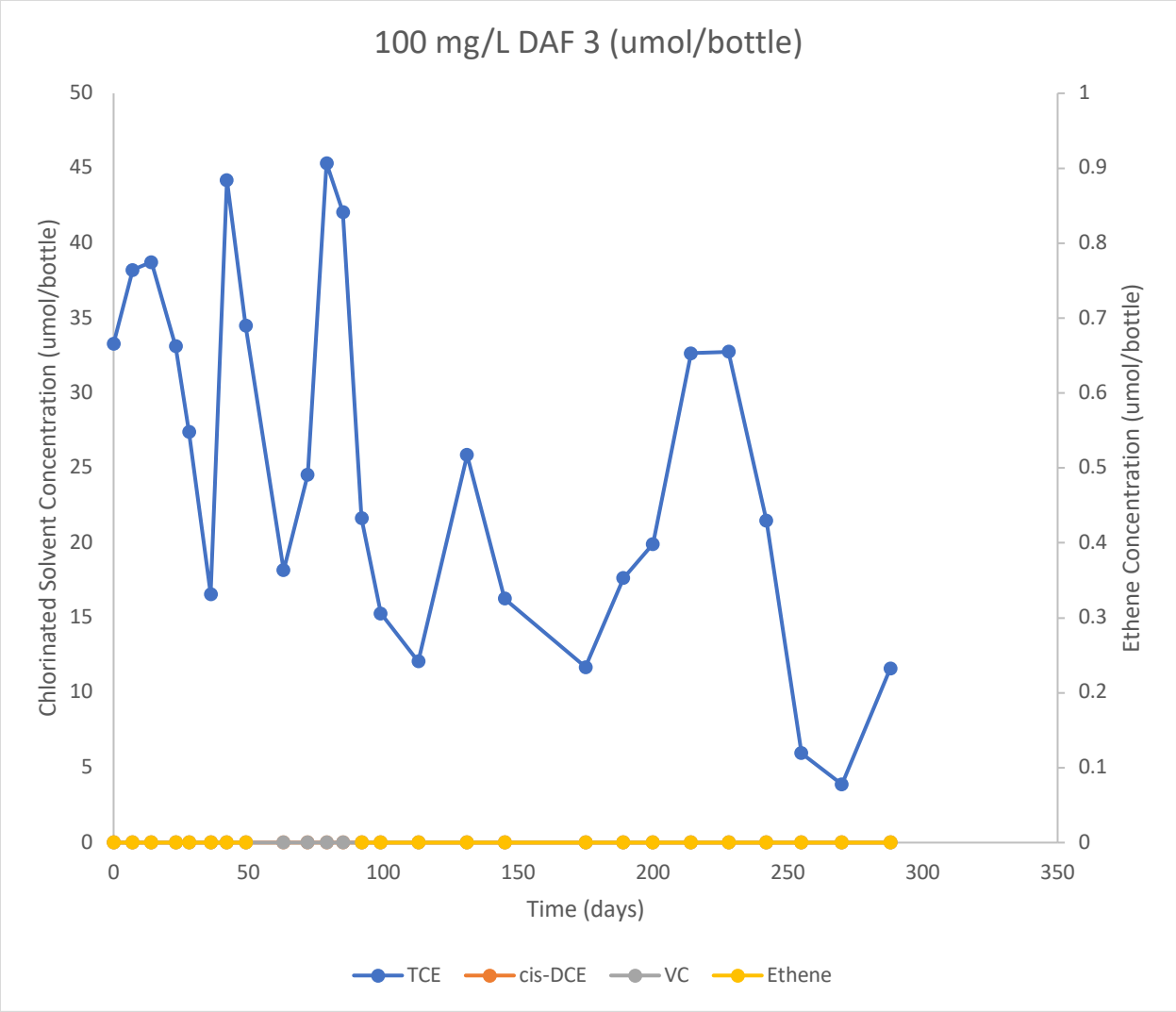
Appendix Figure 69. 1 g/L Feather Meal dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



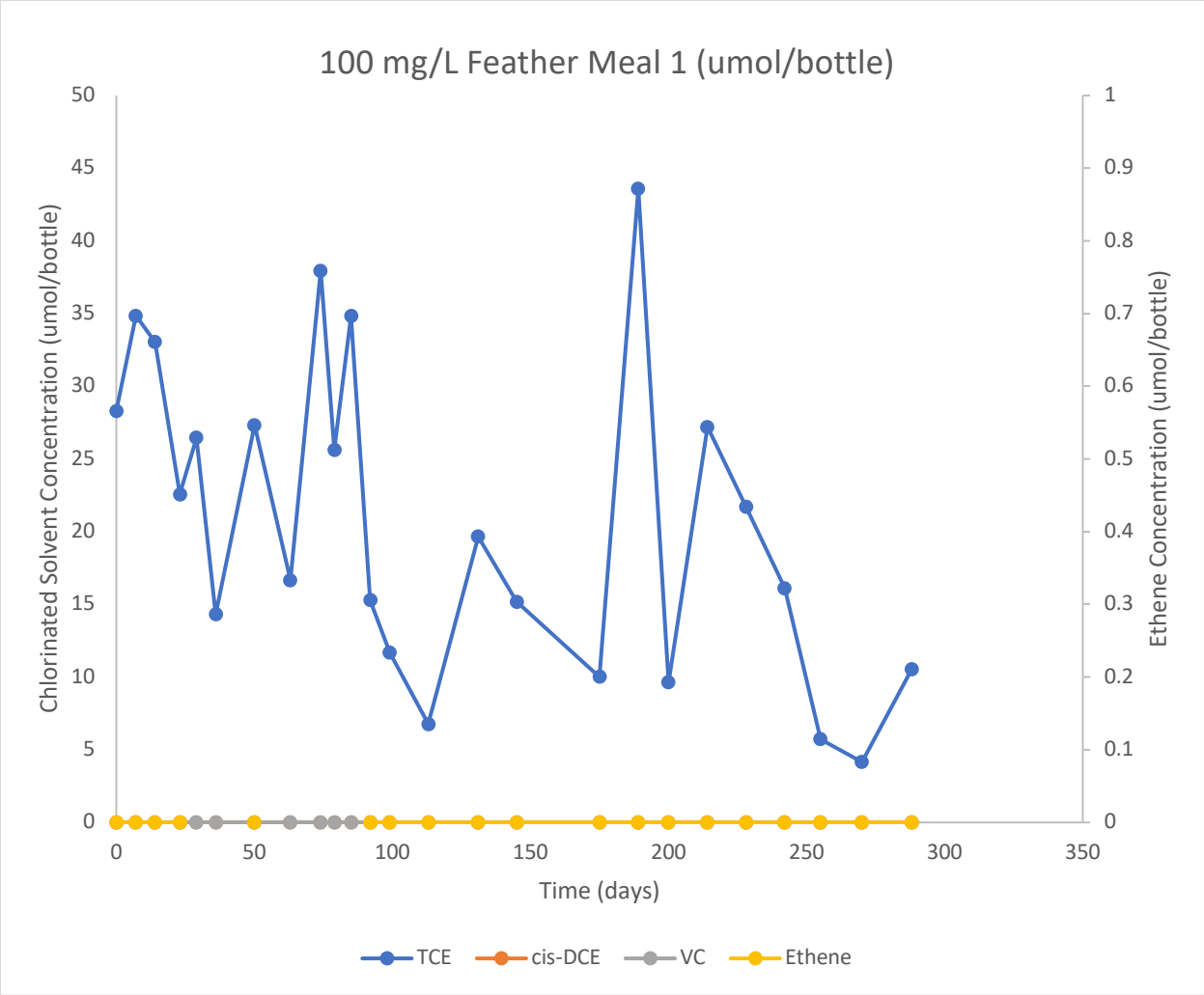
Appendix Figure 70. 100 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



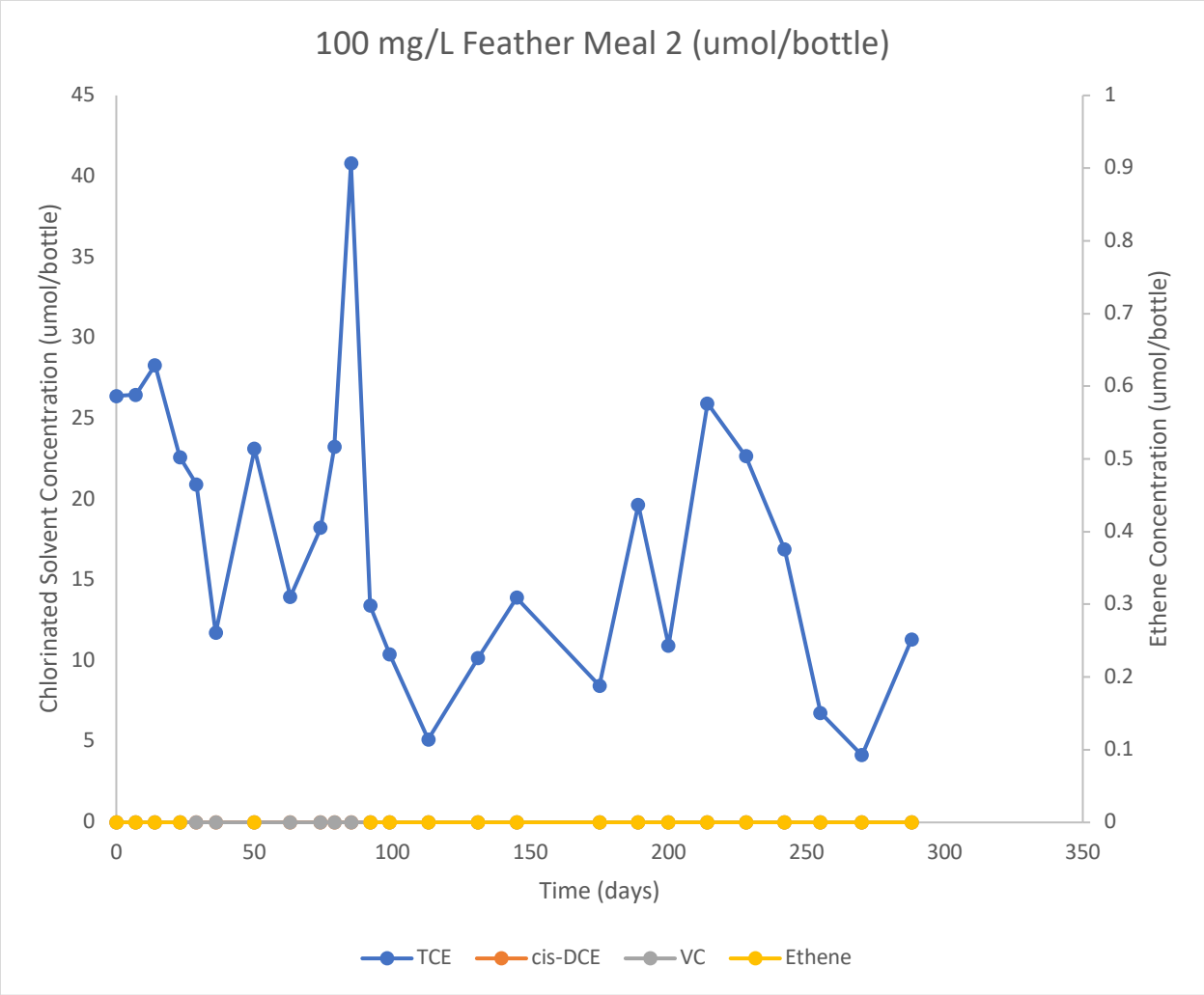
Appendix Figure 71. 100 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



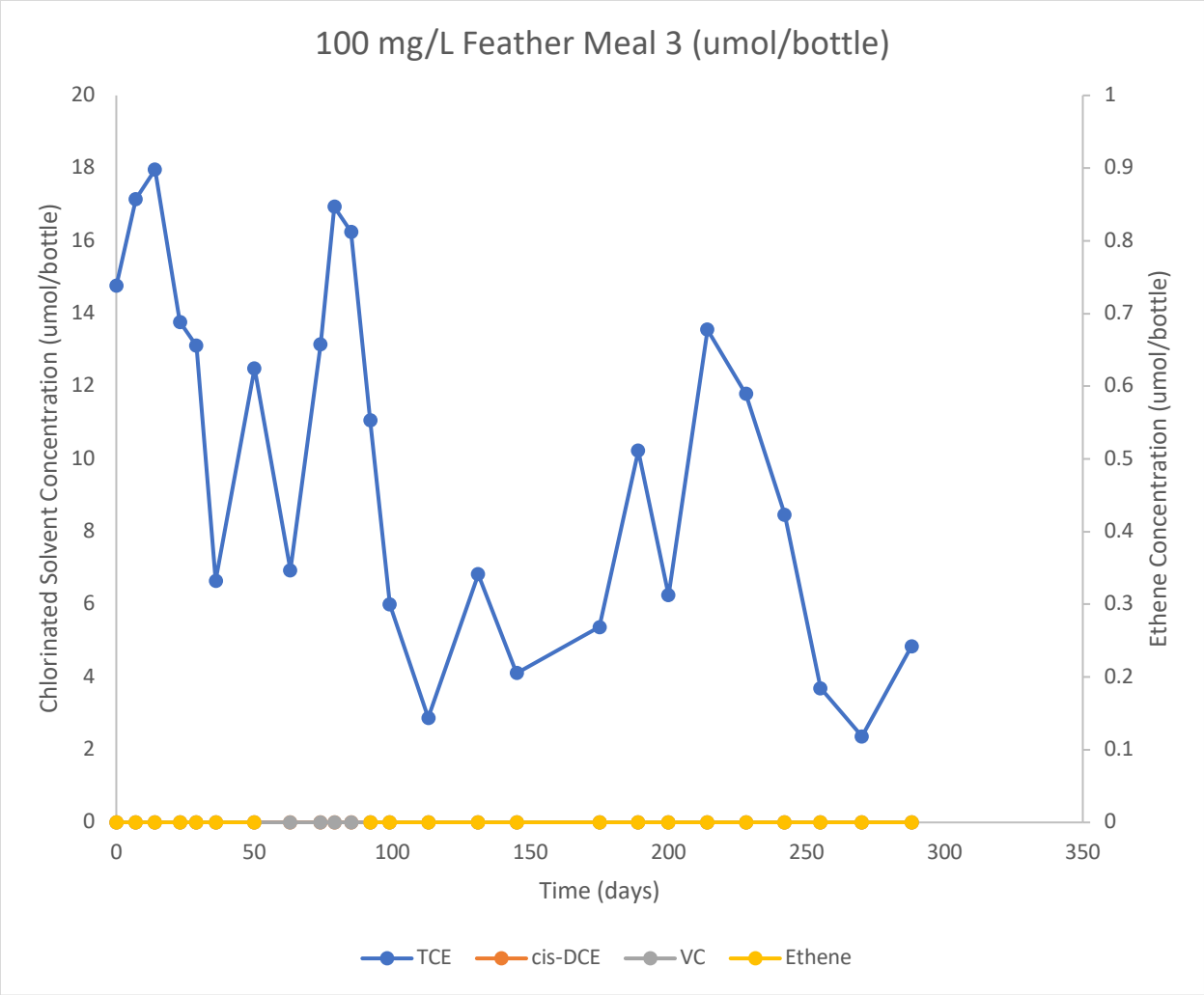
Appendix Figure 72. 100 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



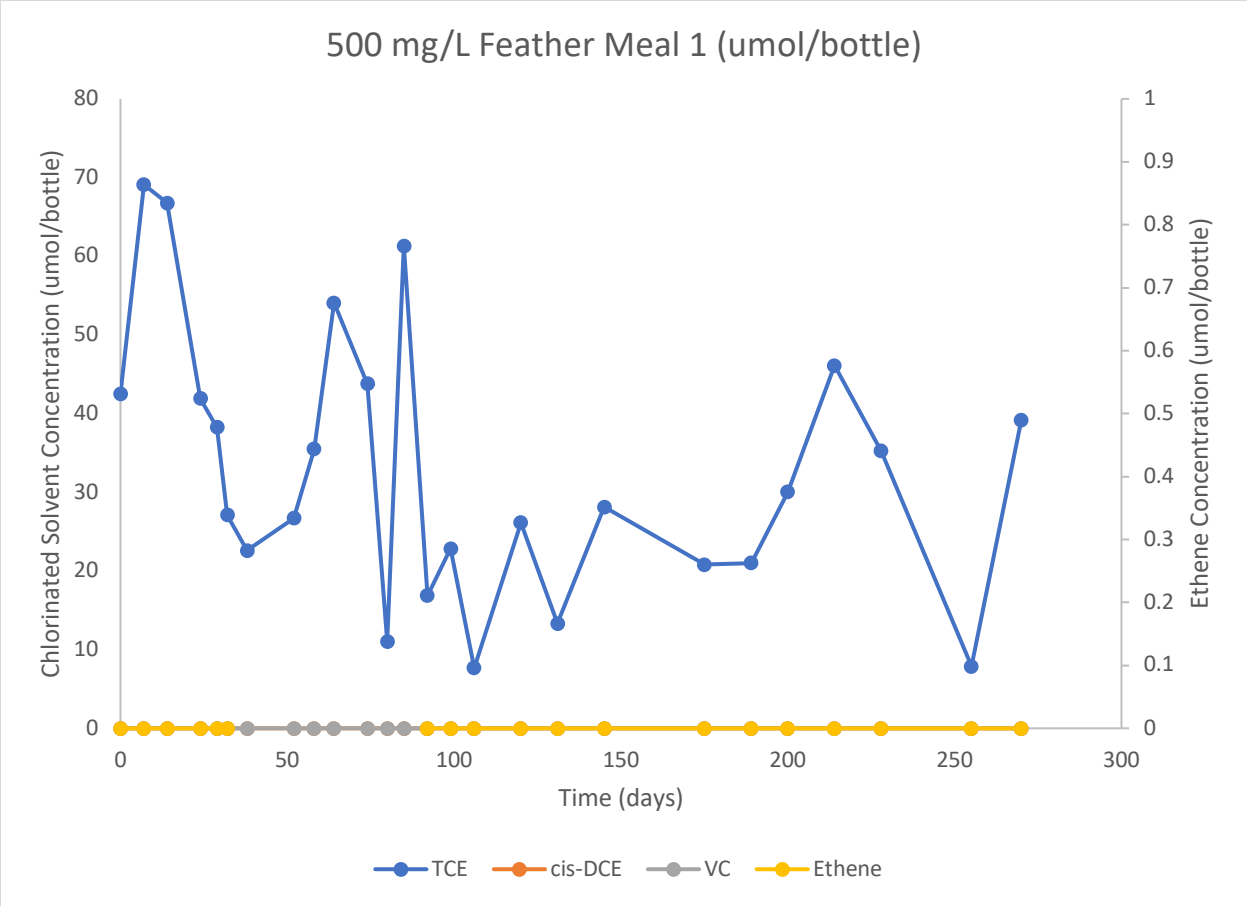
Appendix Figure 73. 100 mg/L Feather Meal dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



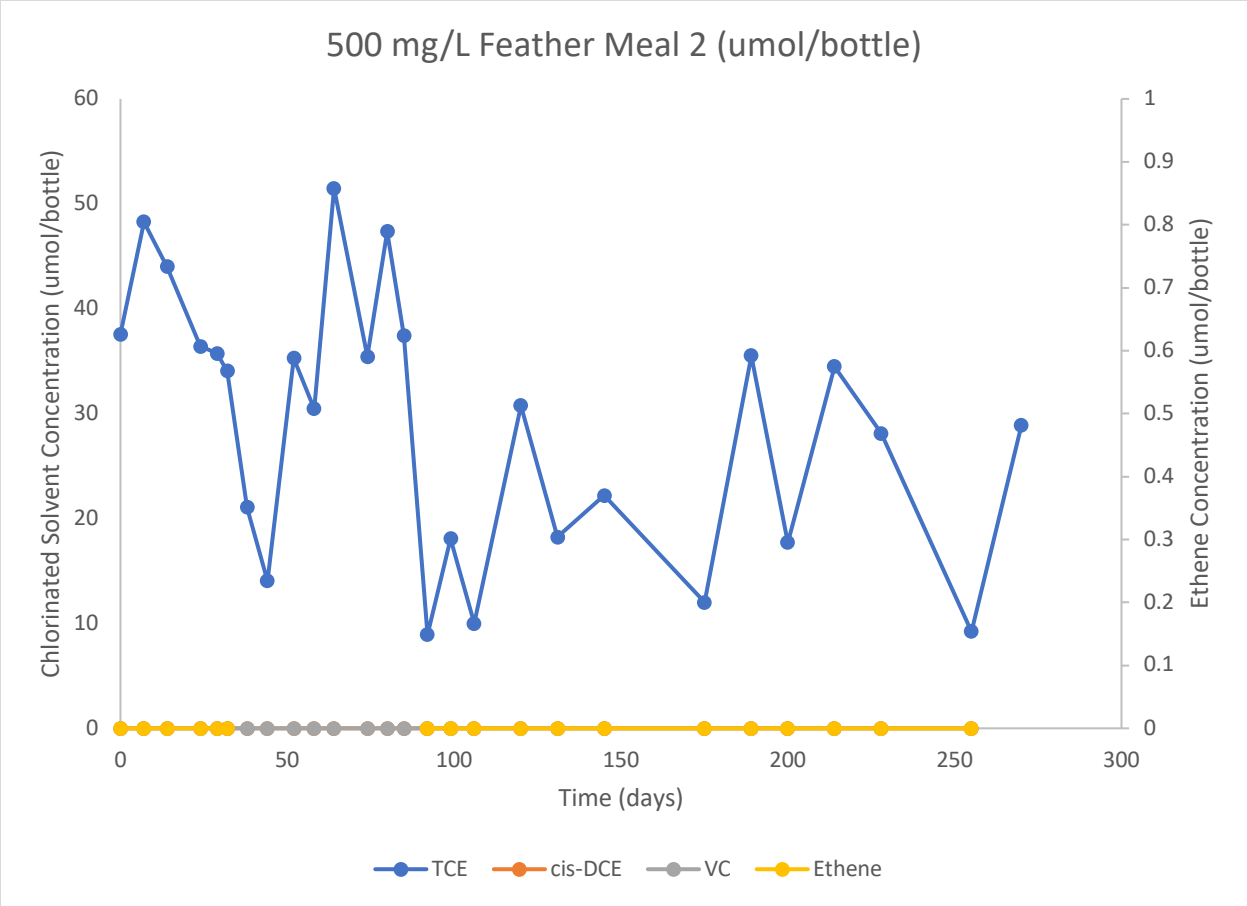
Appendix Figure 74. 100 mg/L Feather Meal dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



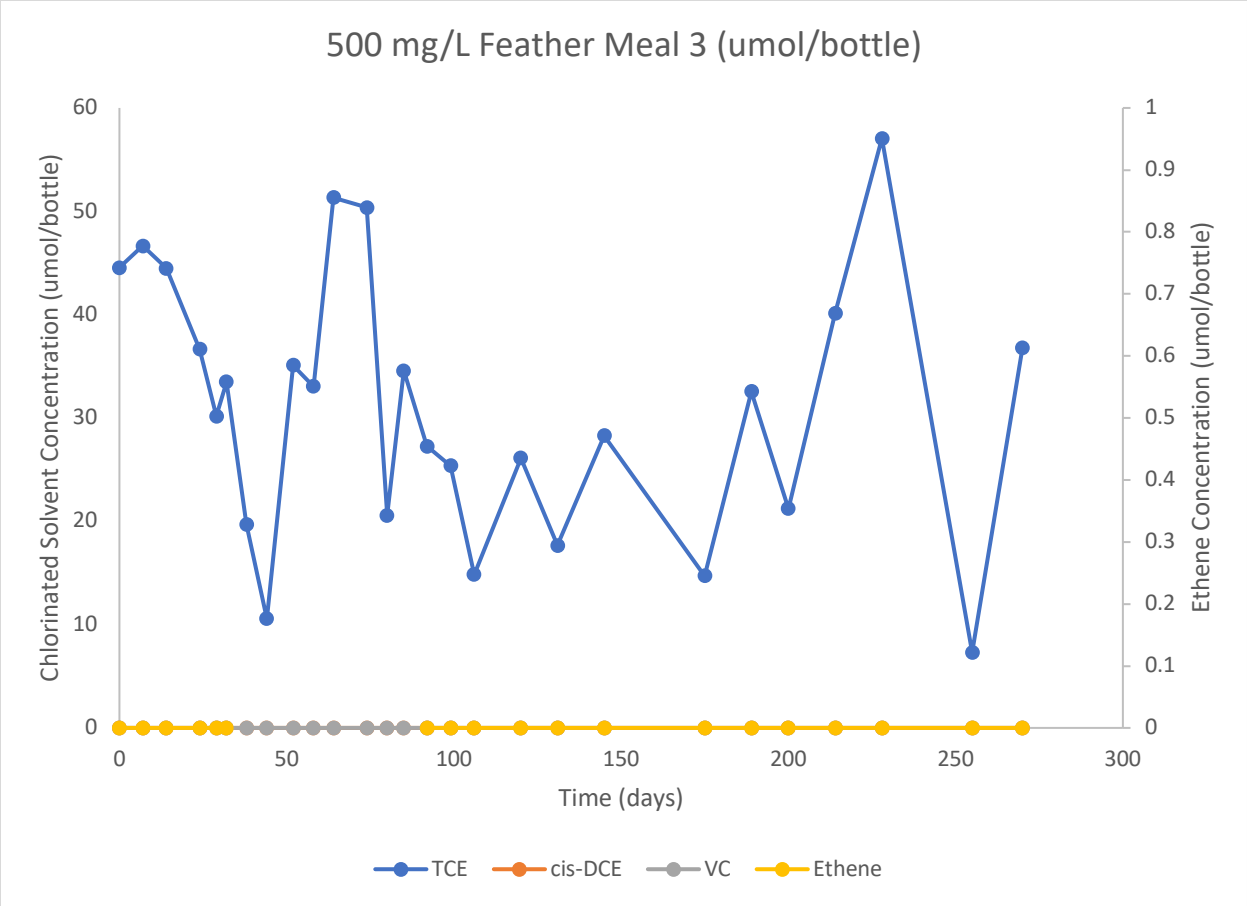
Appendix Figure 75. 100 mg/L Feather Meal dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



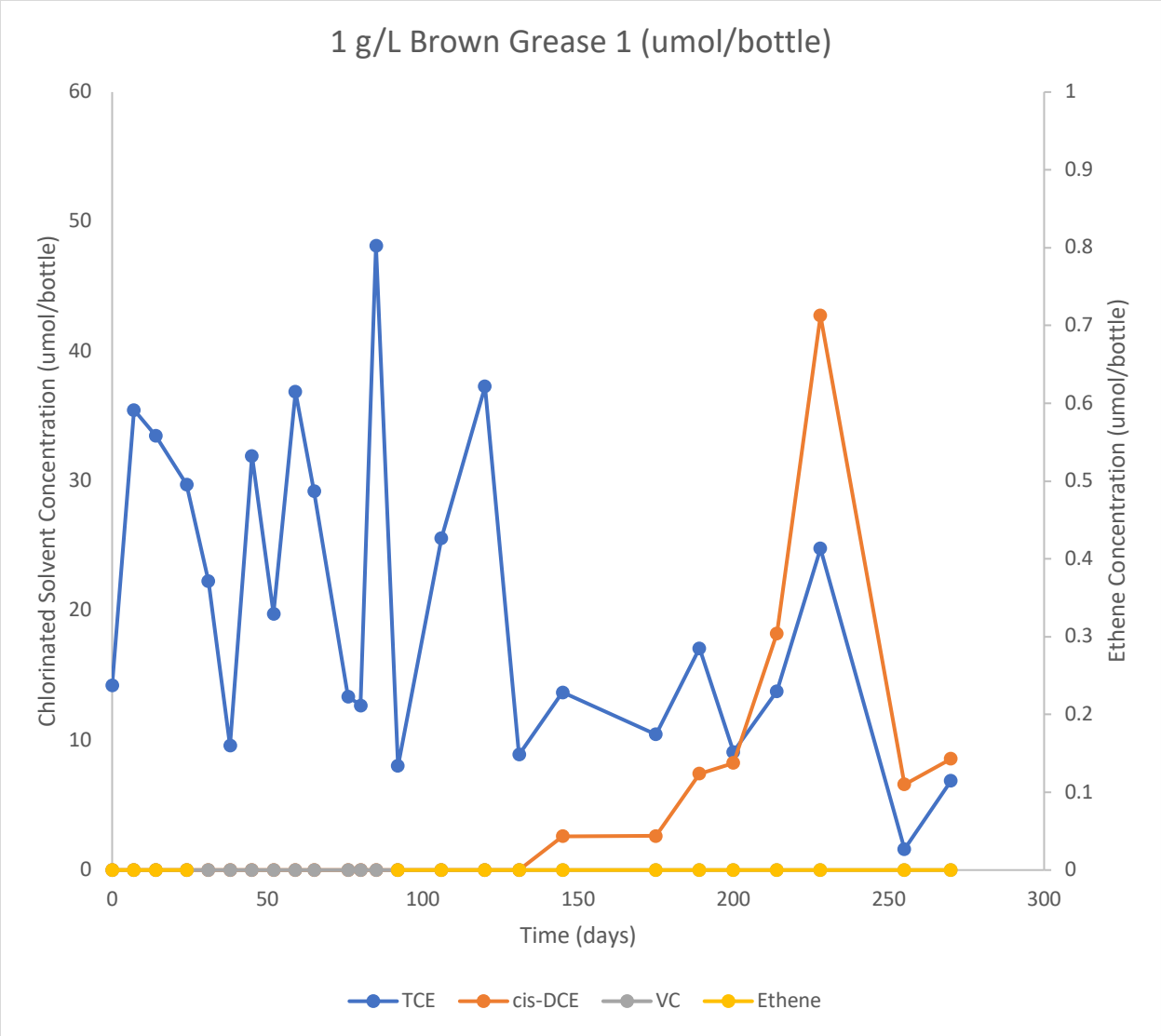
Appendix Figure 76. 500 mg/L Feather Meal dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



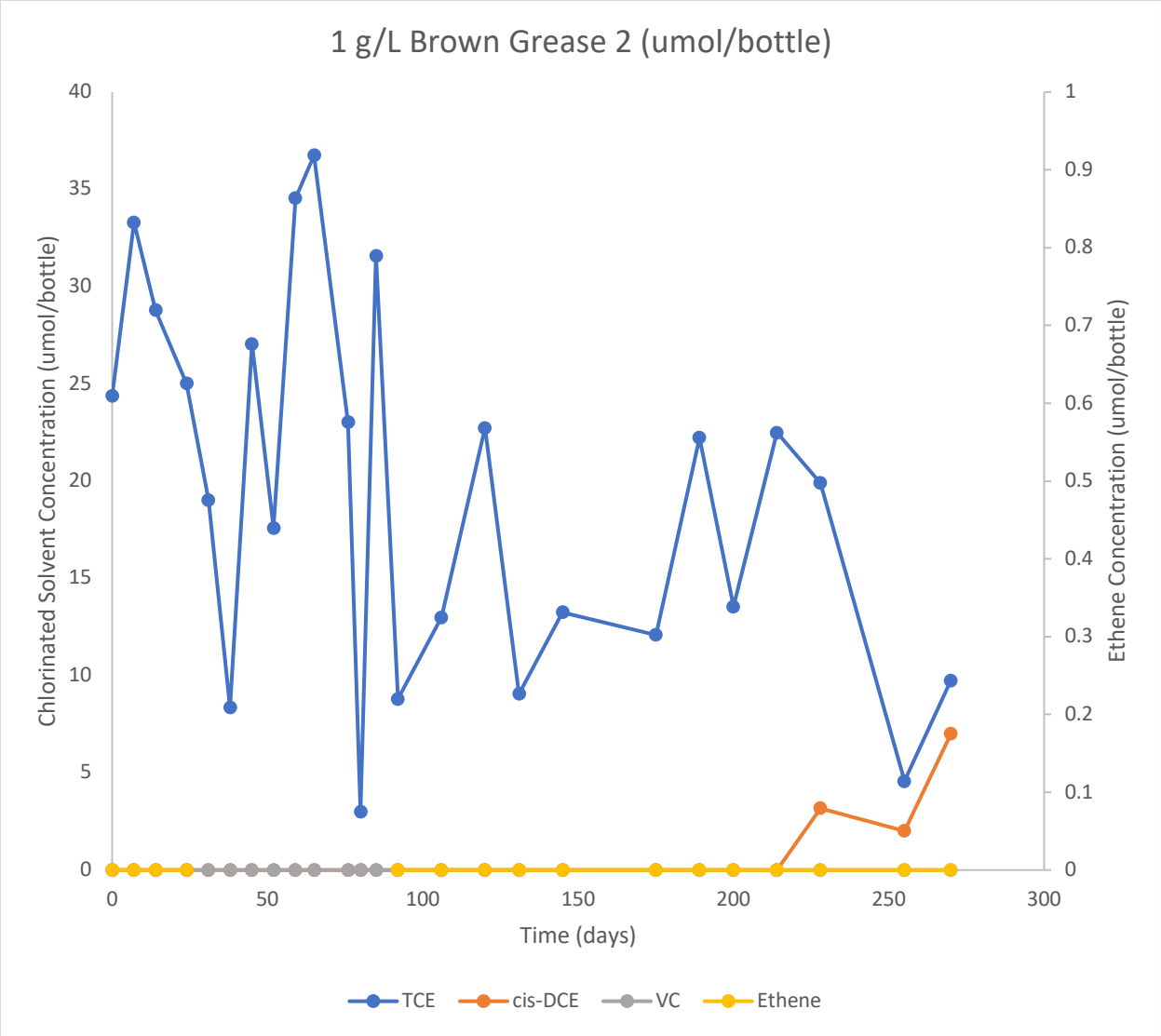
Appendix Figure 77. 500 mg/L Feather Meal dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



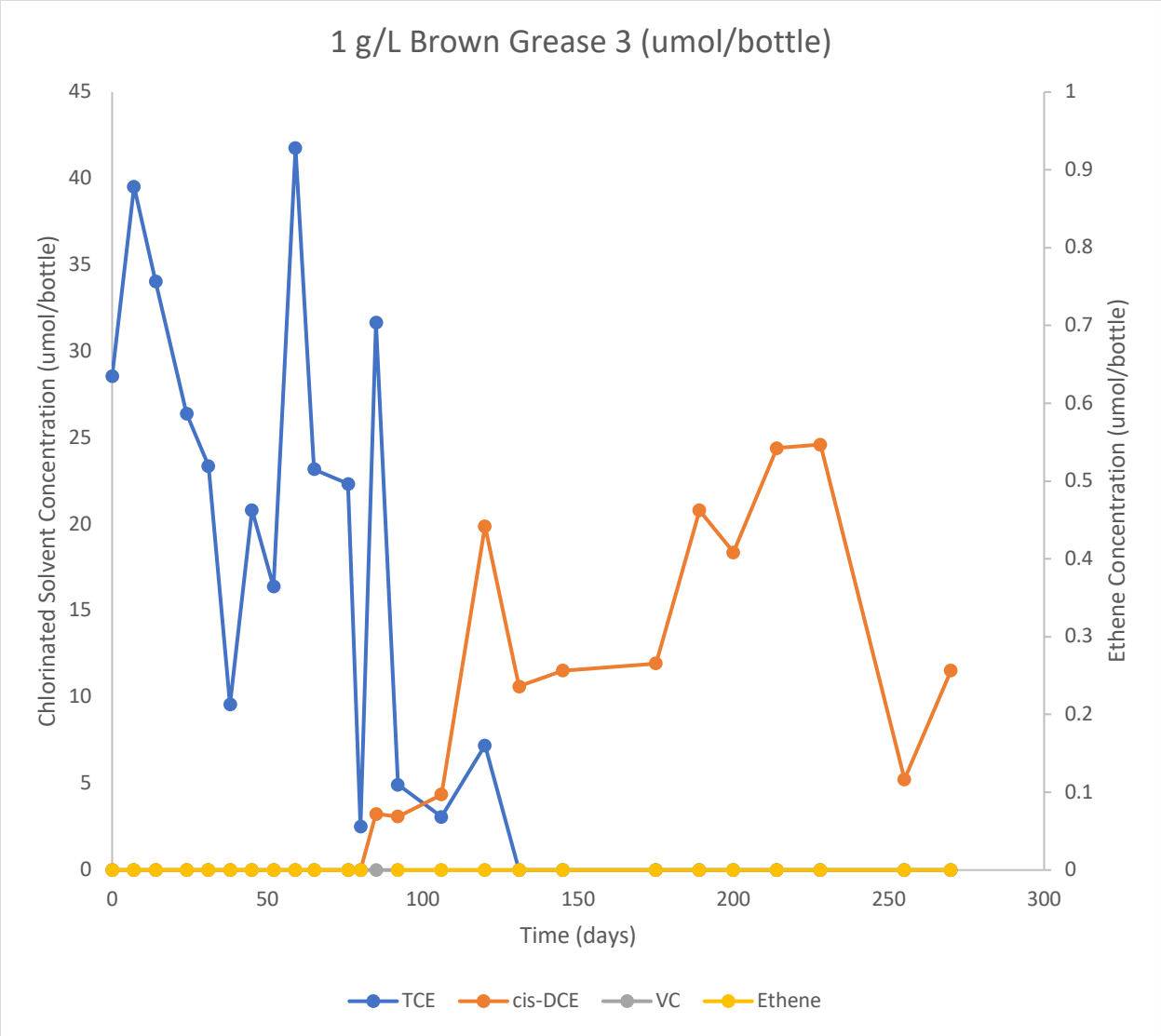
Appendix Figure 78. 500 mg/L Feather Meal dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



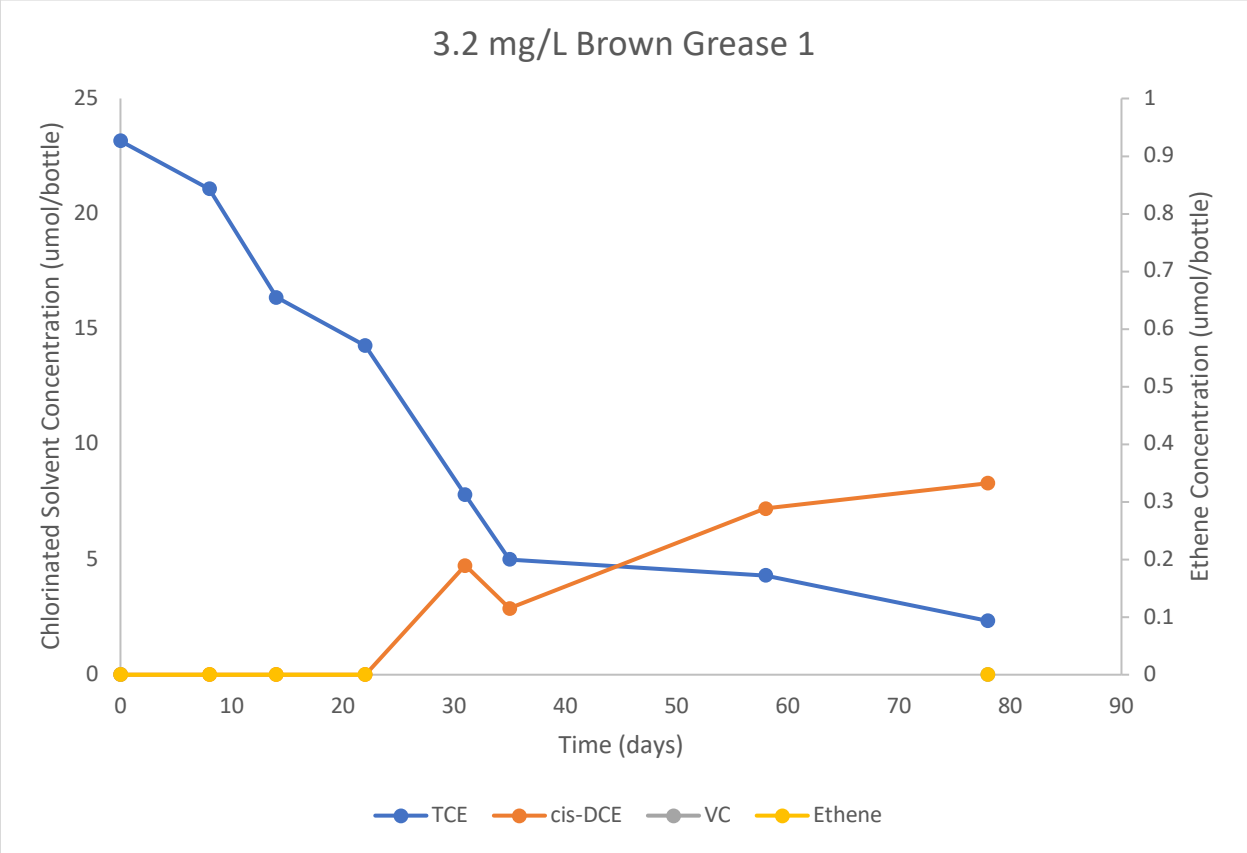
Appendix Figure 79. 1 g/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



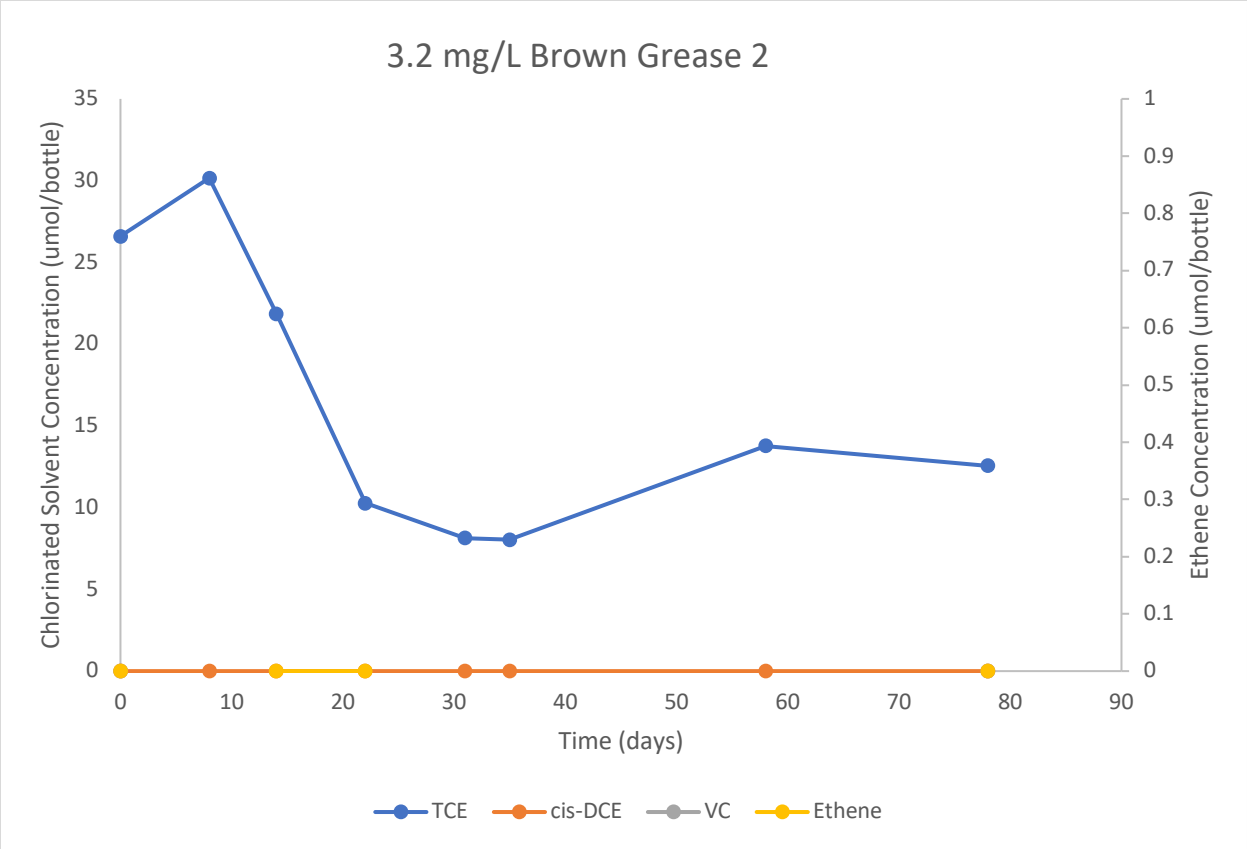
Appendix Figure 80. 1 g/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



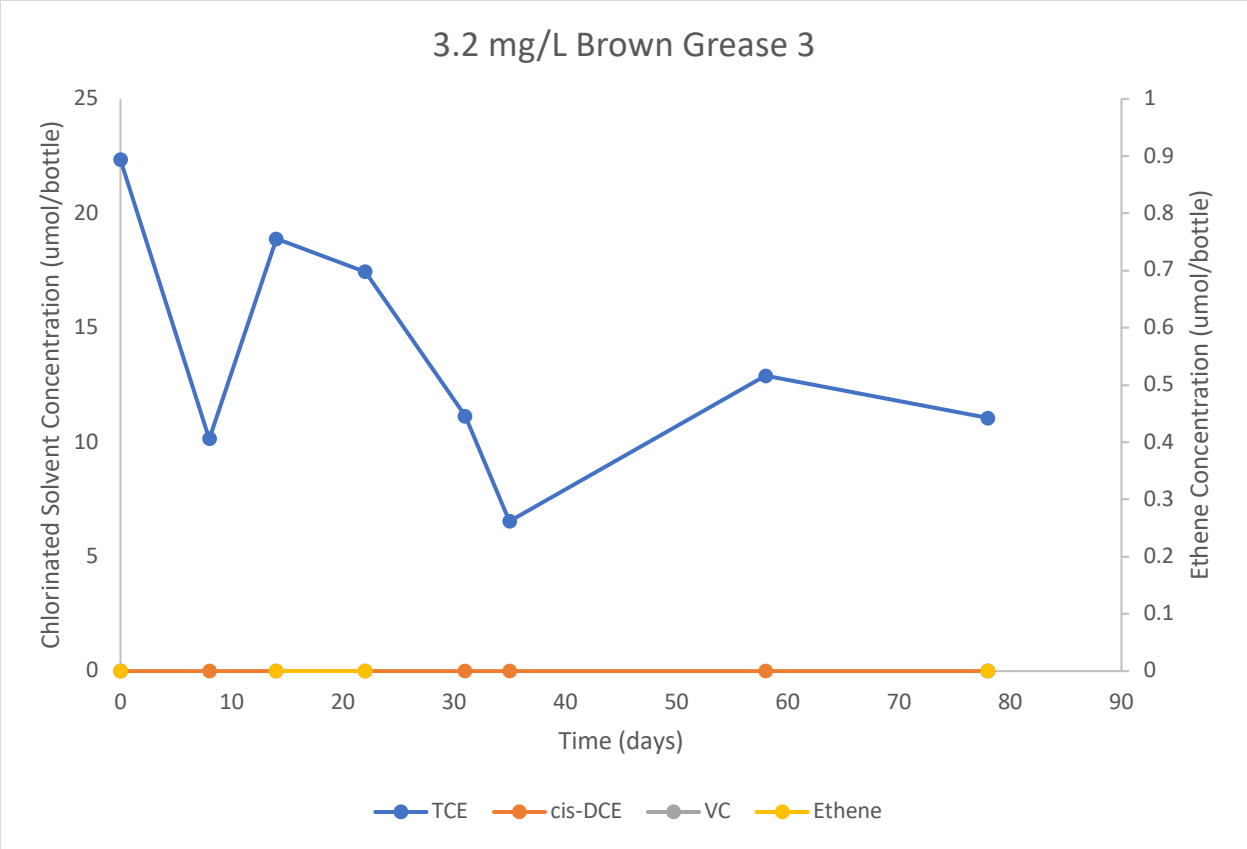
Appendix Figure 81. 1 g/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in feasibility experiment with soil collected from California.



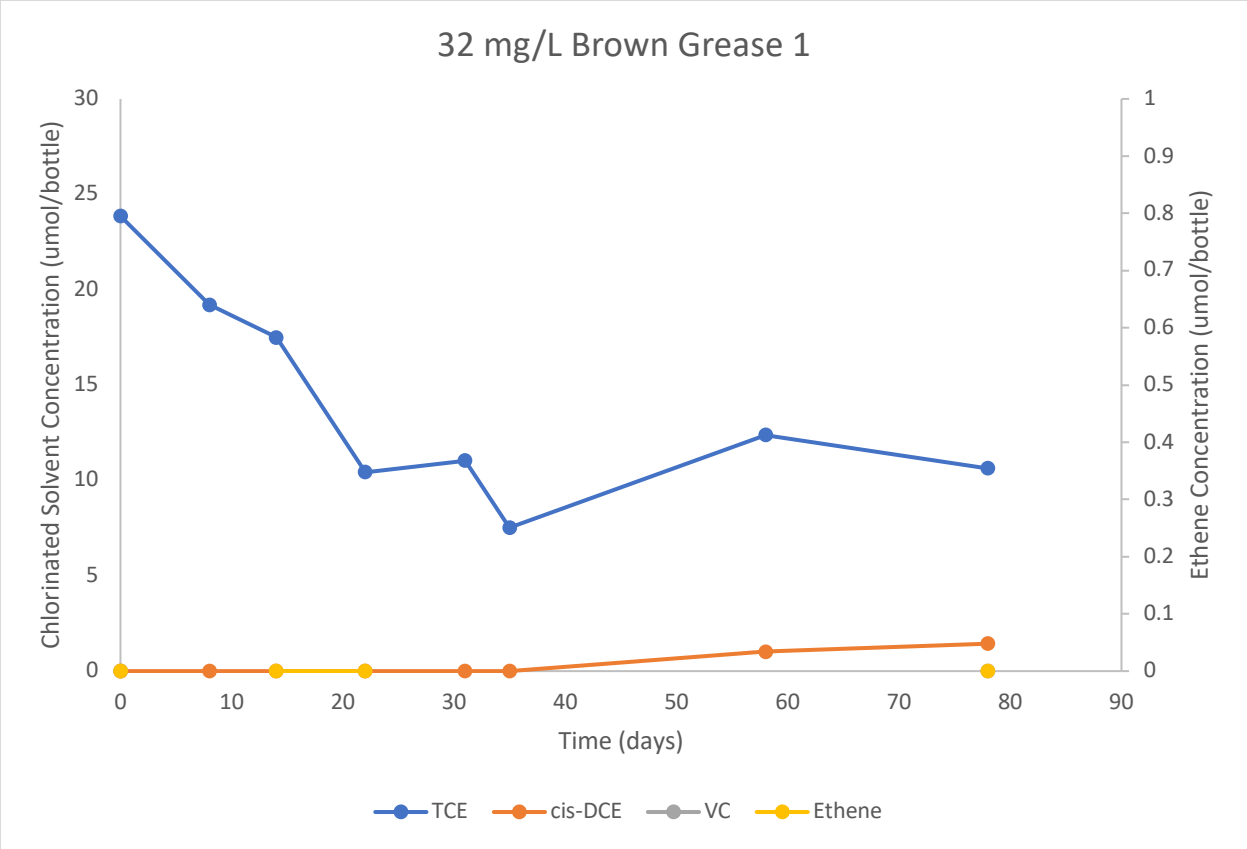
Appendix Figure 82. 3.2 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



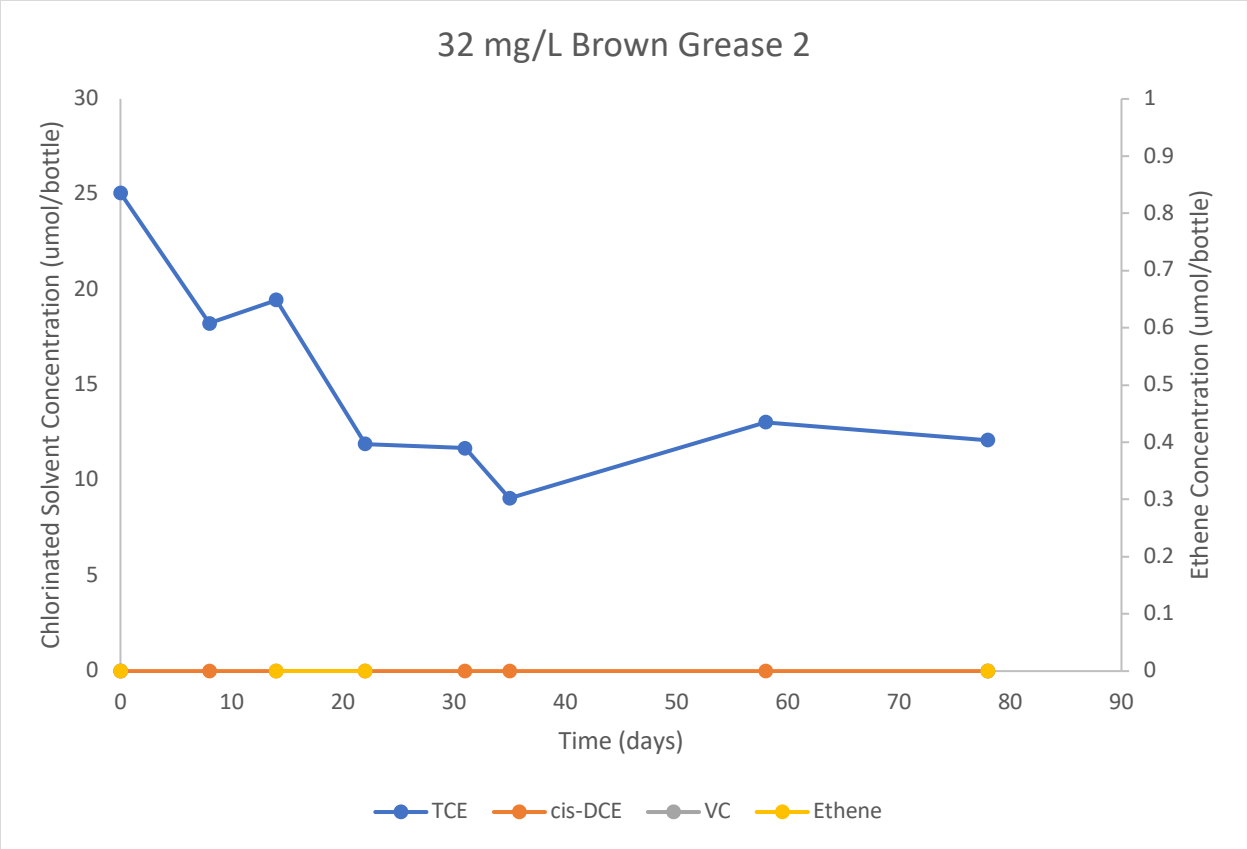
Appendix Figure 83. 3.2 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



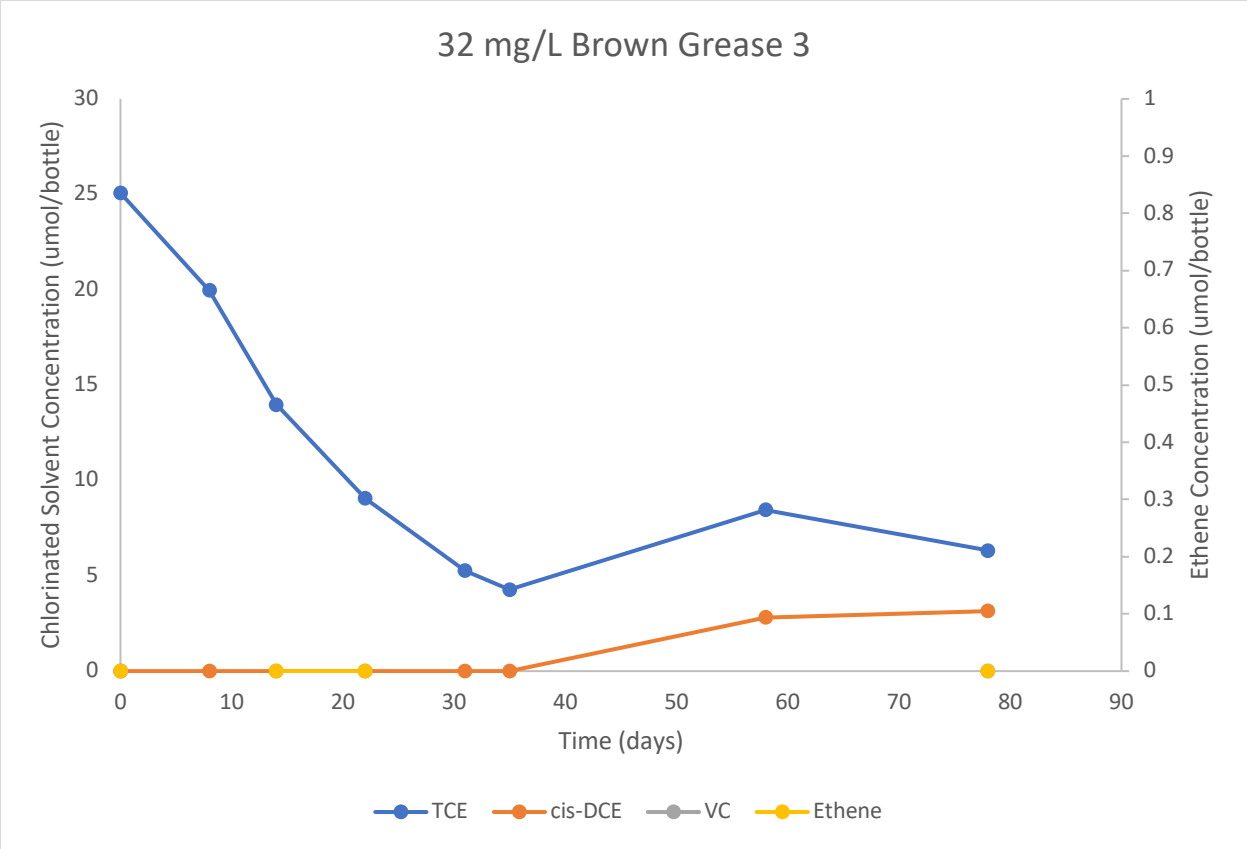
Appendix Figure 84. 3.2 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



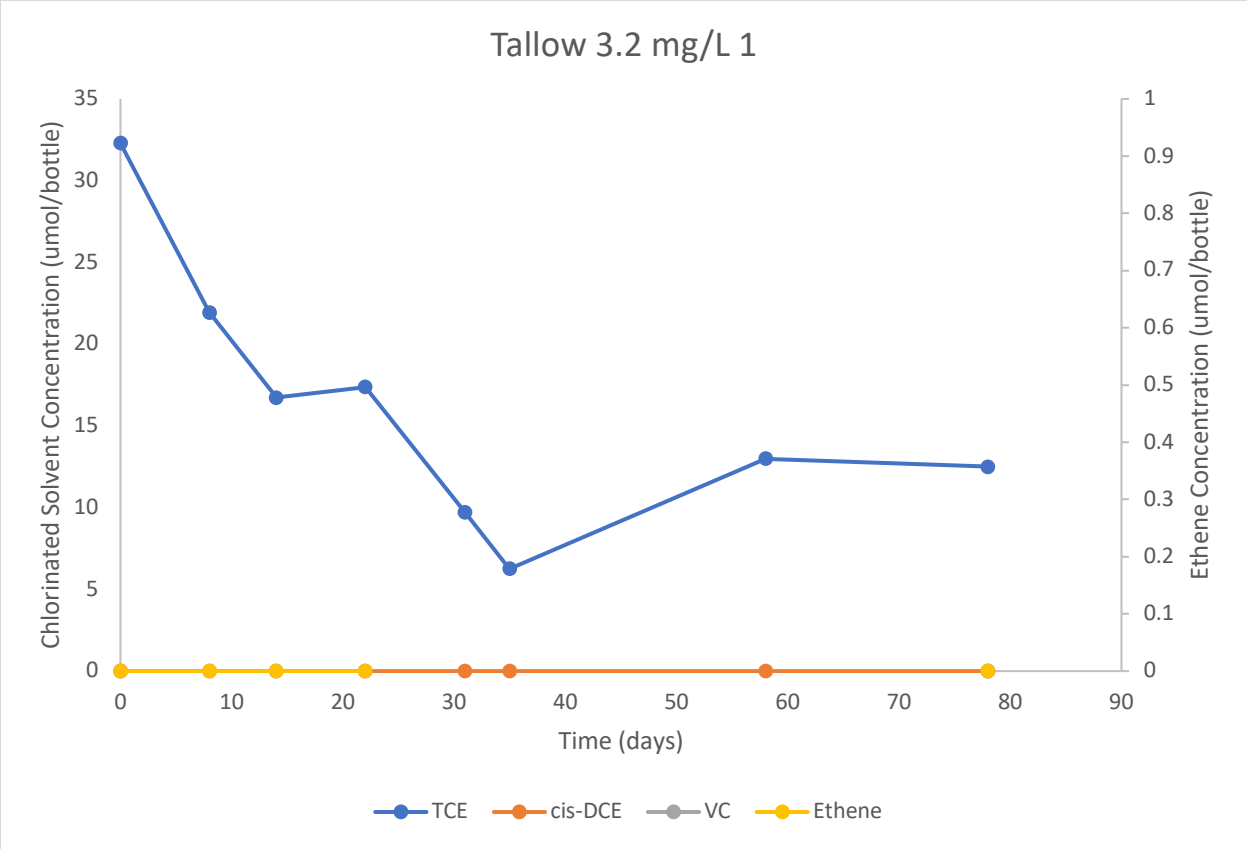
Appendix Figure 85. 32 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



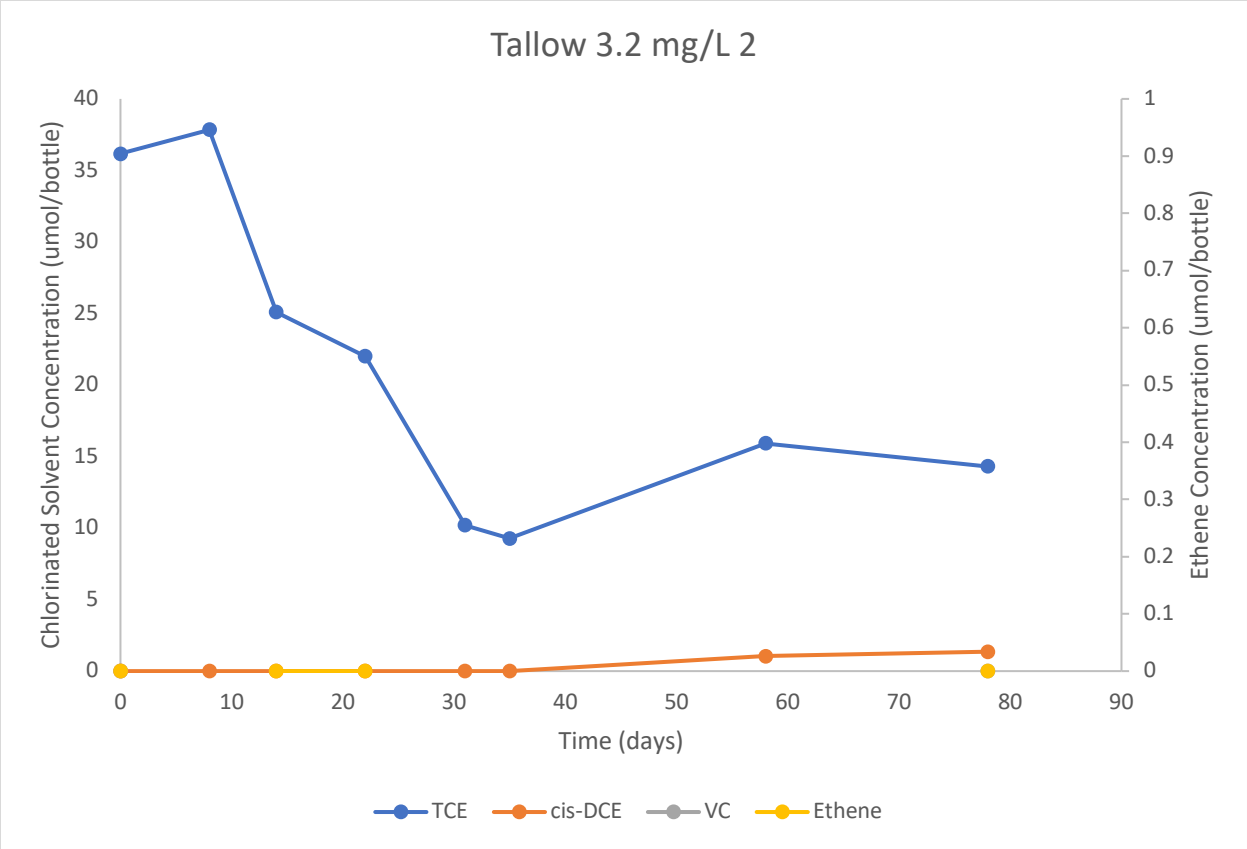
Appendix Figure 86. 32 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



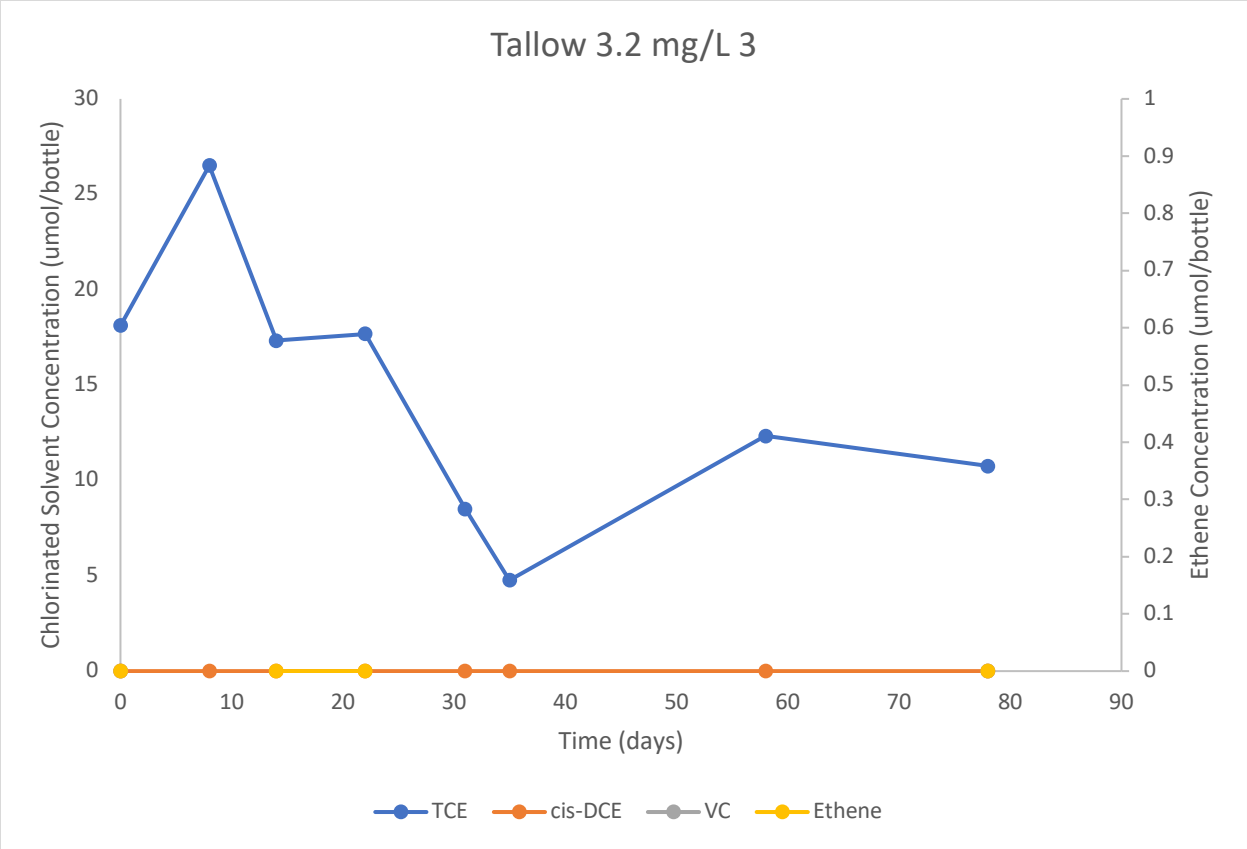
Appendix Figure 87. 32 mg/L Brown Grease dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



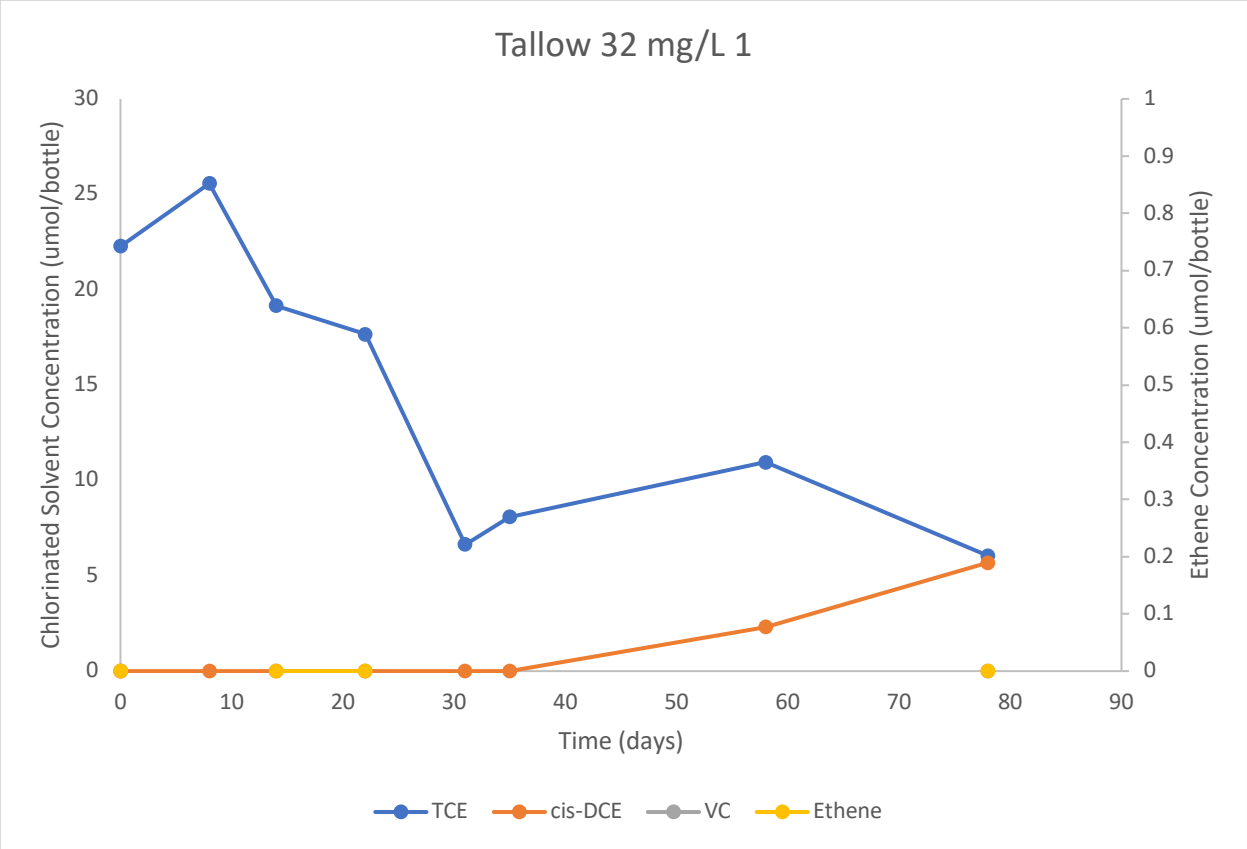
Appendix Figure 88. 3.2 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



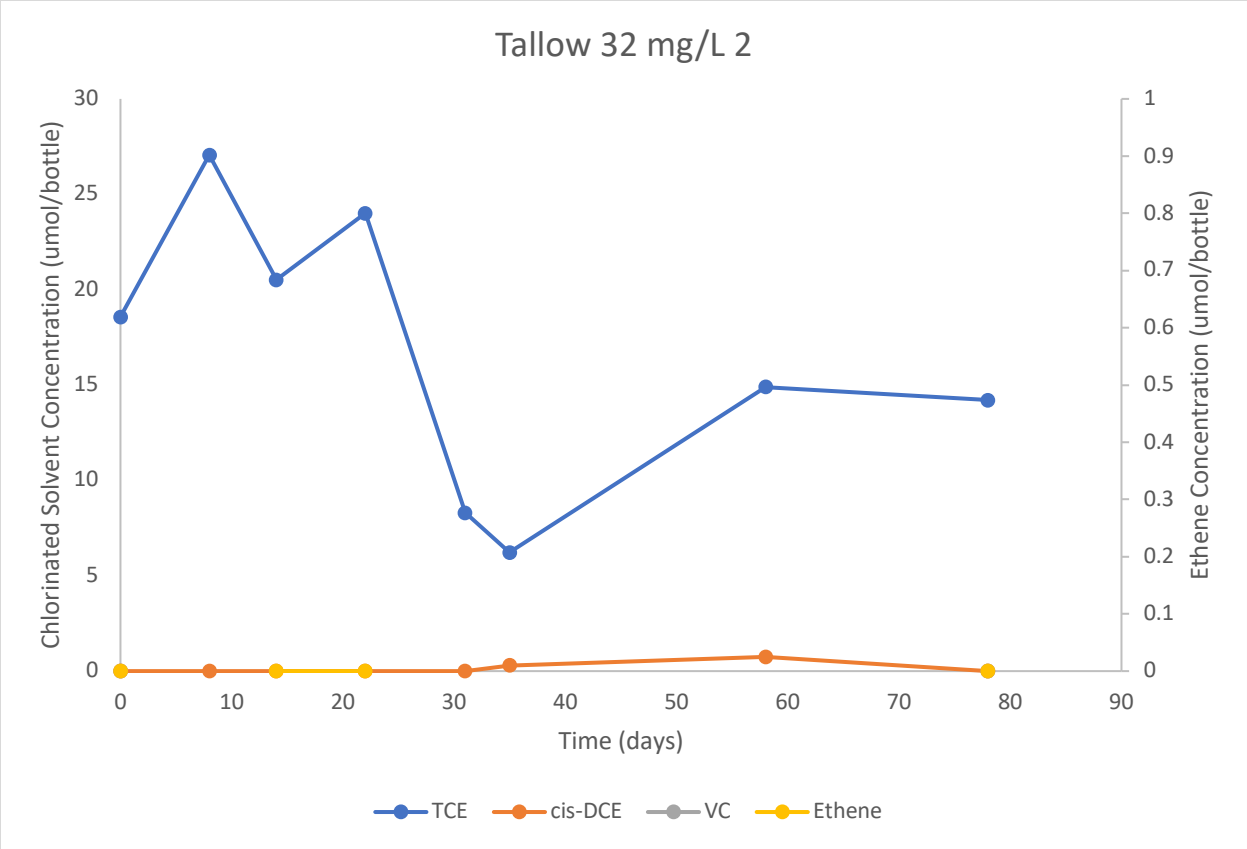
Appendix Figure 89. 3.2 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



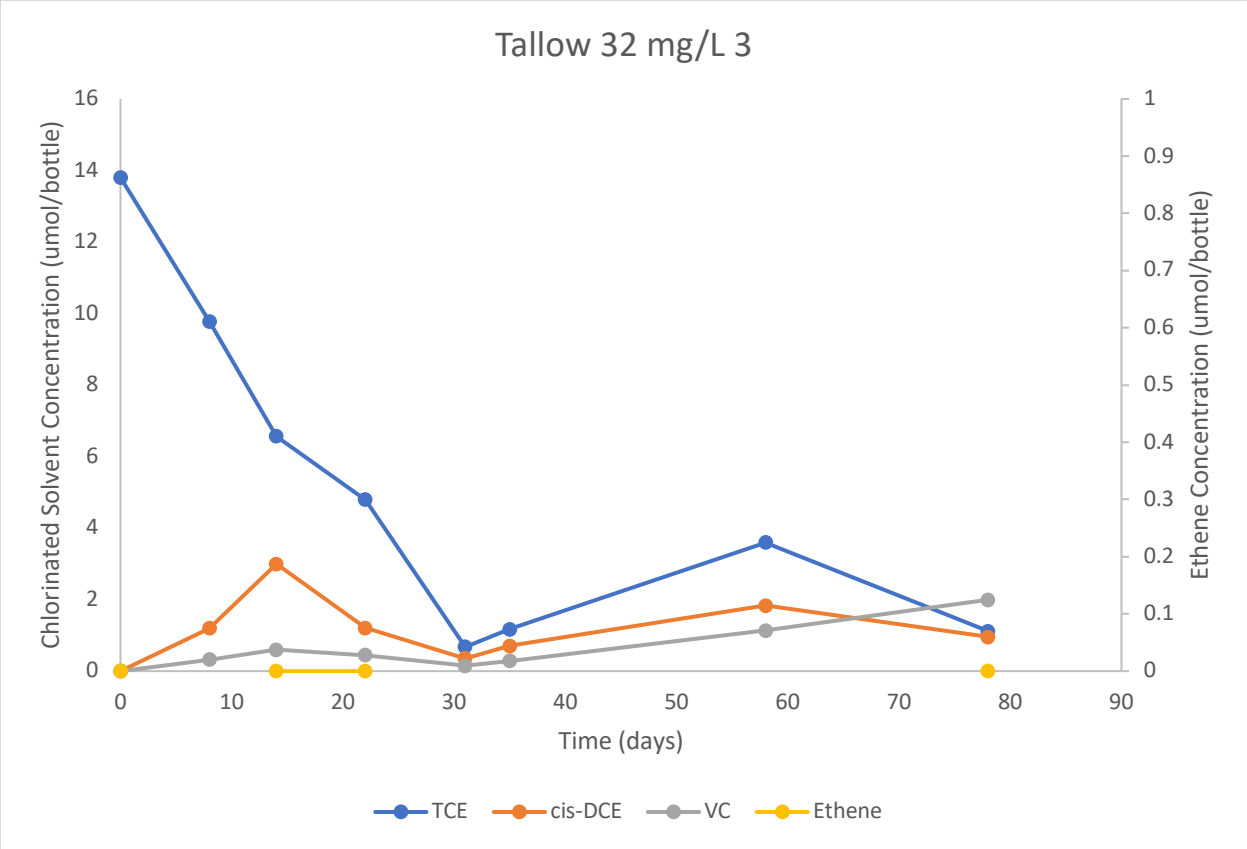
Appendix Figure 90. 3.2 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



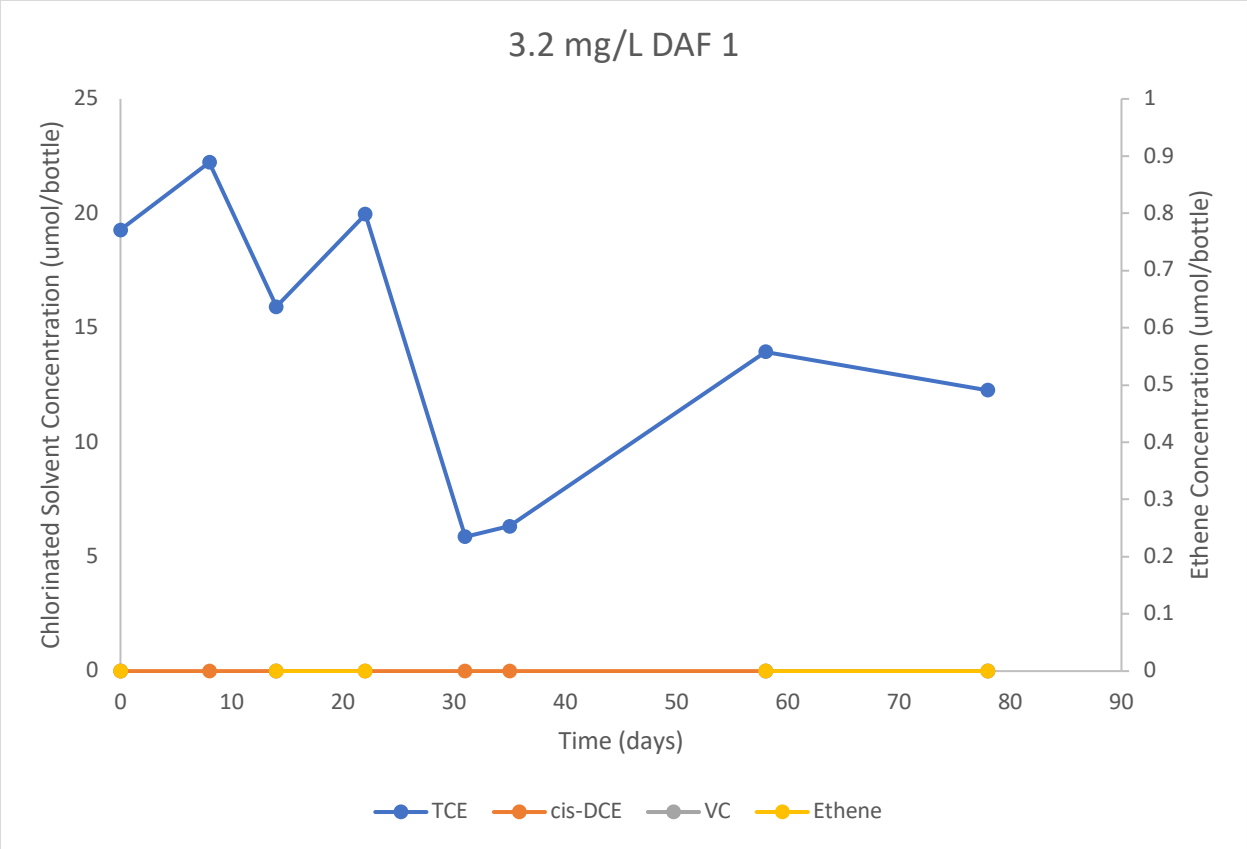
Appendix Figure 91. 32 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



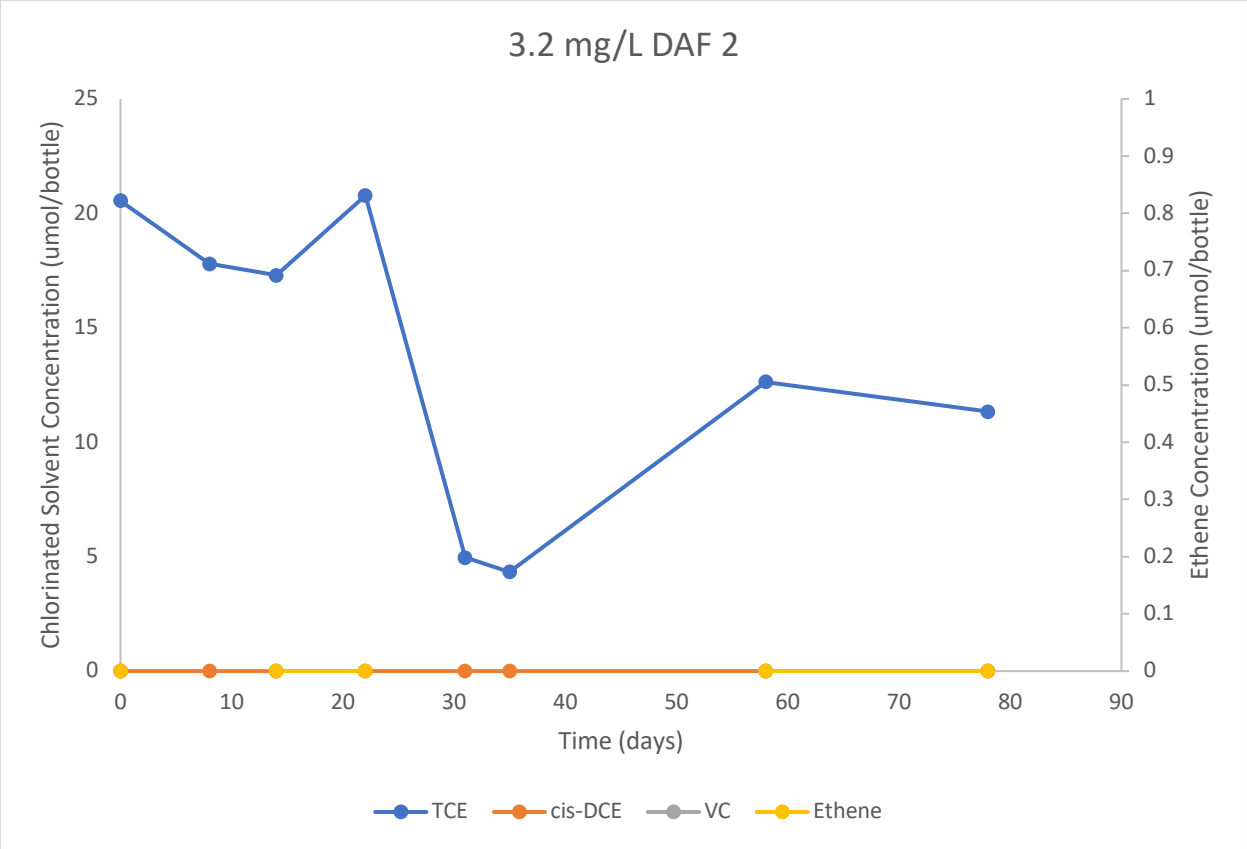
Appendix Figure 92. 32 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



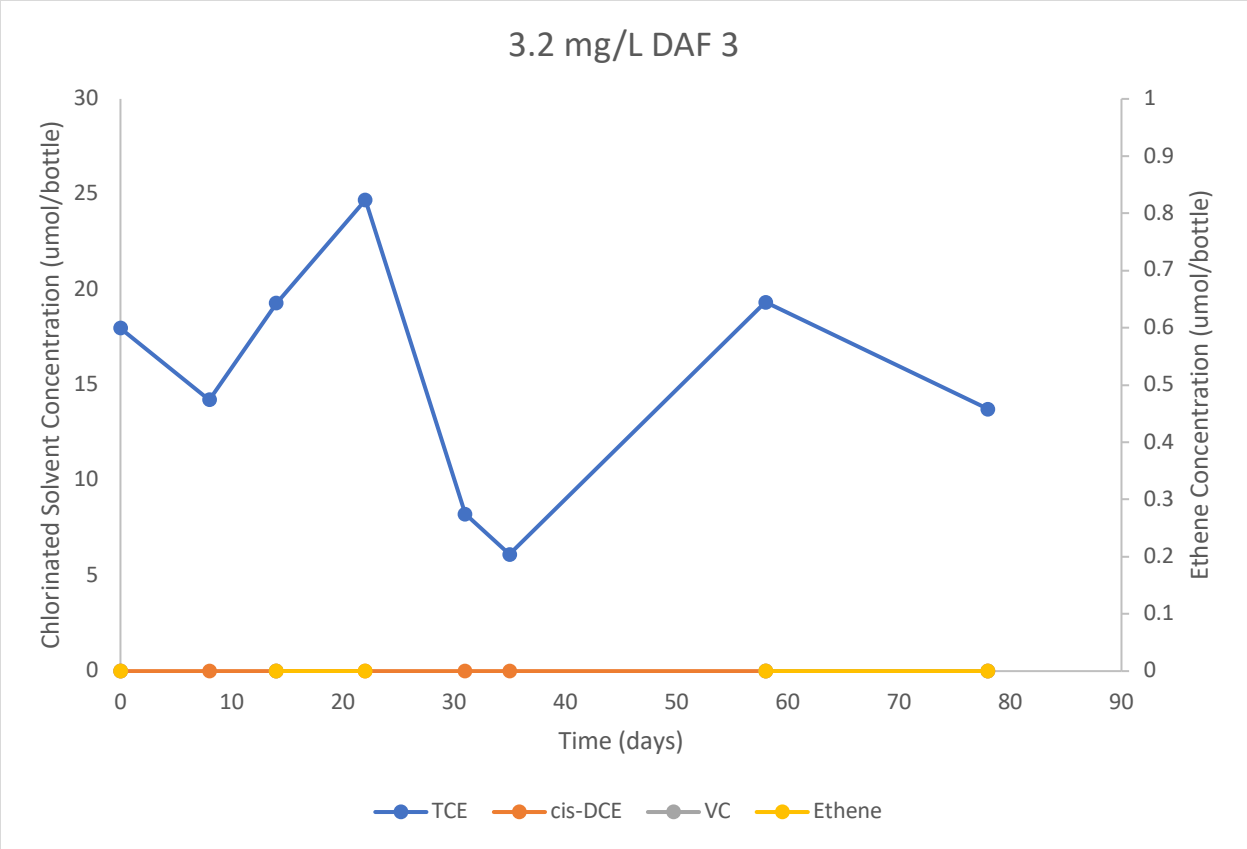
Appendix Figure 93. 32 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



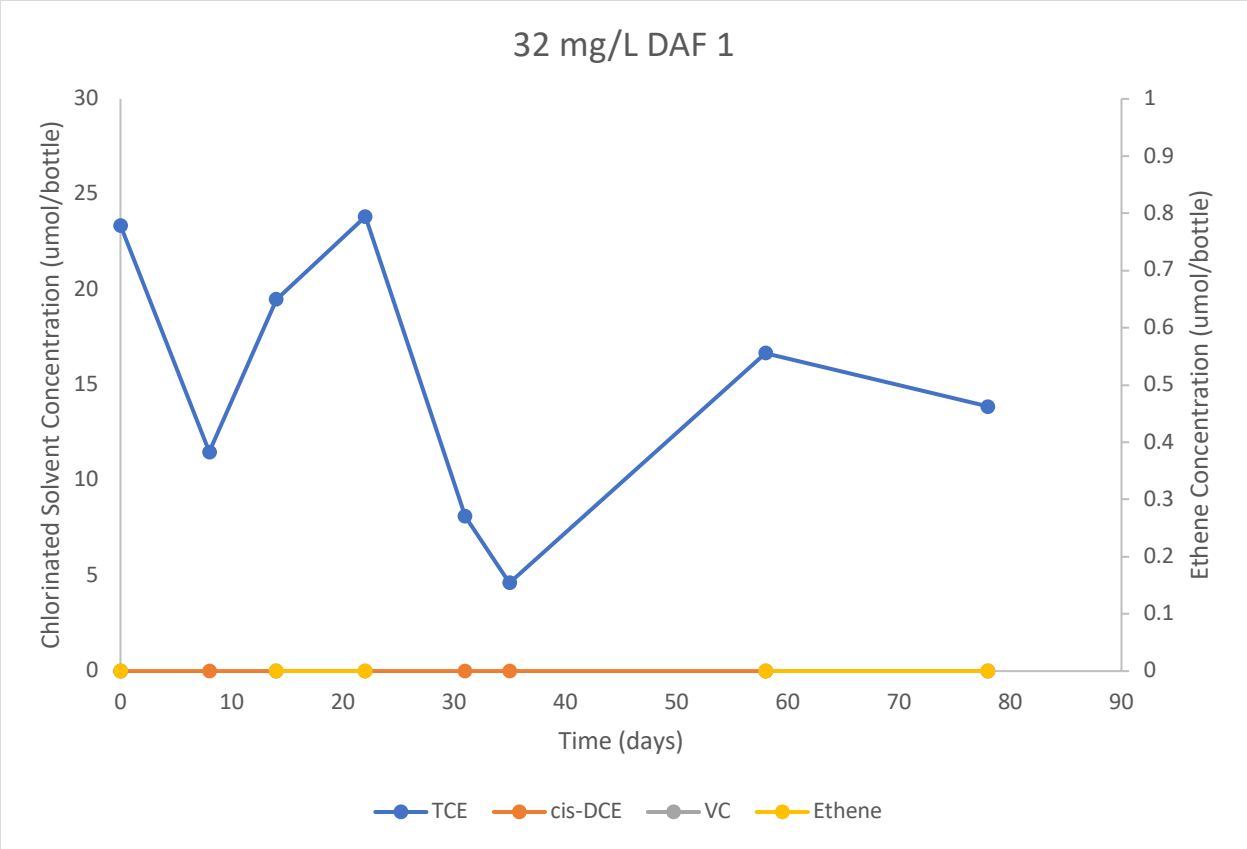
Appendix Figure 94. 3.2 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



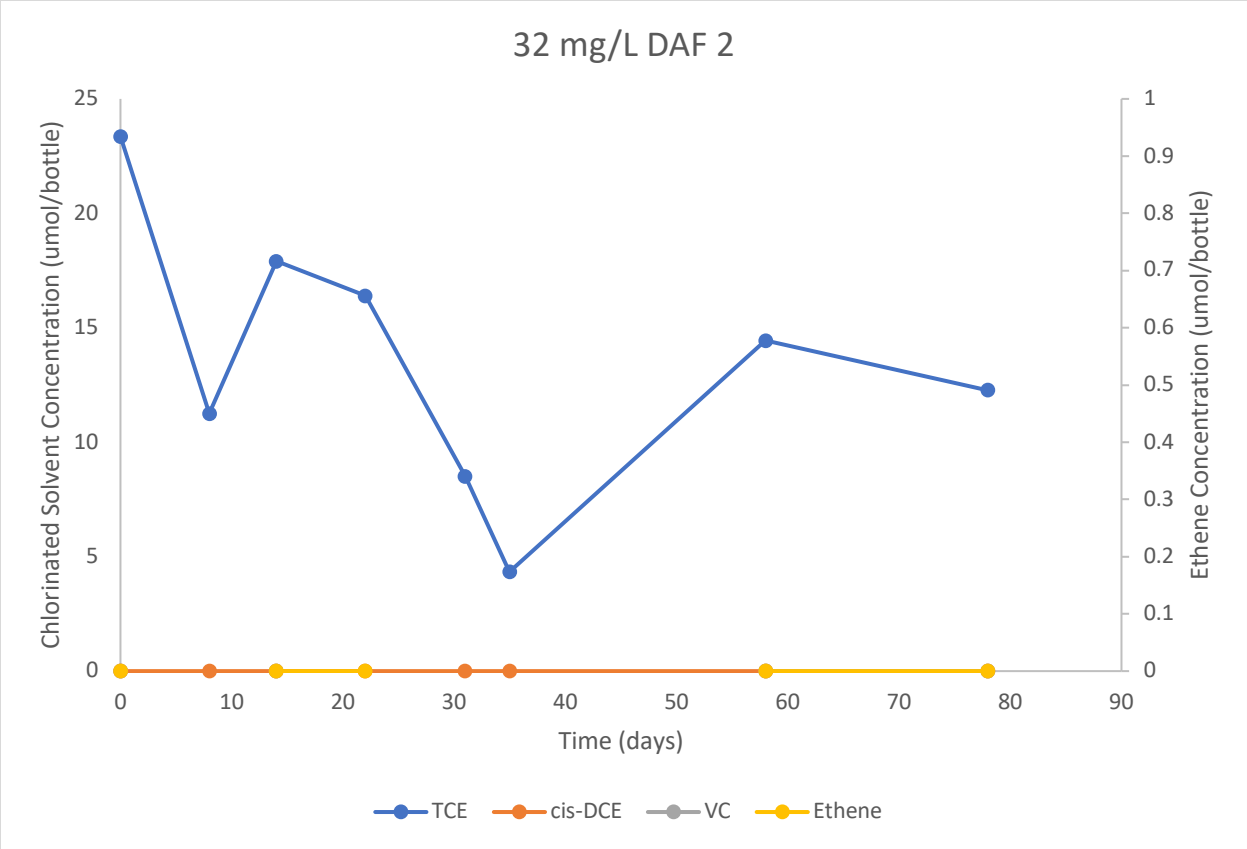
Appendix Figure 95. 3.2 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



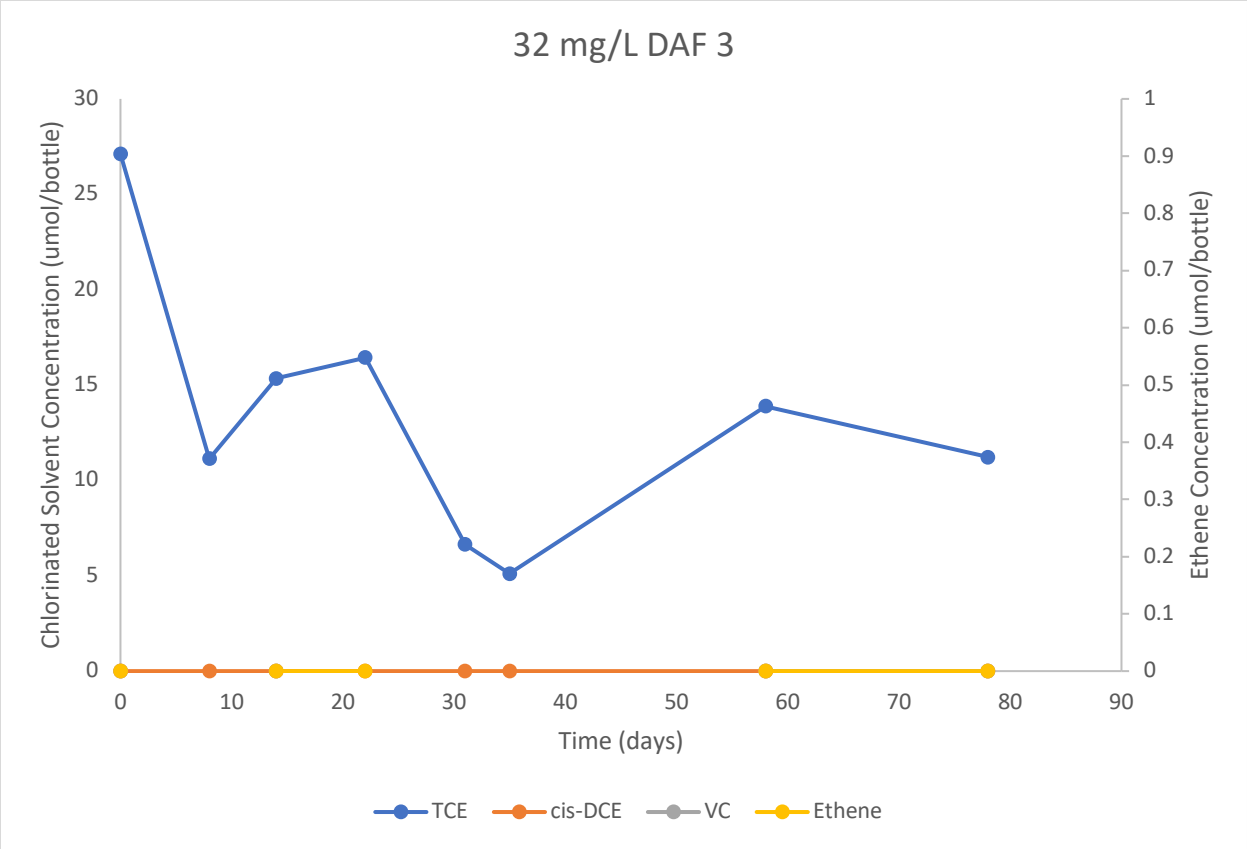
Appendix Figure 96. 3.2 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



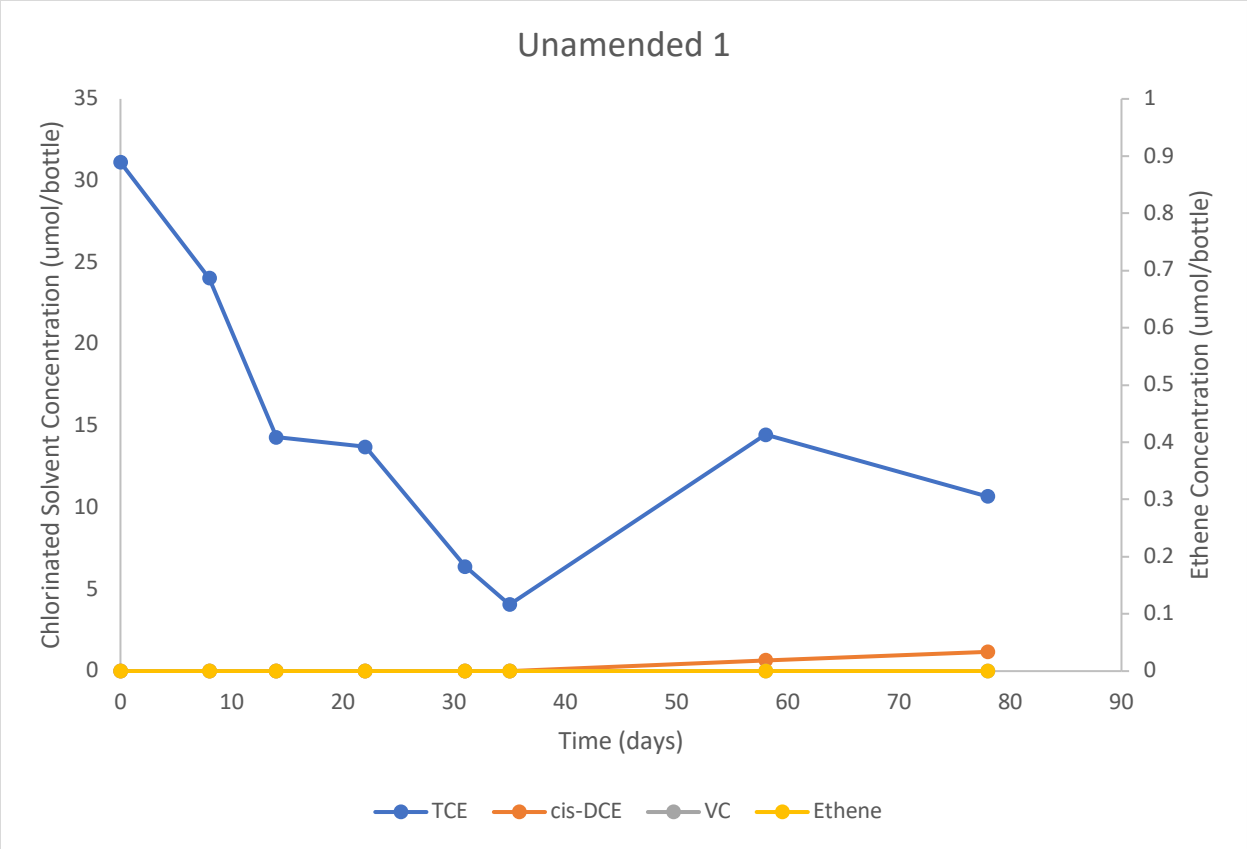
Appendix Figure 97. 32 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



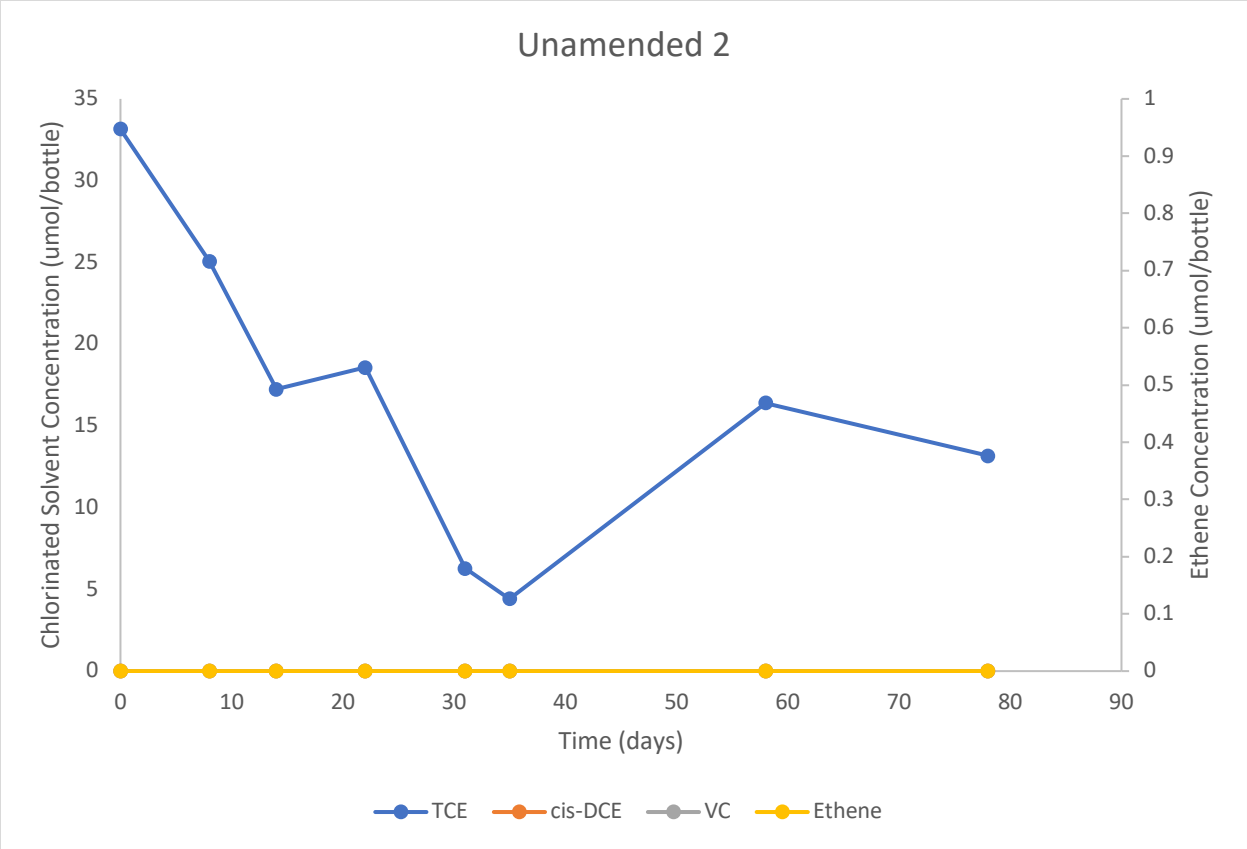
Appendix Figure 98. 32 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



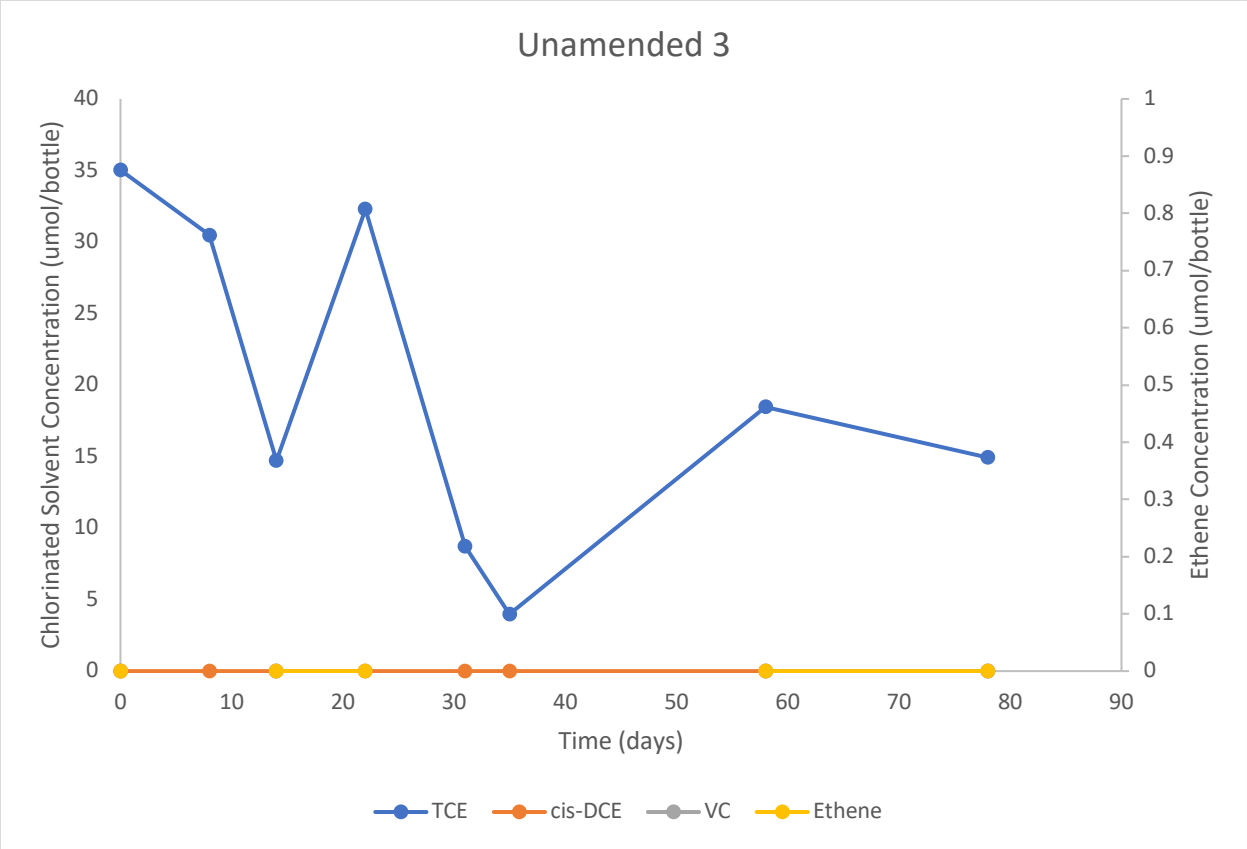
Appendix Figure 99. 32 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



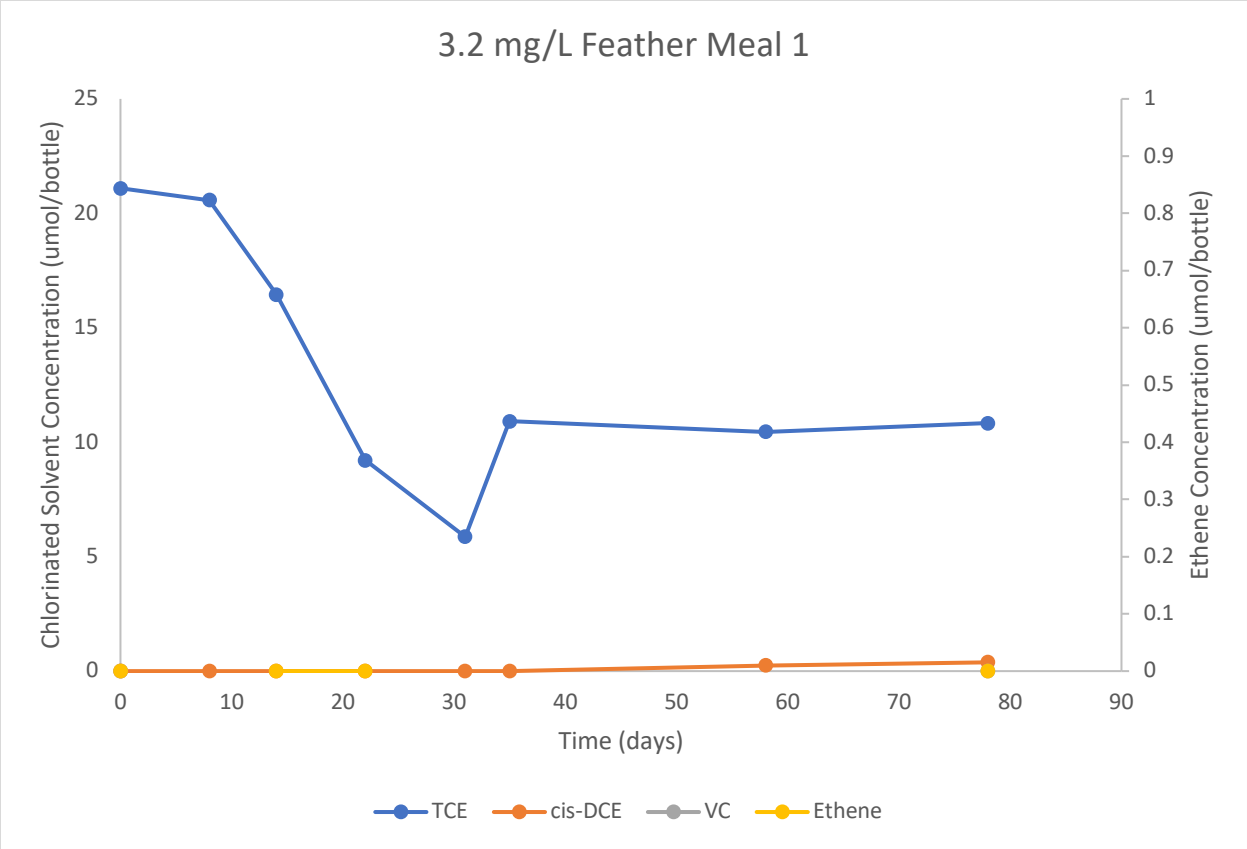
Appendix Figure 100. Unamended control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



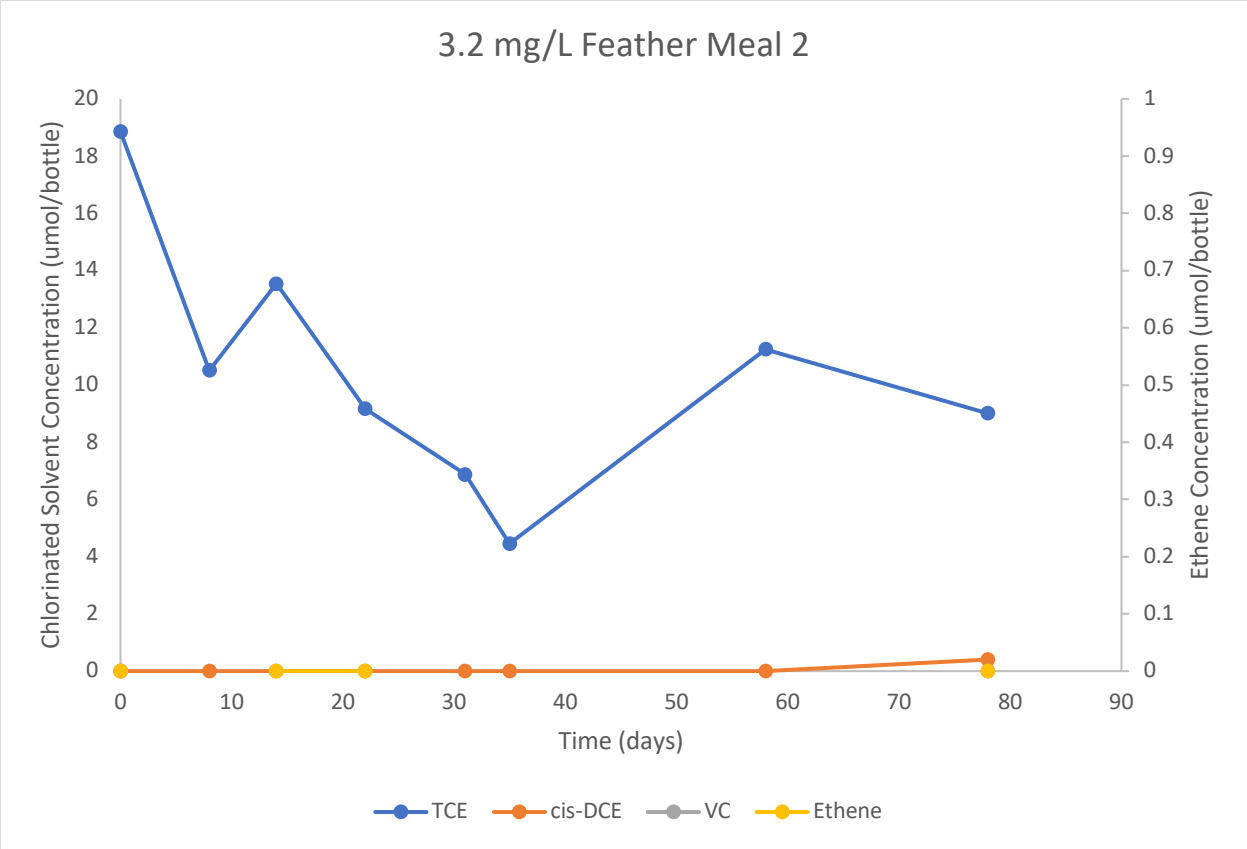
Appendix Figure 101. Unamended control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



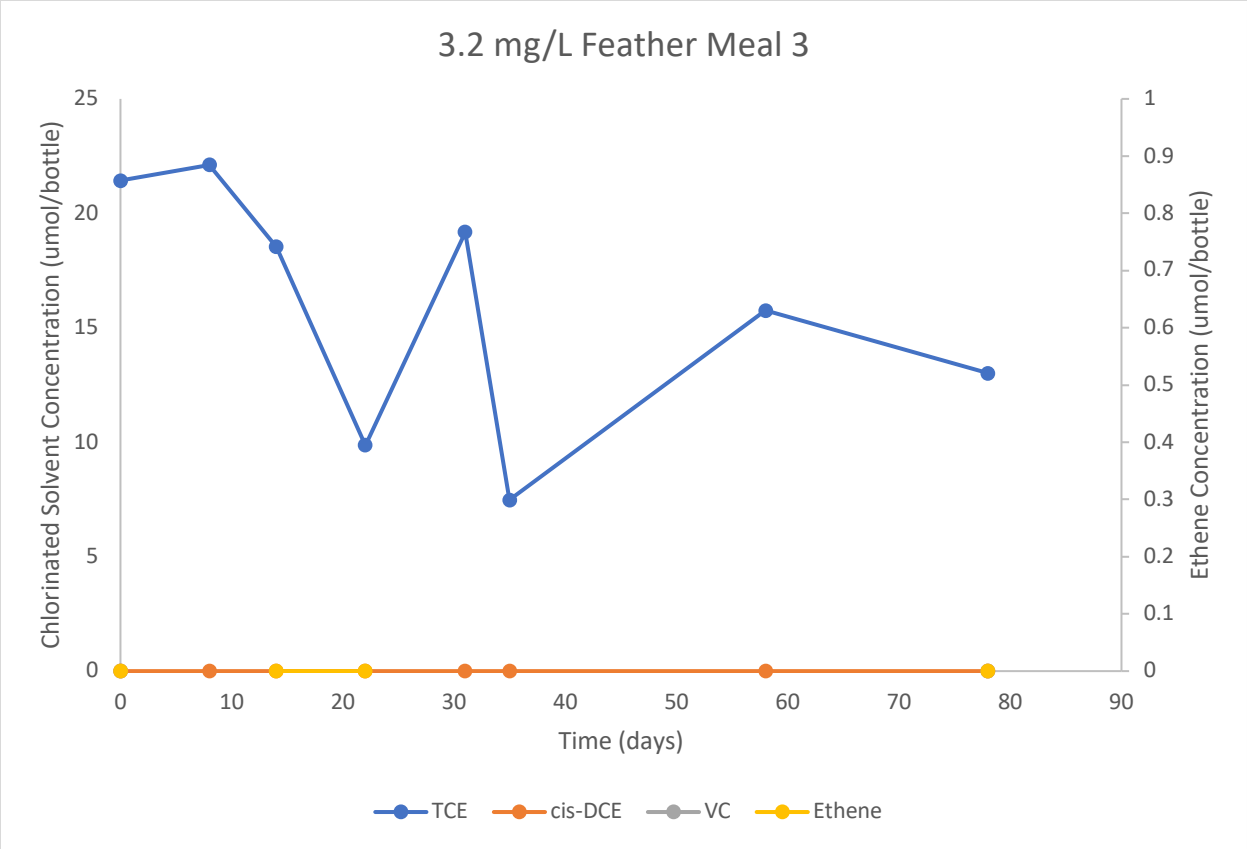
Appendix Figure 102. Unamended control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



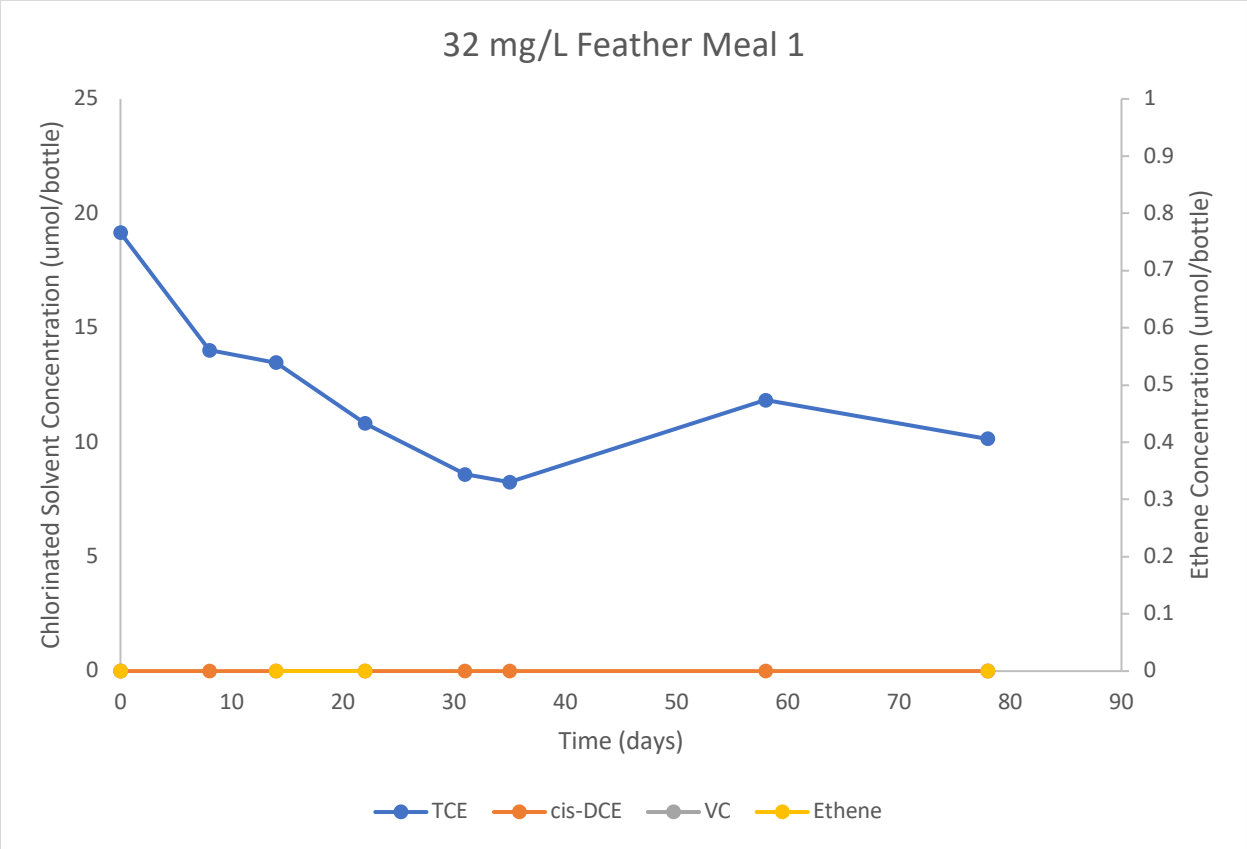
Appendix Figure 103. 3.2 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



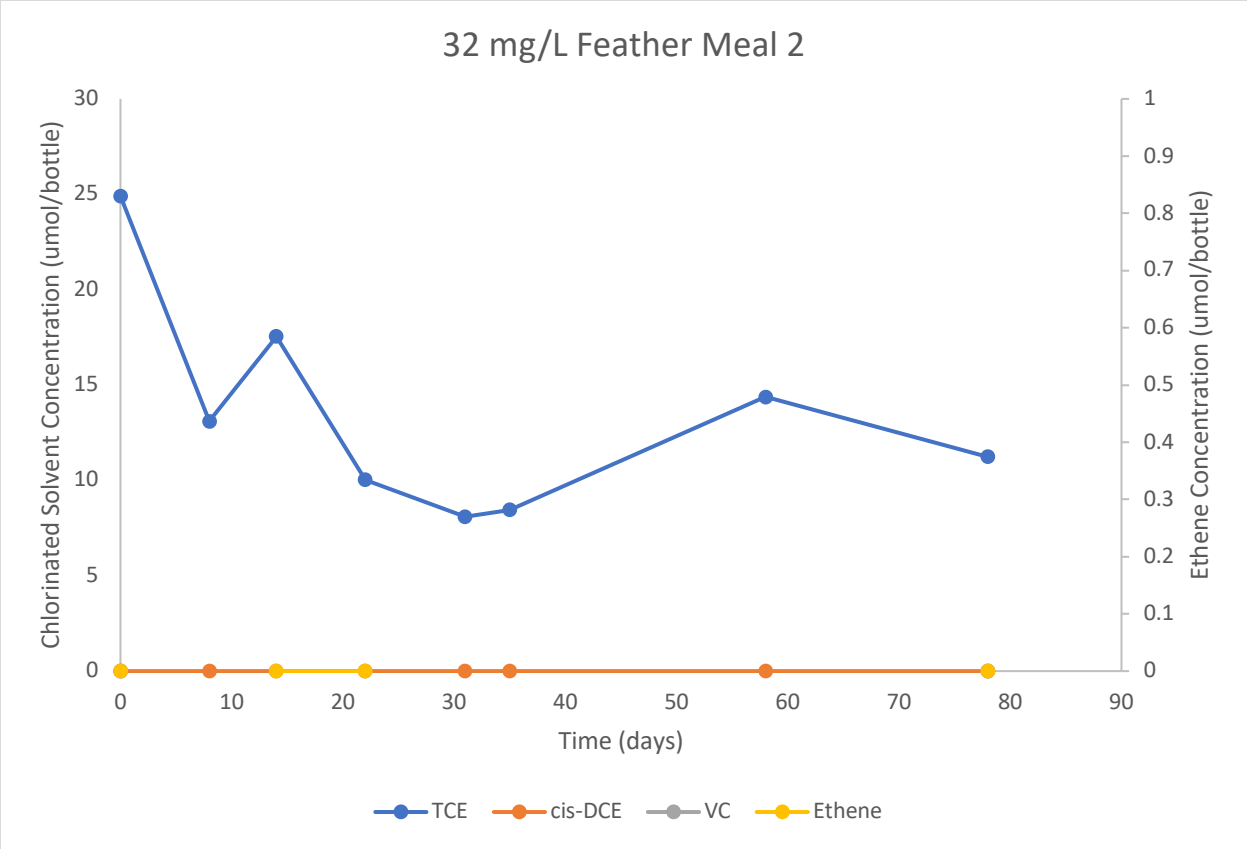
Appendix Figure 104. 3.2 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



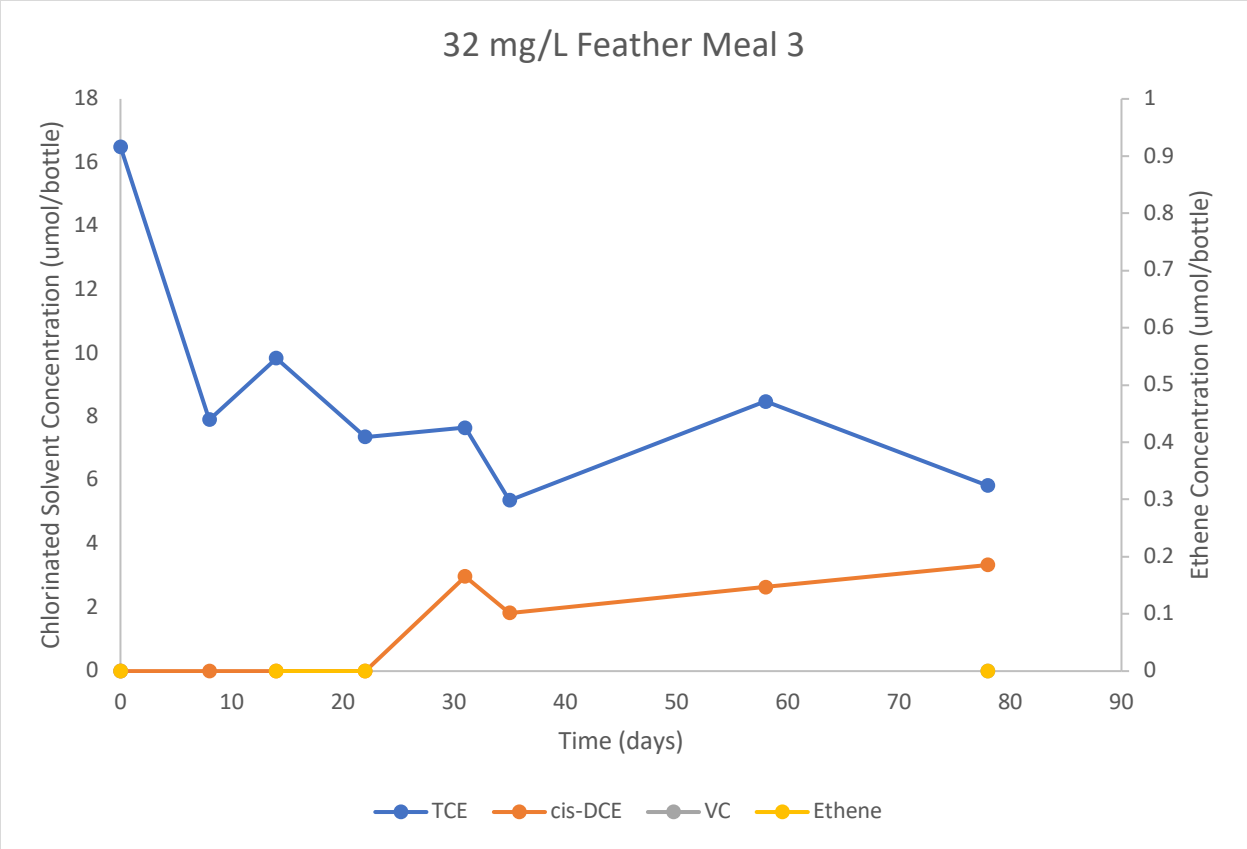
Appendix Figure 105. 3.2 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



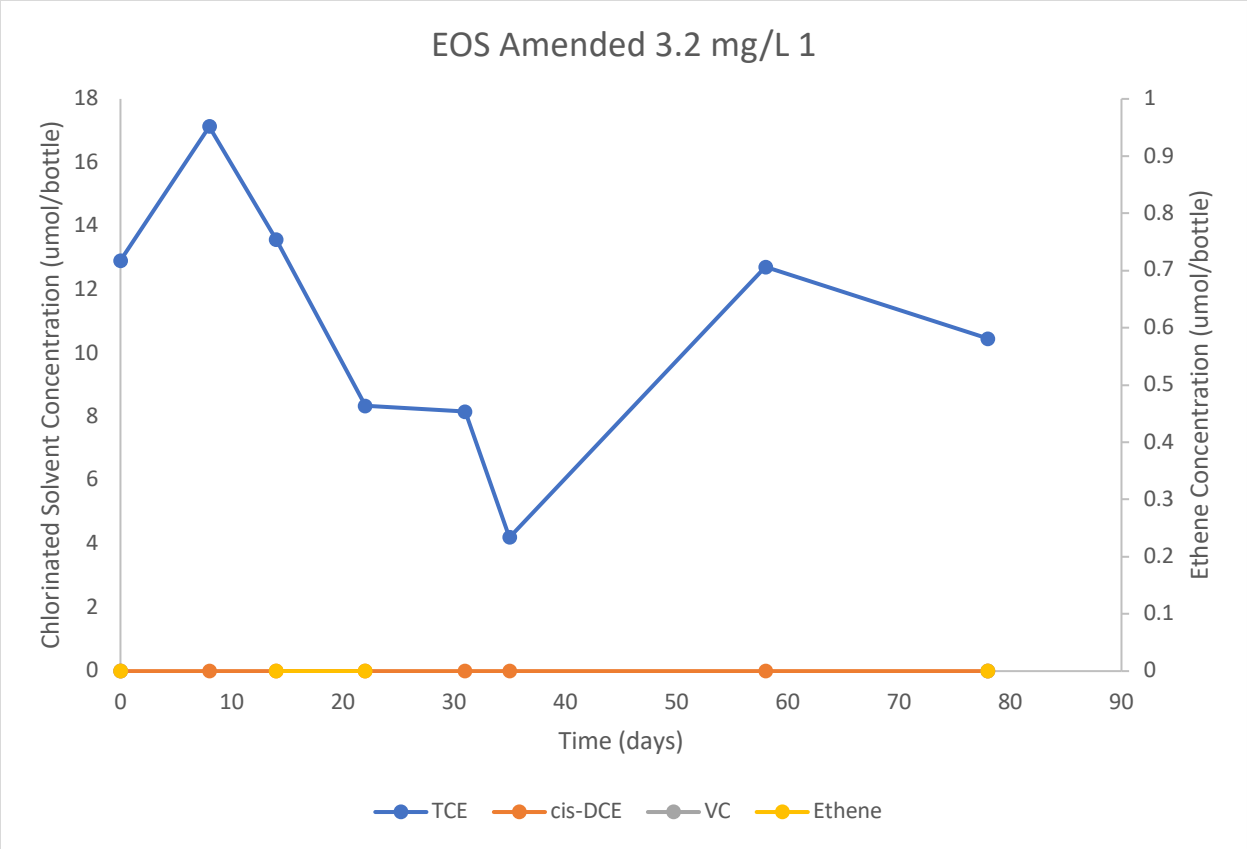
Appendix Figure 106. 32 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



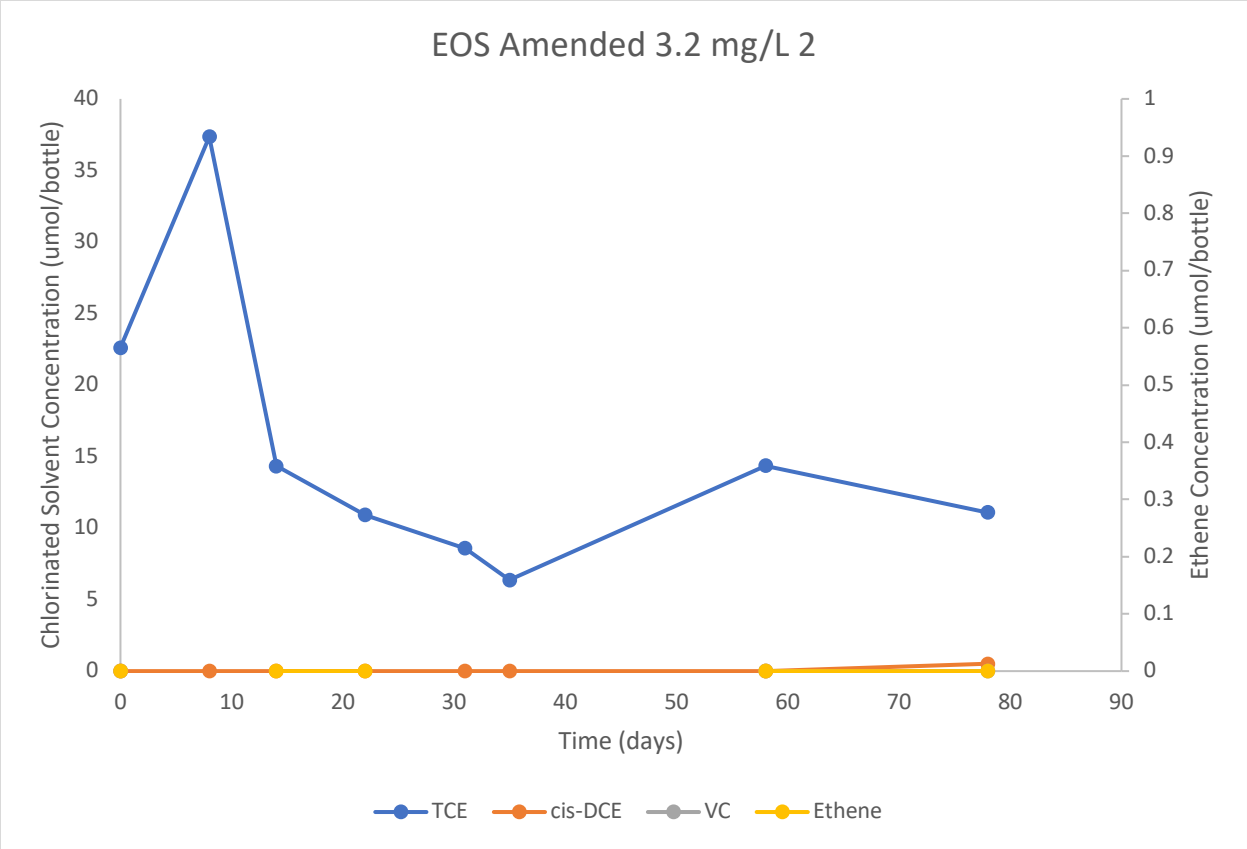
Appendix Figure 107. 32 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



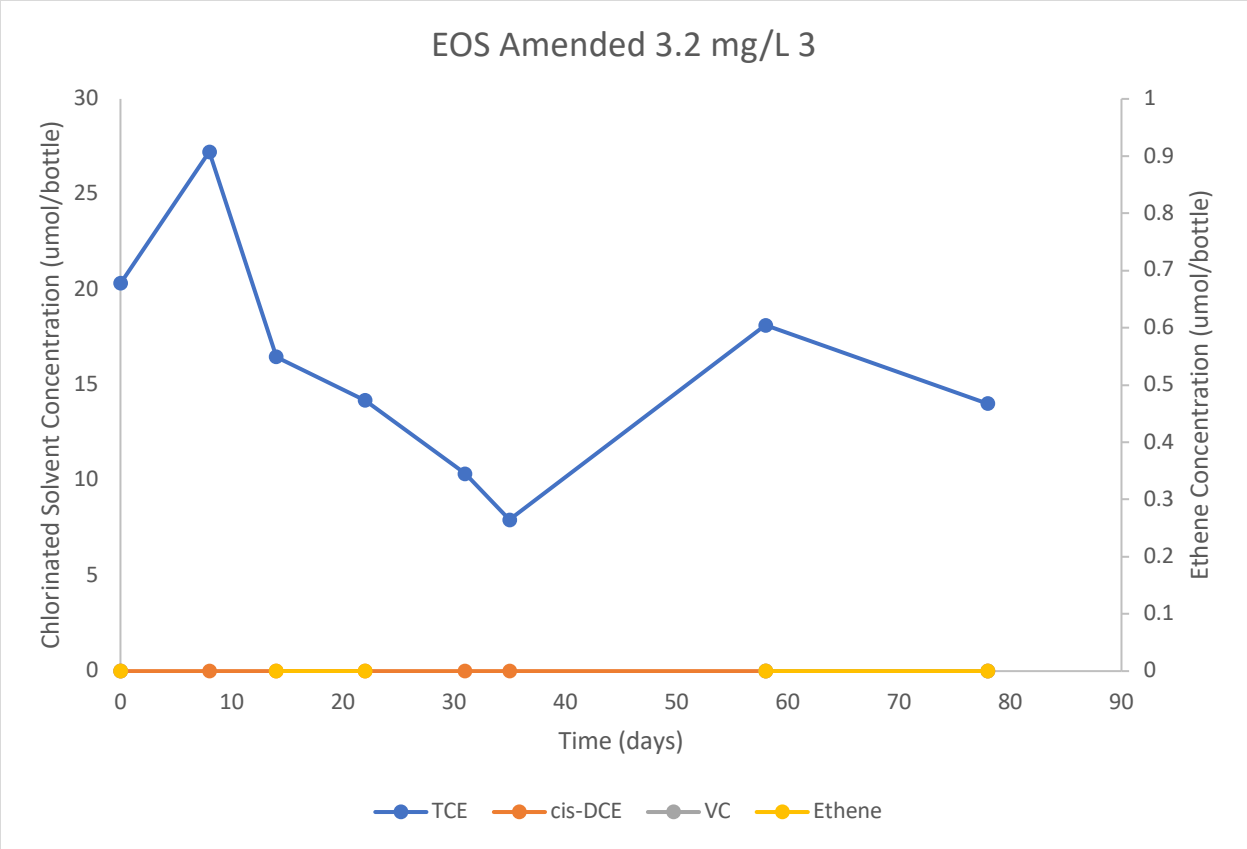
Appendix Figure 108. 32 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



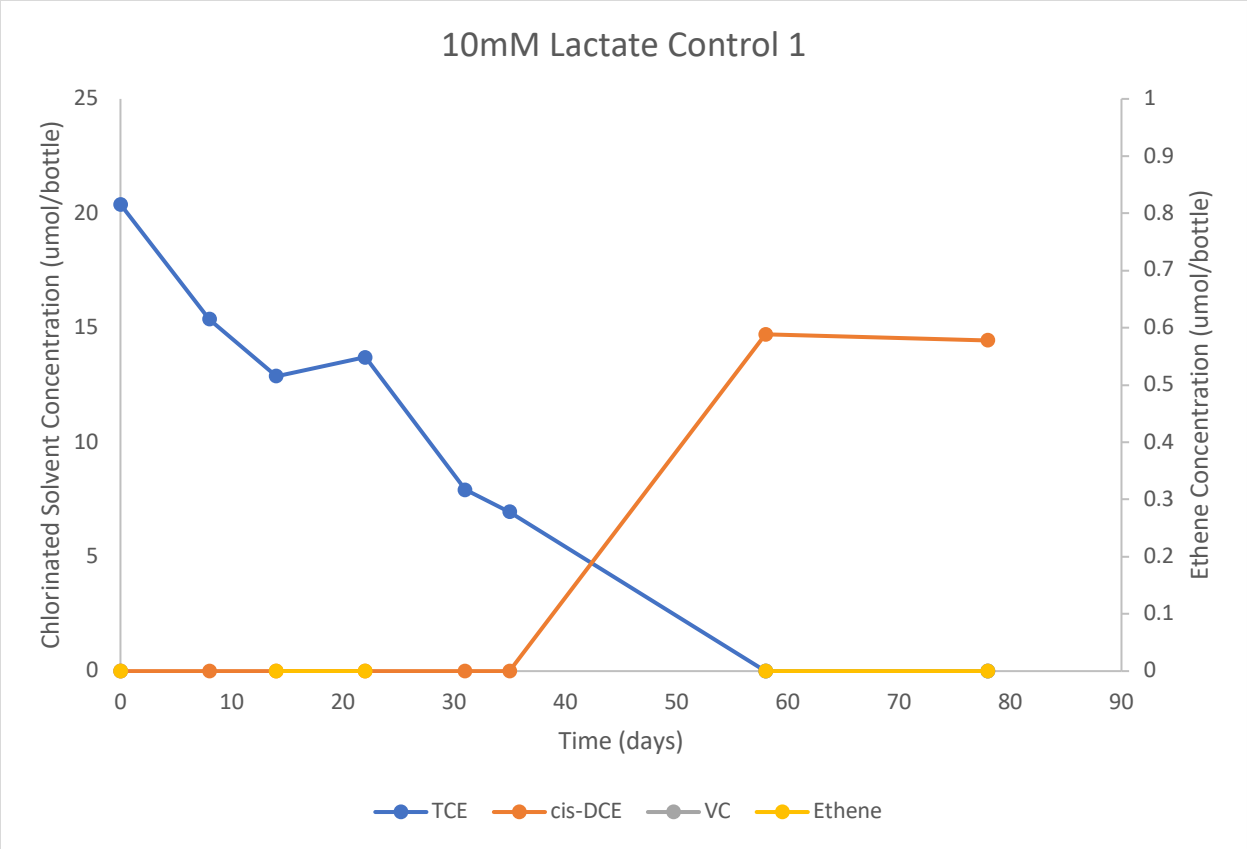
Appendix Figure 109. 3.2 mg/L EOS control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



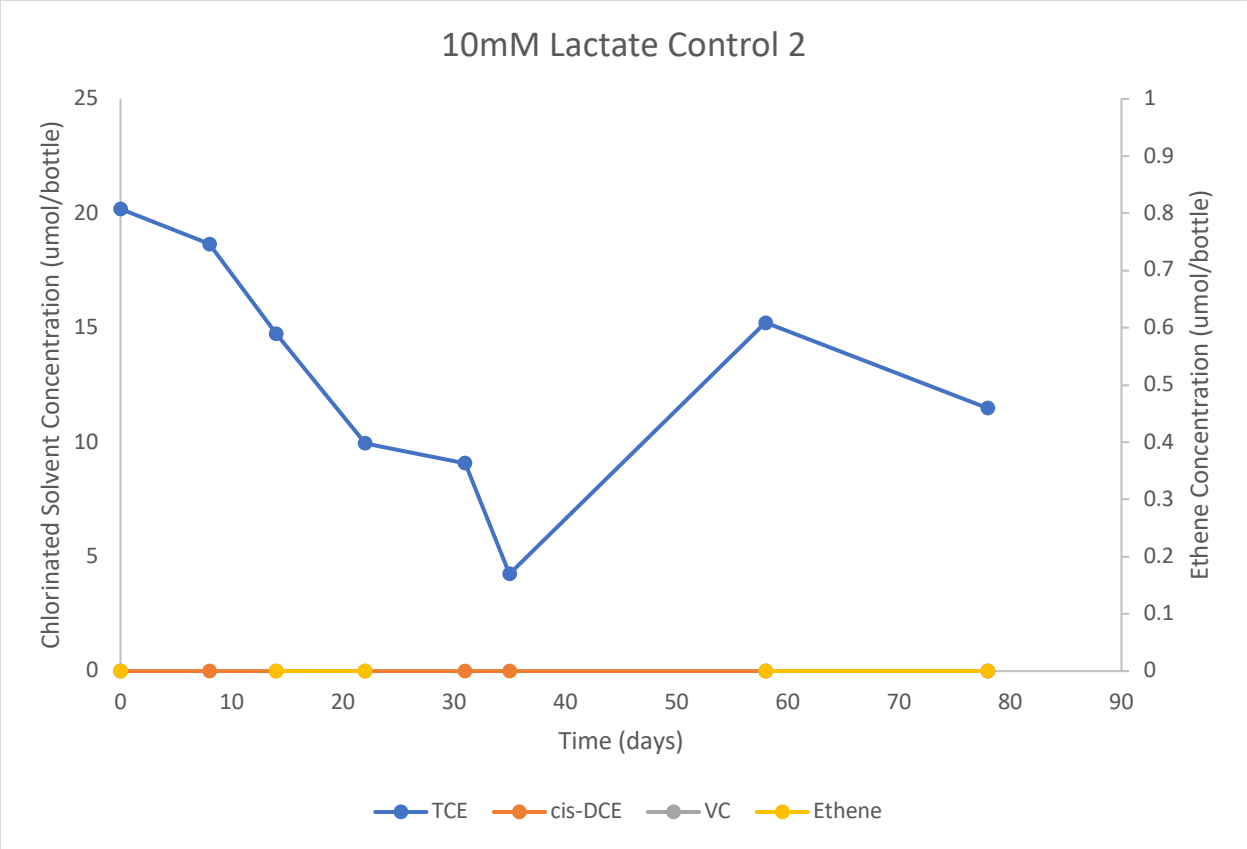
Appendix Figure 110. 3.2 mg/L EOS control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



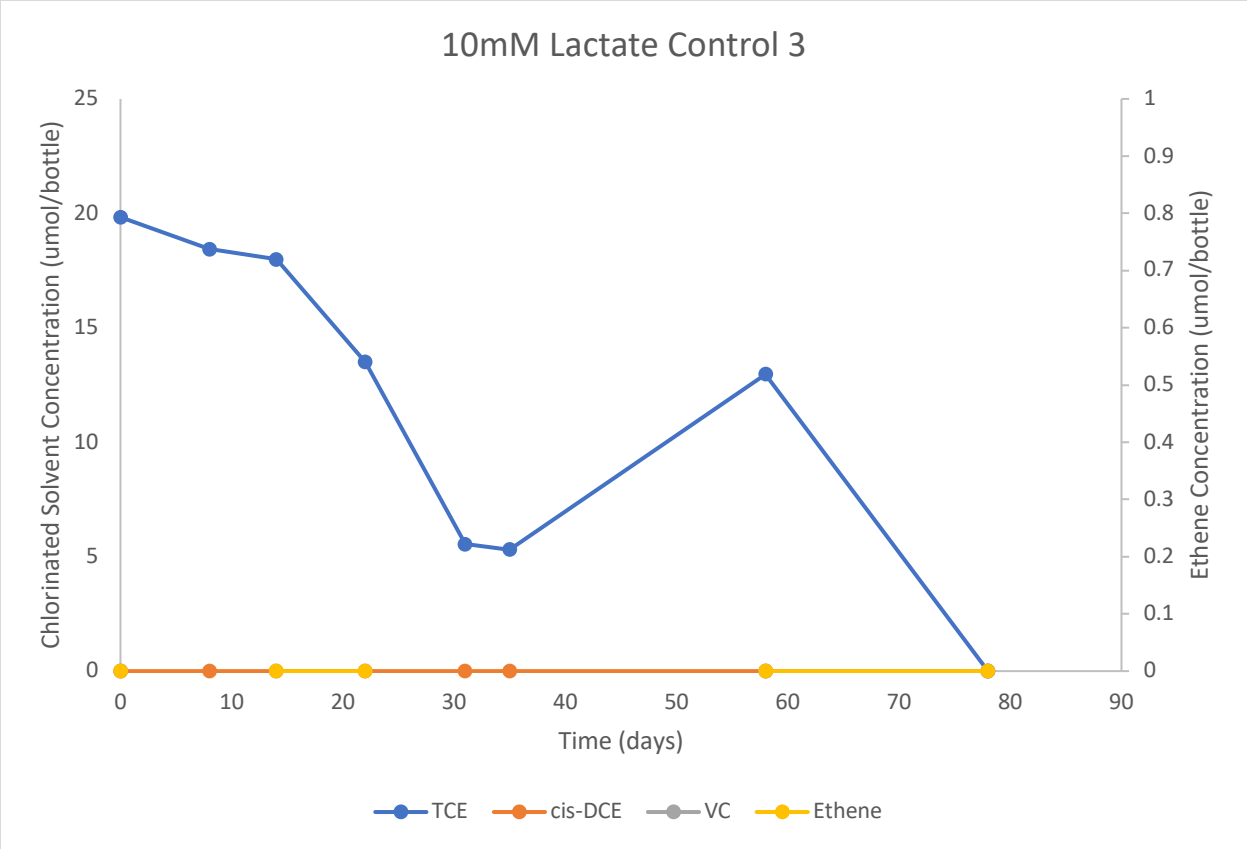
Appendix Figure 111. 3.2 mg/L EOS control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



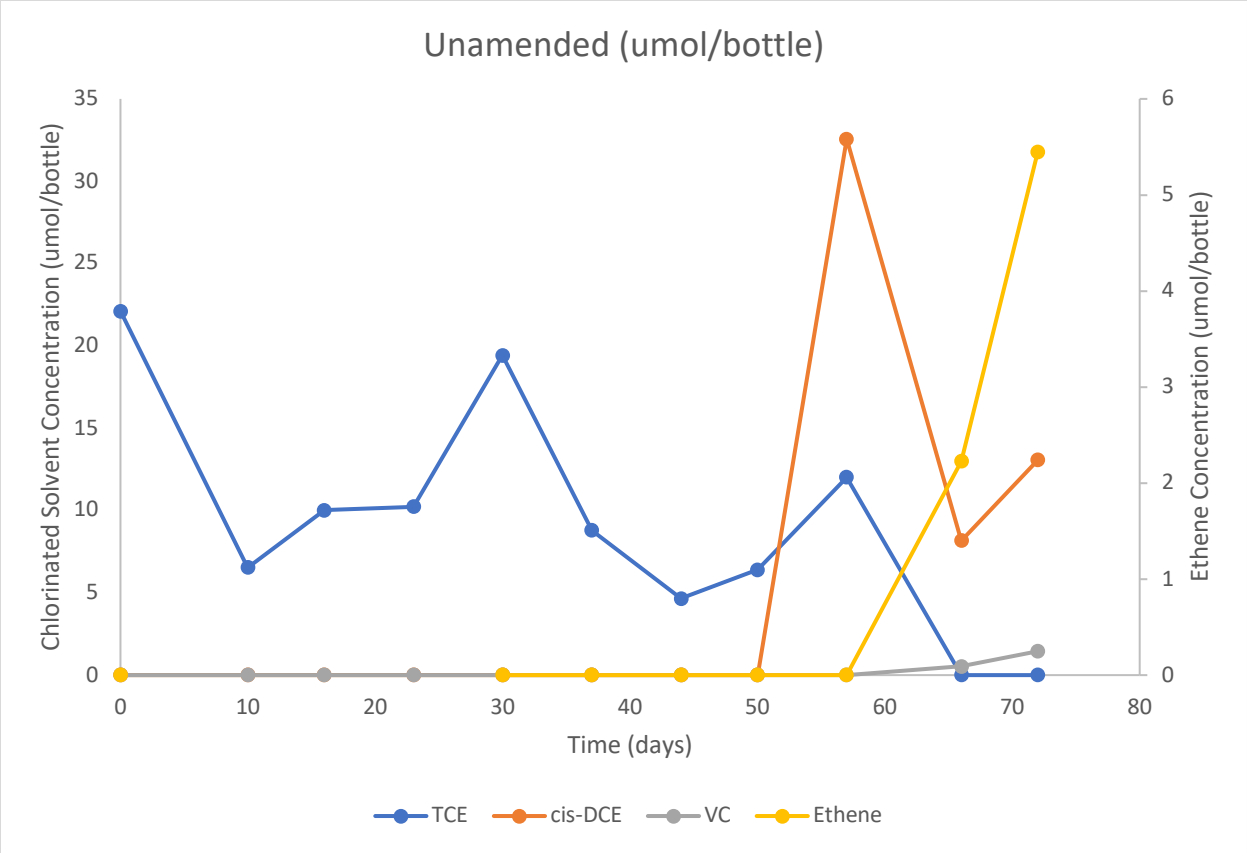
Appendix Figure 112. 10 mM Lactate control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



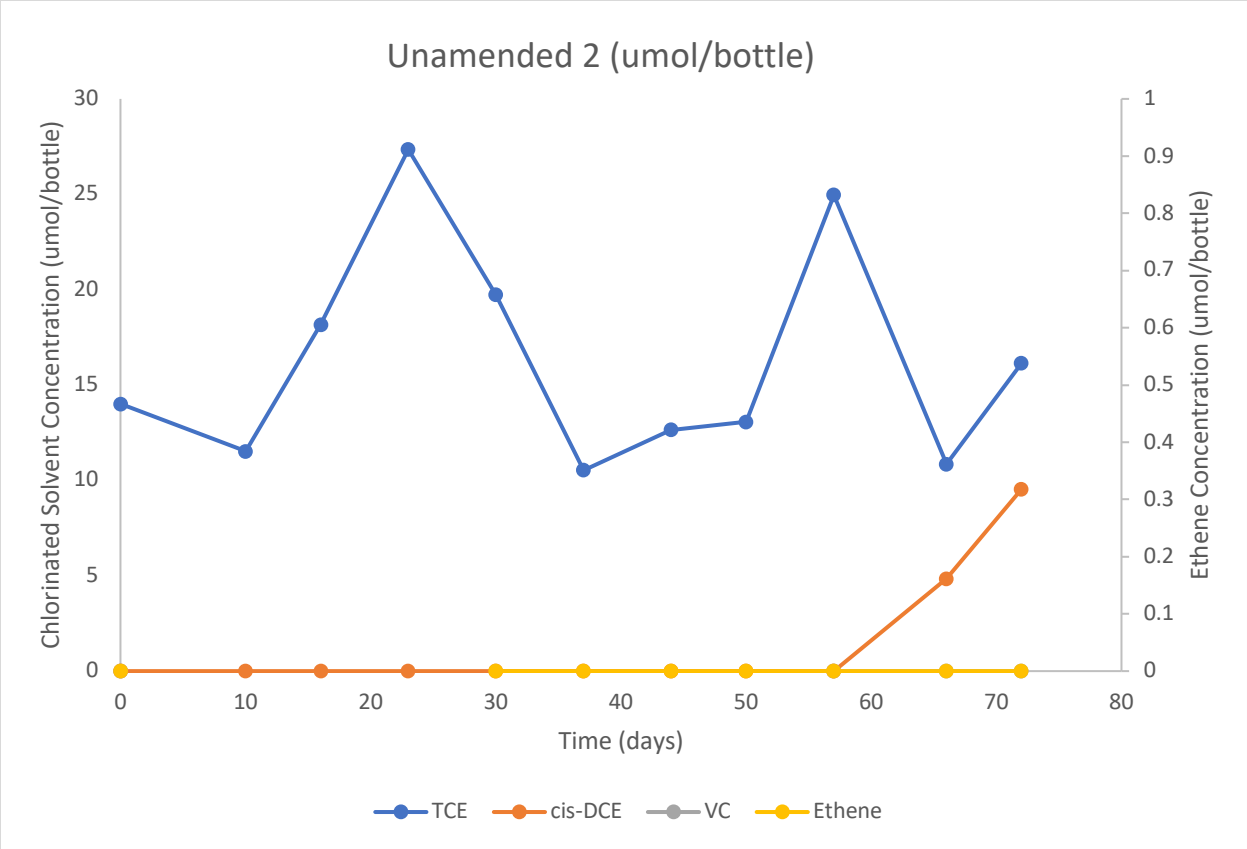
Appendix Figure 113. 10 mM Lactate control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



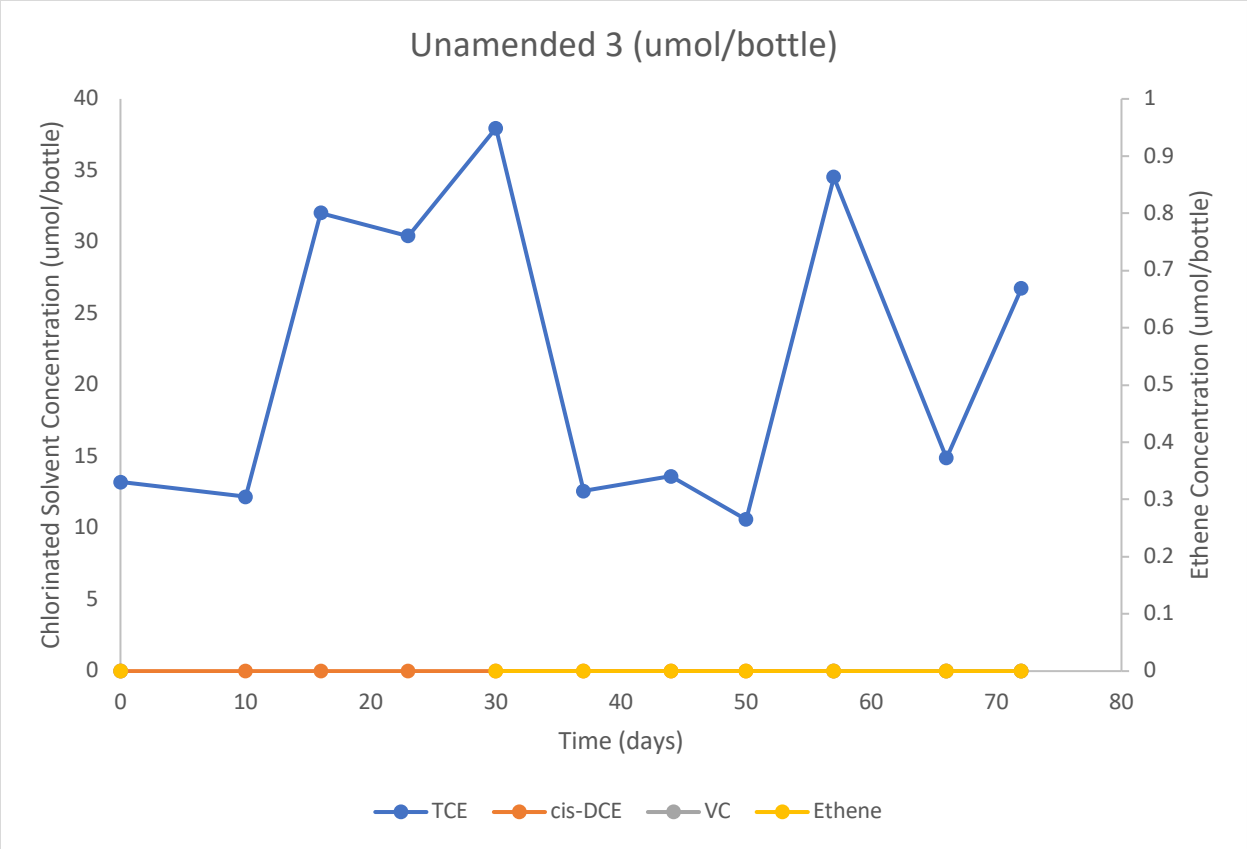
Appendix Figure 114. 10 mM Lactate control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



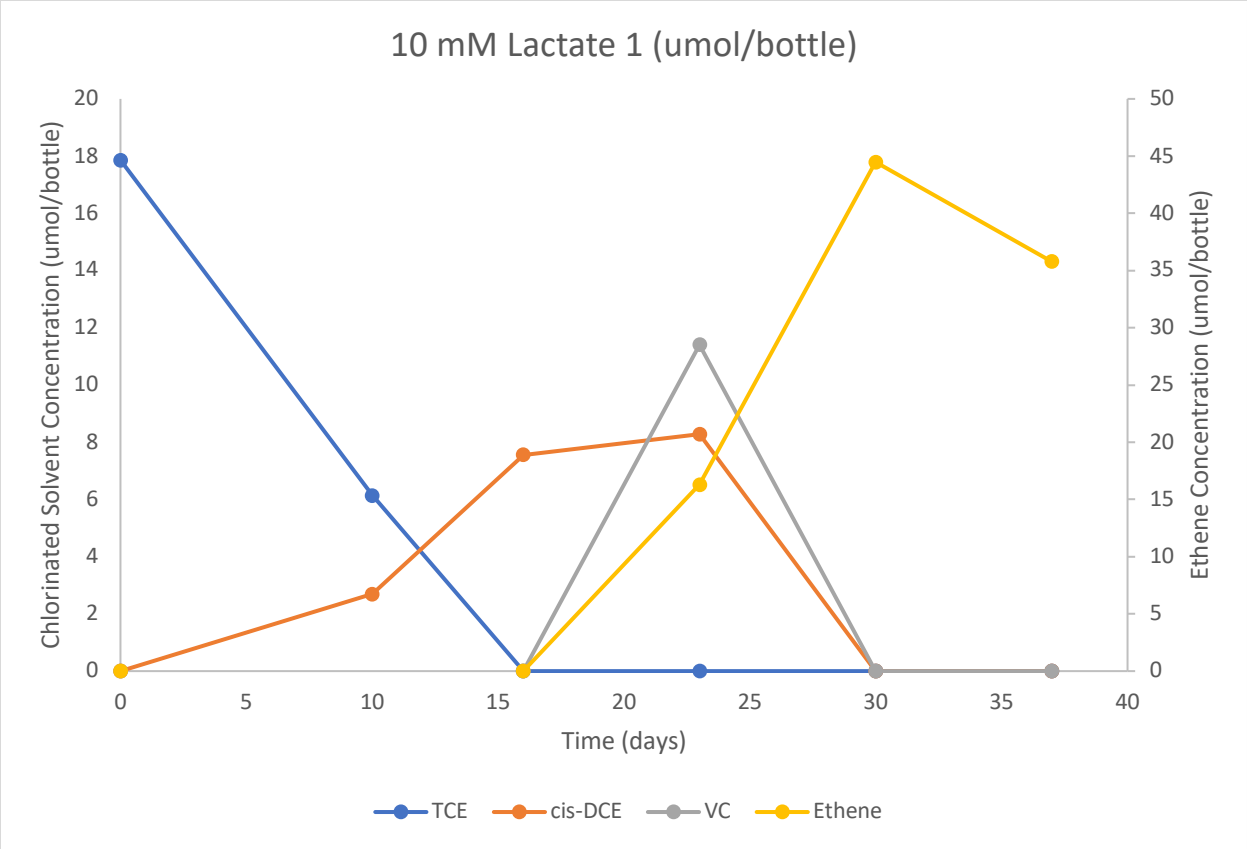
Appendix Figure 115. Unamended control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



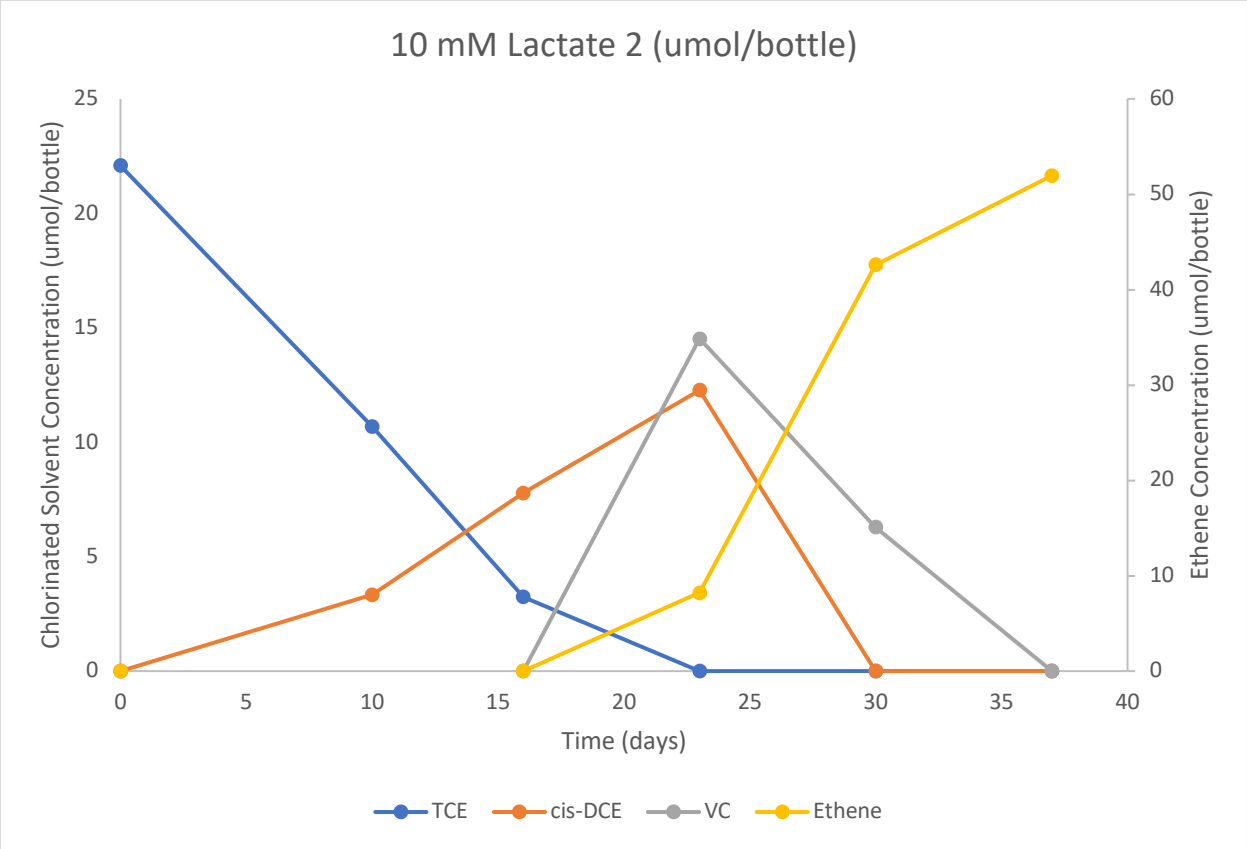
Appendix Figure 116. Unamended control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



Appendix Figure 117. Unamended control bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.

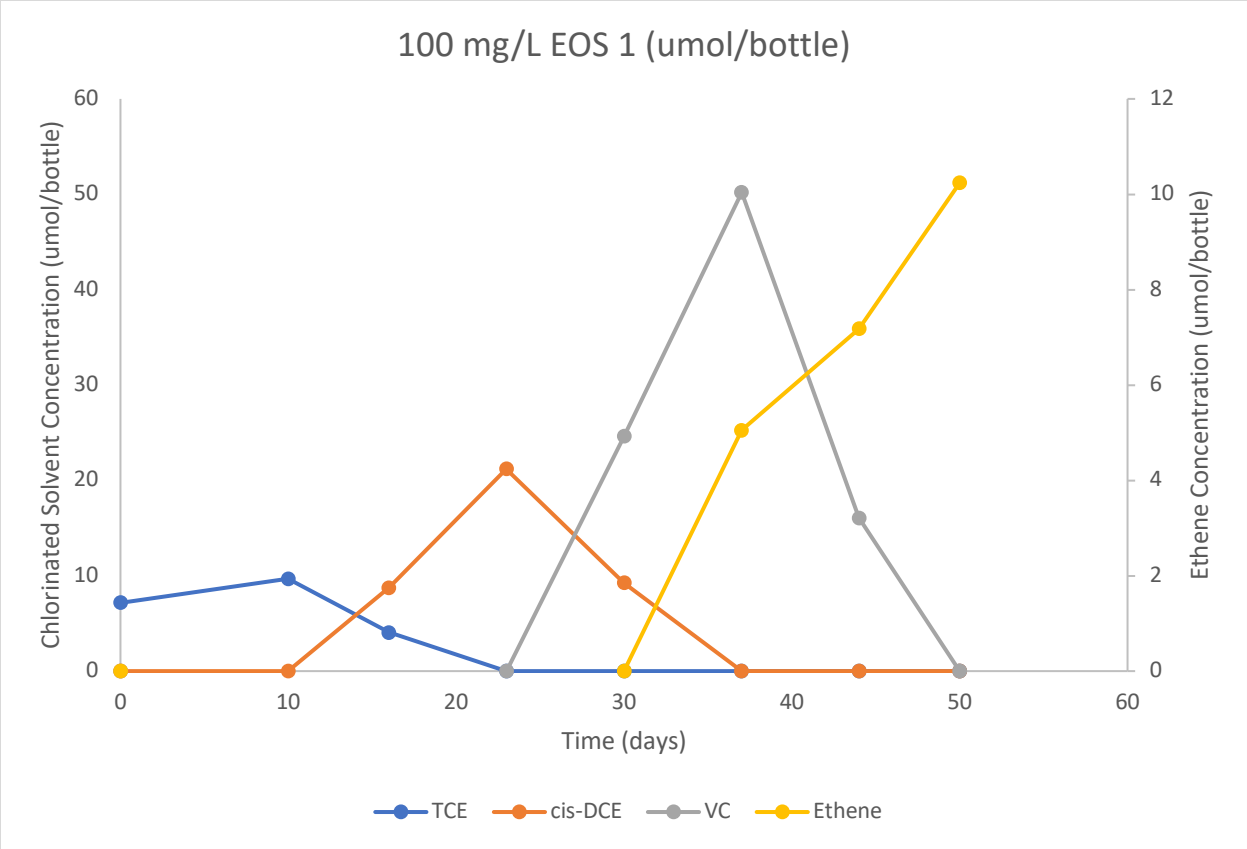


Appendix Figure 118. 10 mM Lactate control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.

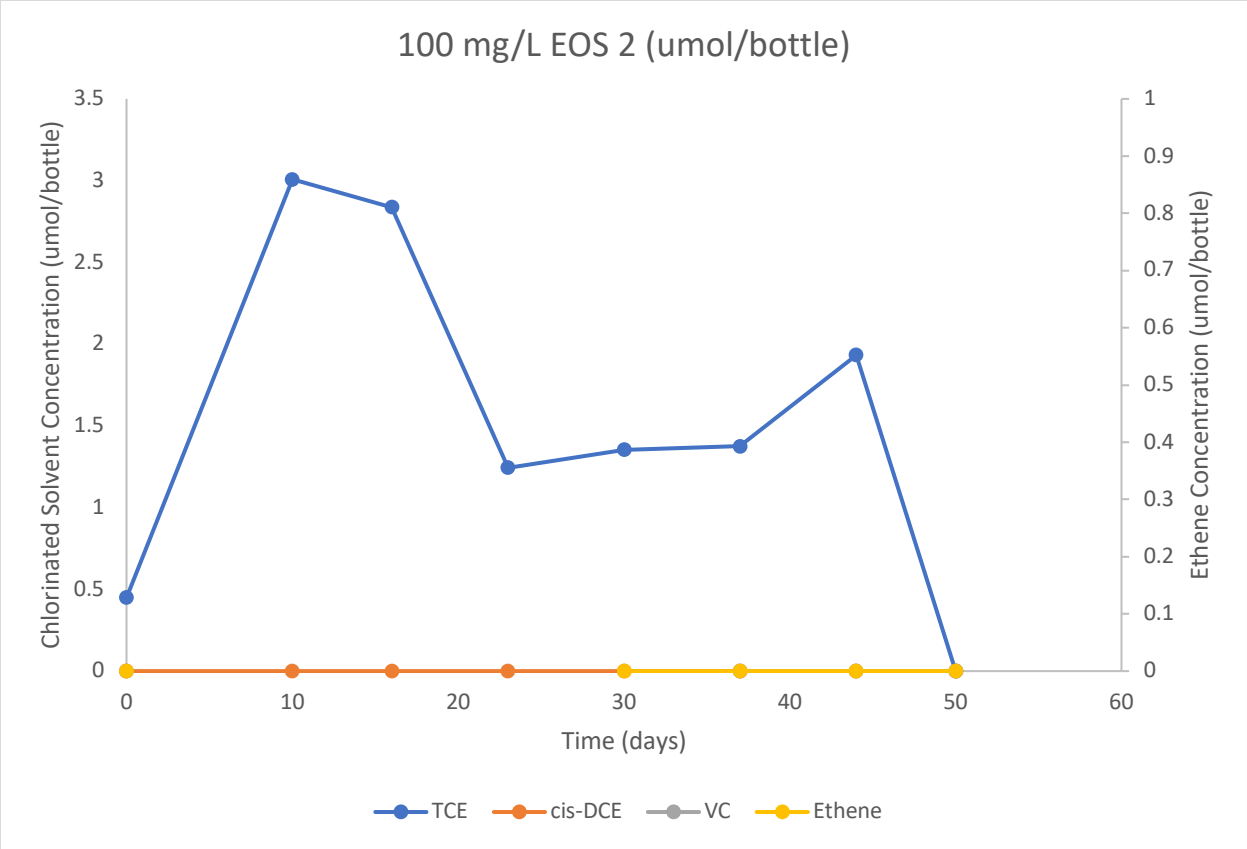


Appendix Figure 119. 10 mM Lactate control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.

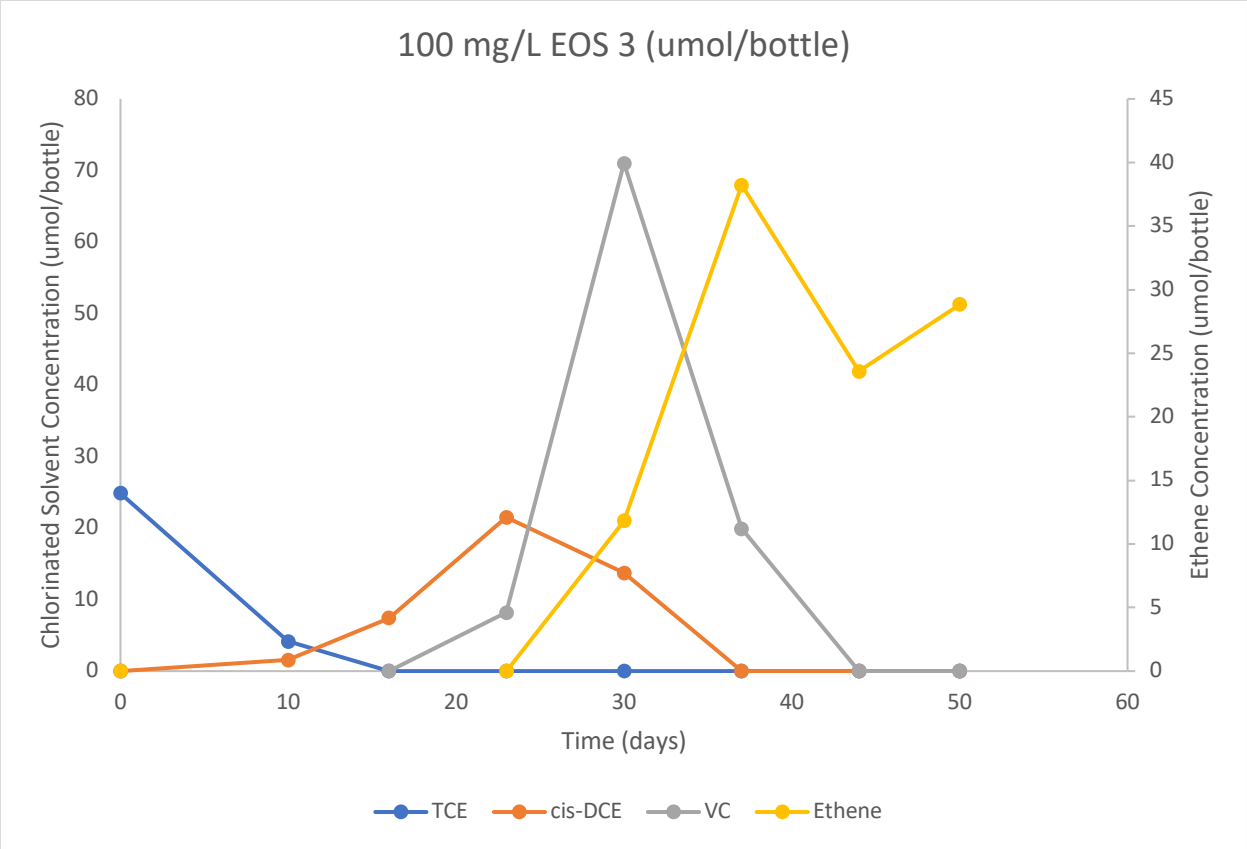
Appendix Figure 120. 10 mM Lactate control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



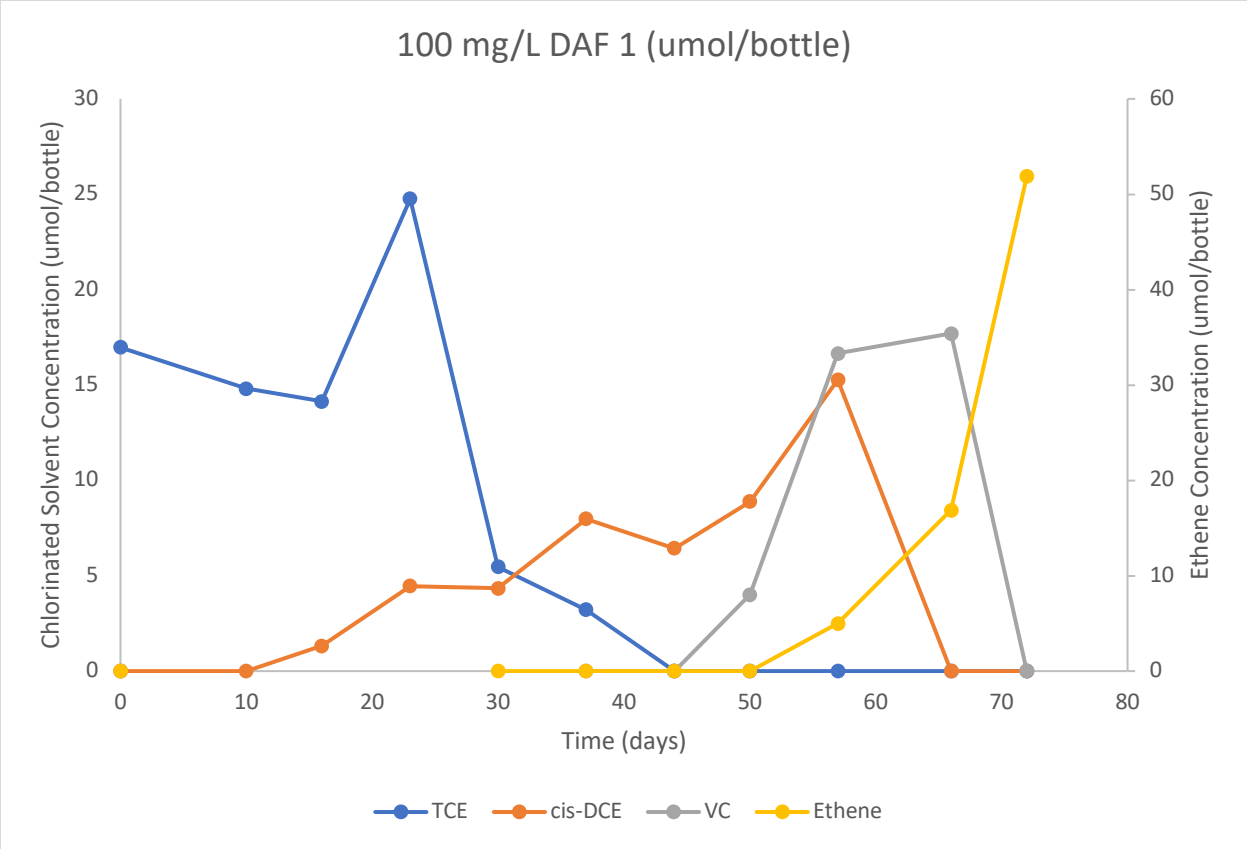
Appendix Figure 121. 100 mg/L EOS control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



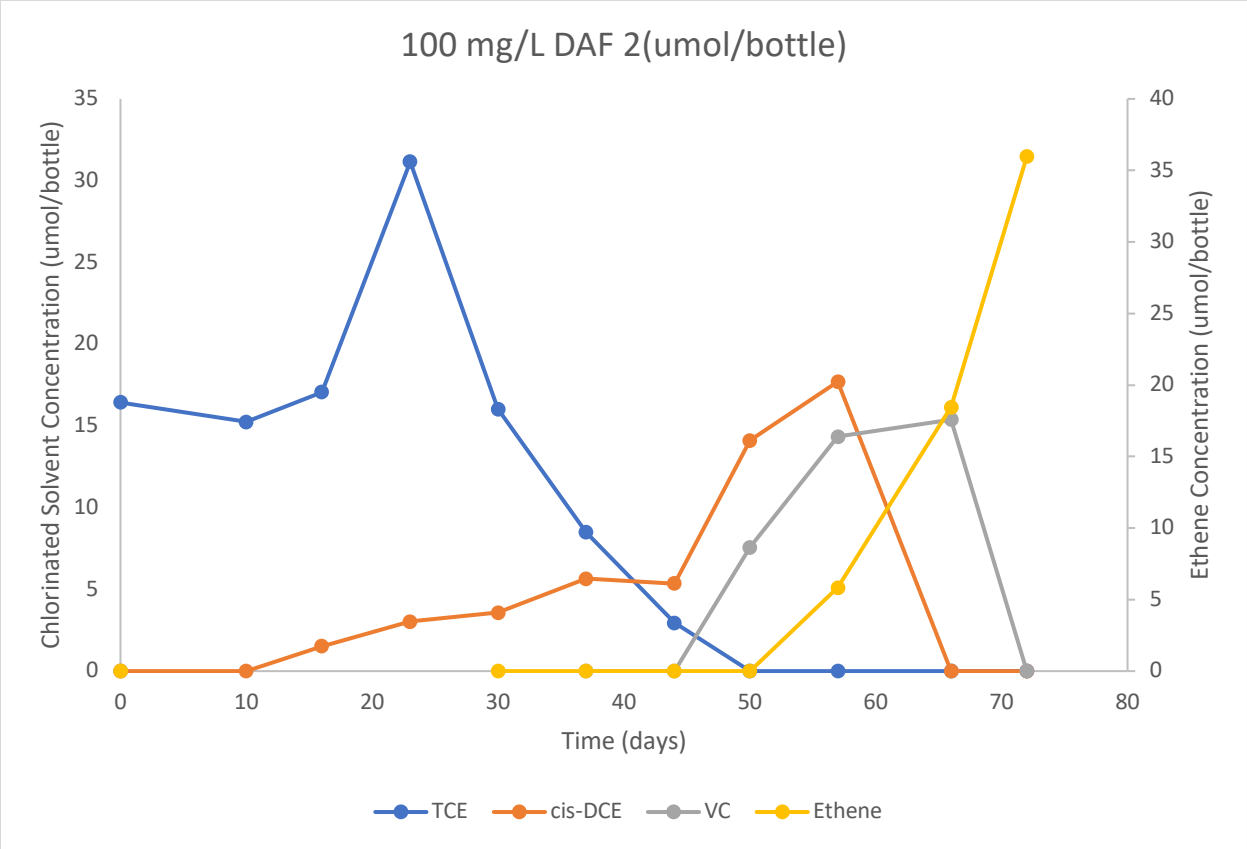
Appendix Figure 122. 100 mg/L EOS control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



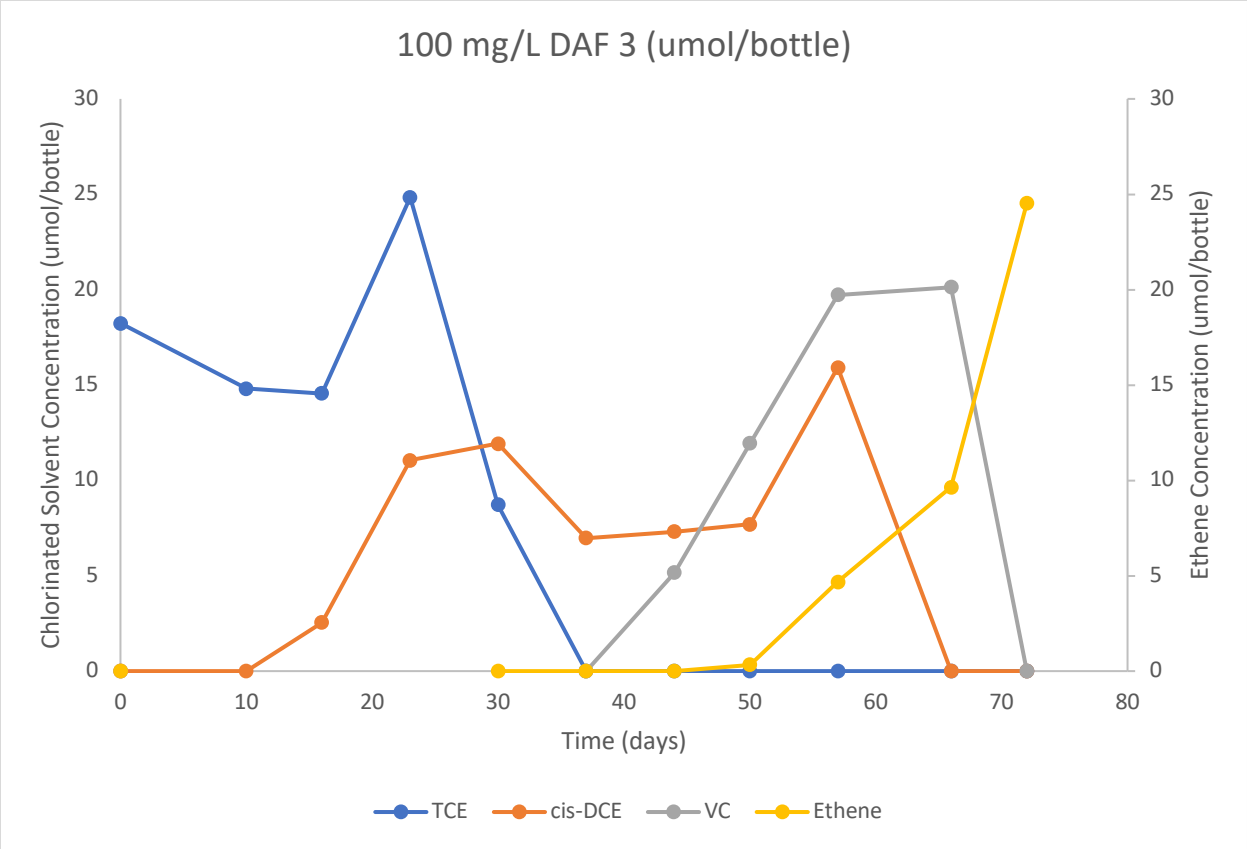
Appendix Figure 123. 100 mg/L EOS control dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



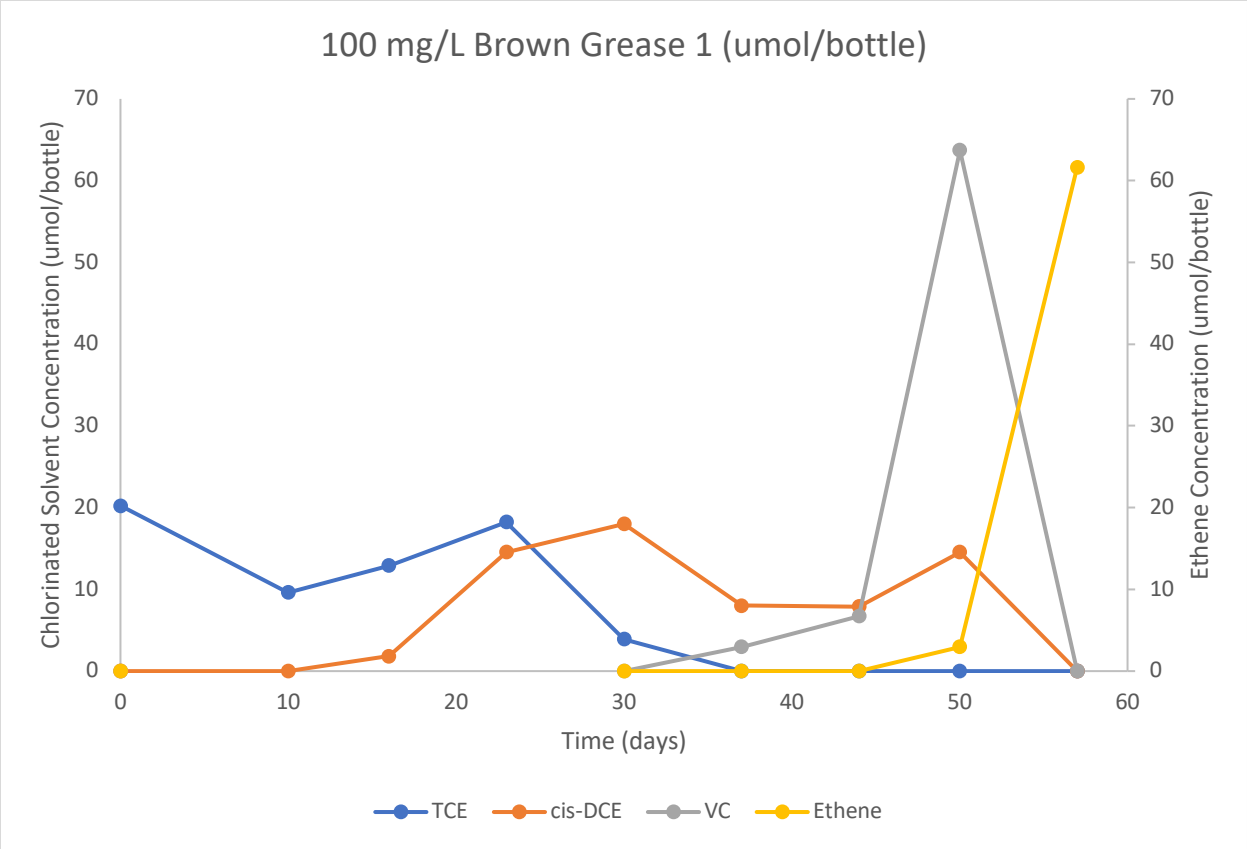
Appendix Figure 124. 100 mg/L DAF dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



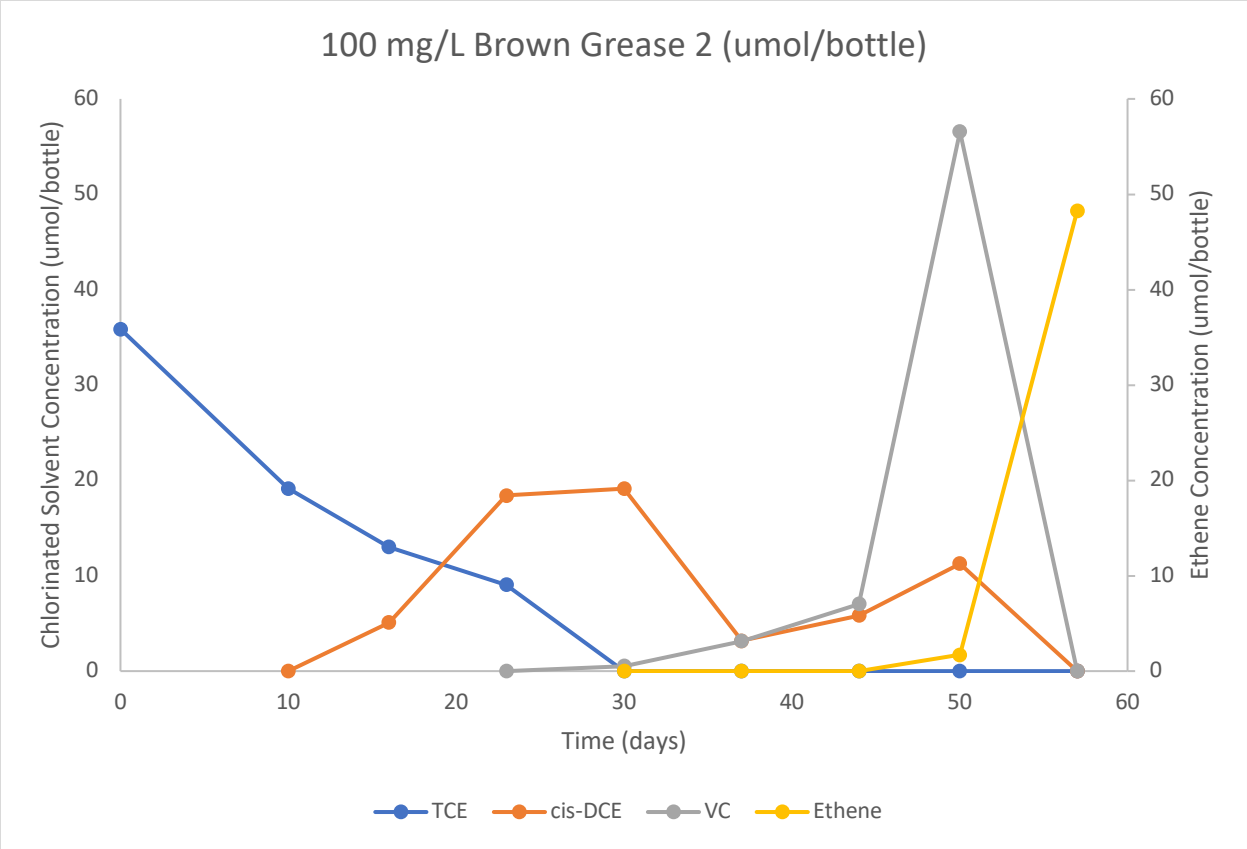
Appendix Figure 125. 100 mg/L DAF dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



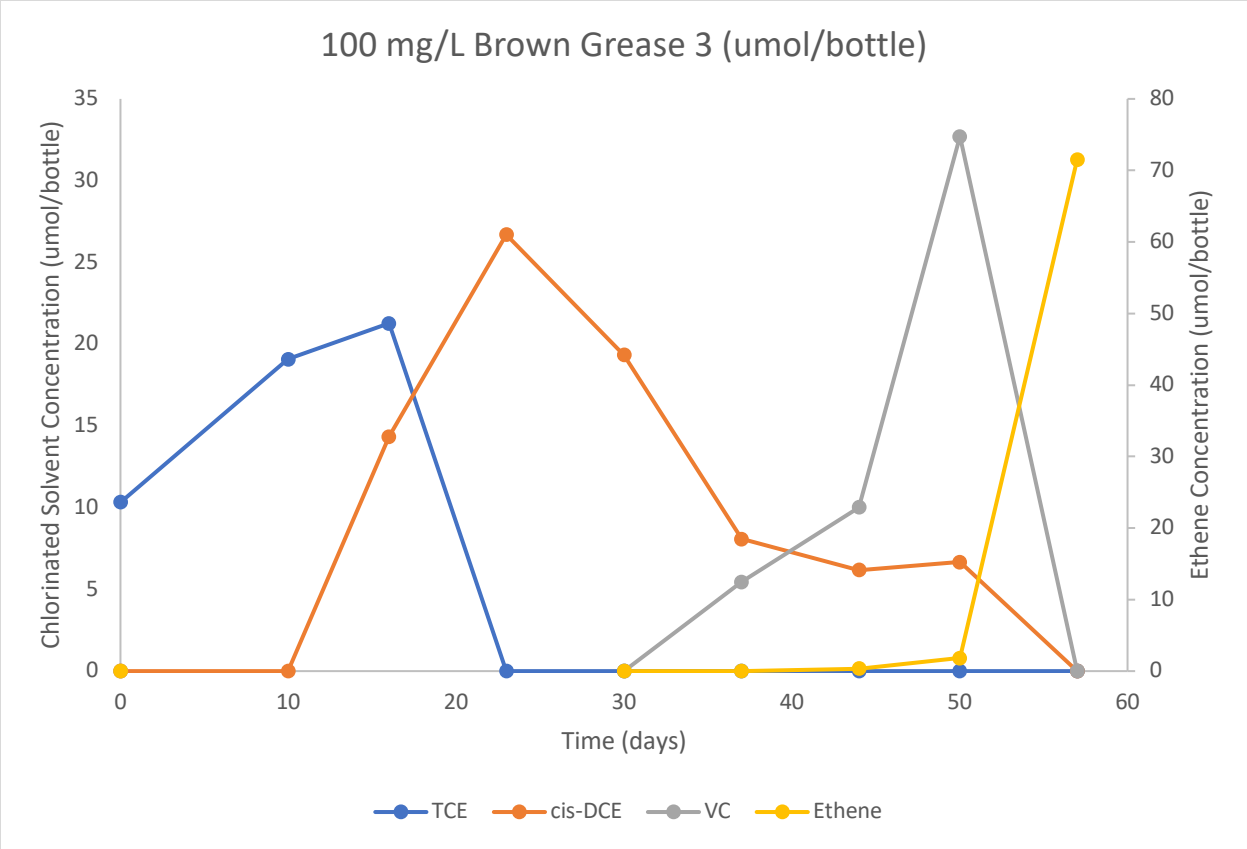
Appendix Figure 126. 100 mg/L DAF dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



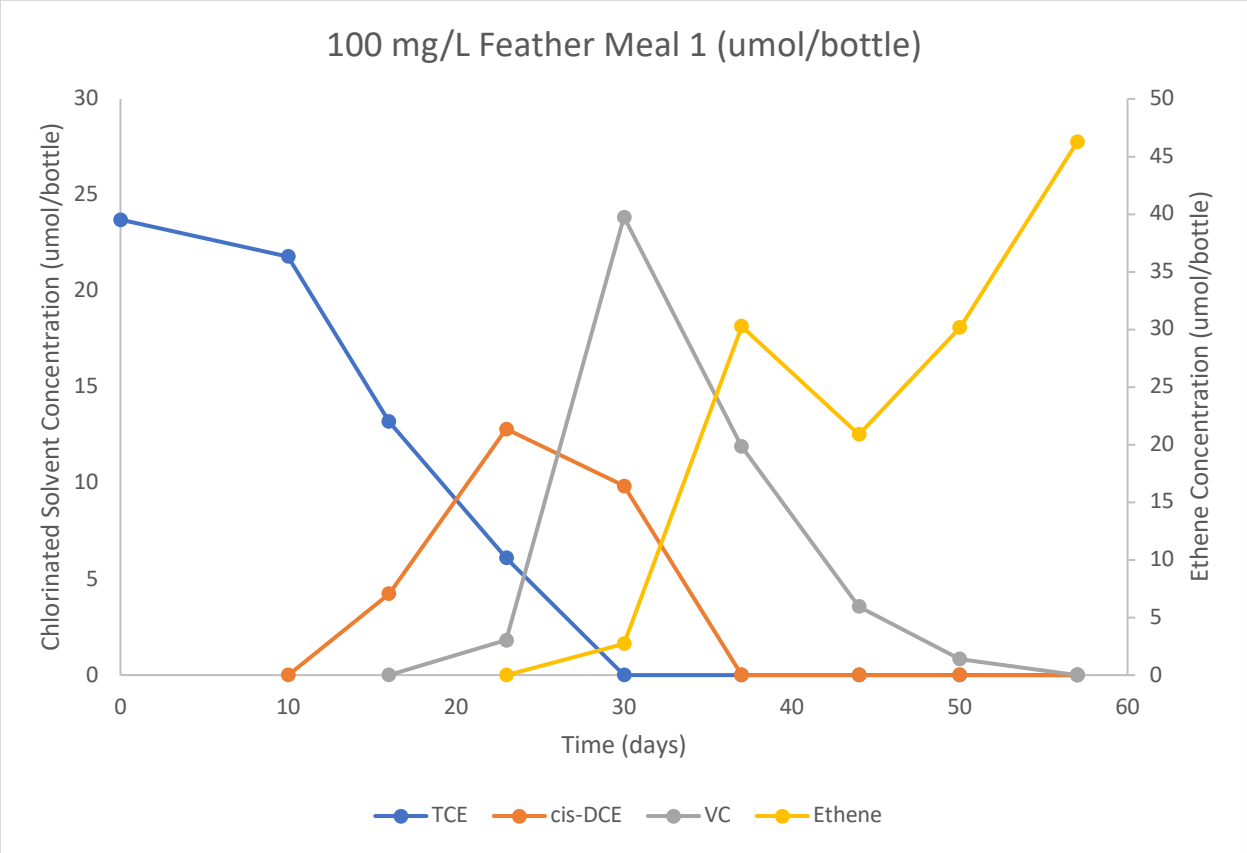
Appendix Figure 127. 100 mg/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



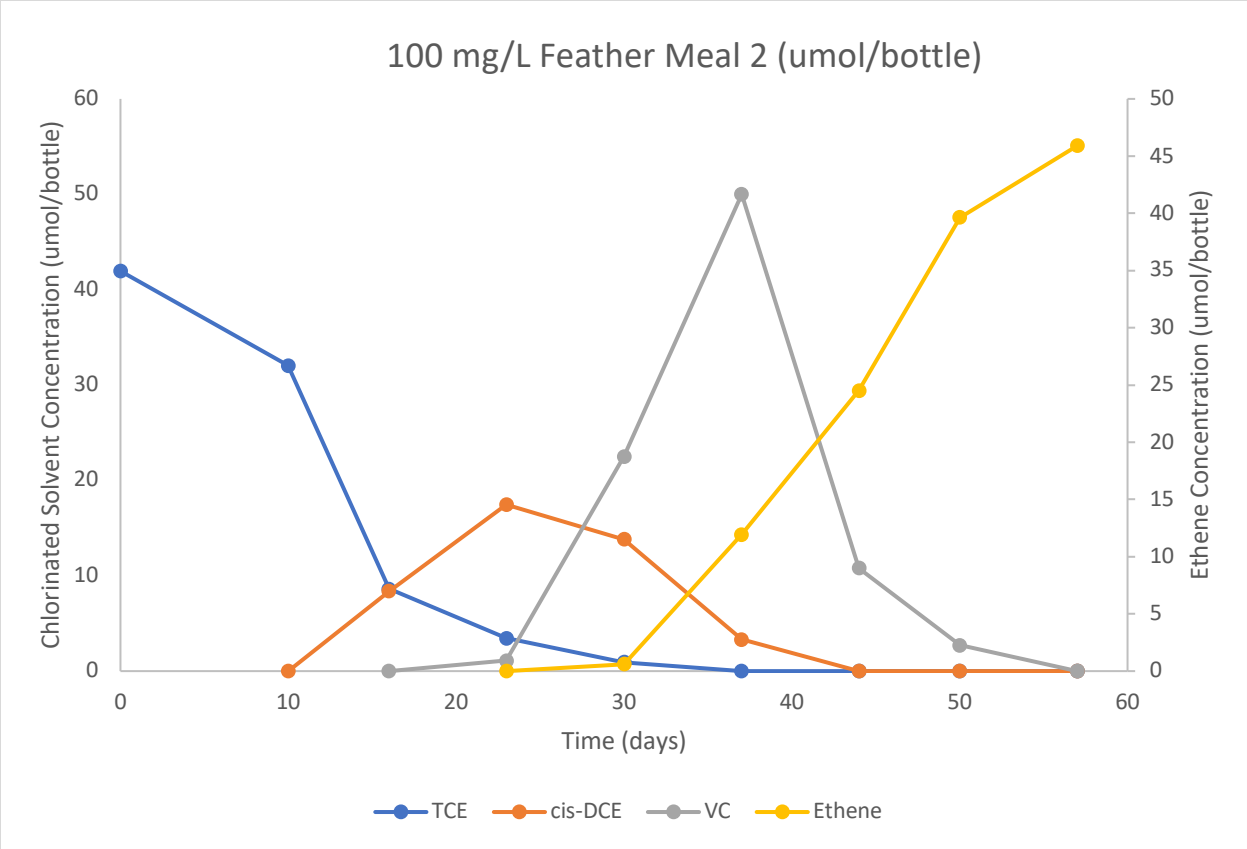
Appendix Figure 128. 100 mg/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



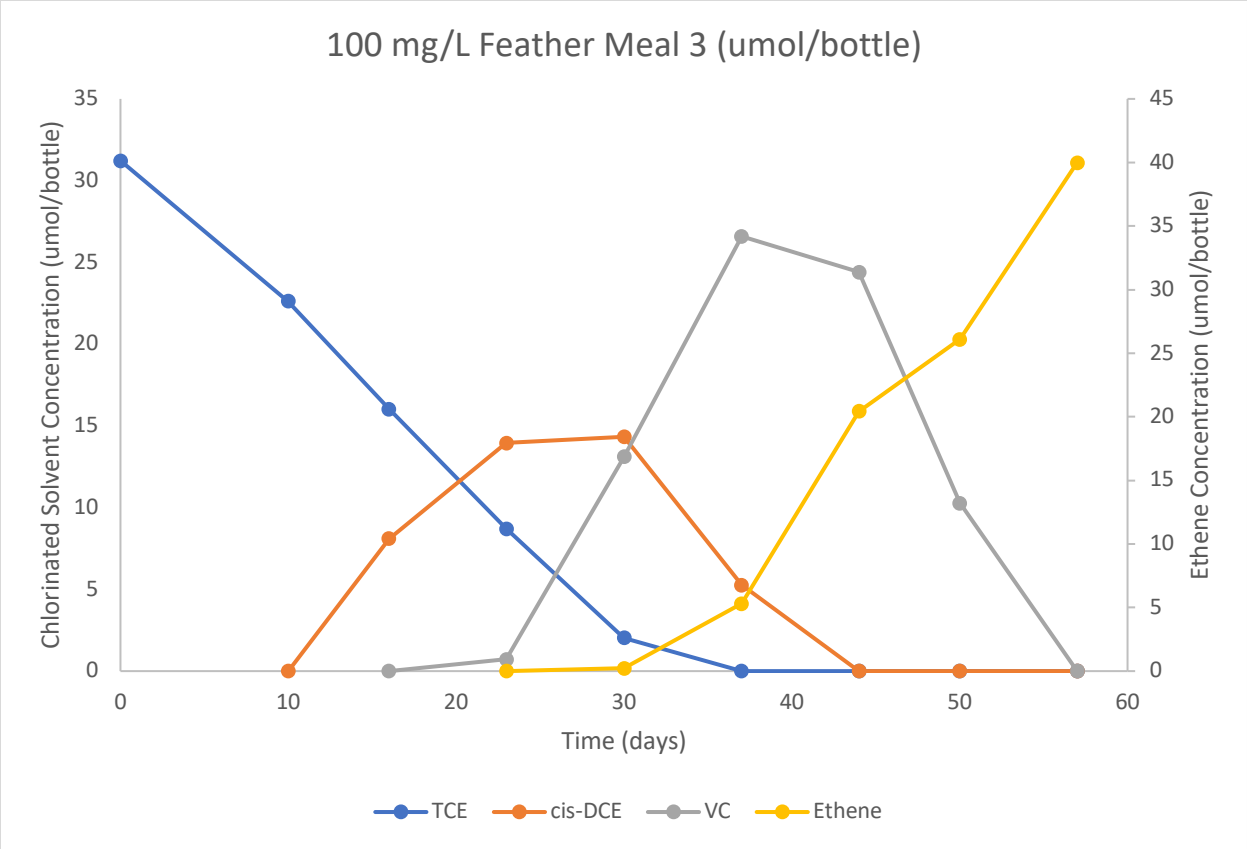
Appendix Figure 129. 100 mg/L Brown Grease dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



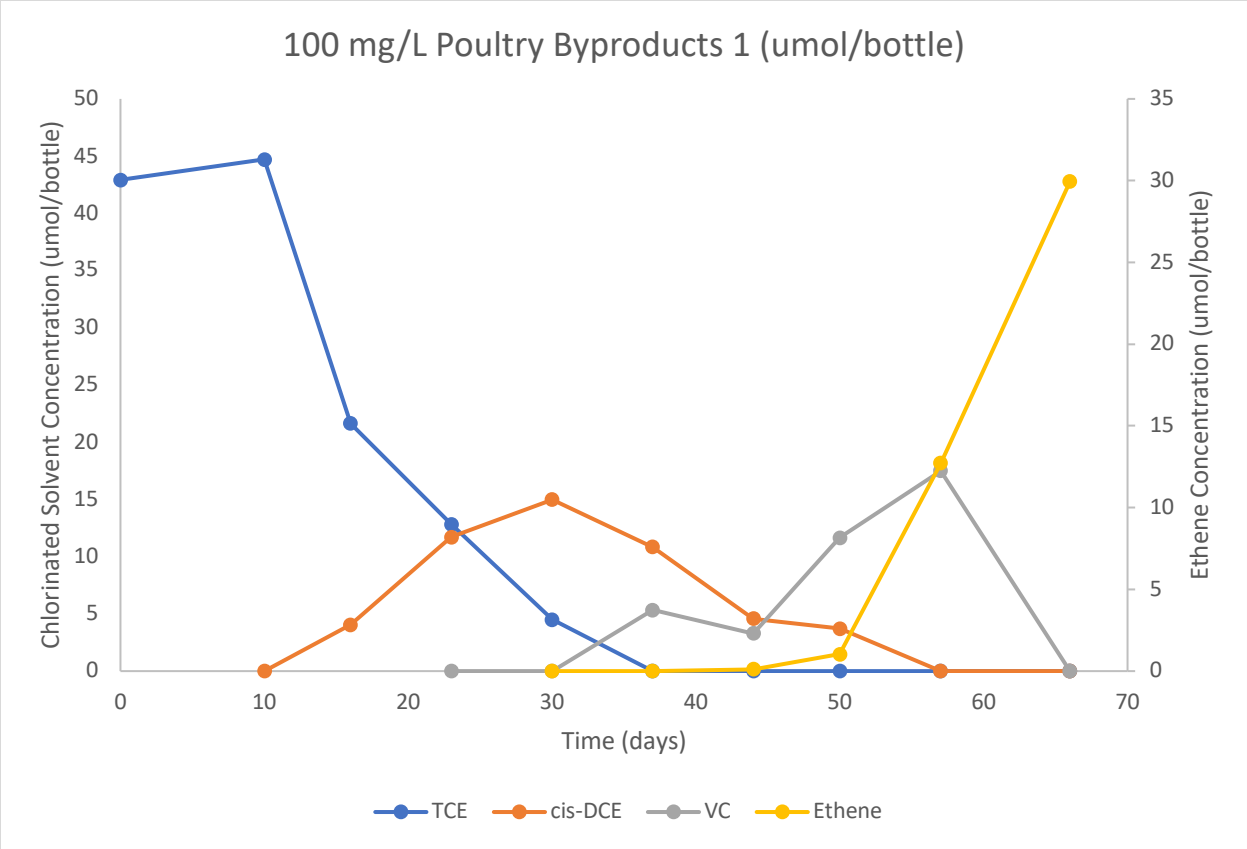
Appendix Figure 130. 100 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



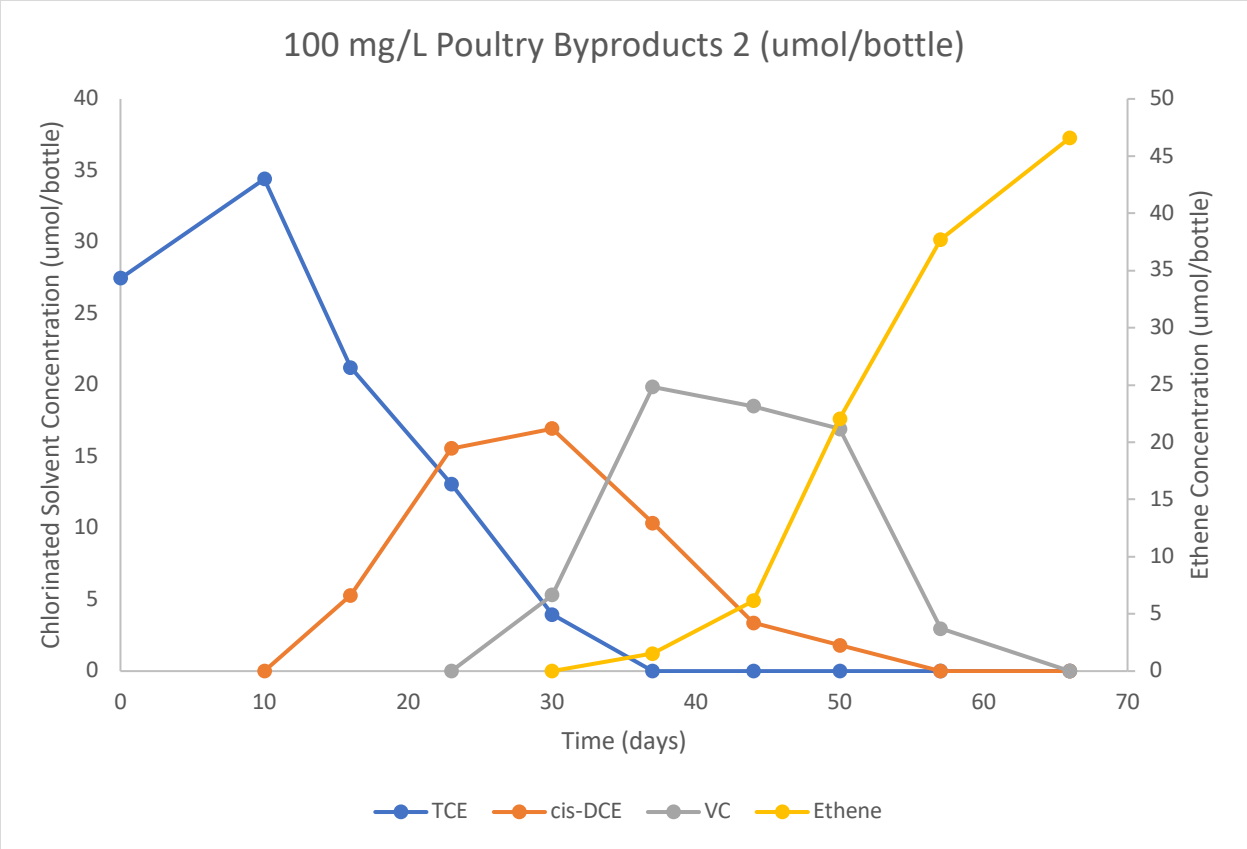
Appendix Figure 131. 100 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



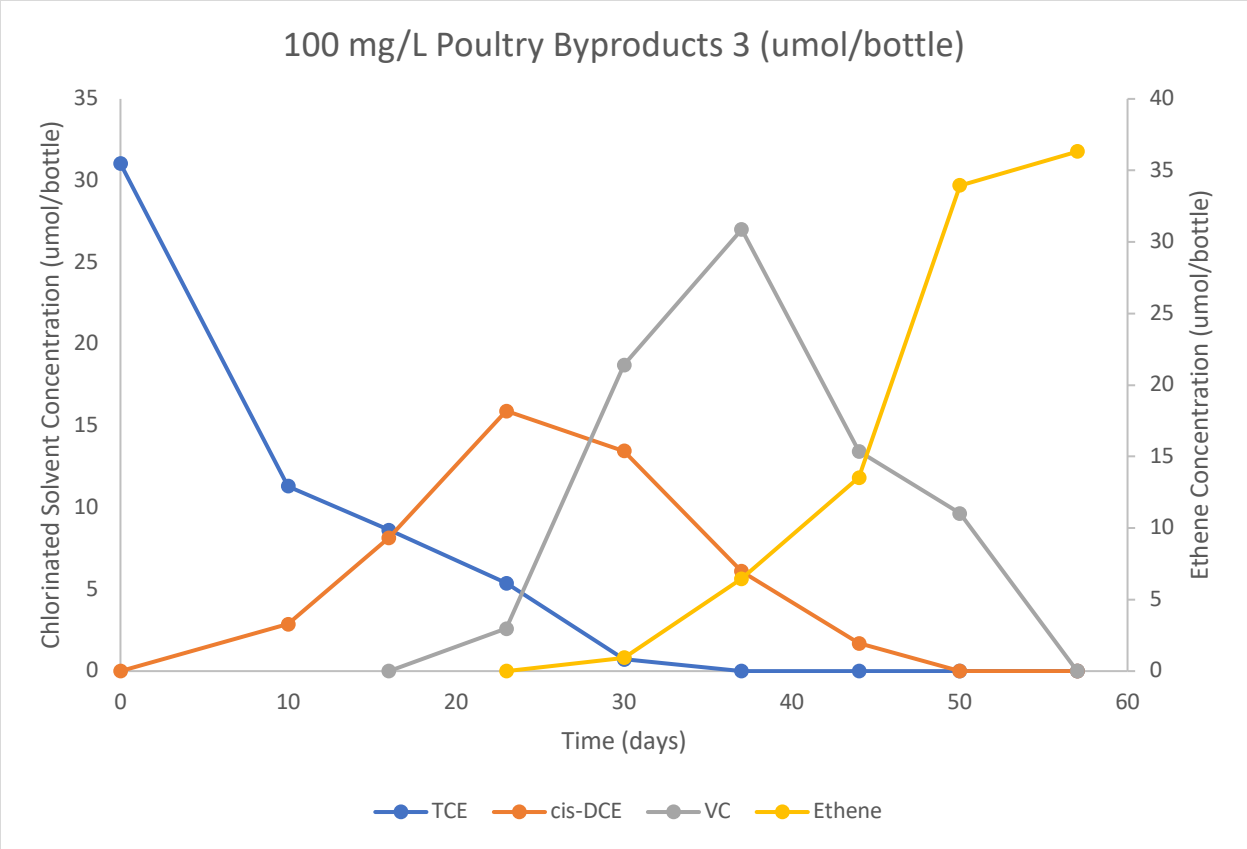
Appendix Figure 132. 100 mg/L Feather Meal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



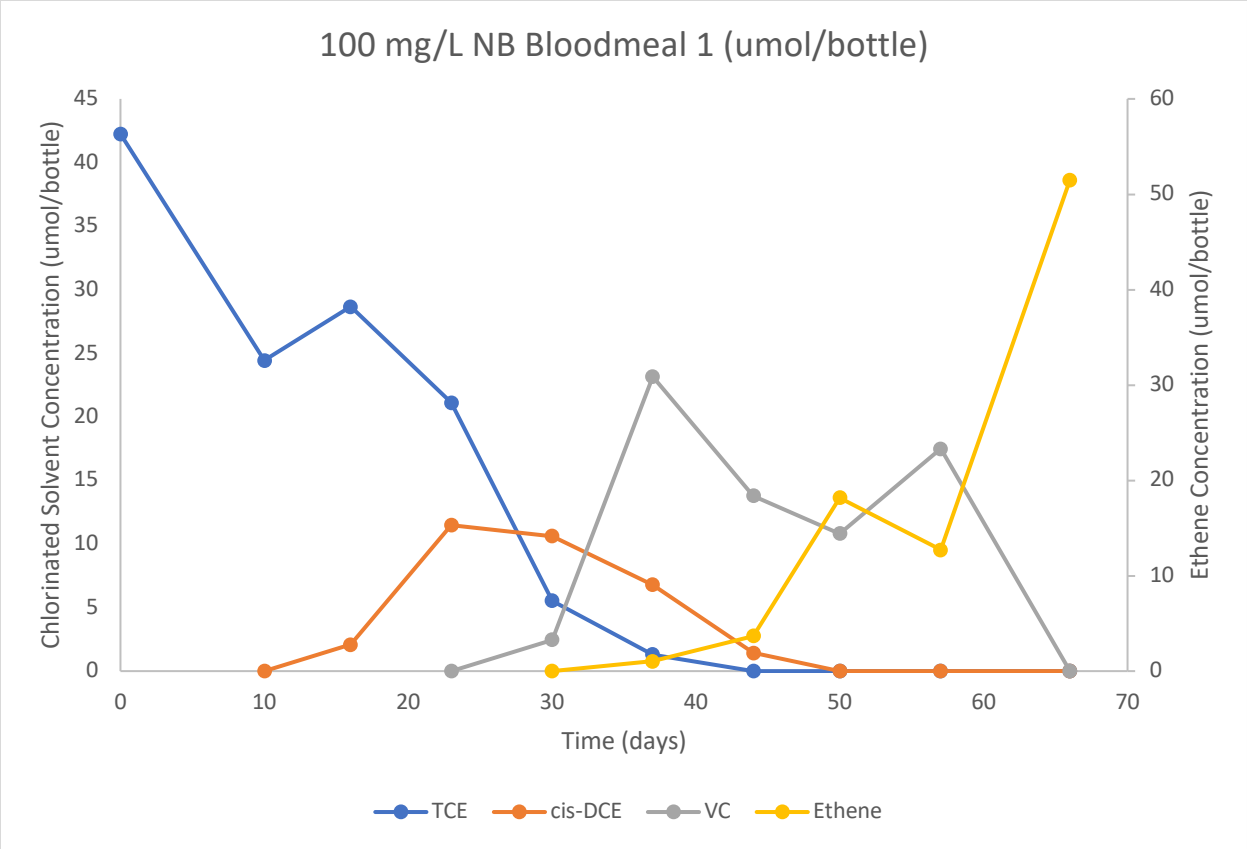
Appendix Figure 133. 100 mg/L Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



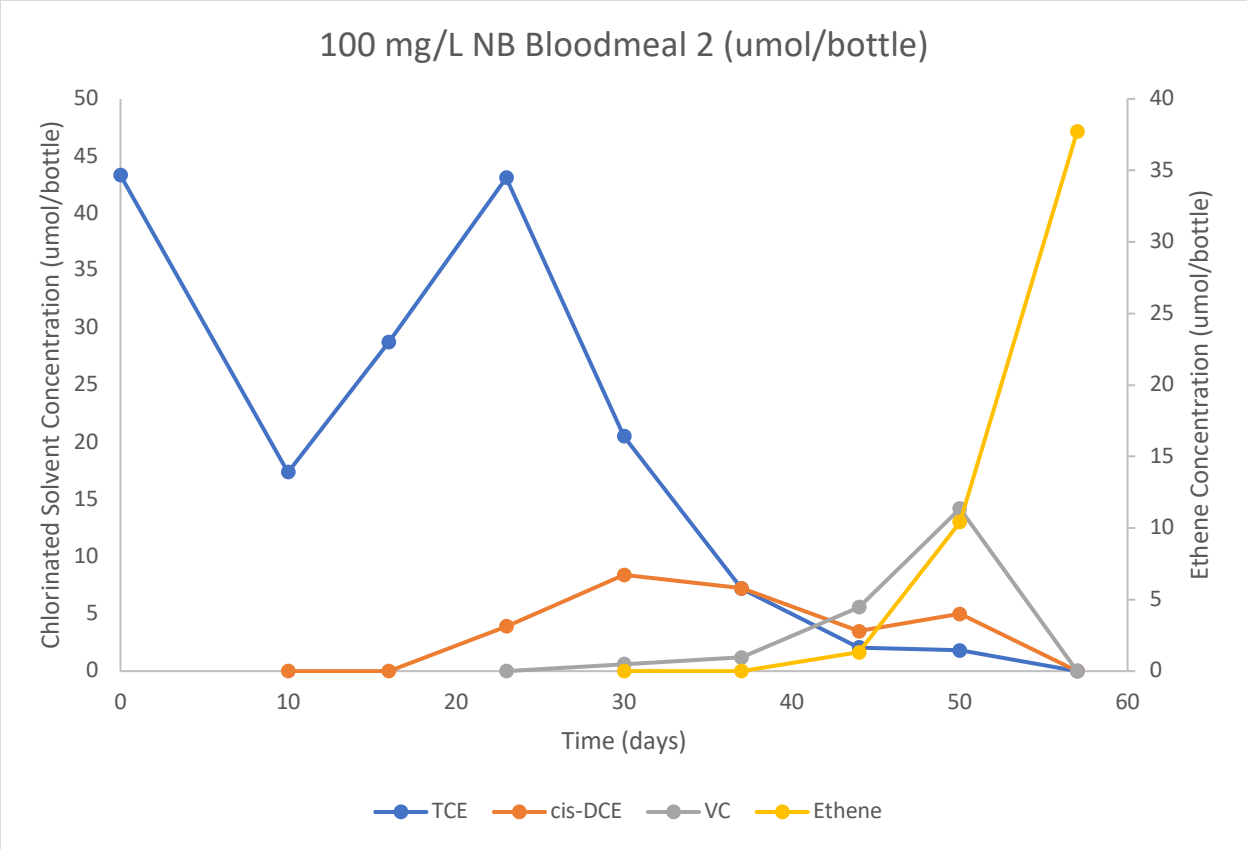
Appendix Figure 134. 100 mg/L Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



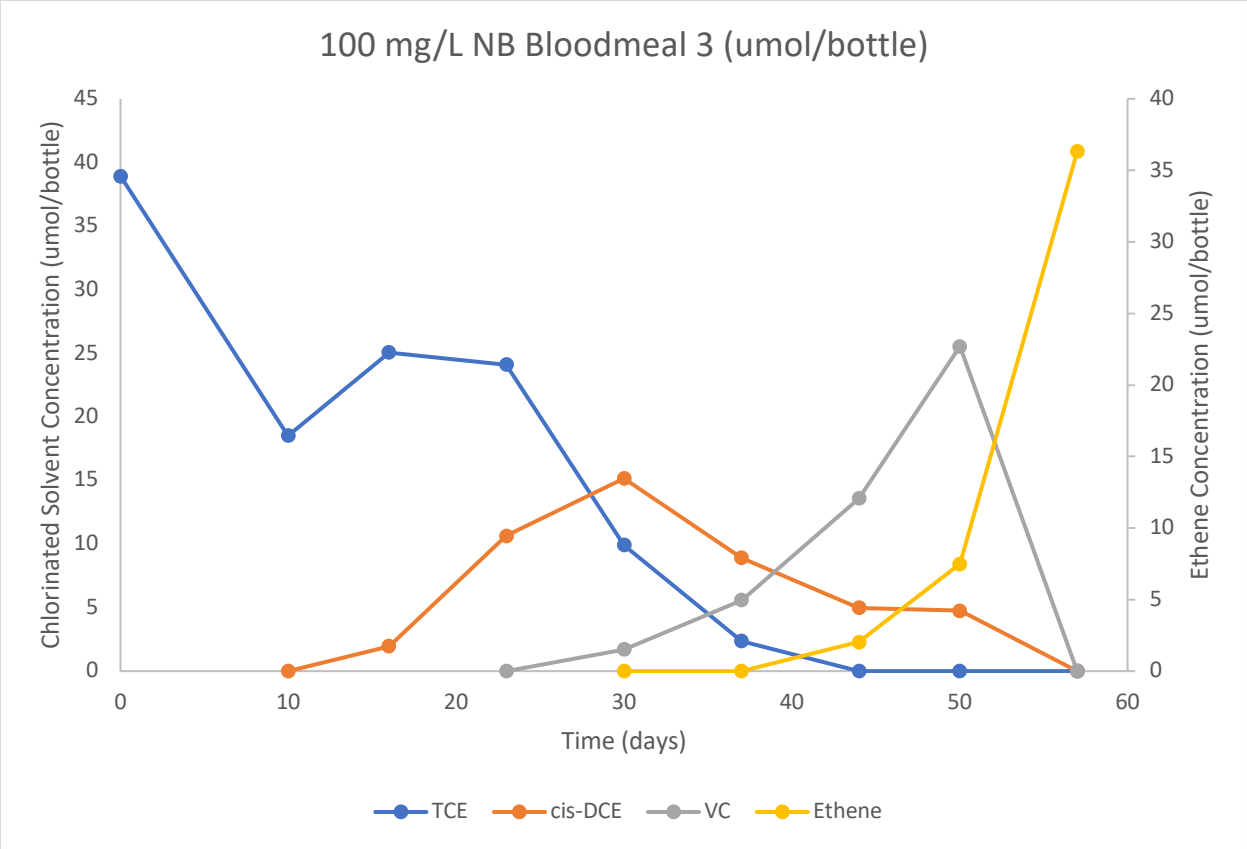
Appendix Figure 135. 100 mg/L Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



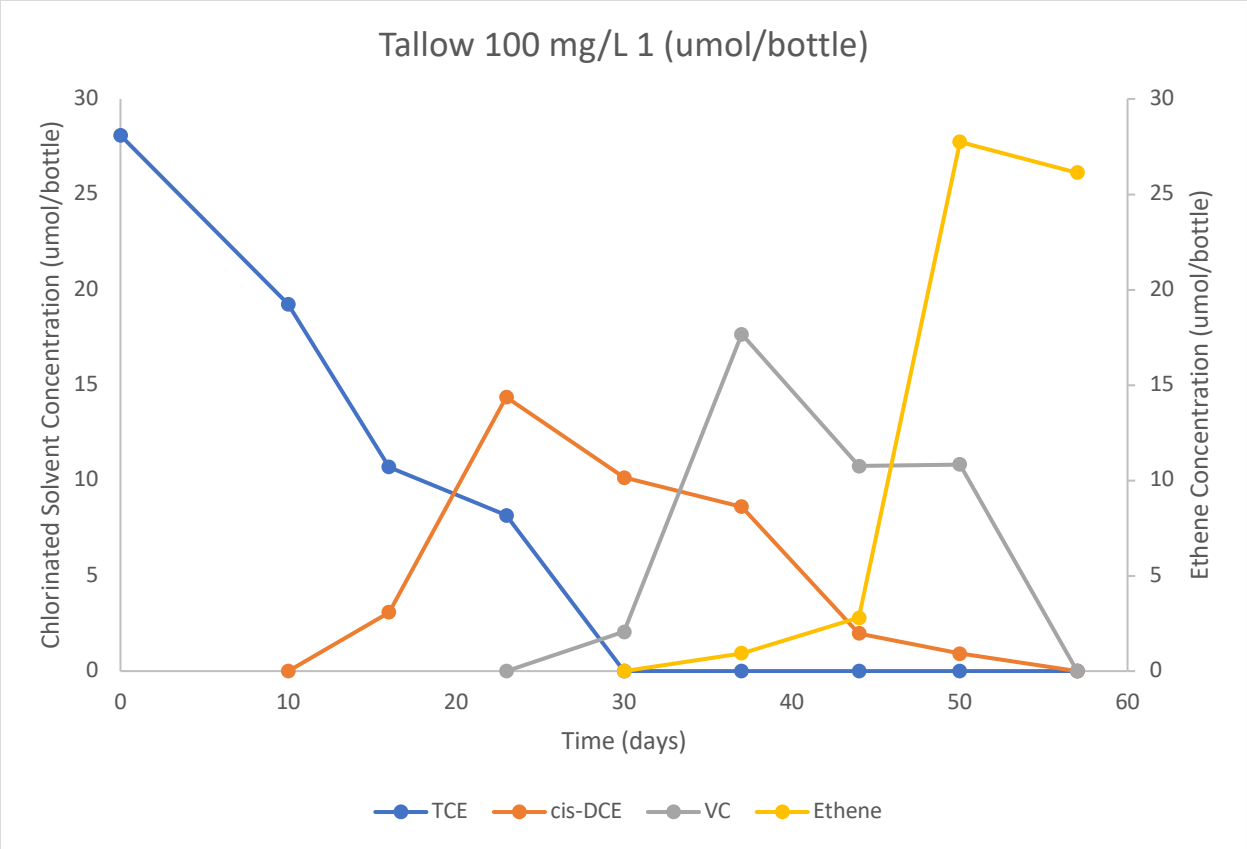
Appendix Figure 136. 100 mg/L NB Bloodmeal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



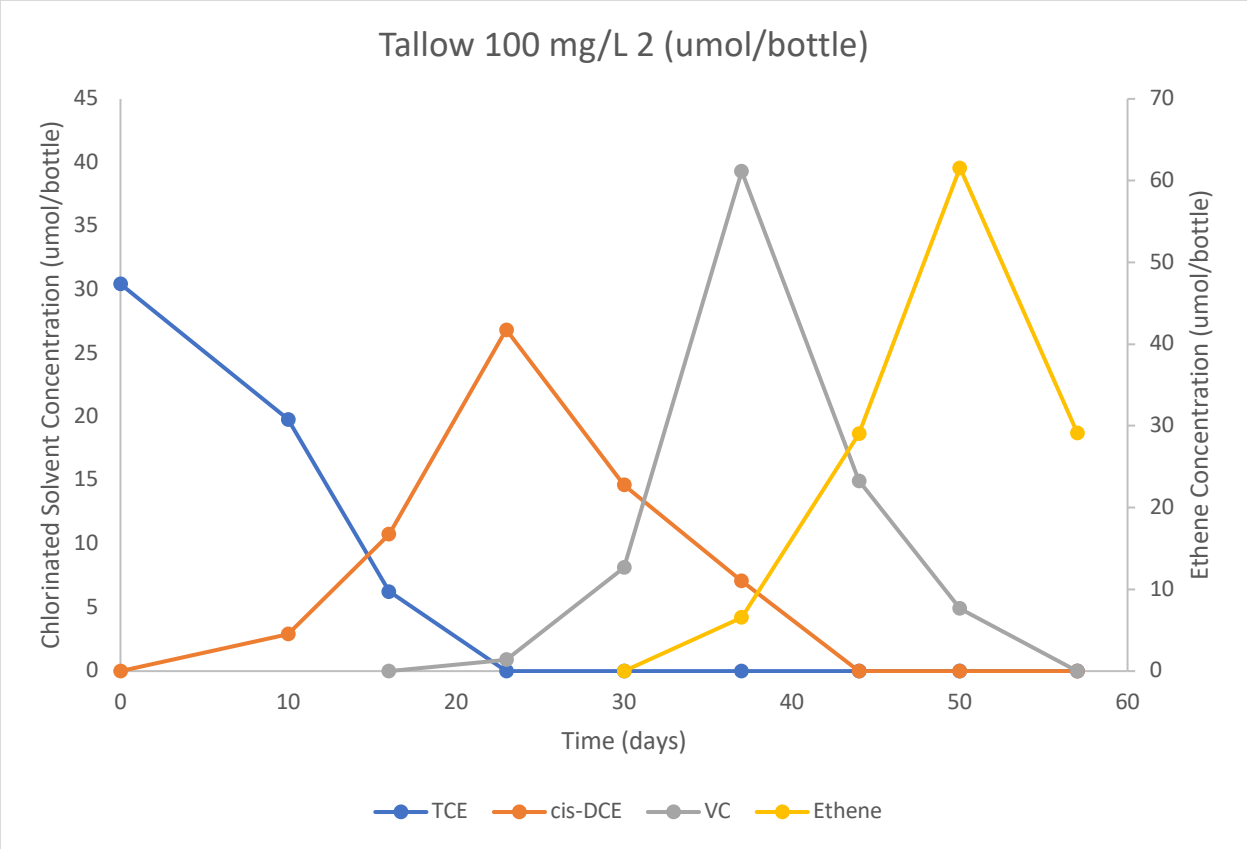
Appendix Figure 137. 100 mg/L NB Bloodmeal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



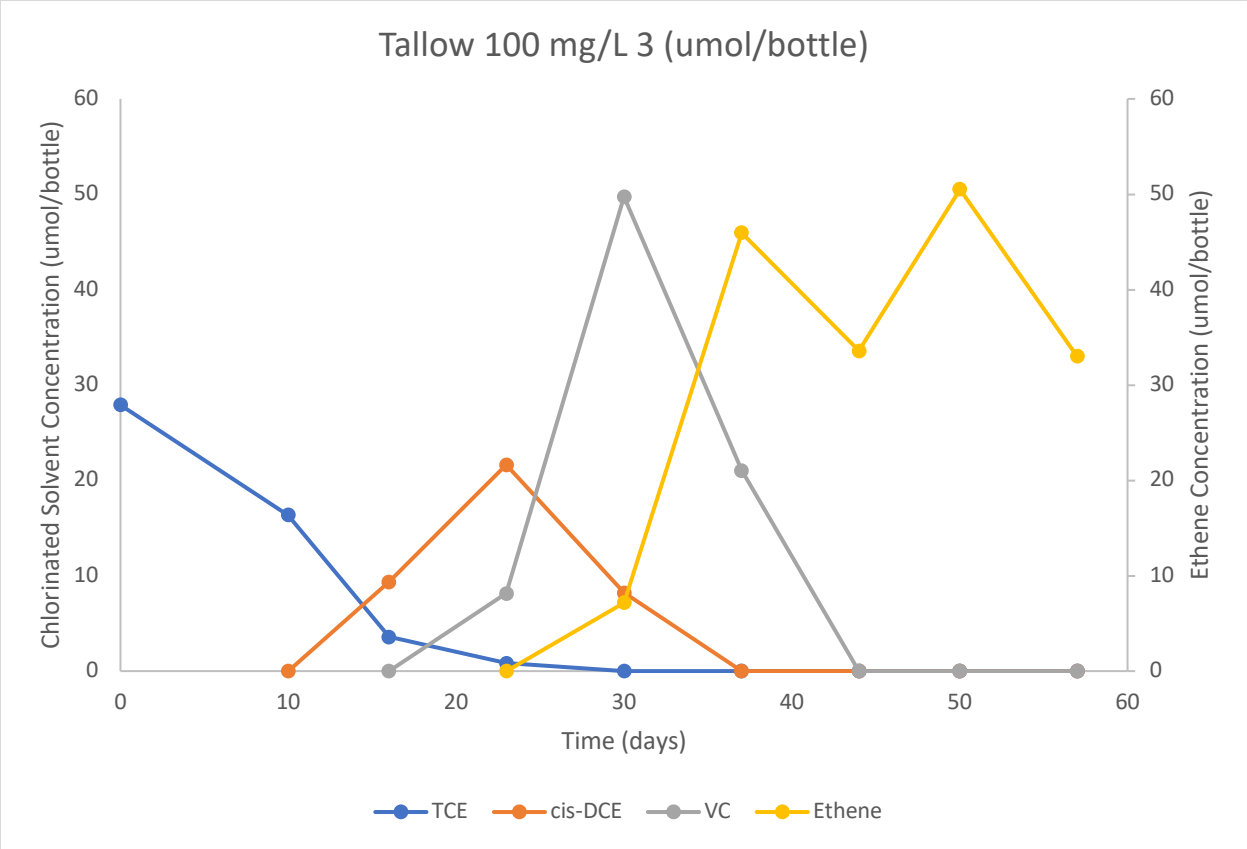
Appendix Figure 138. 100 mg/L NB Bloodmeal dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



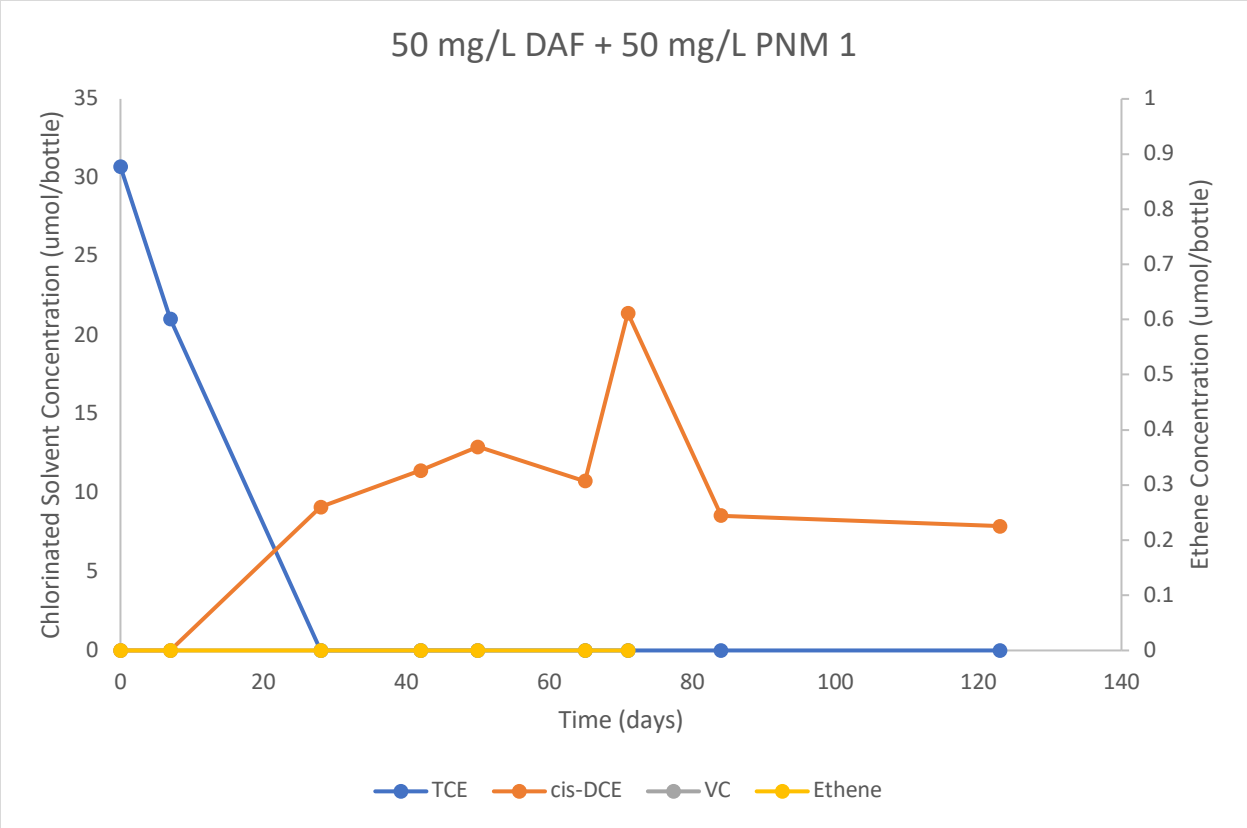
Appendix Figure 139. 100 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



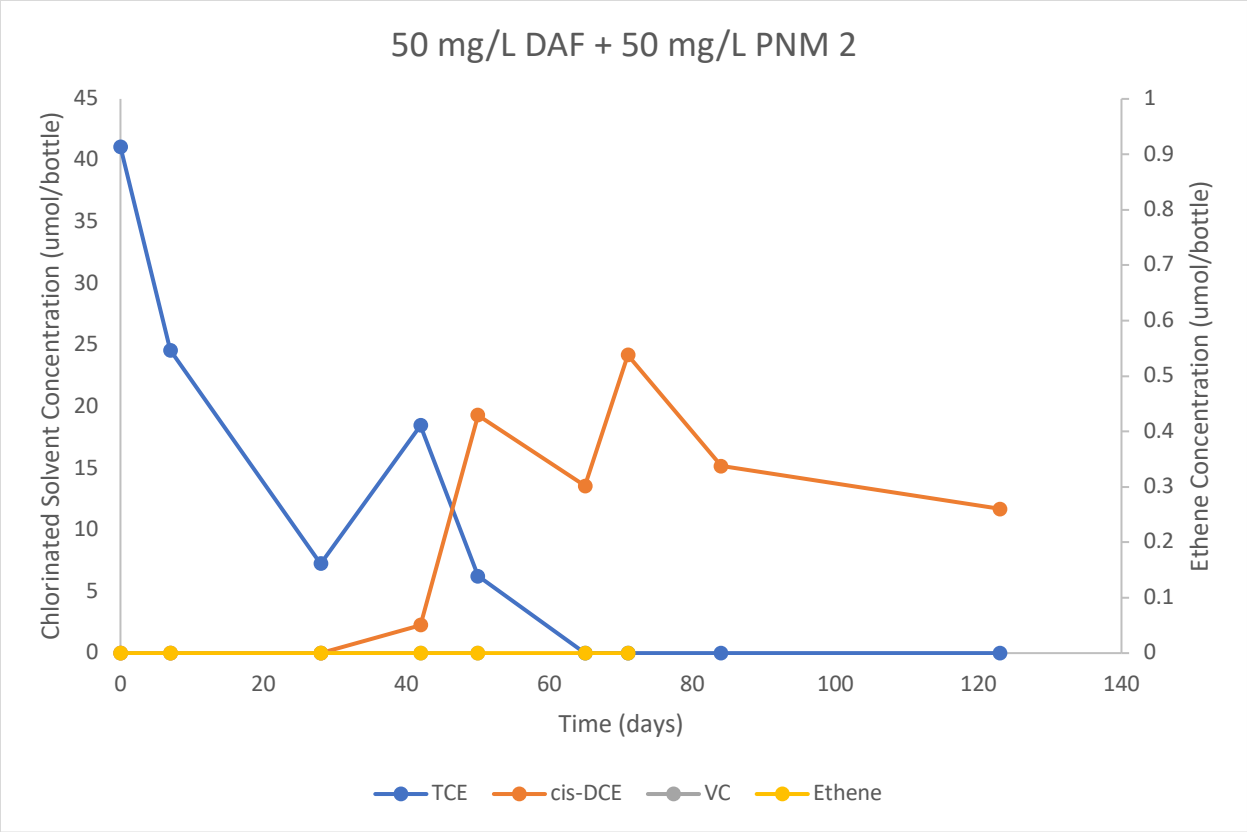
Appendix Figure 140. 100 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



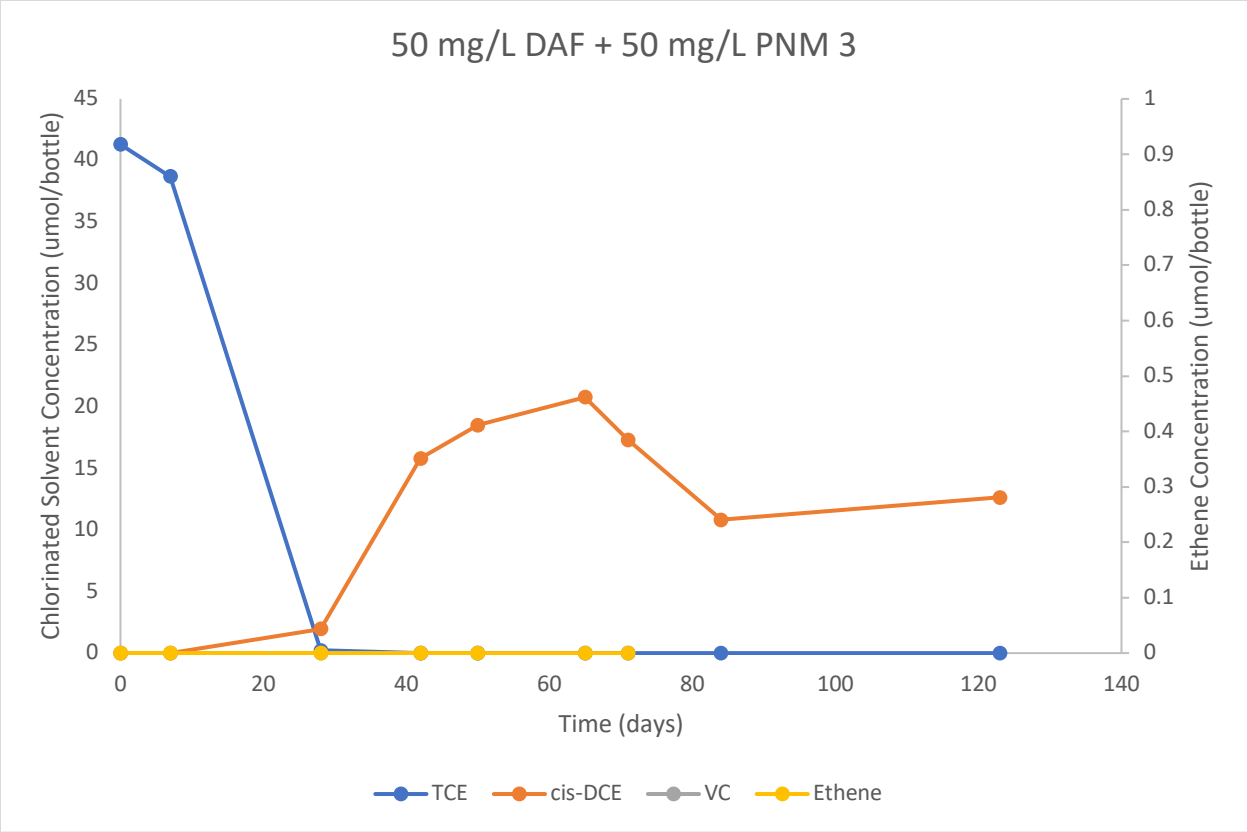
Appendix Figure 141. 100 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product concentration optimization experiment with soil collected from Easley, South Carolina.



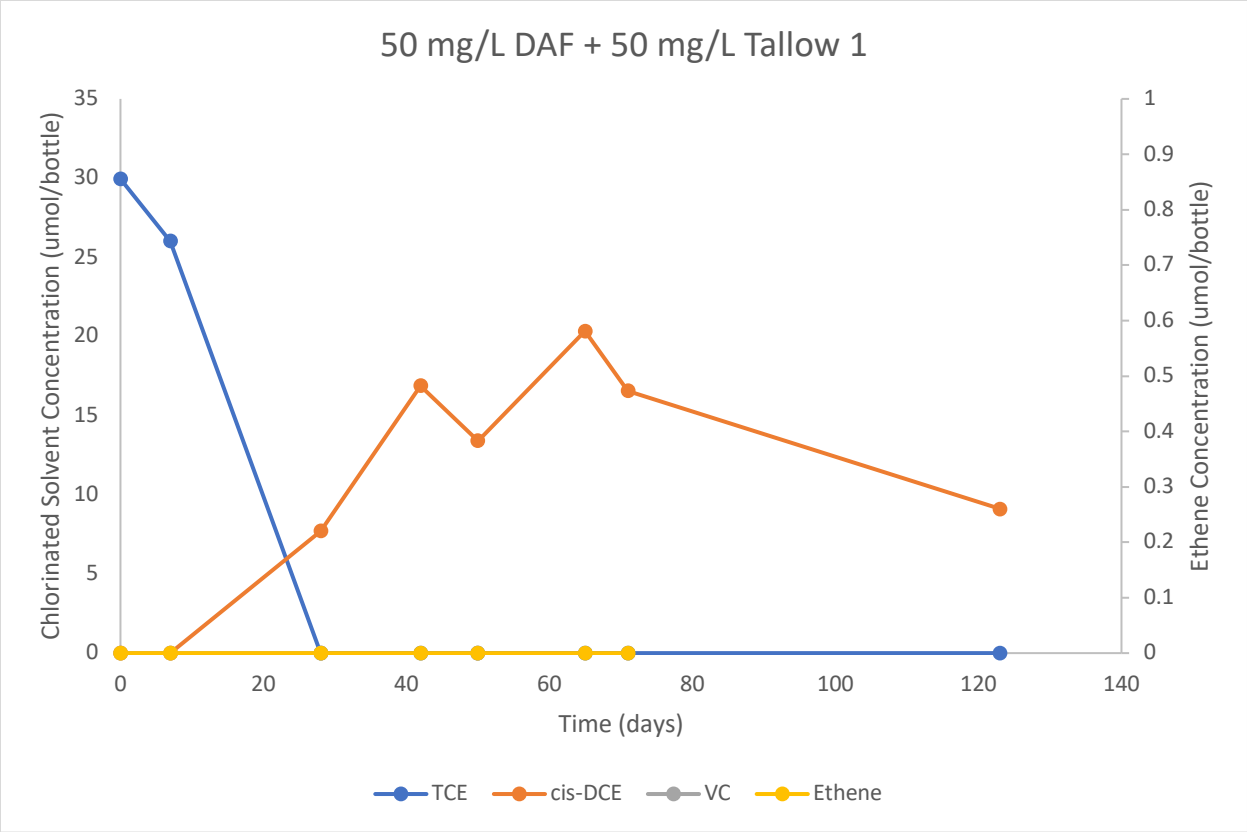
Appendix Figure 142. 50 mg/L DAF + 50 mg/L PNM dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



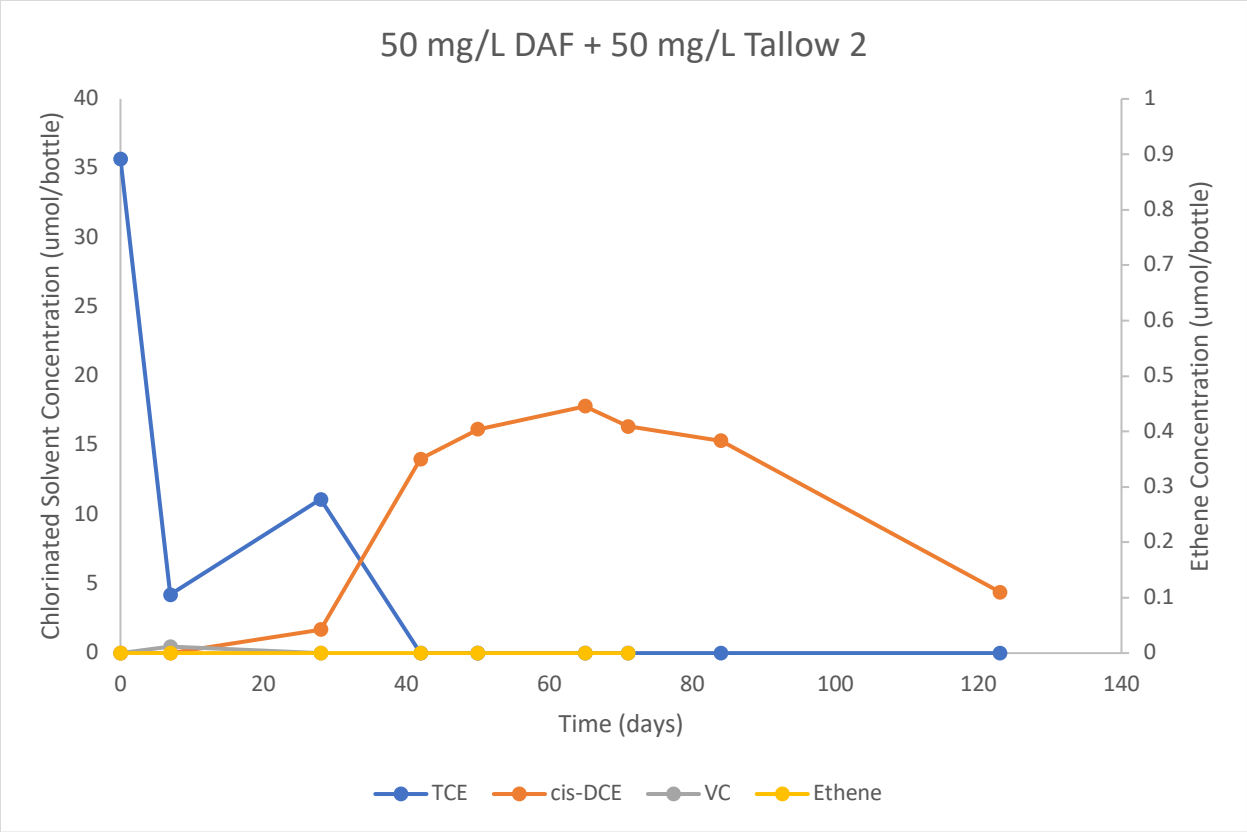
Appendix Figure 143. 50 mg/L DAF + 50 mg/L PNM dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



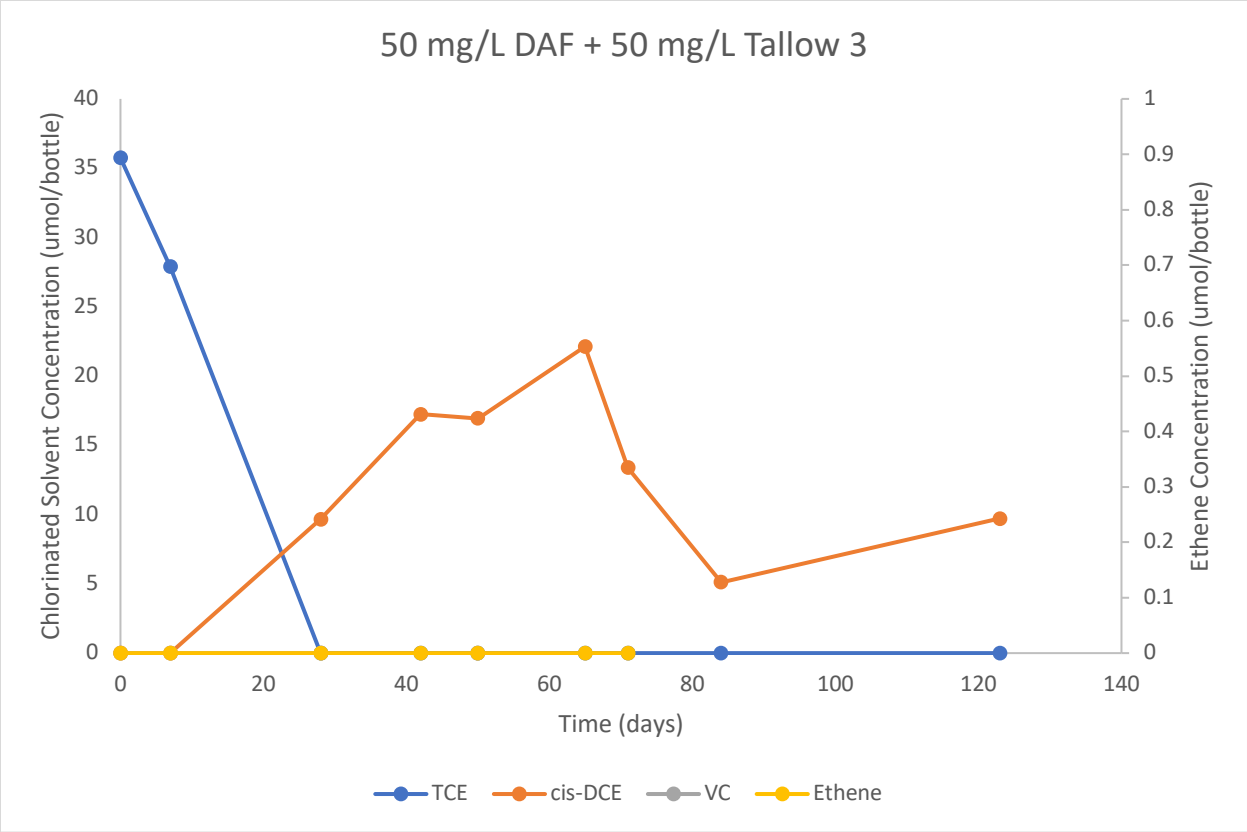
Appendix Figure 144. 50 mg/L DAF + 50 mg/L PNM dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



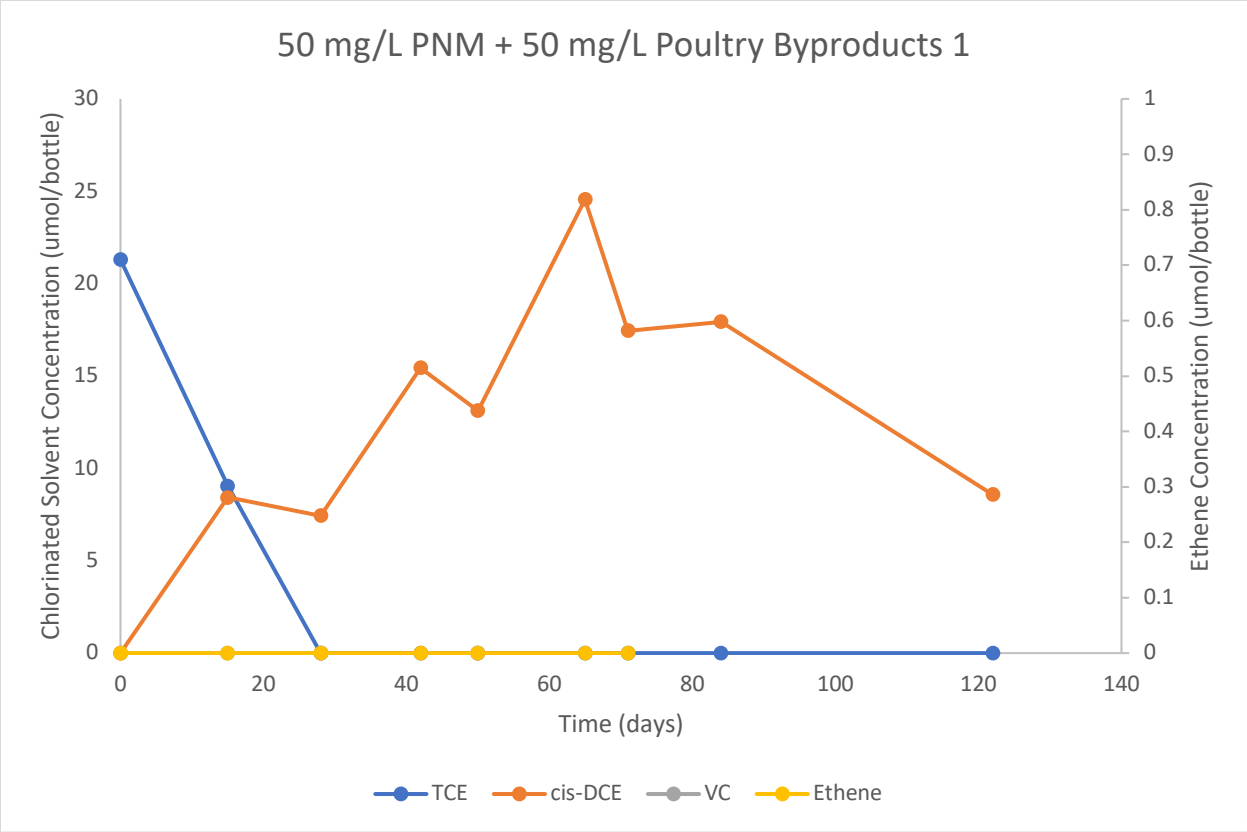
Appendix Figure 145. 50 mg/L DAF + 50 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



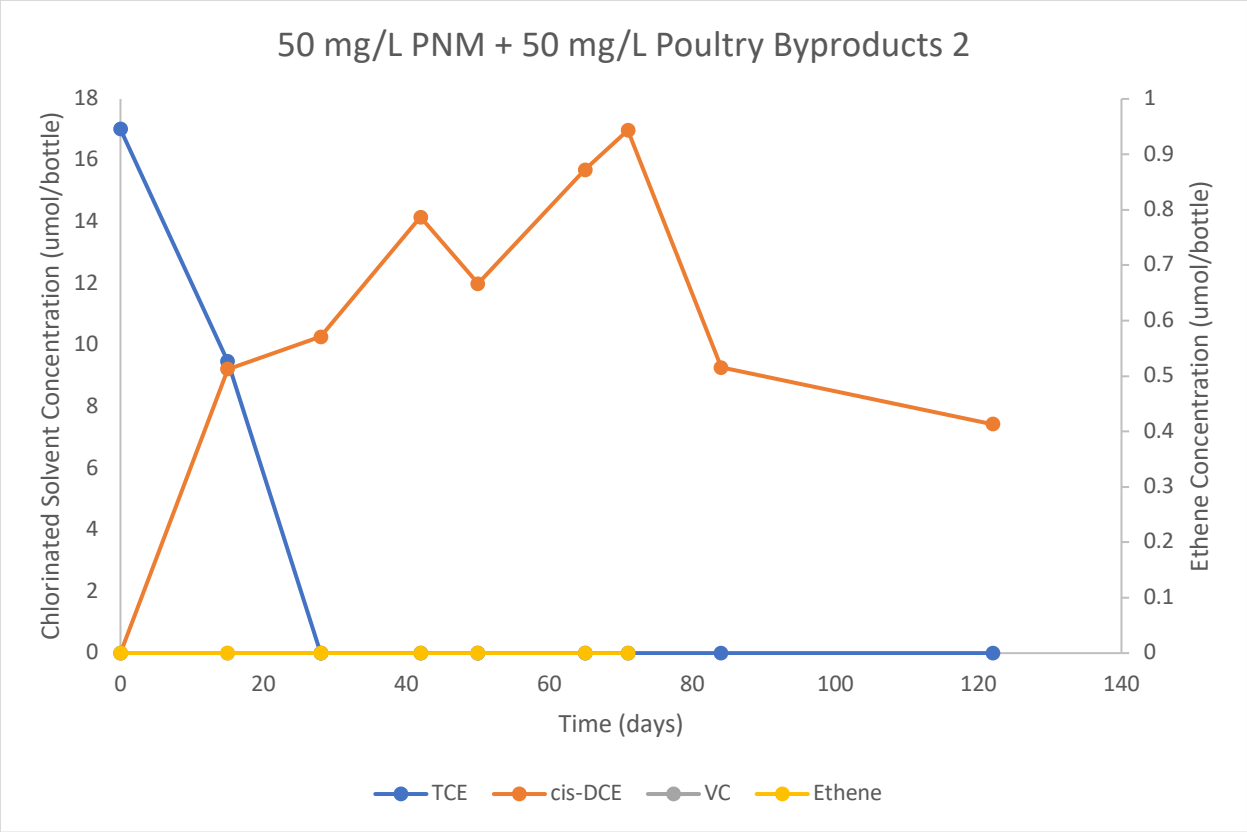
Appendix Figure 146. 50 mg/L DAF + 50 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



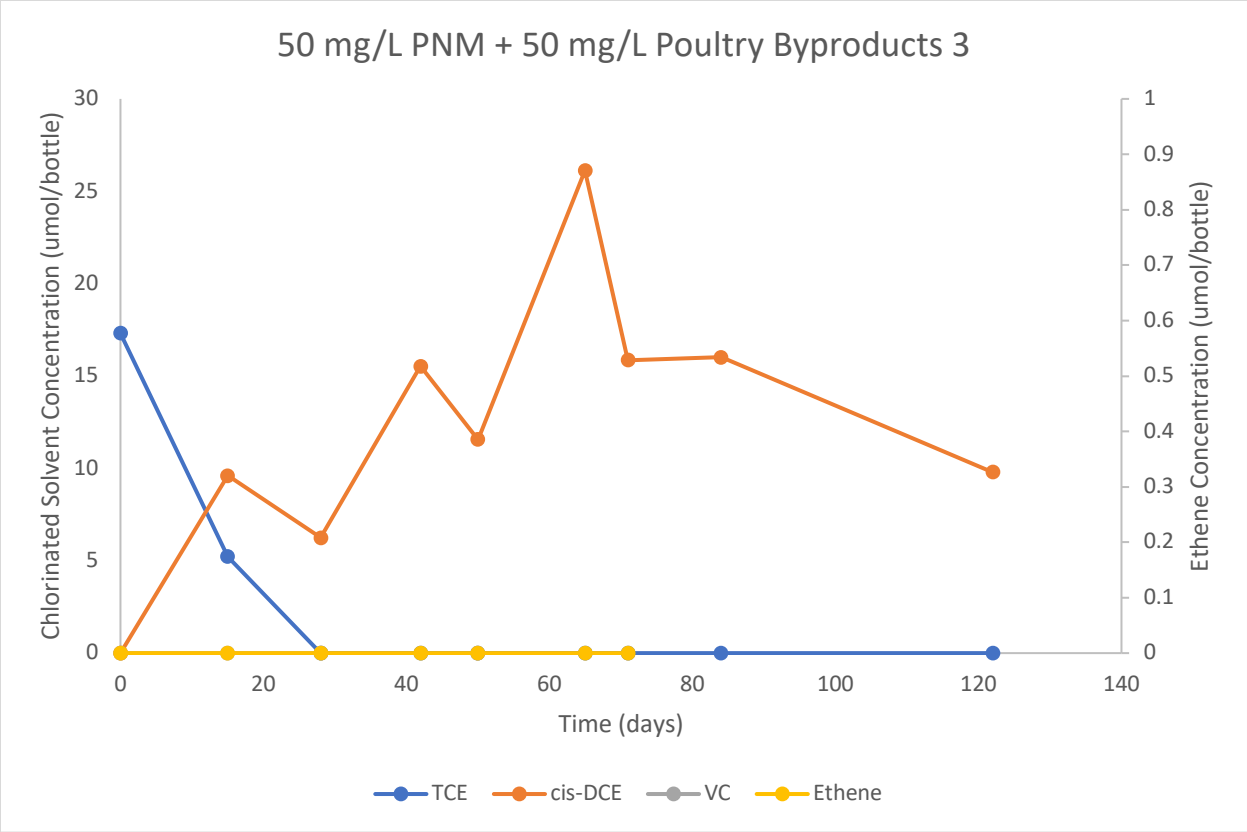
Appendix Figure 147. 50 mg/L DAF + 50 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



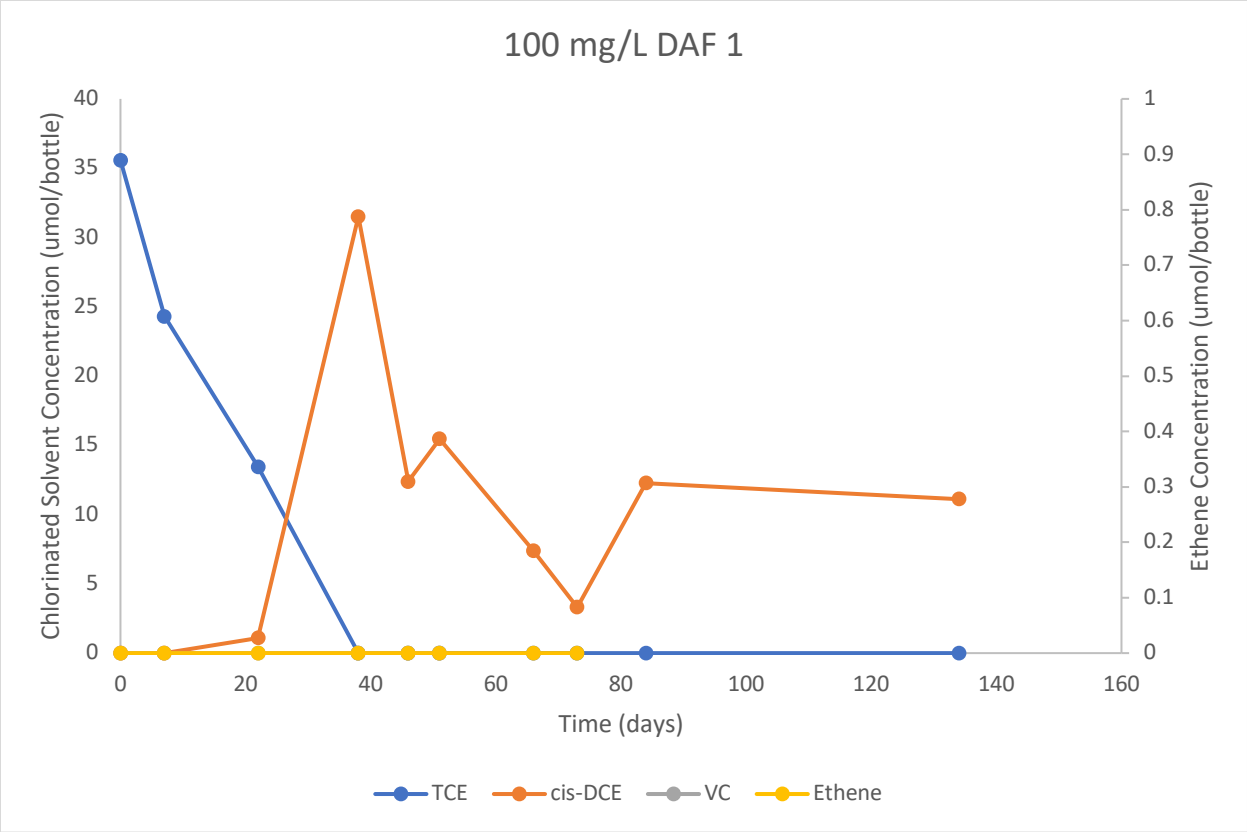
Appendix Figure 148. 50 mg/L PNM + 50 mg/L Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



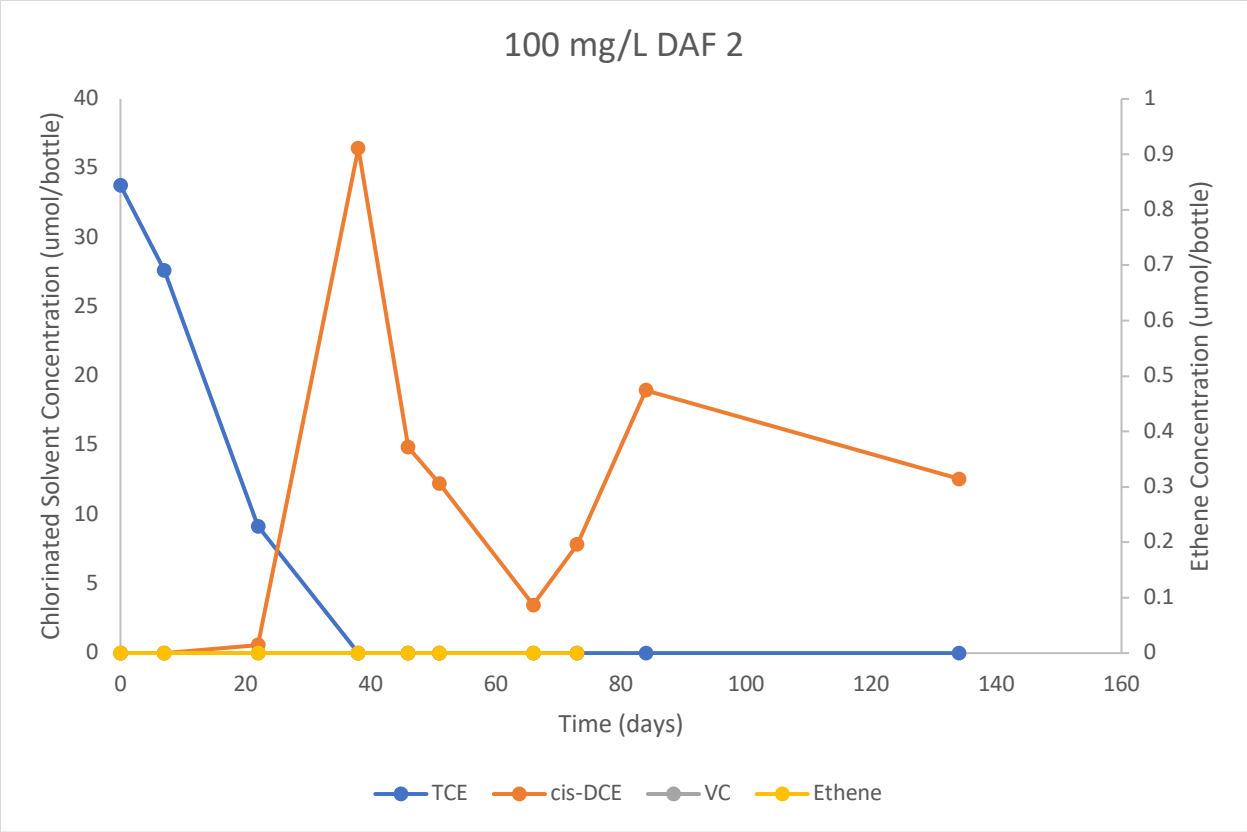
Appendix Figure 149. 50 mg/L PNM + 50 mg/L Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



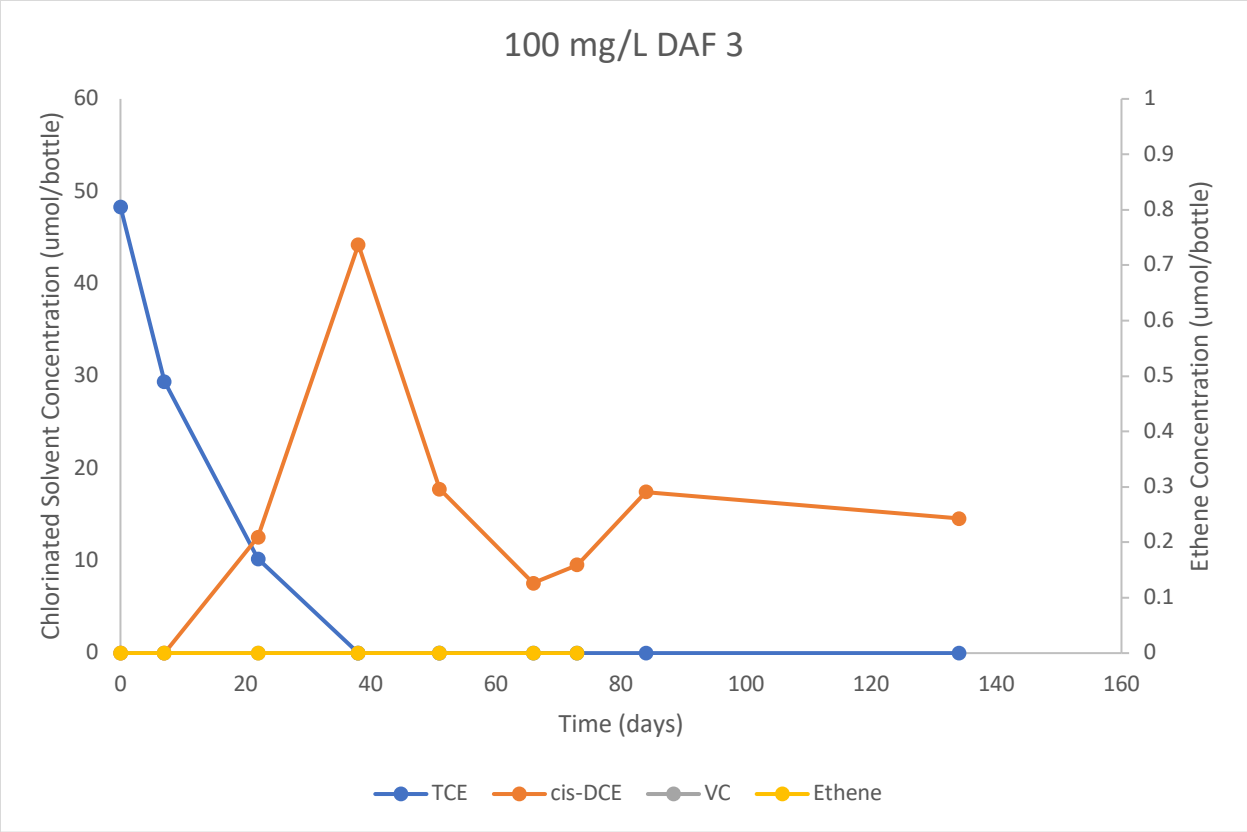
Appendix Figure 150. 50 mg/L PNM + 50 mg/L Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



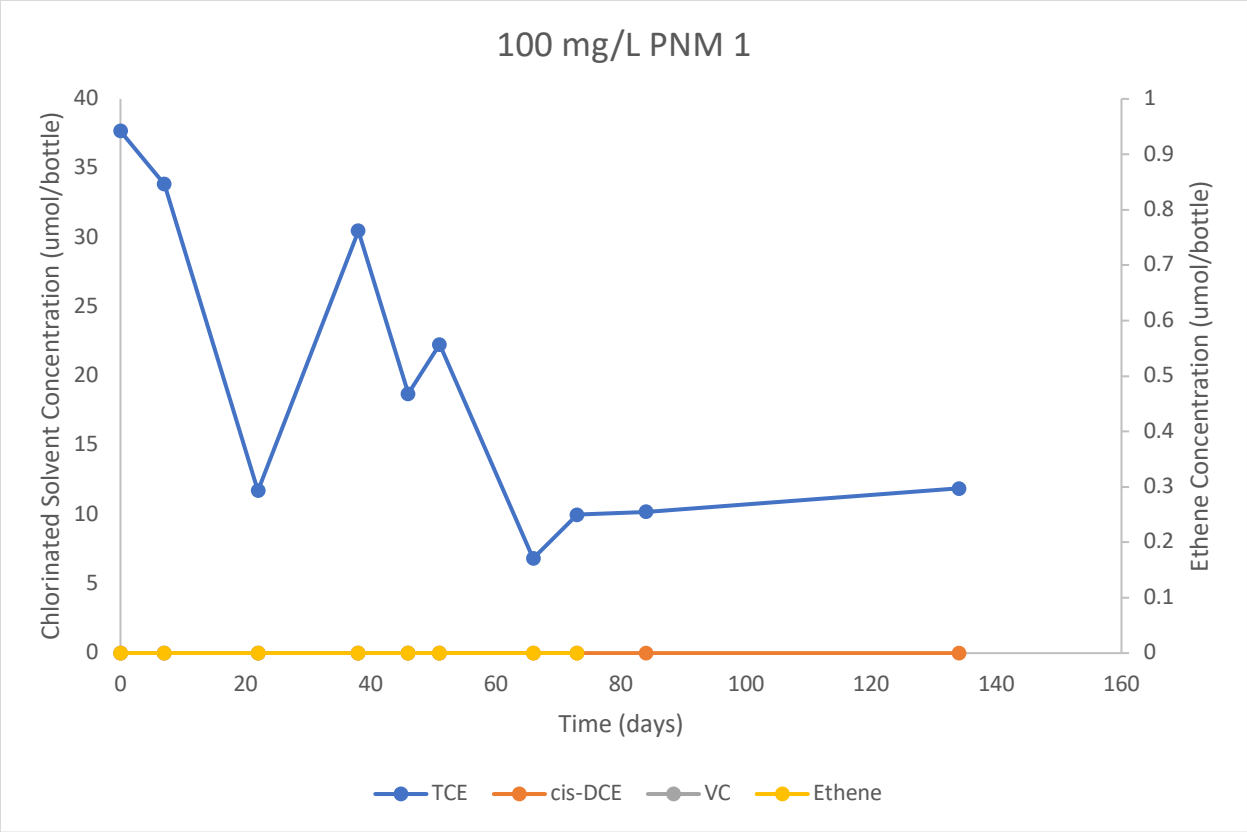
Appendix Figure 151. 100 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



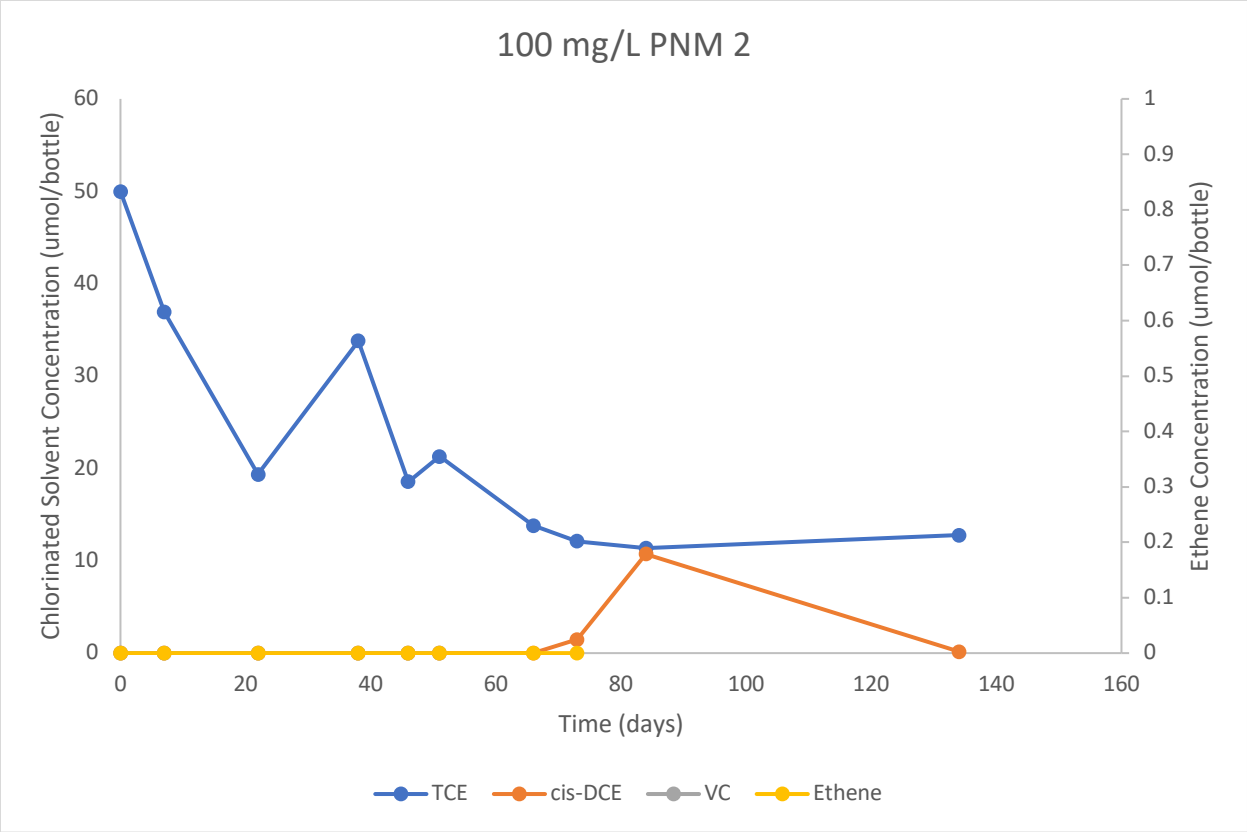
Appendix Figure 152. 100 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



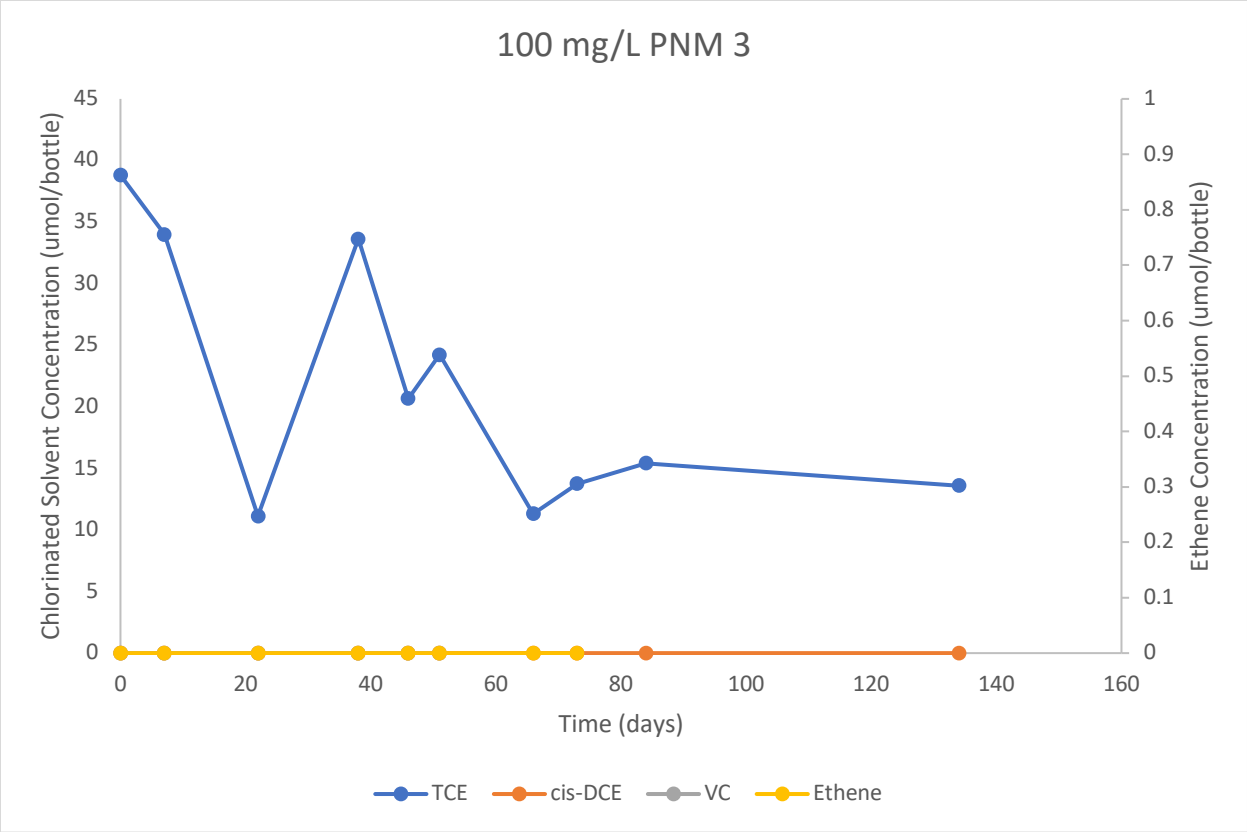
Appendix Figure 153. 100 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



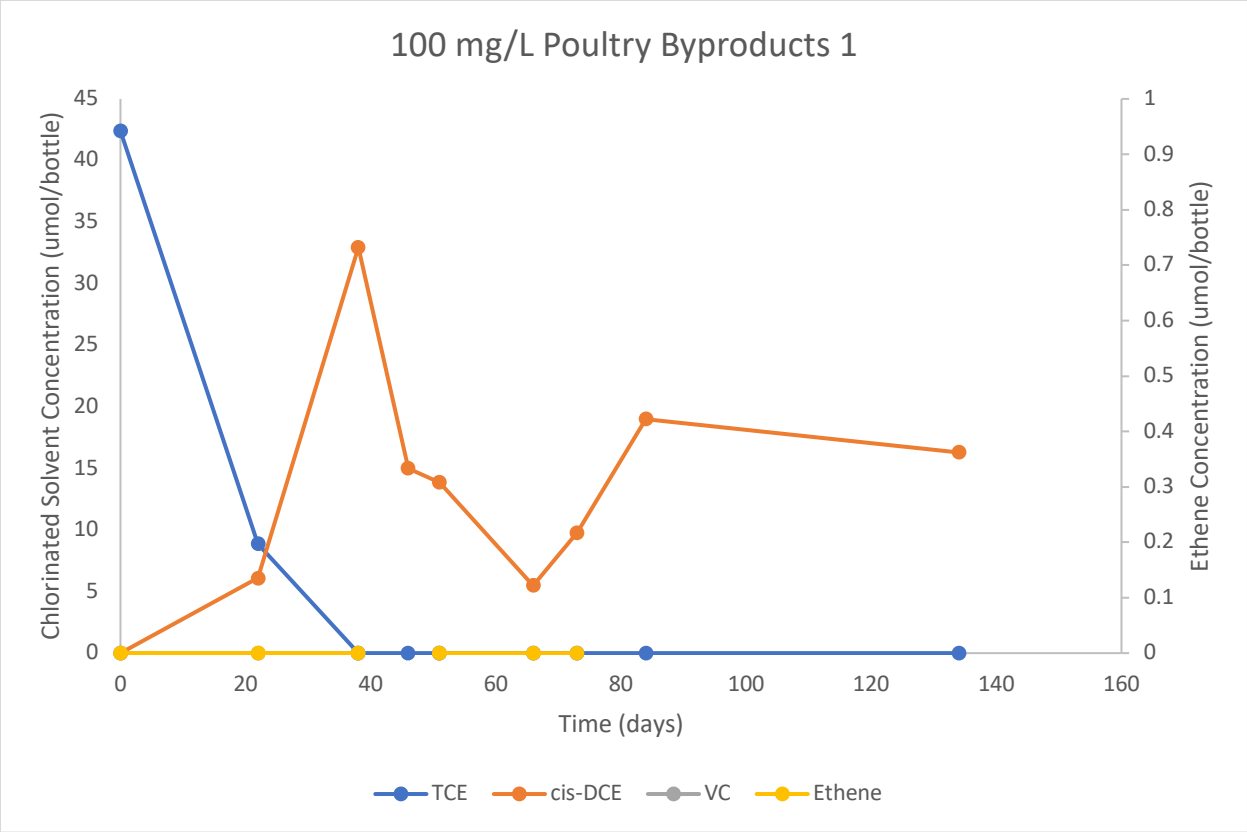
Appendix Figure 154. 100 mg/L PNM dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



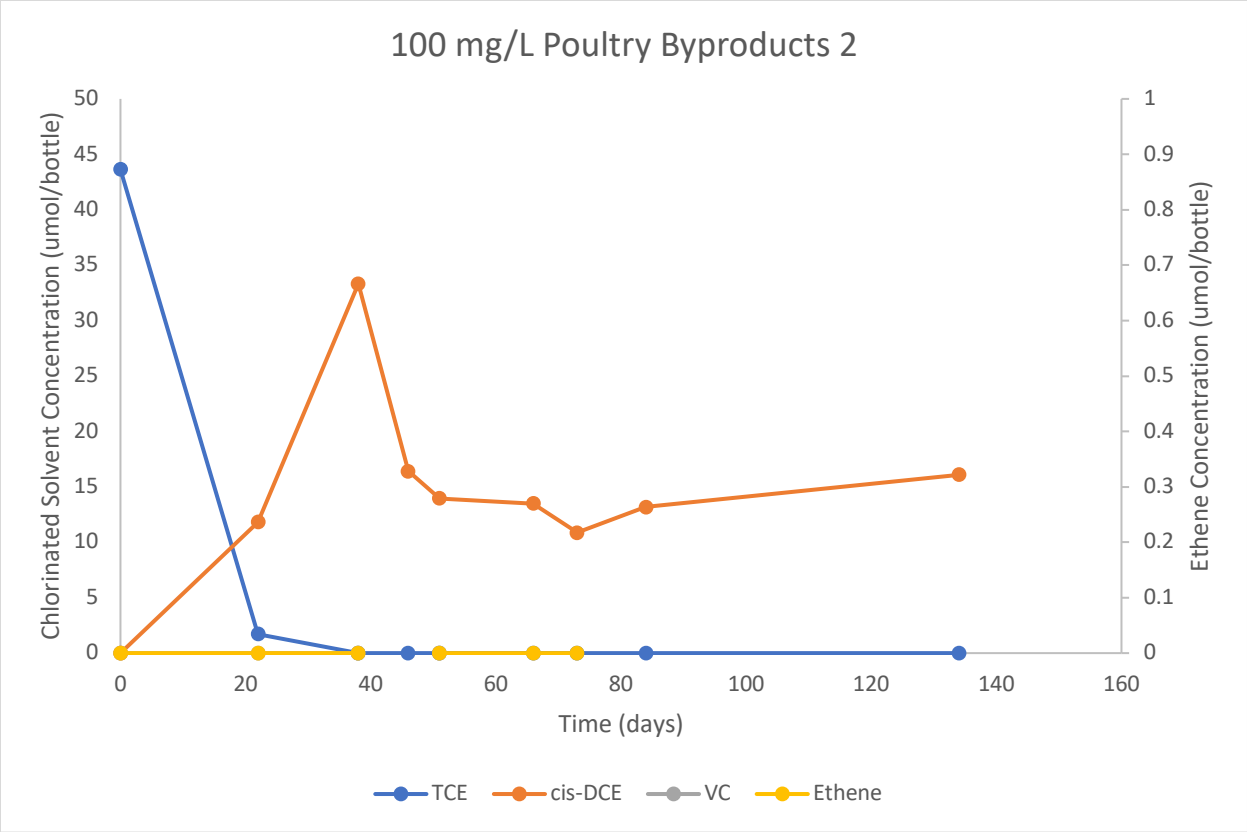
Appendix Figure 155. 100 mg/L PNM dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



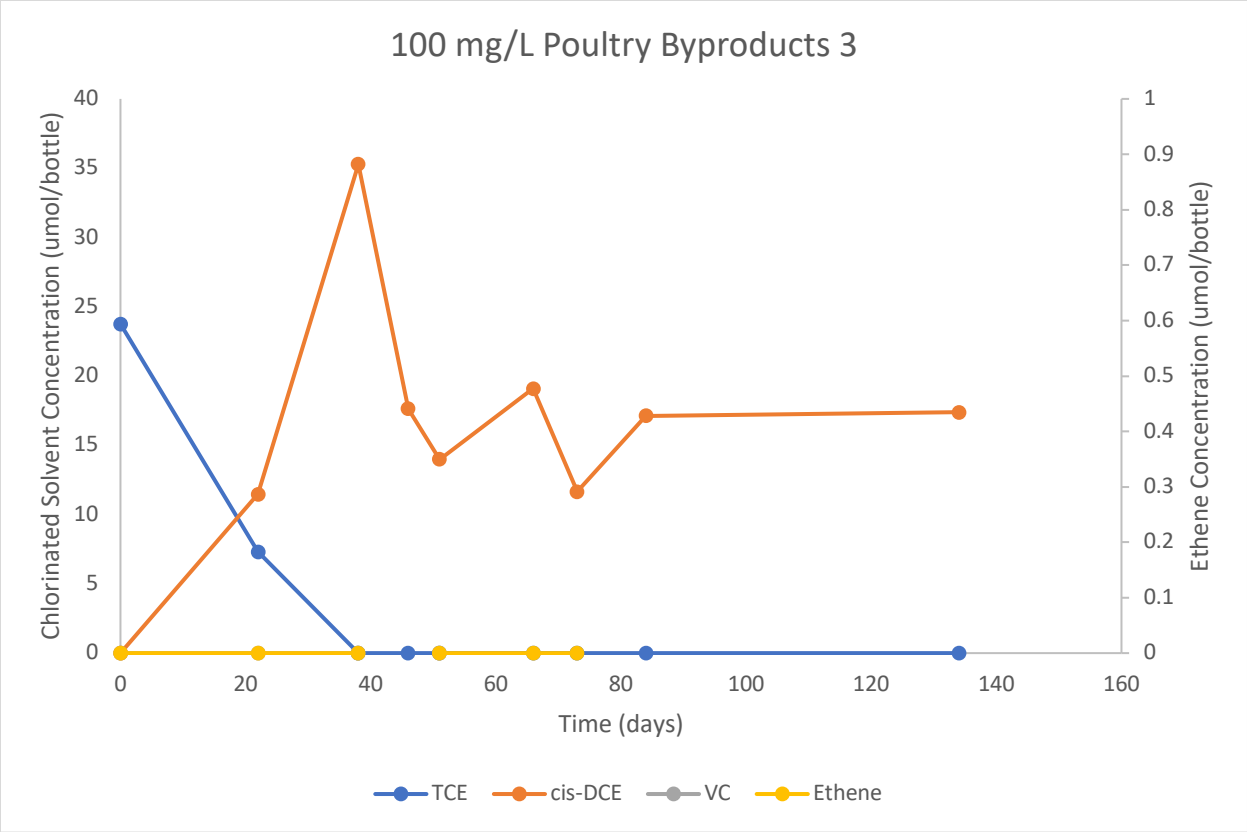
Appendix Figure 156. 100 mg/L PNM dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



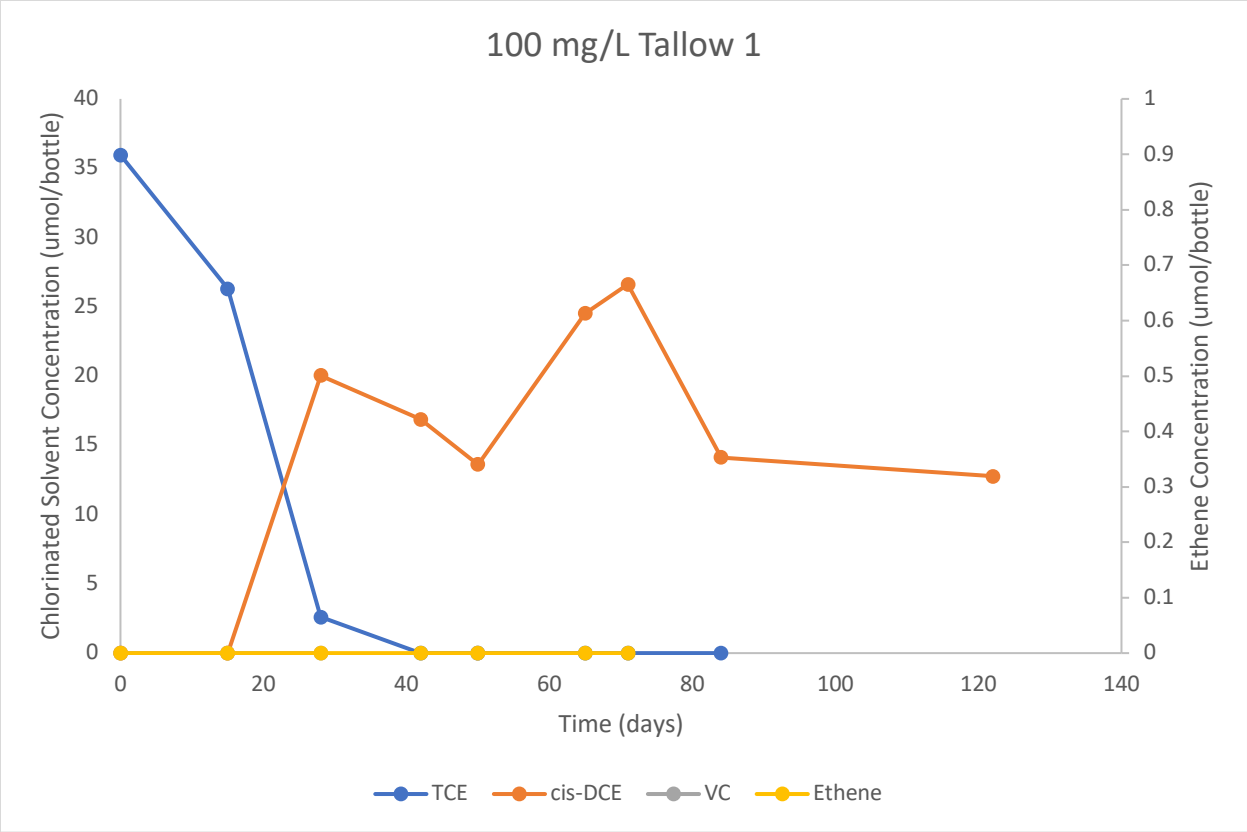
Appendix Figure 157. 100 mg/L Poultry Byproducts dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



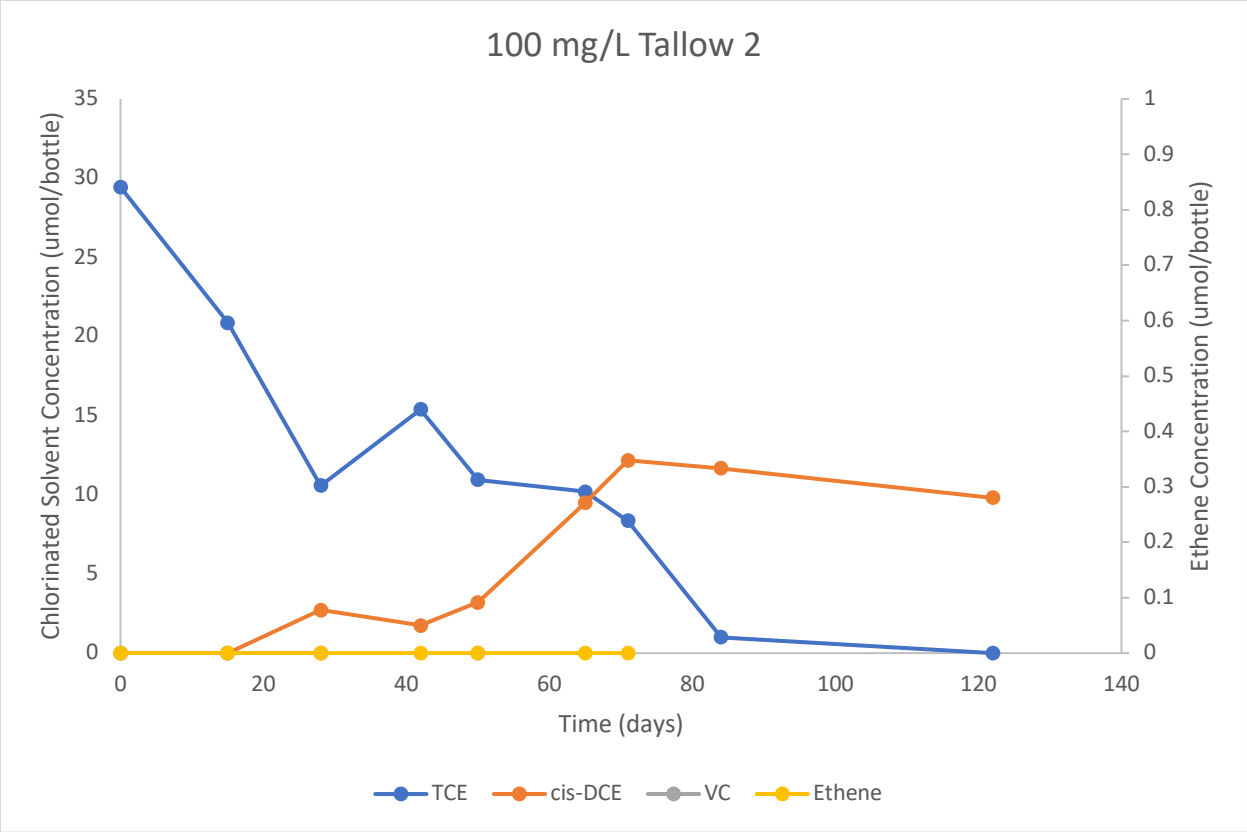
Appendix Figure 158. 100 mg/L Poultry Byproducts dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



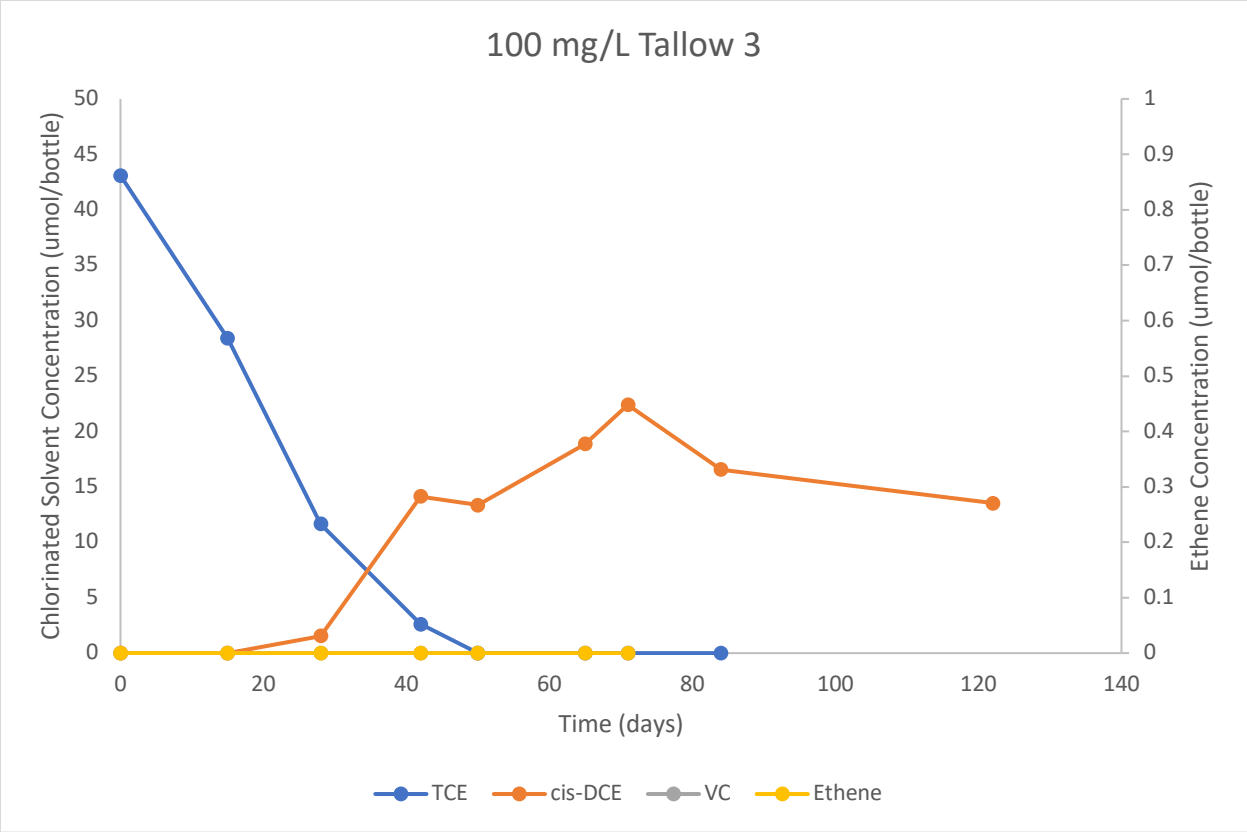
Appendix Figure 159. 100 mg/L Poultry Byproducts dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



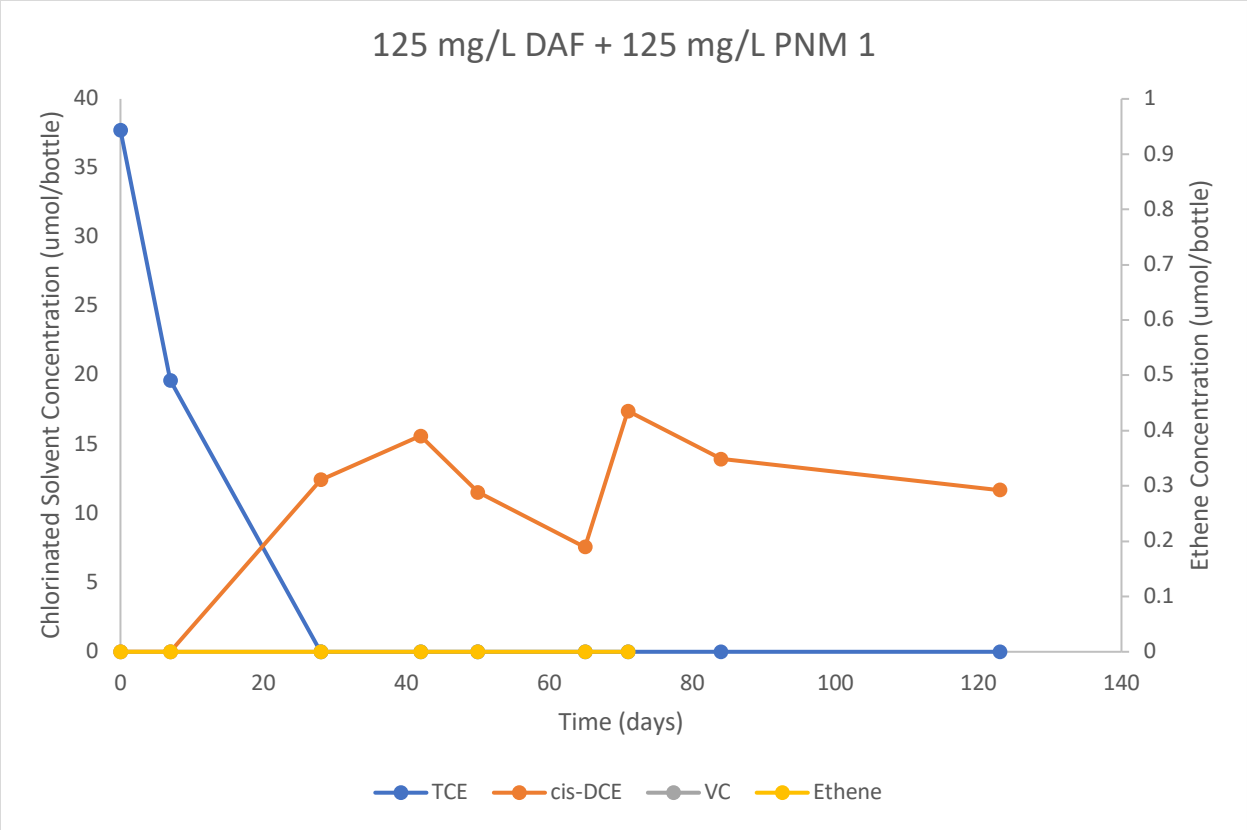
Appendix Figure 160. 100 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



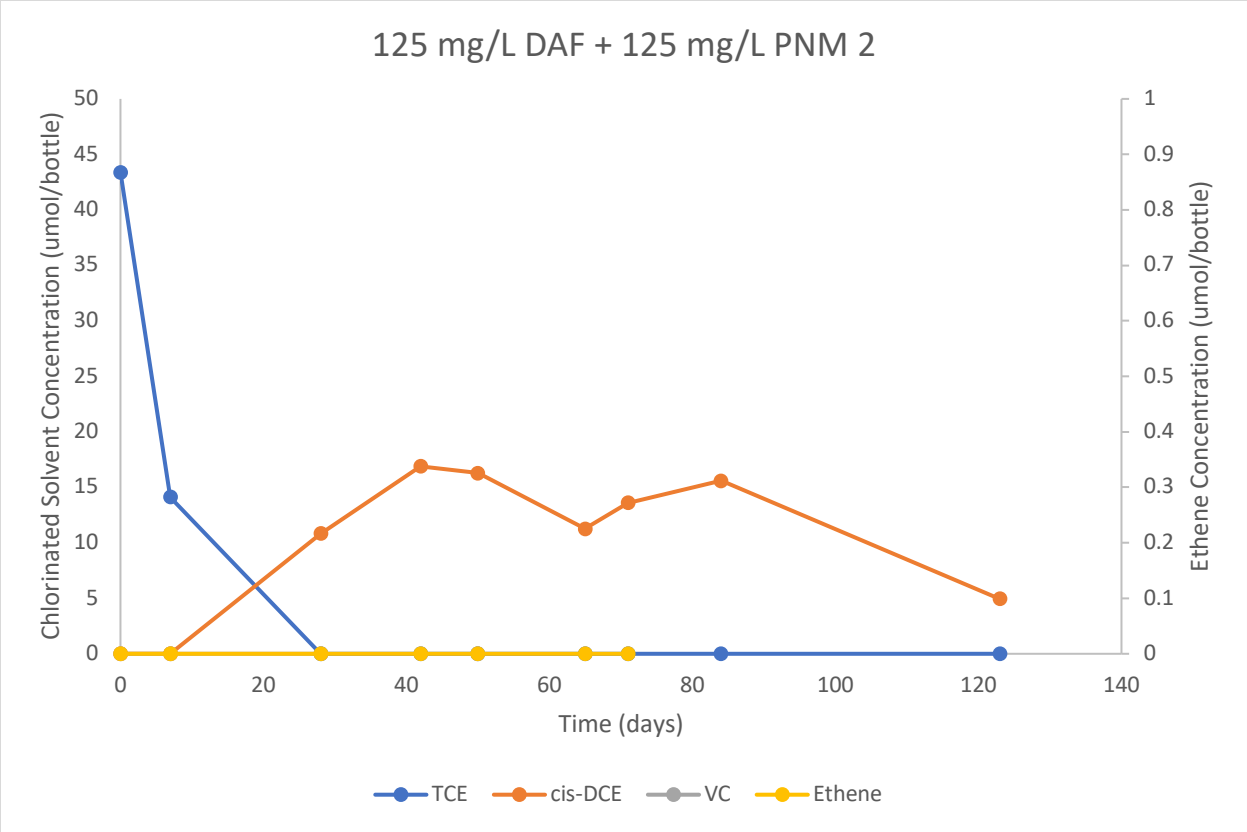
Appendix Figure 161. 100 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



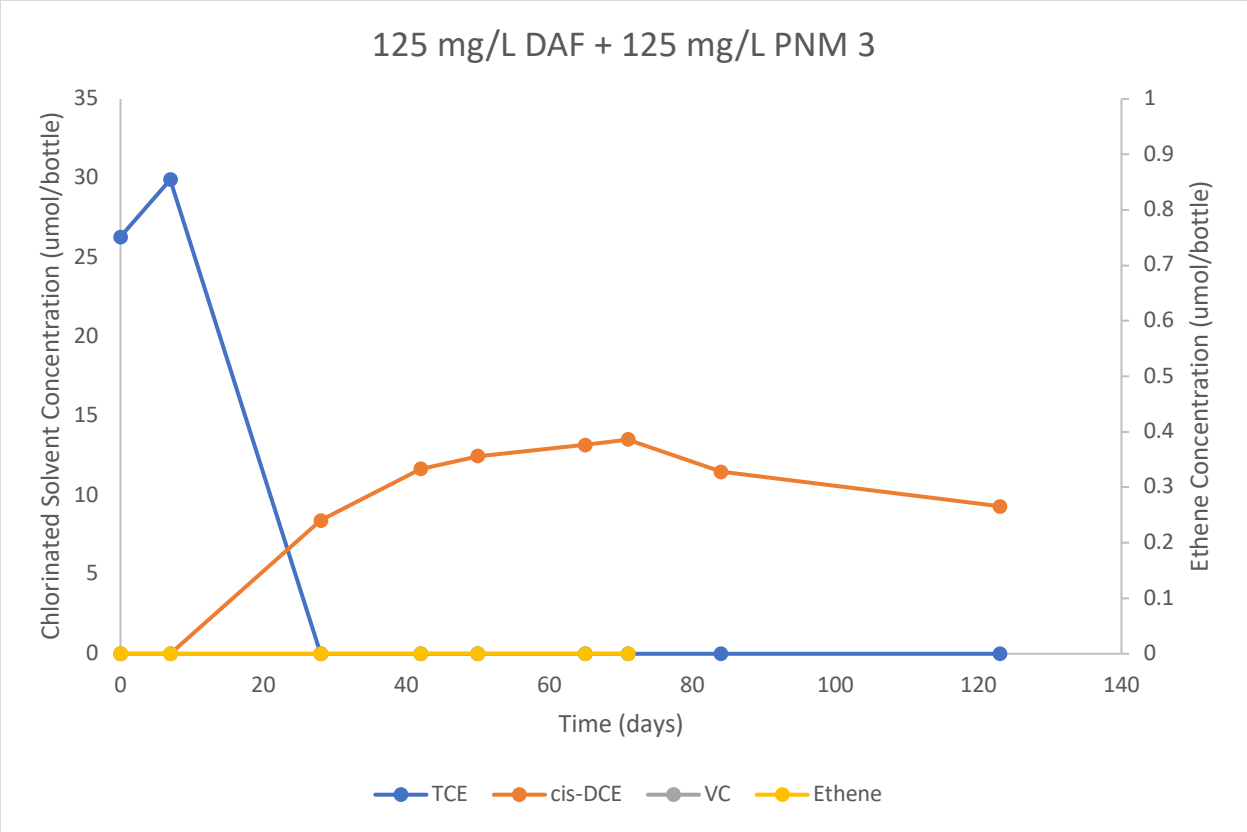
Appendix Figure 162. 100 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



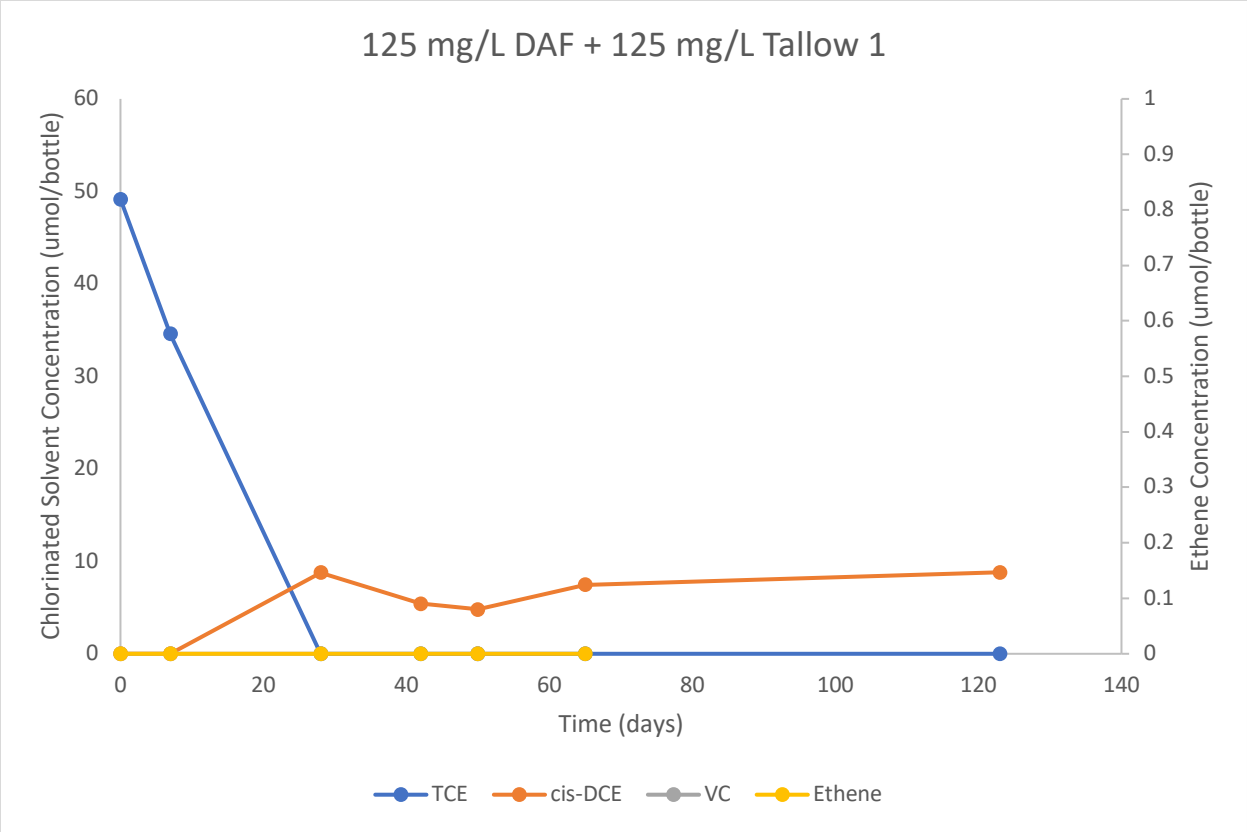
Appendix Figure 163. 125 mg/L DAF + 125 mg/L PNM dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



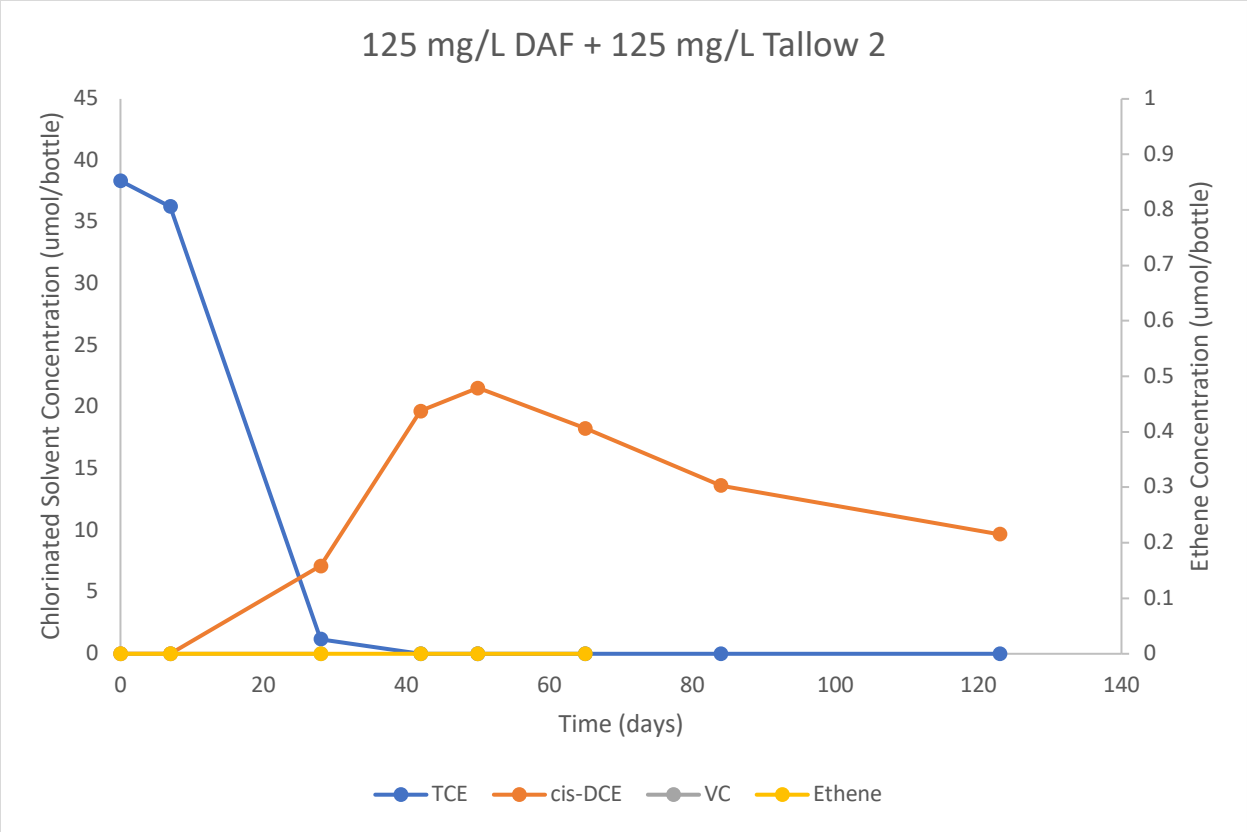
Appendix Figure 164. 125 mg/L DAF + 125 mg/L PNM dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



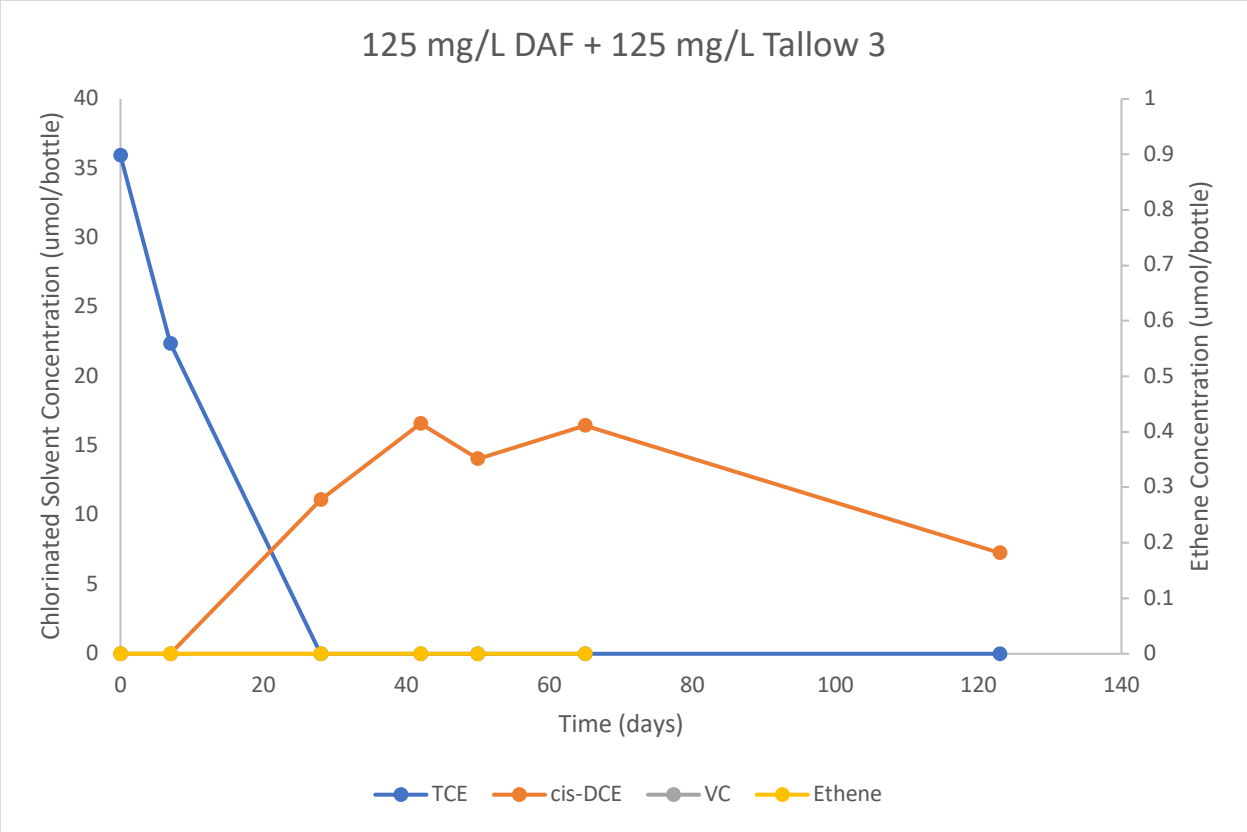
Appendix Figure 165. 125 mg/L DAF + 125 mg/L PNM dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



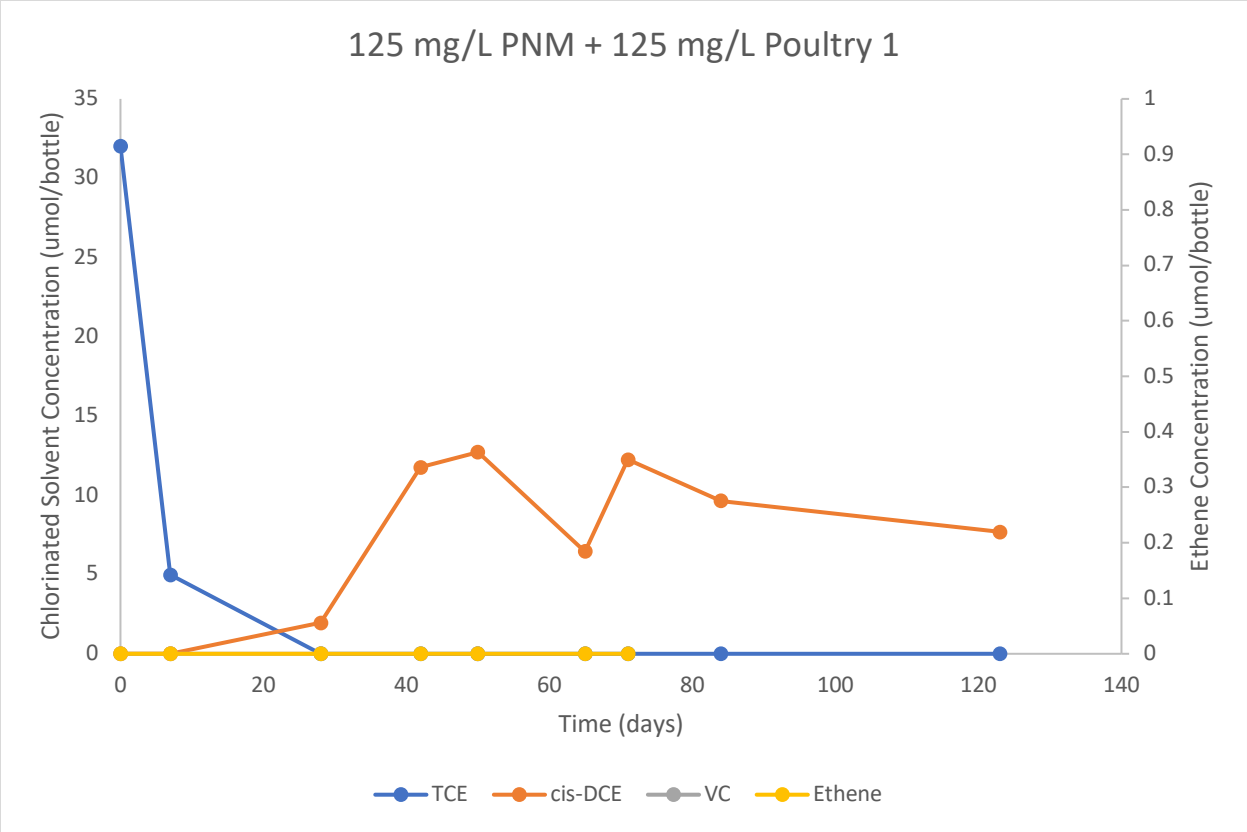
Appendix Figure 166. 125 mg/L DAF + 125 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



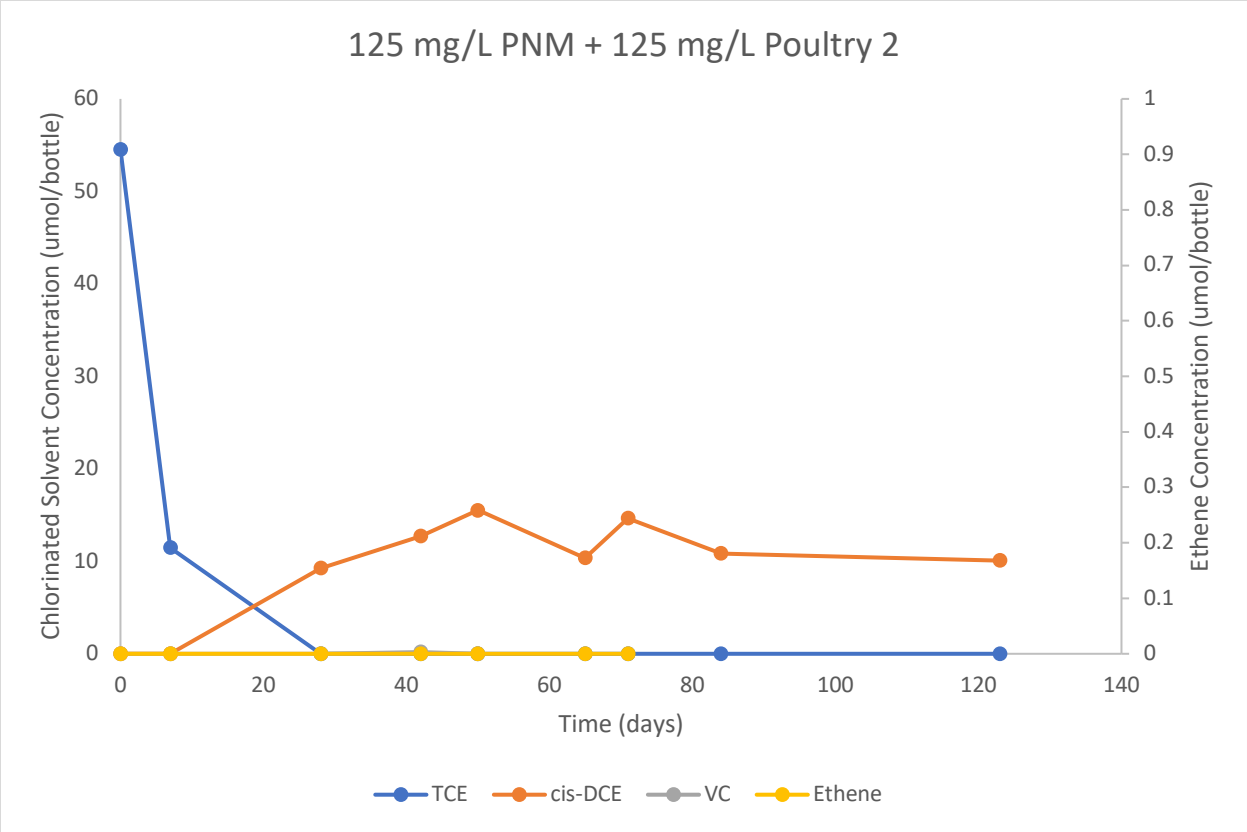
Appendix Figure 167. 125 mg/L DAF + 125 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



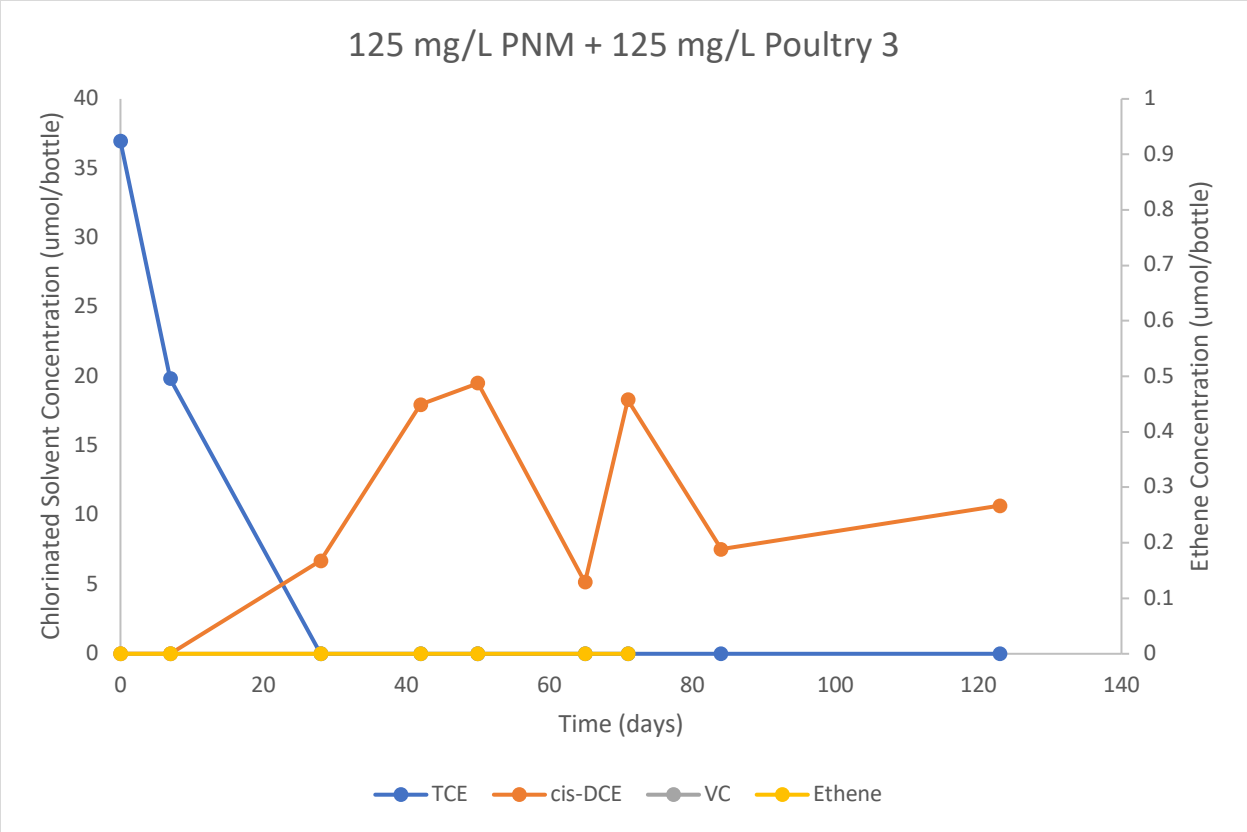
Appendix Figure 168. 125 mg/L DAF + 125 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



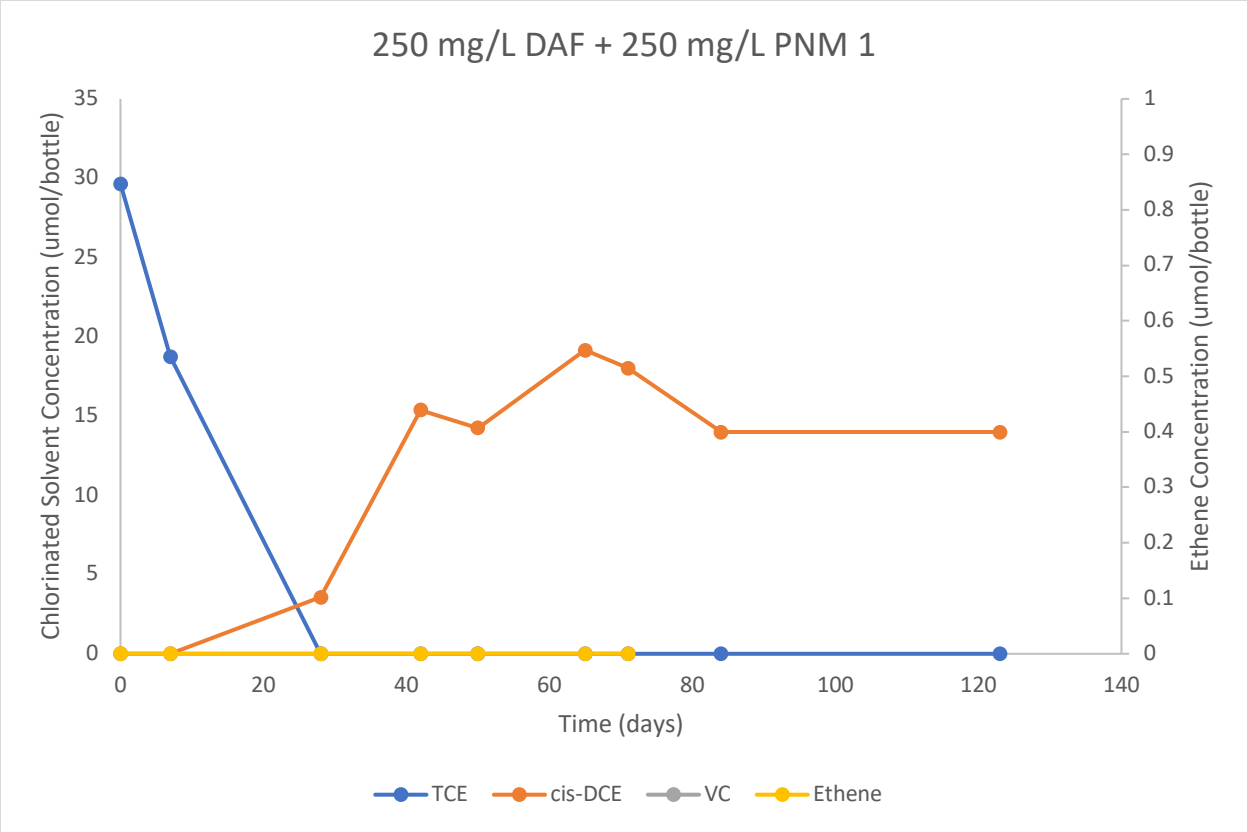
Appendix Figure 169. 125 mg/L PNM + 125 mg/L Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



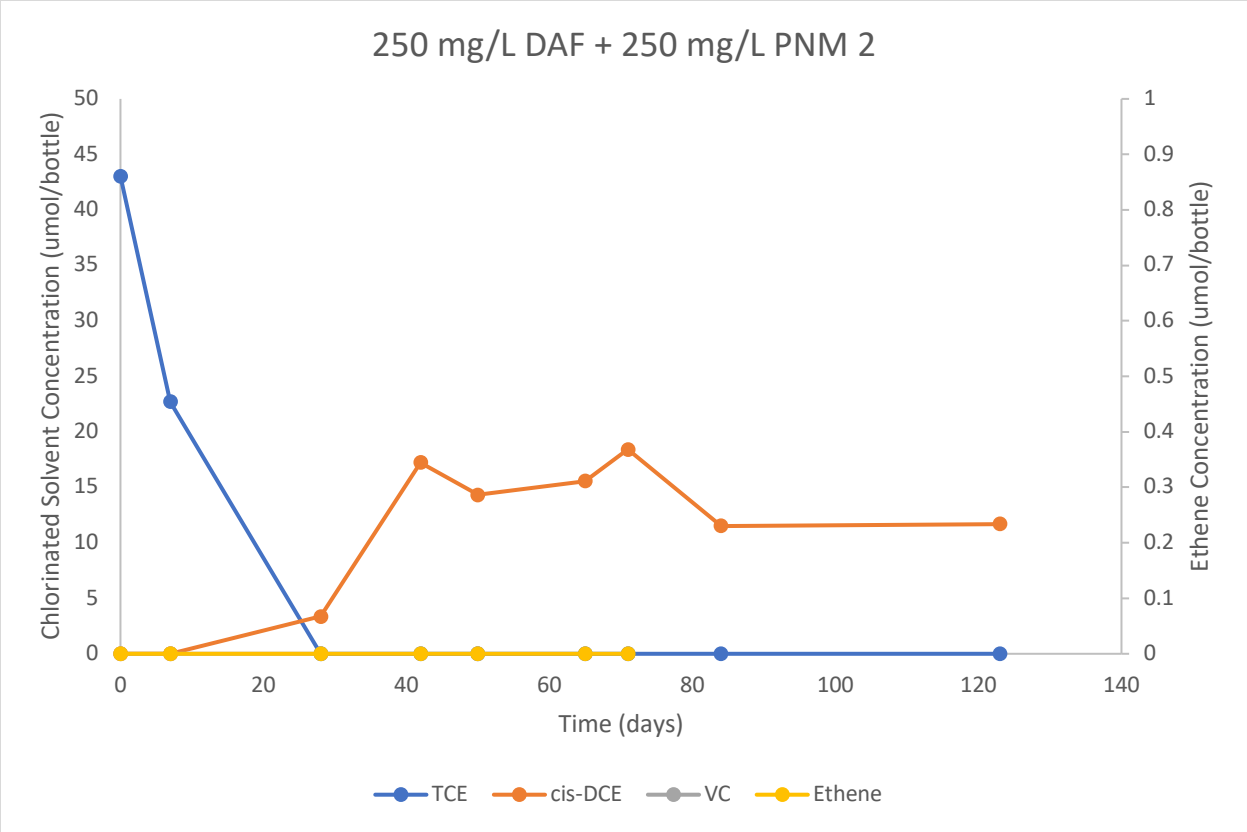
Appendix Figure 170. 125 mg/L PNM + 125 mg/L Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



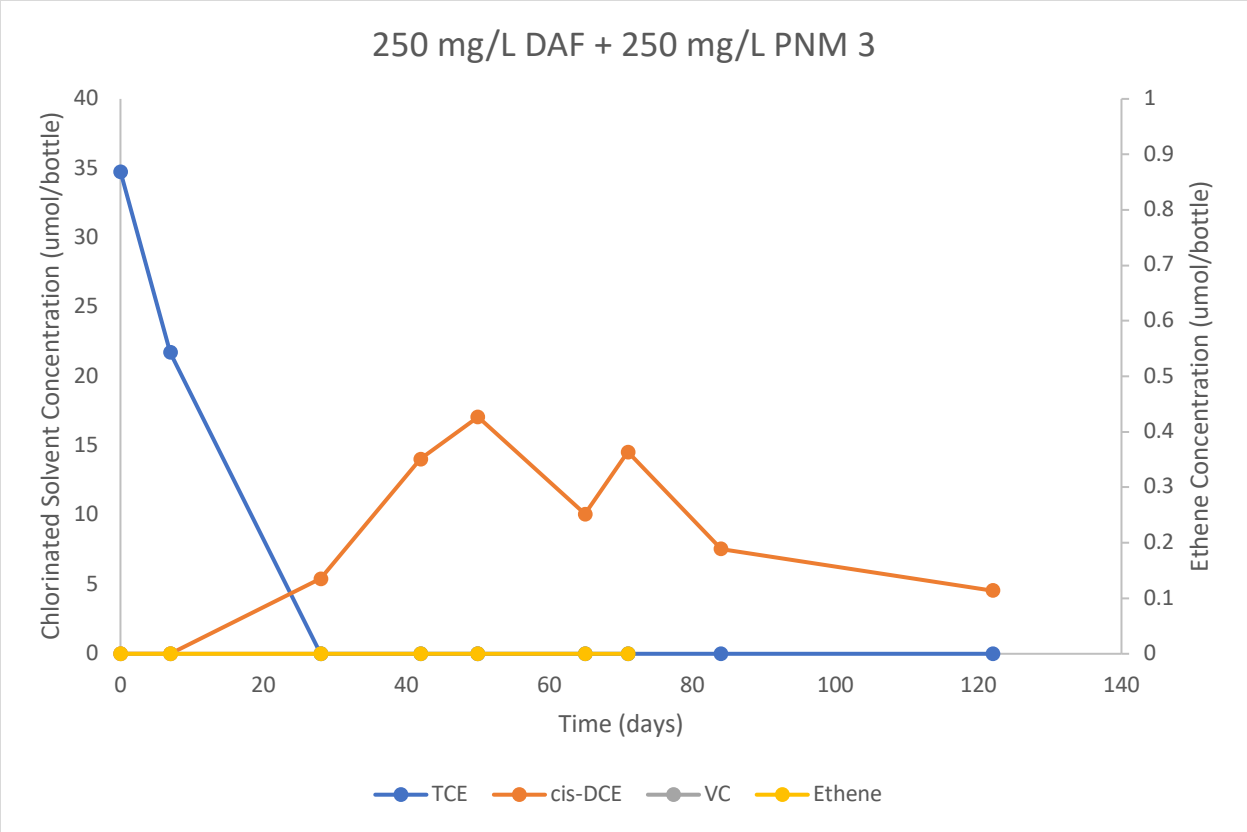
Appendix Figure 171. 125 mg/L PNM + 125 mg/L Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



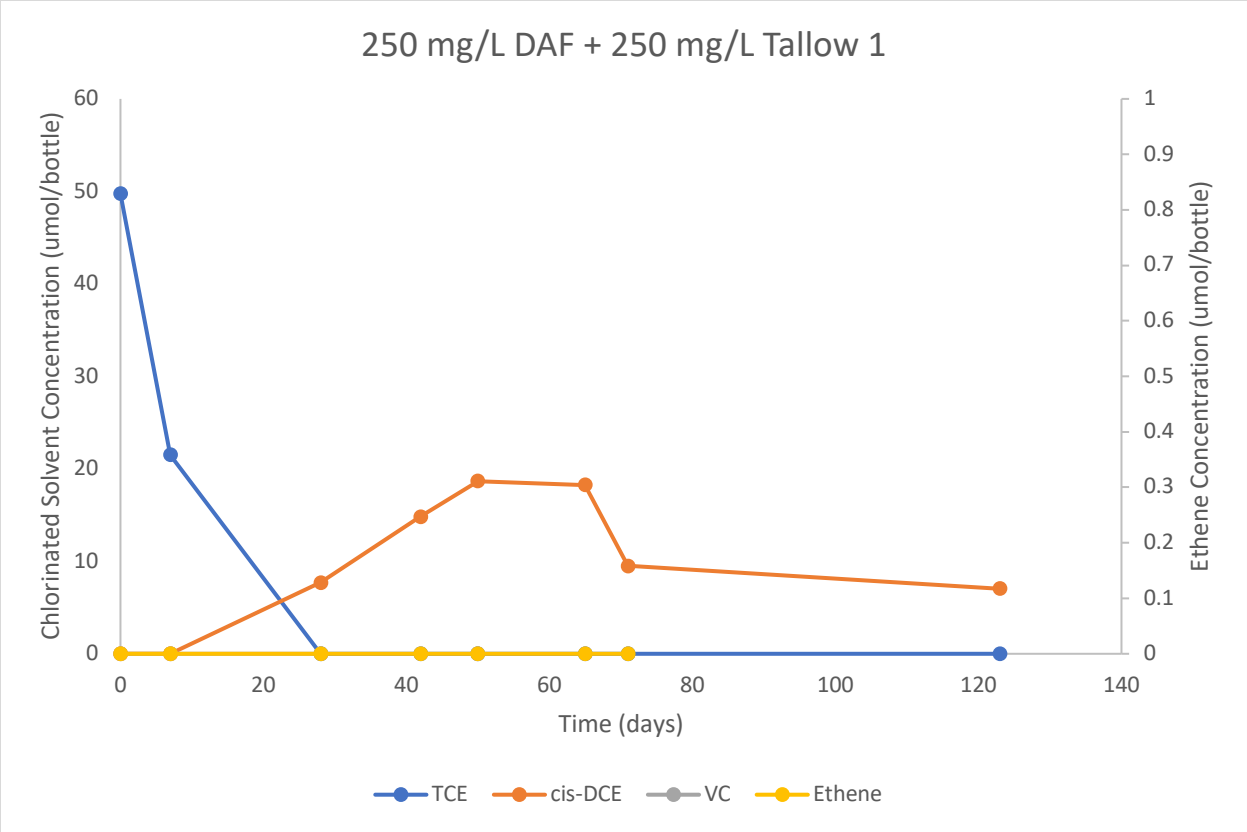
Appendix Figure 172. 250 mg/L DAF + 250 mg/L PNM dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



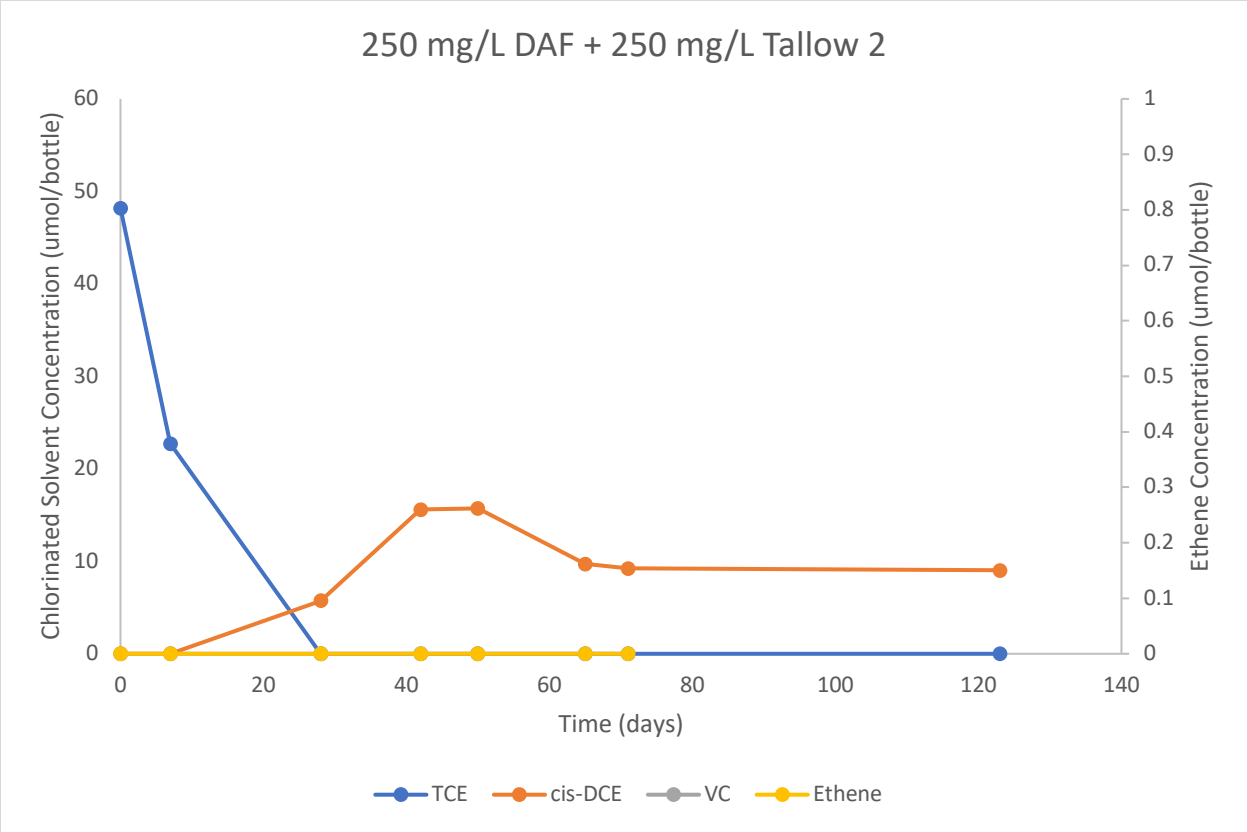
Appendix Figure 173. 250 mg/L DAF + 250 mg/L PNM dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



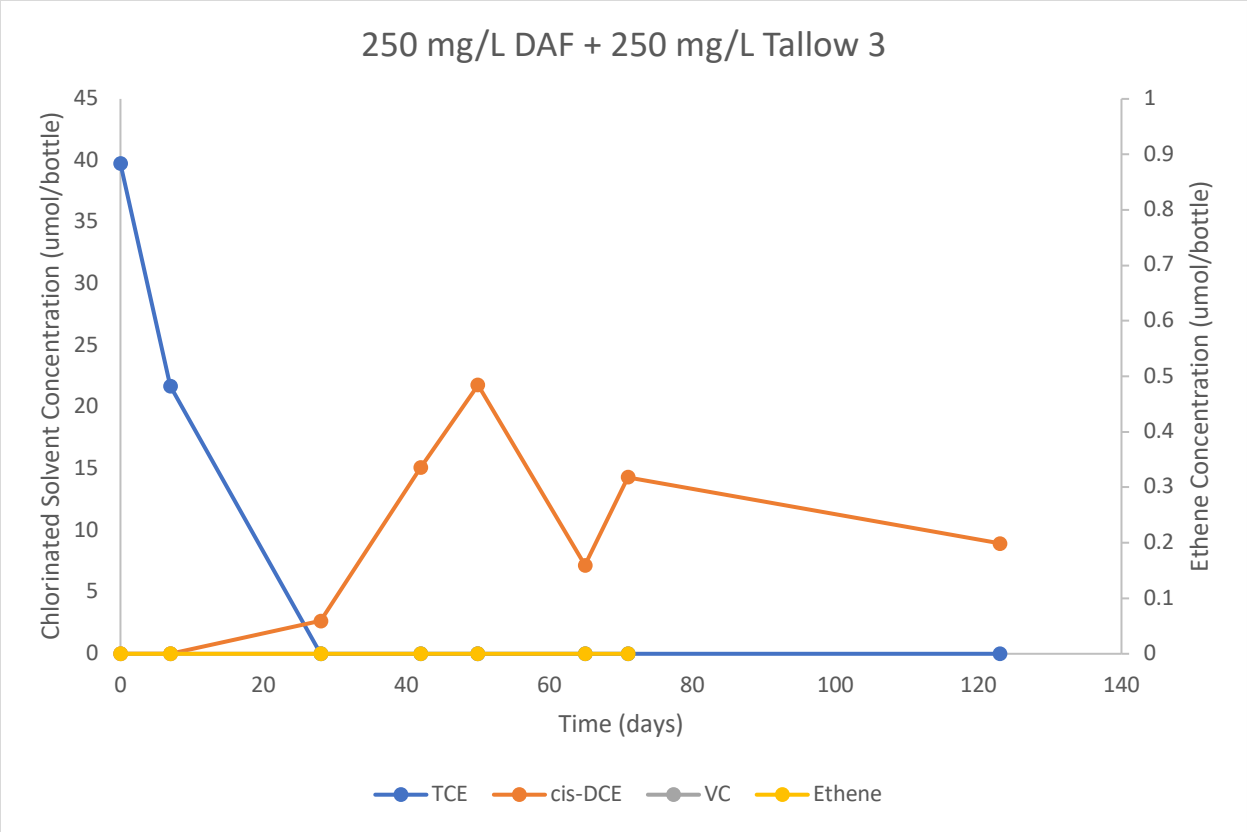
Appendix Figure 174. 250 mg/L DAF + 250 mg/L PNM dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



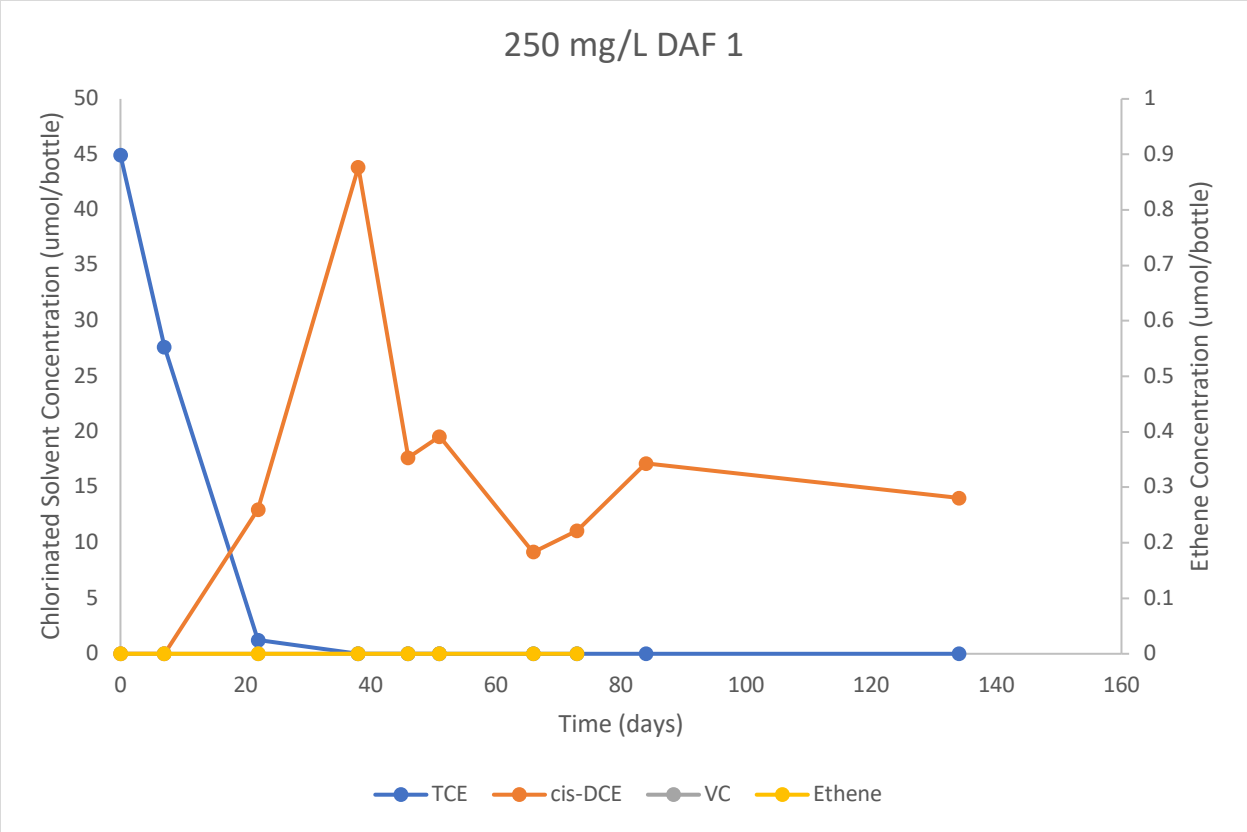
Appendix Figure 175. 250 mg/L DAF + 250 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



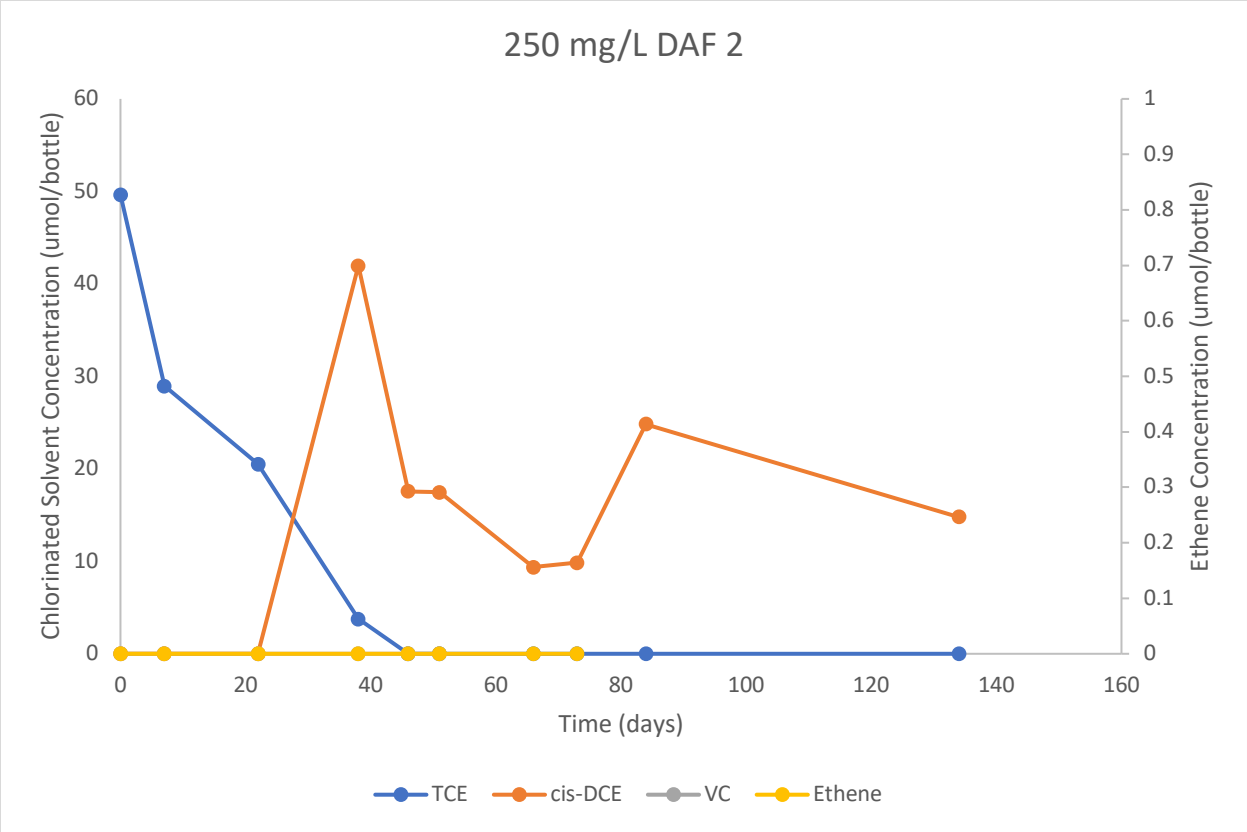
Appendix Figure 176. 250 mg/L DAF + 250 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



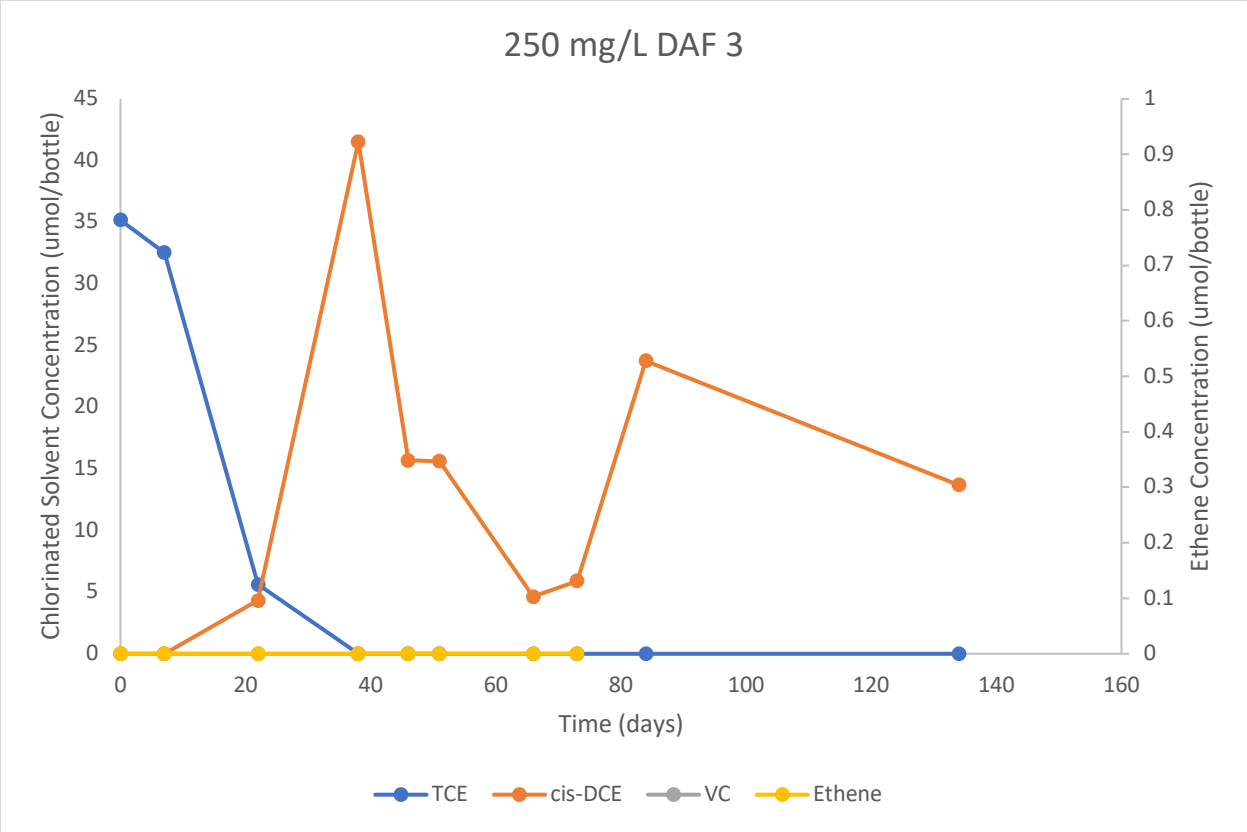
Appendix Figure 177. 250 mg/L DAF + 250 mg/L Tallow dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



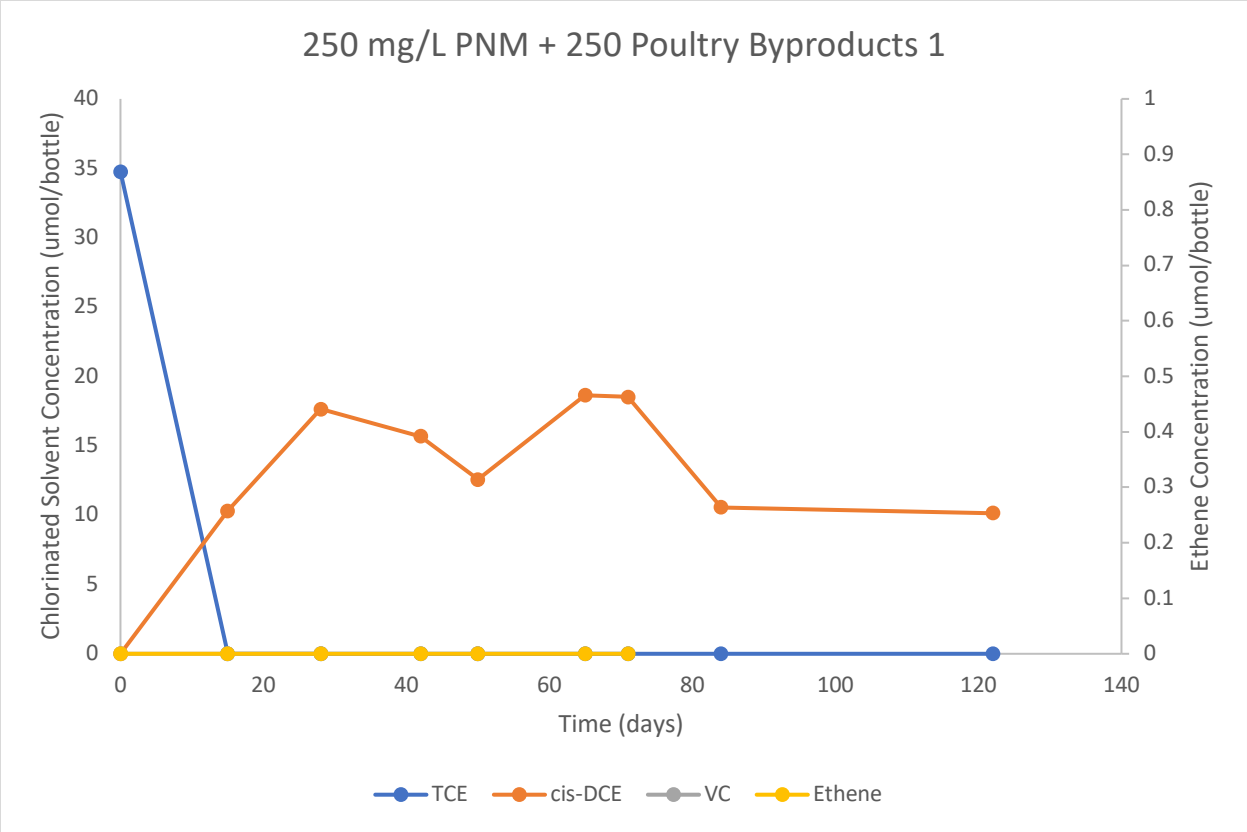
Appendix Figure 178. 250 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



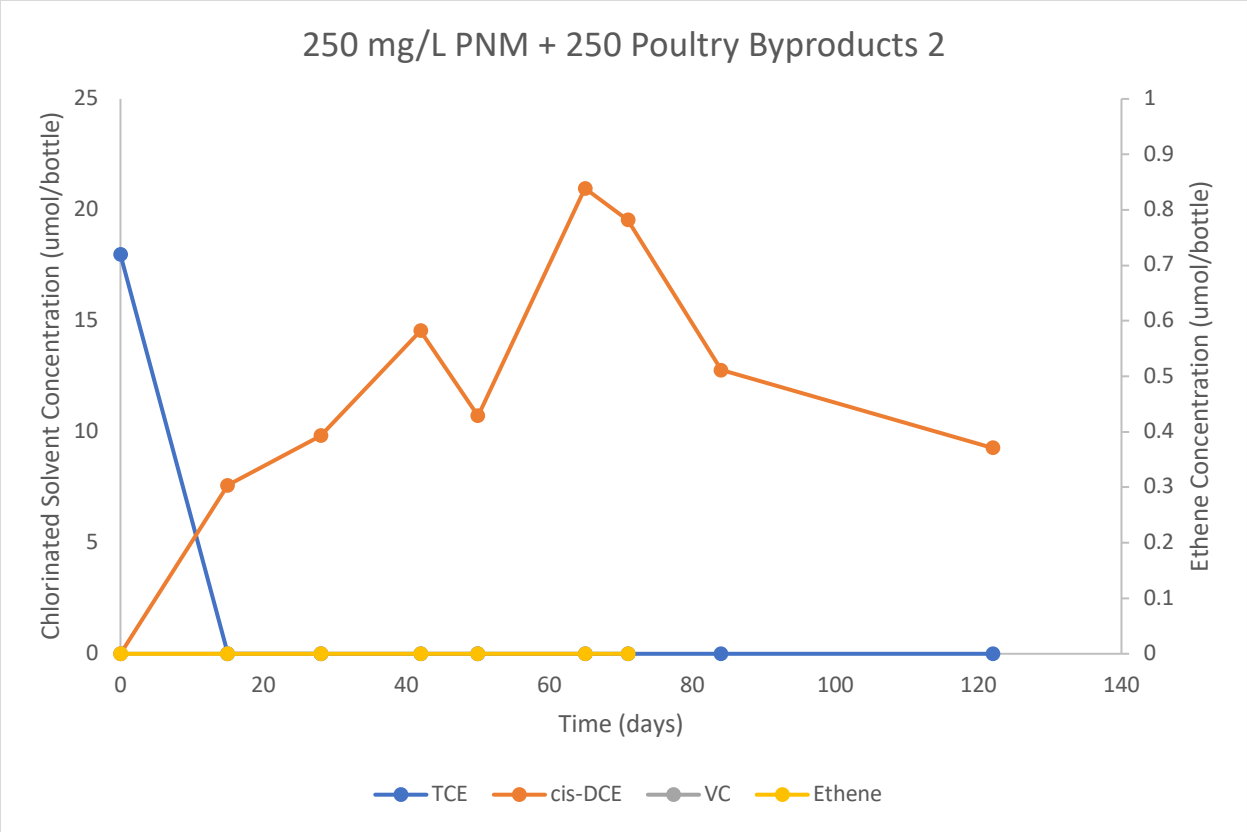
Appendix Figure 179. 250 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



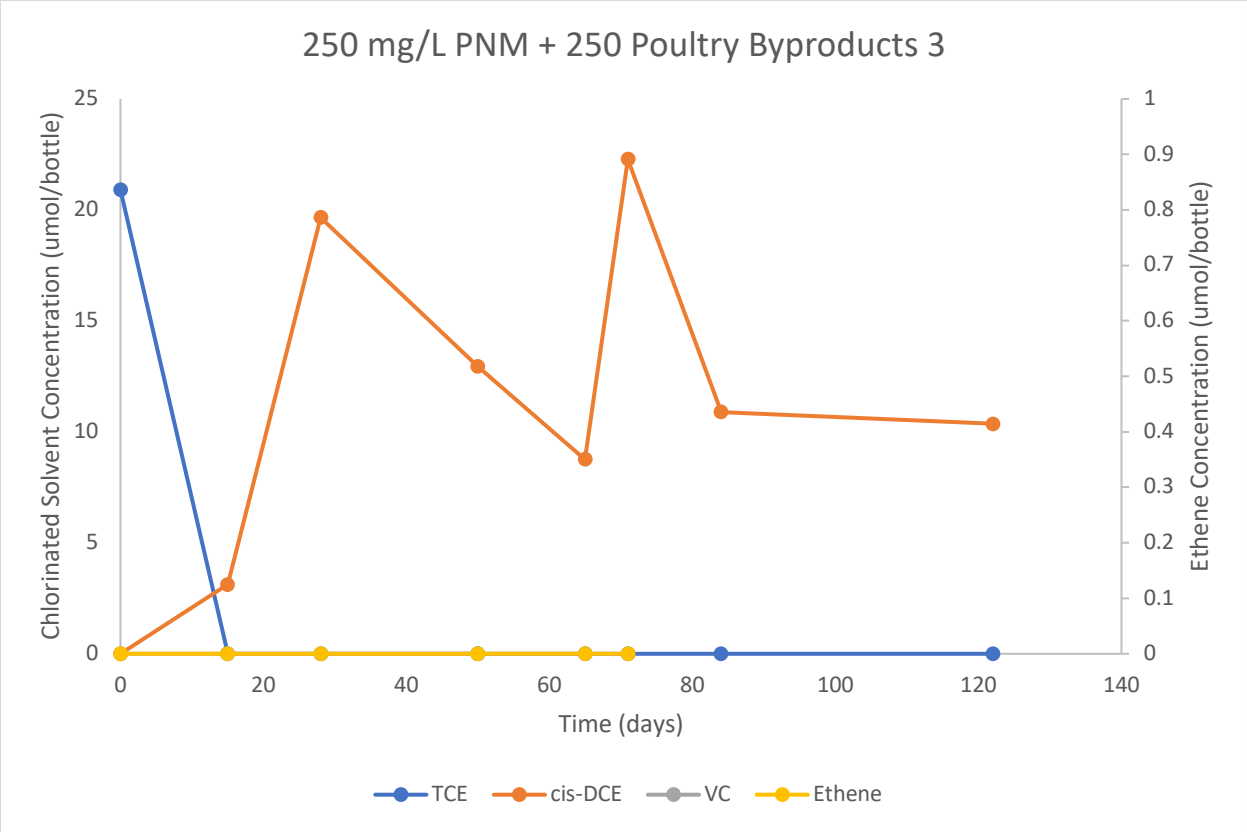
Appendix Figure 180. 250 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



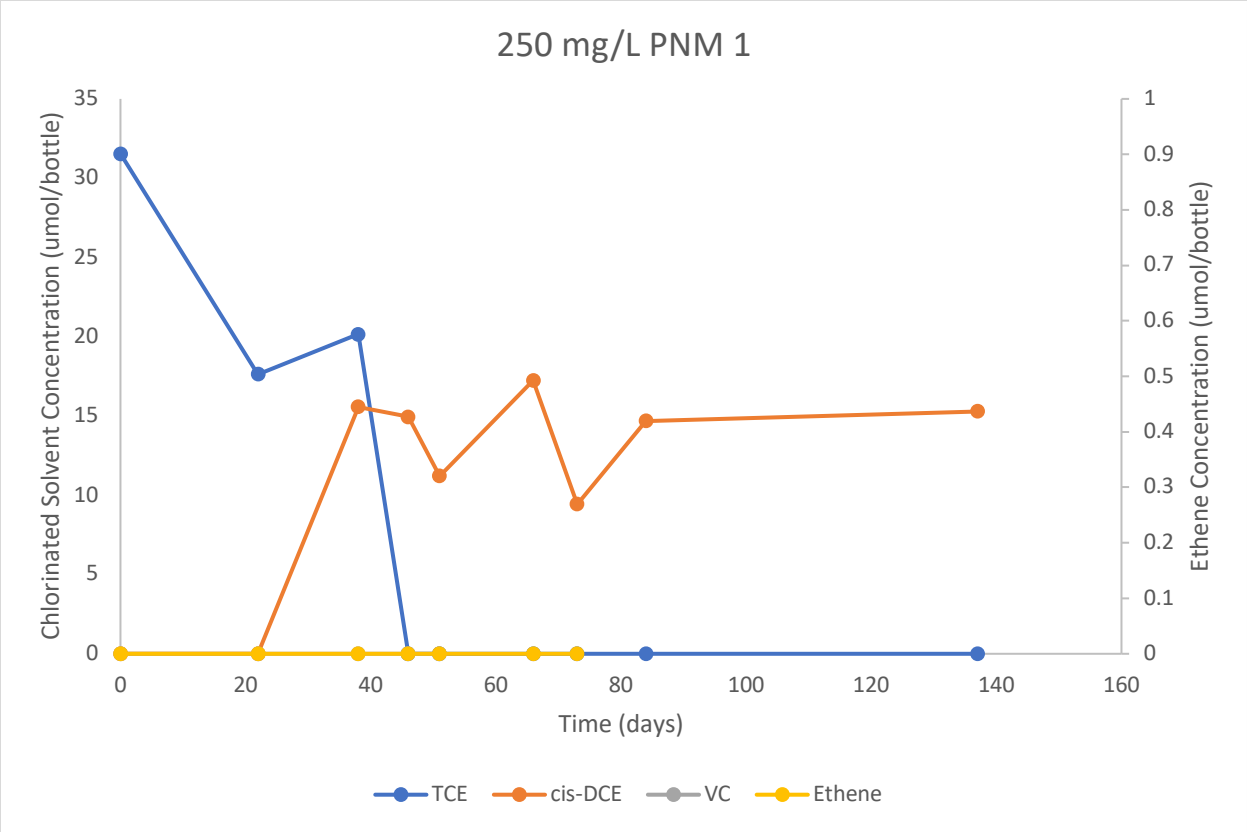
Appendix Figure 181. 250 mg/L PNM + 250 Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



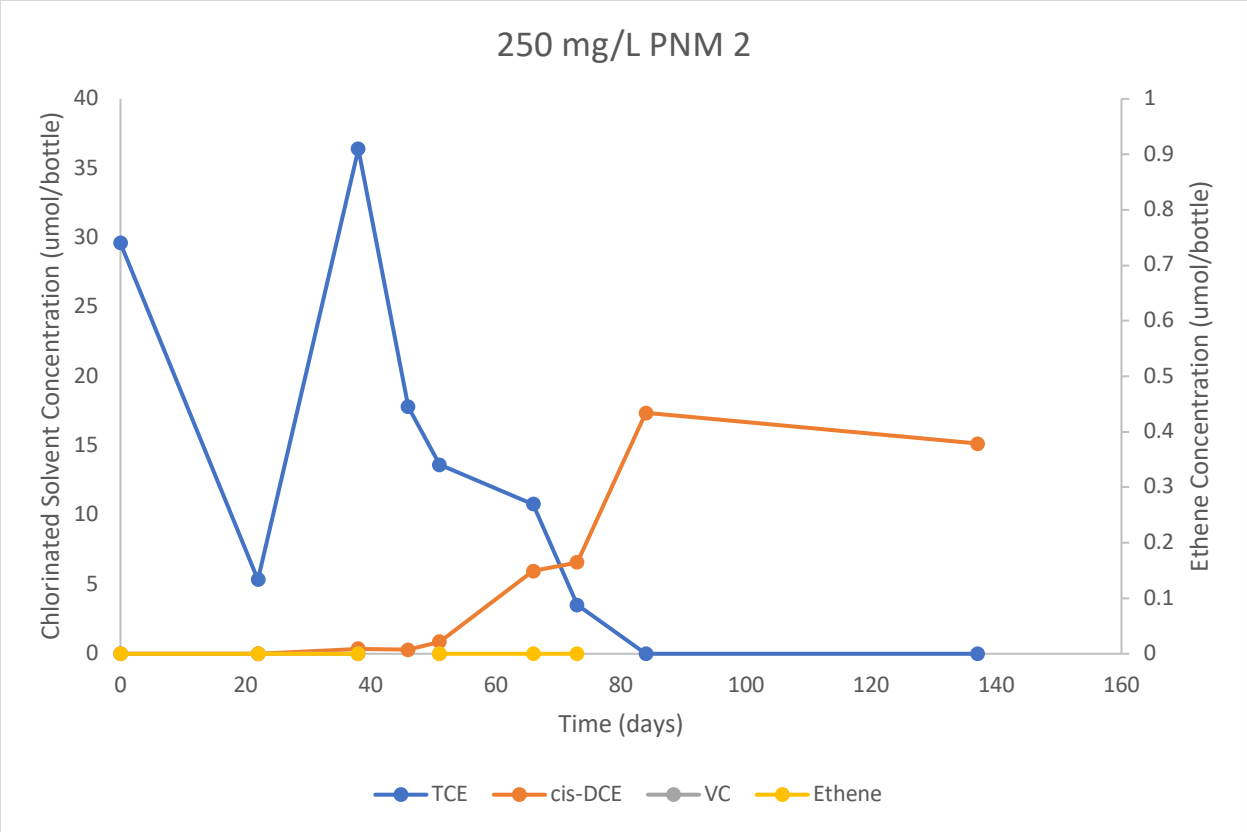
Appendix Figure 182. 250 mg/L PNM + 250 Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



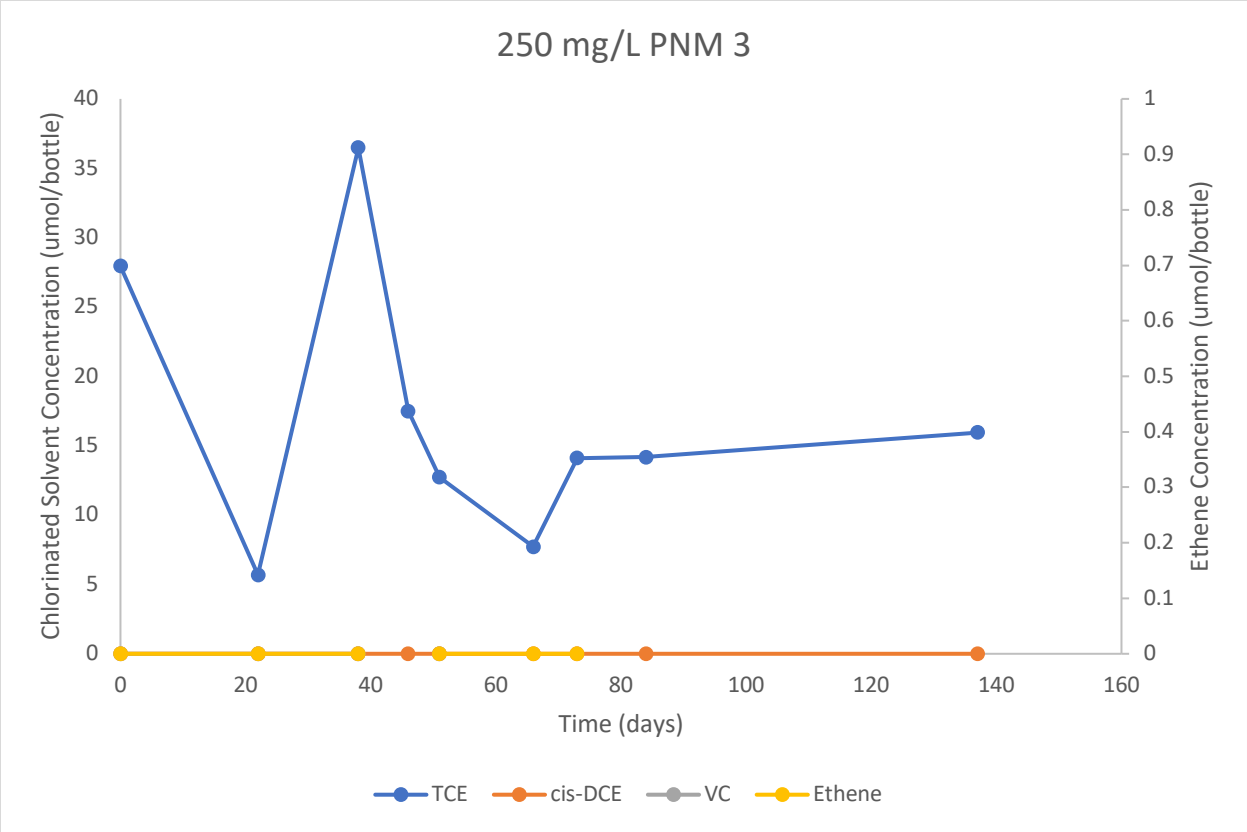
Appendix Figure 183. 250 mg/L PNM + 250 Poultry Byproducts dosed bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



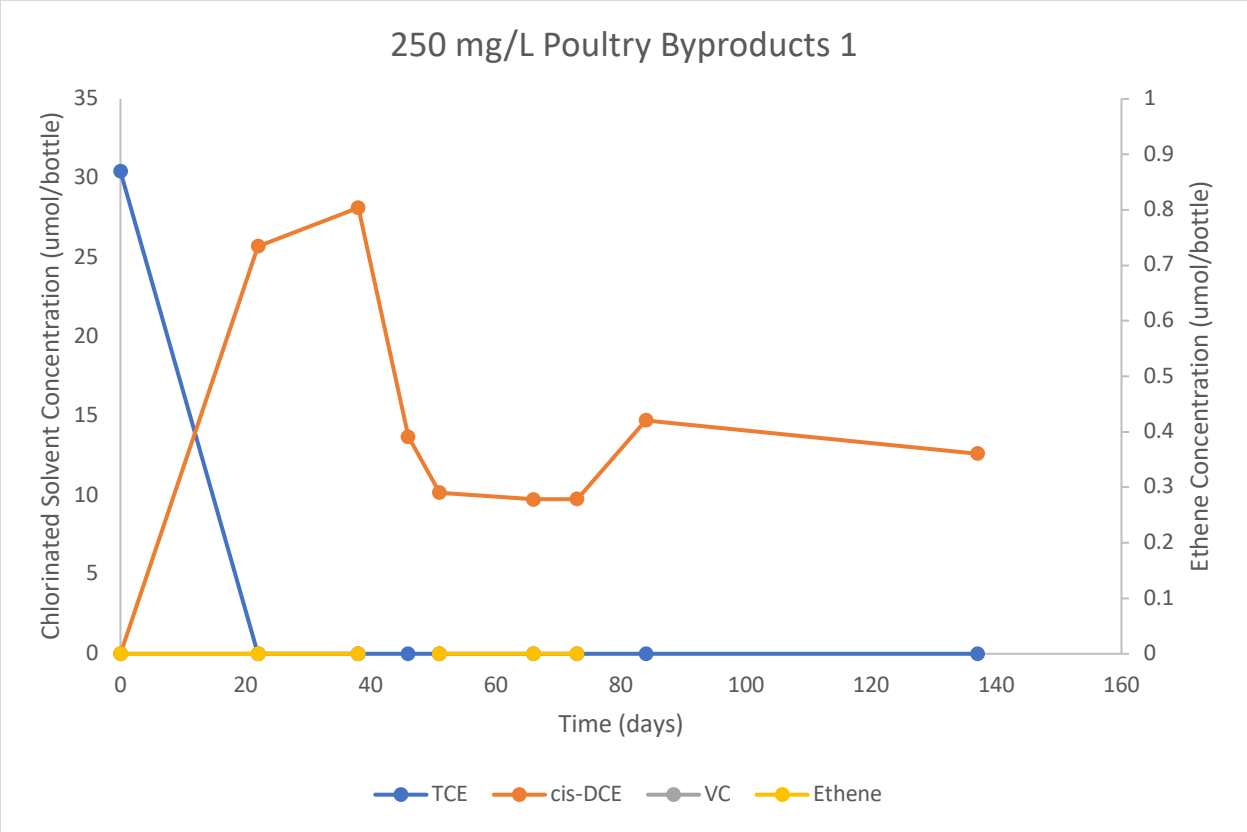
Appendix Figure 184. 250 mg/L PNM dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



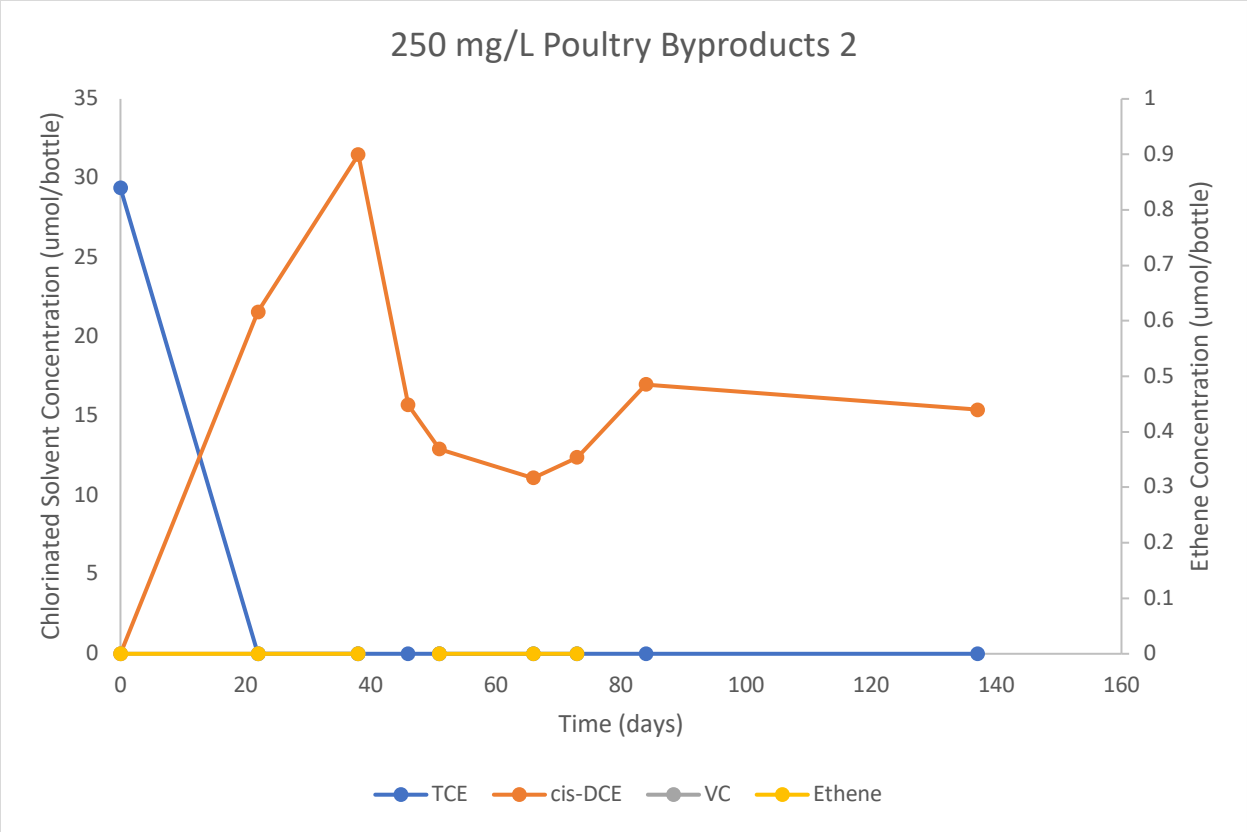
Appendix Figure 185. 250 mg/L PNM dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



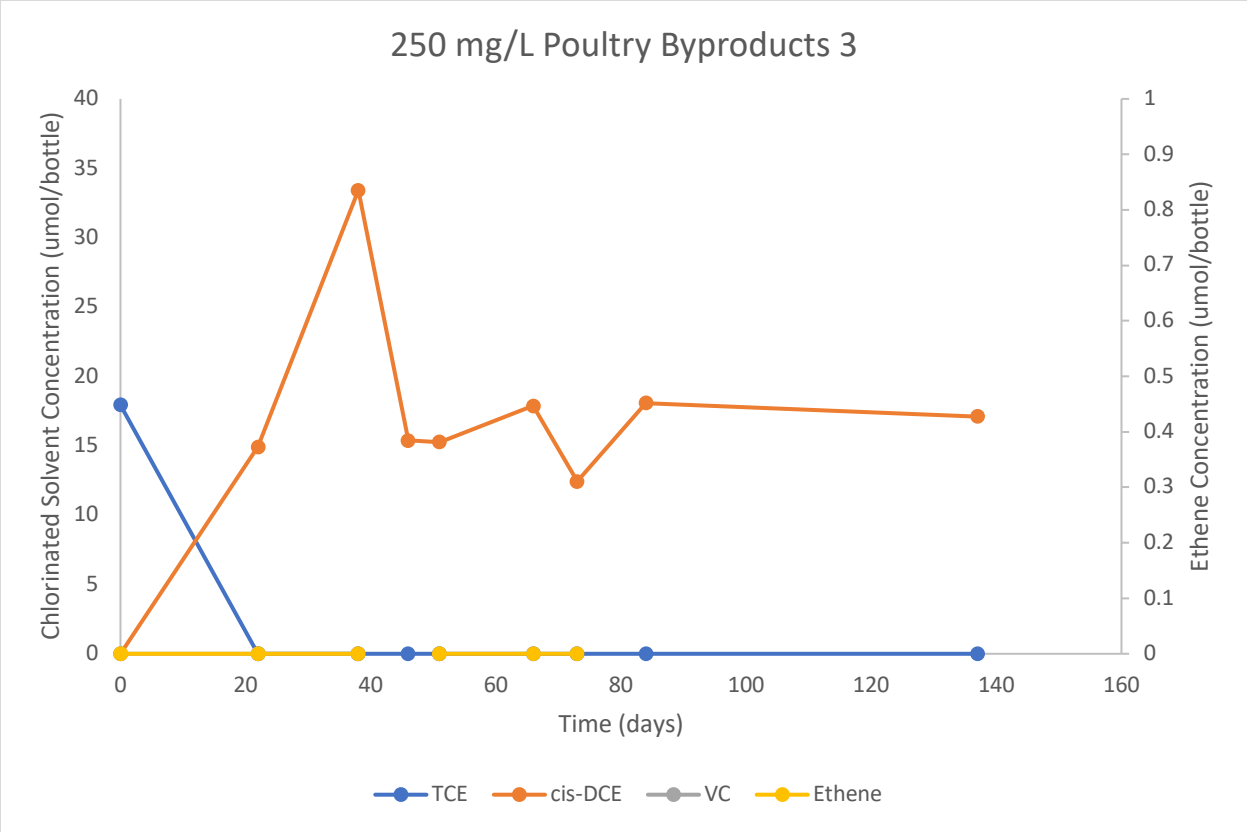
Appendix Figure 186. 250 mg/L PNM dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



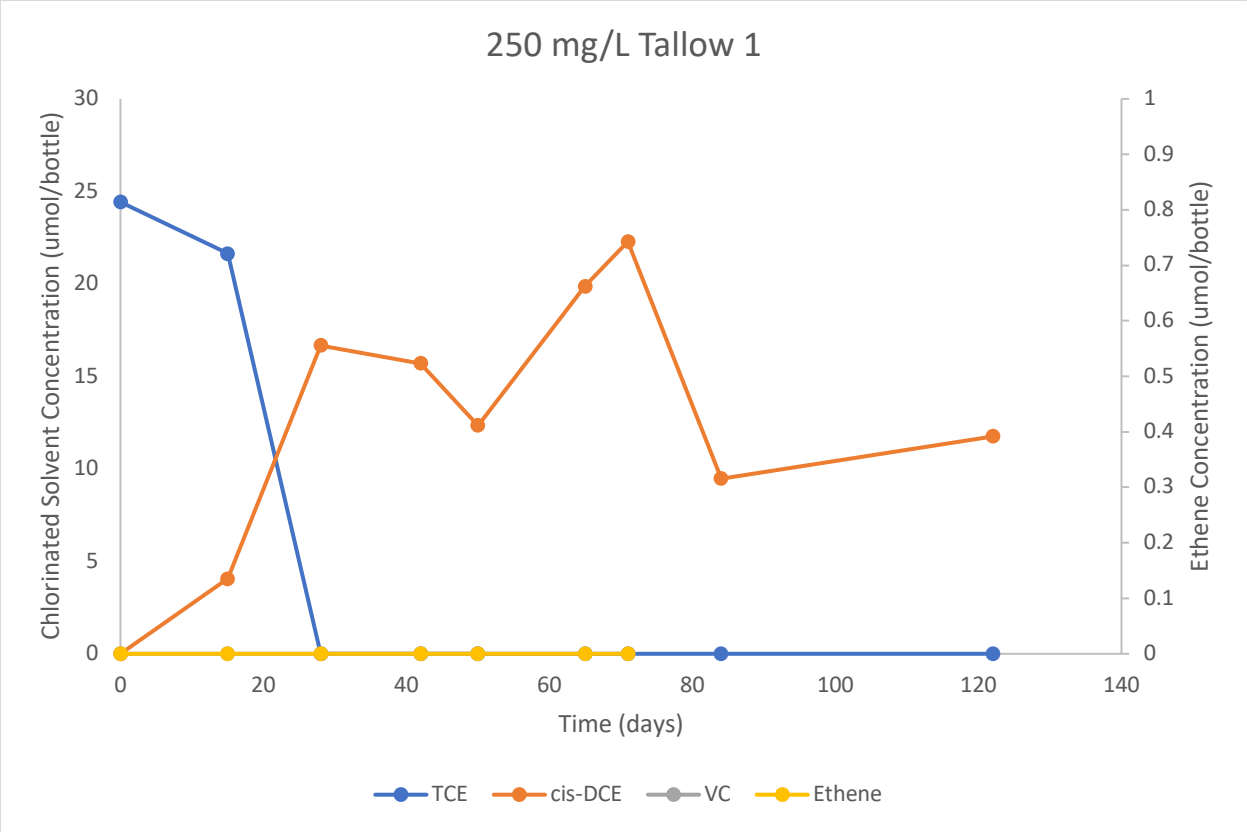
Appendix Figure 187. 250 mg/L Poultry Byproducts dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



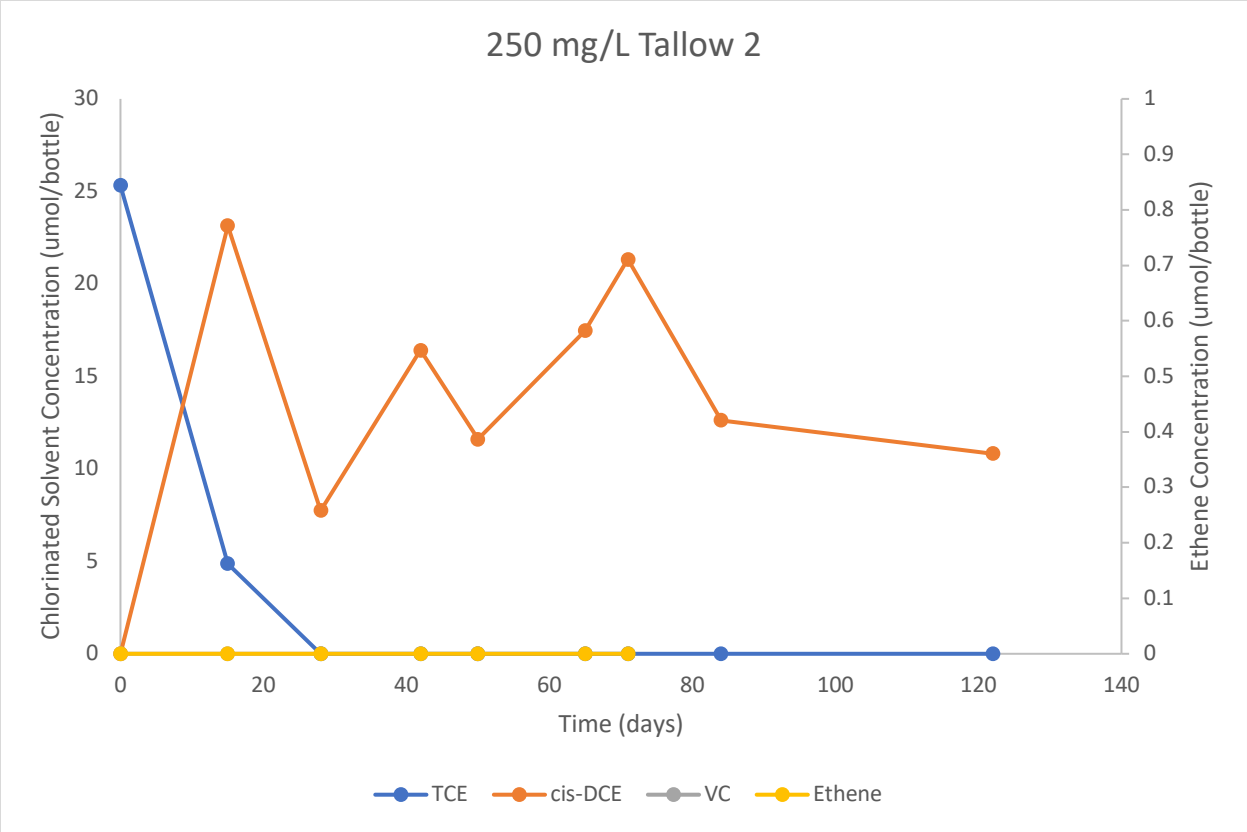
Appendix Figure 188. 250 mg/L Poultry Byproducts dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



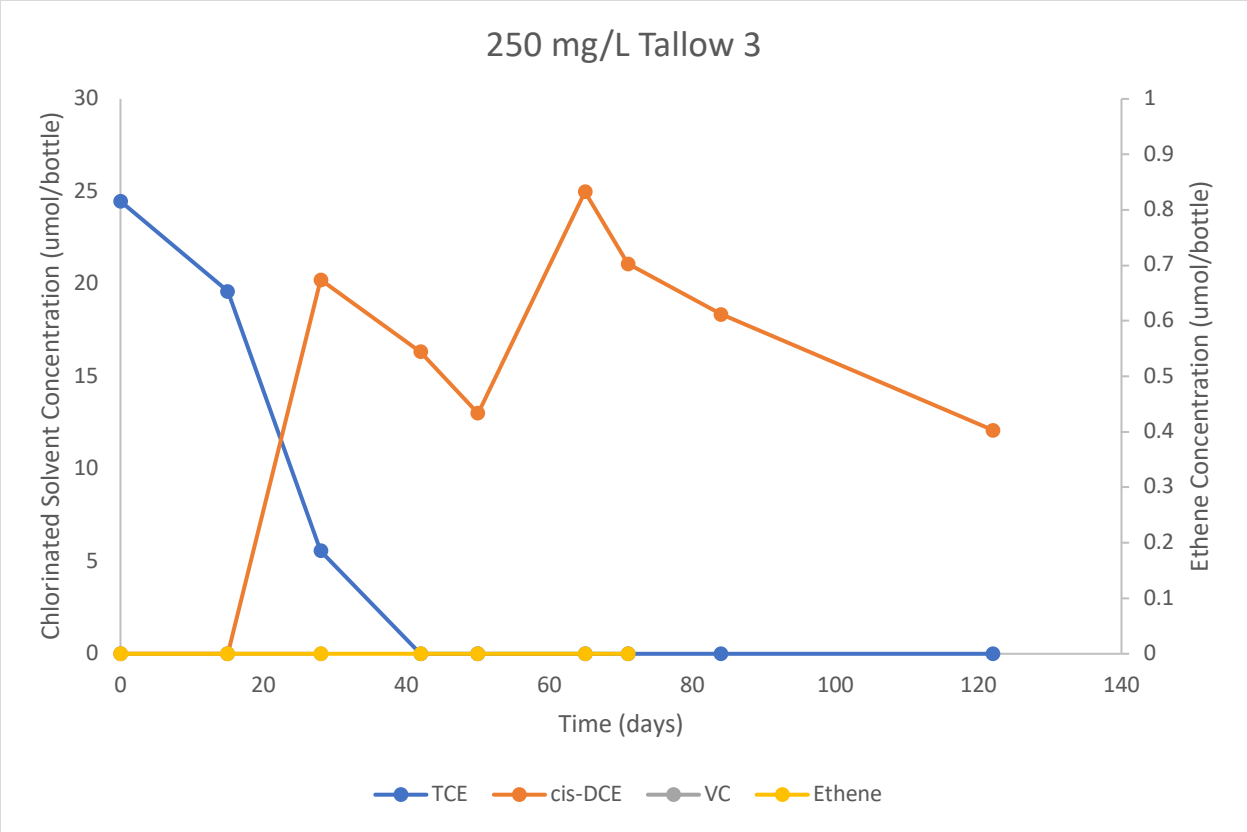
Appendix Figure 189. 250 mg/L Poultry Byproducts dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



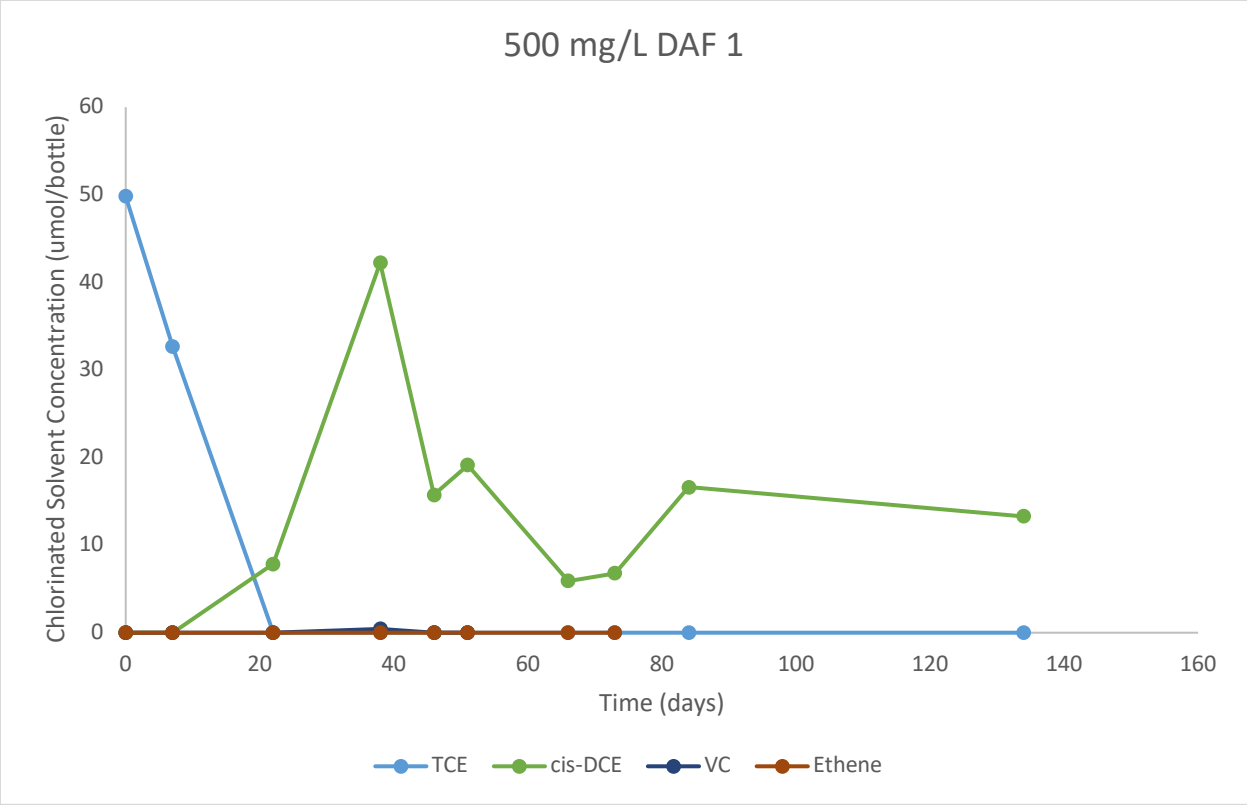
Appendix Figure 190. 250 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



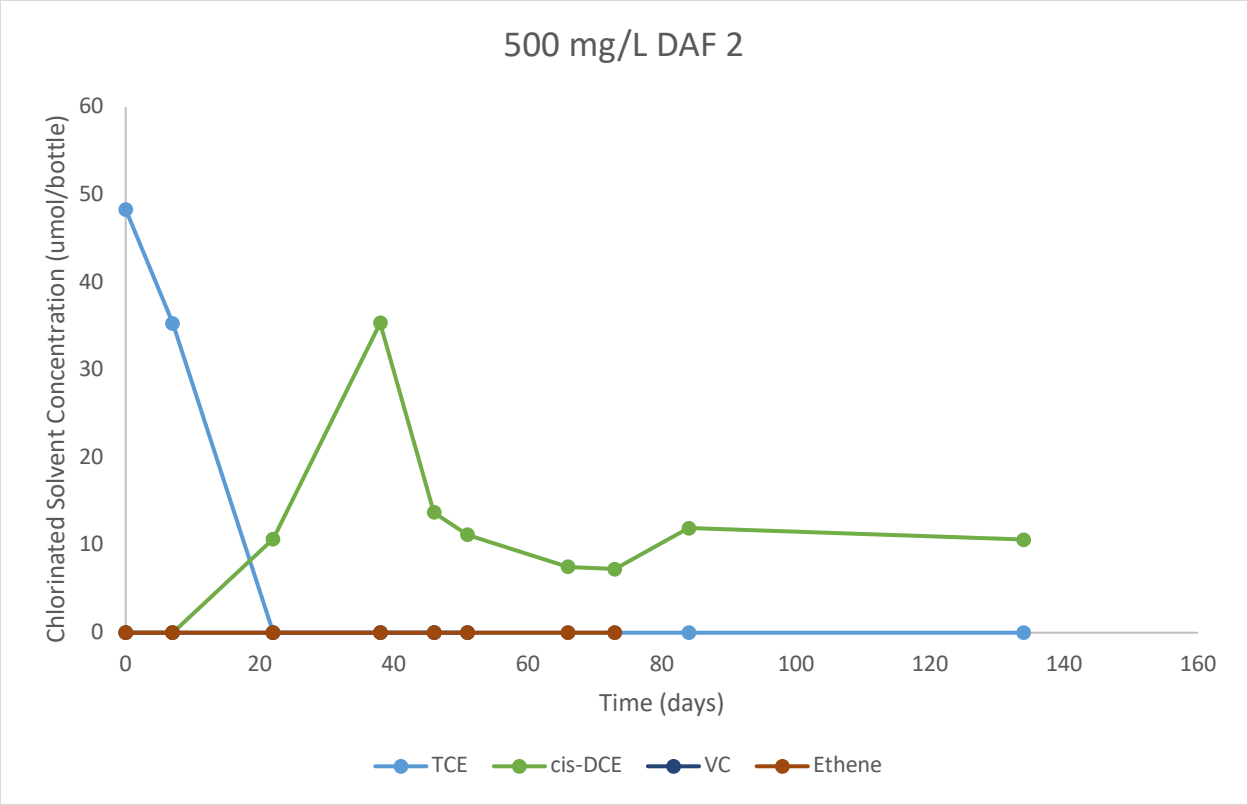
Appendix Figure 191. 250 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



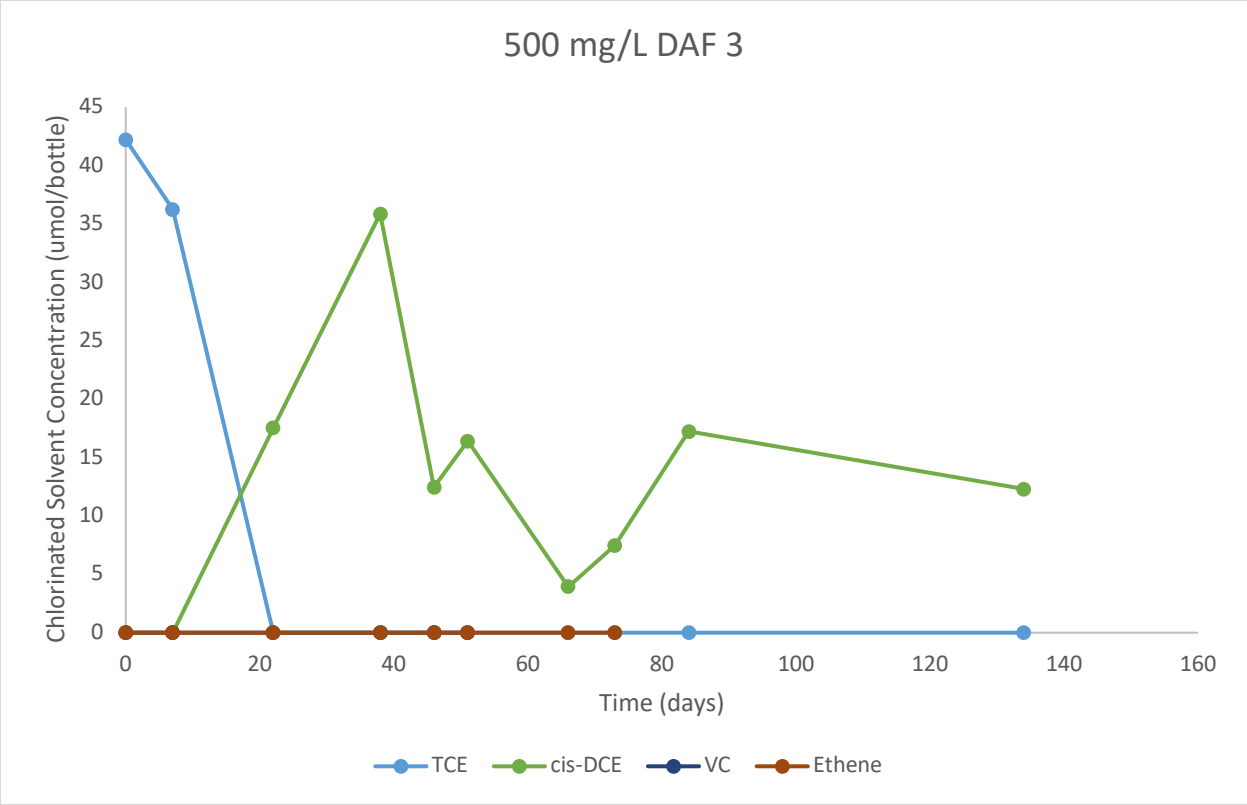
Appendix Figure 192. 250 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



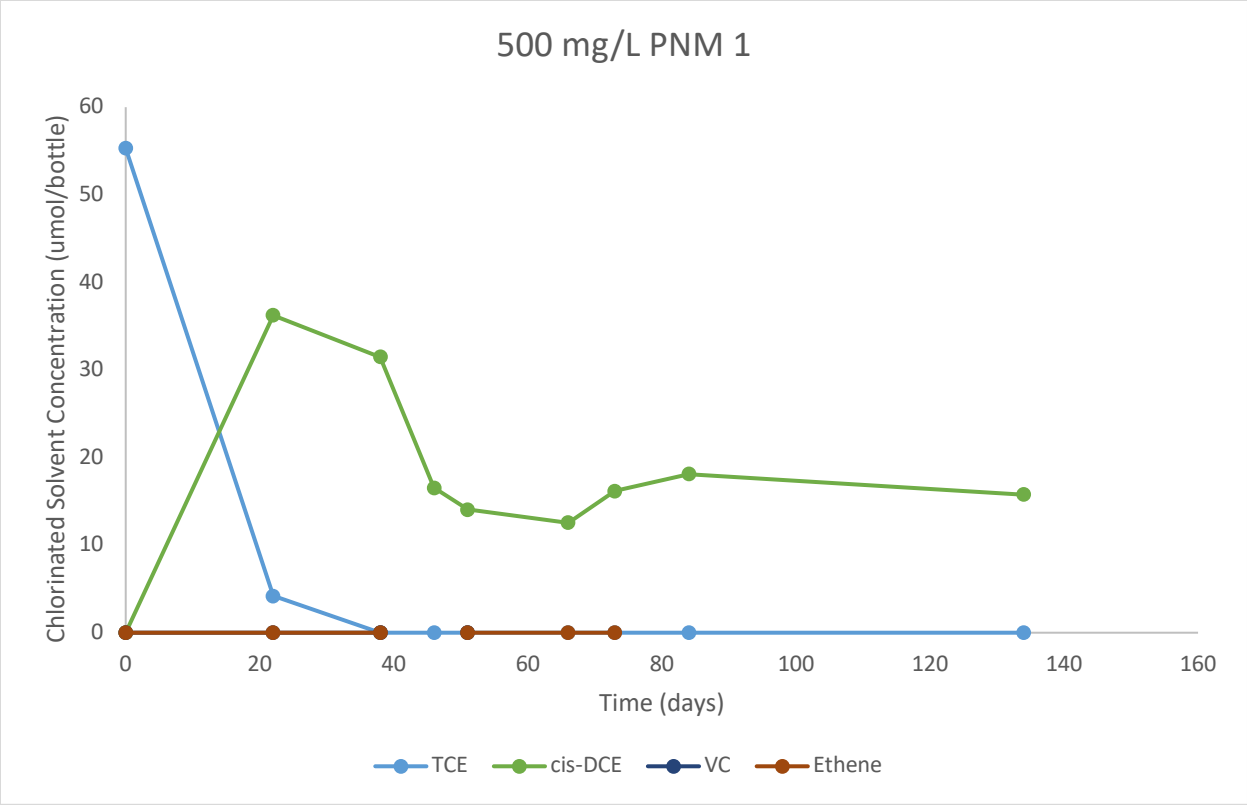
Appendix Figure 193. 500 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



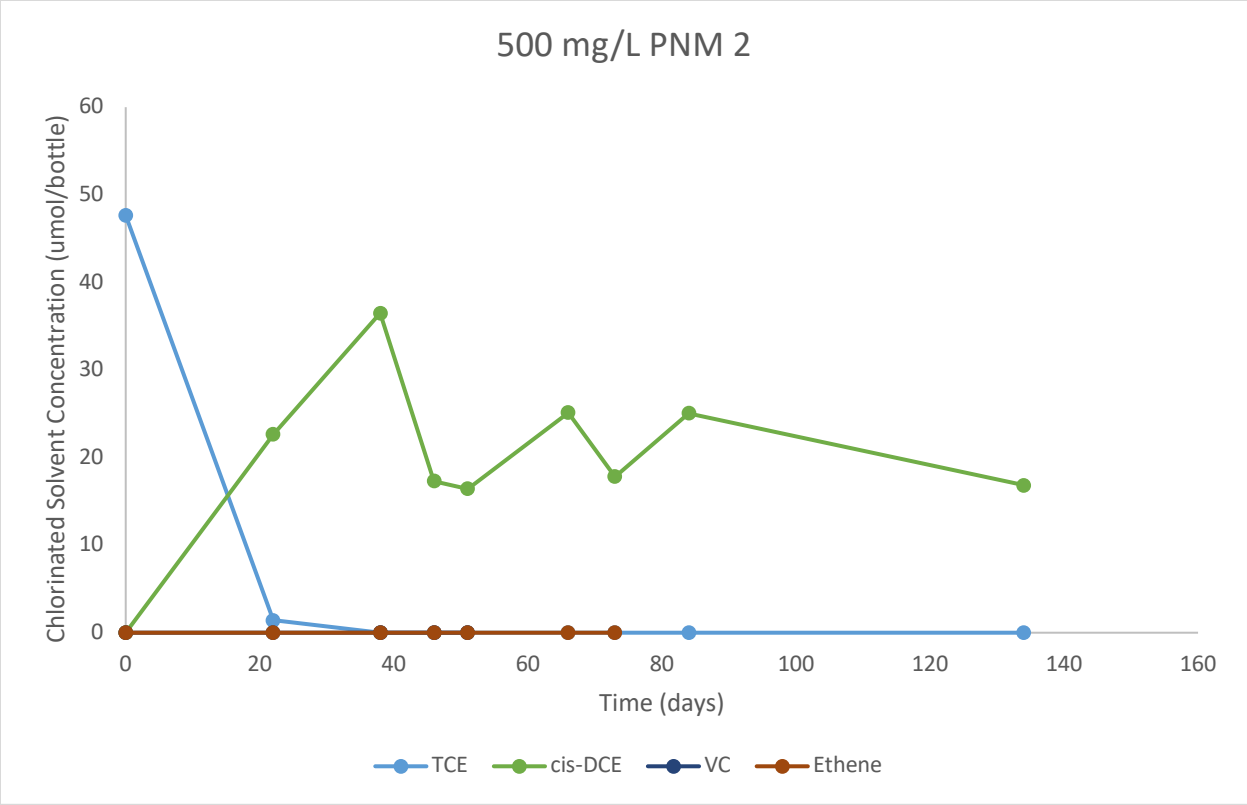
Appendix Figure 194. 500 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



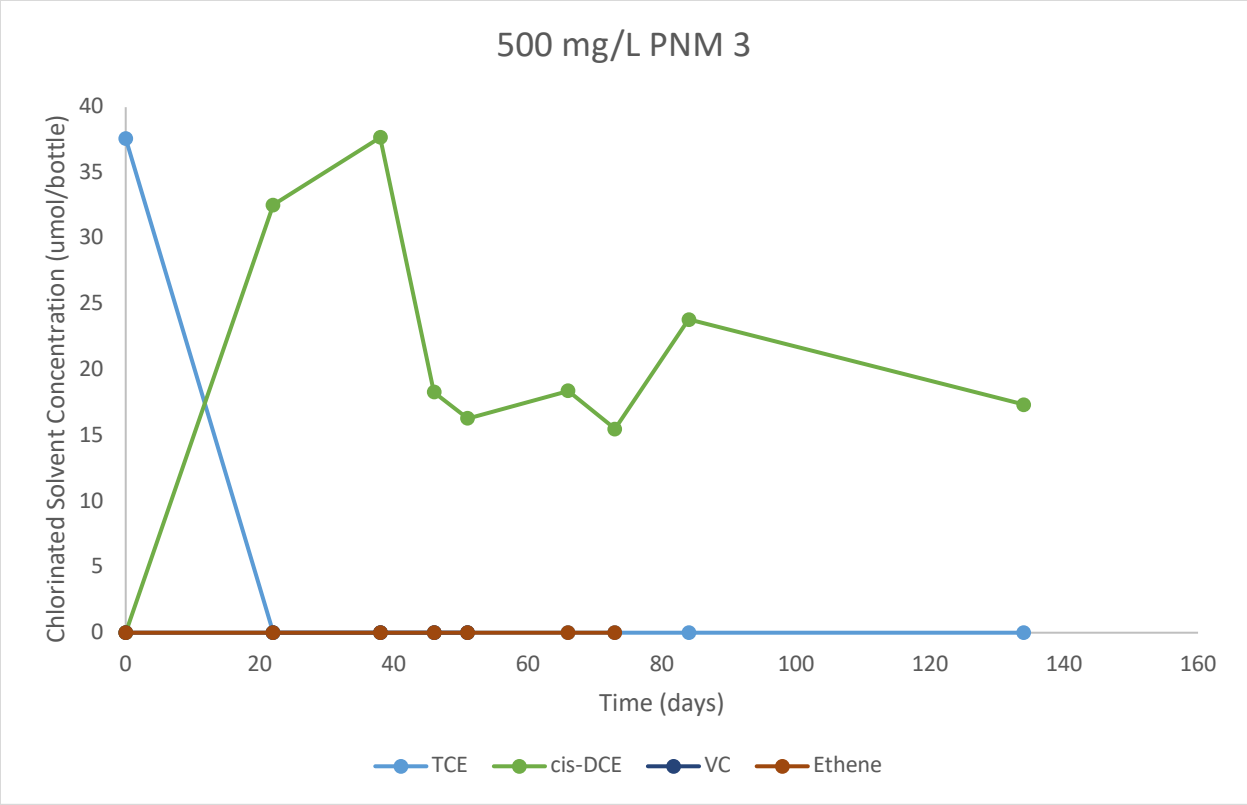
Appendix Figure 195. 500 mg/L DAF dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



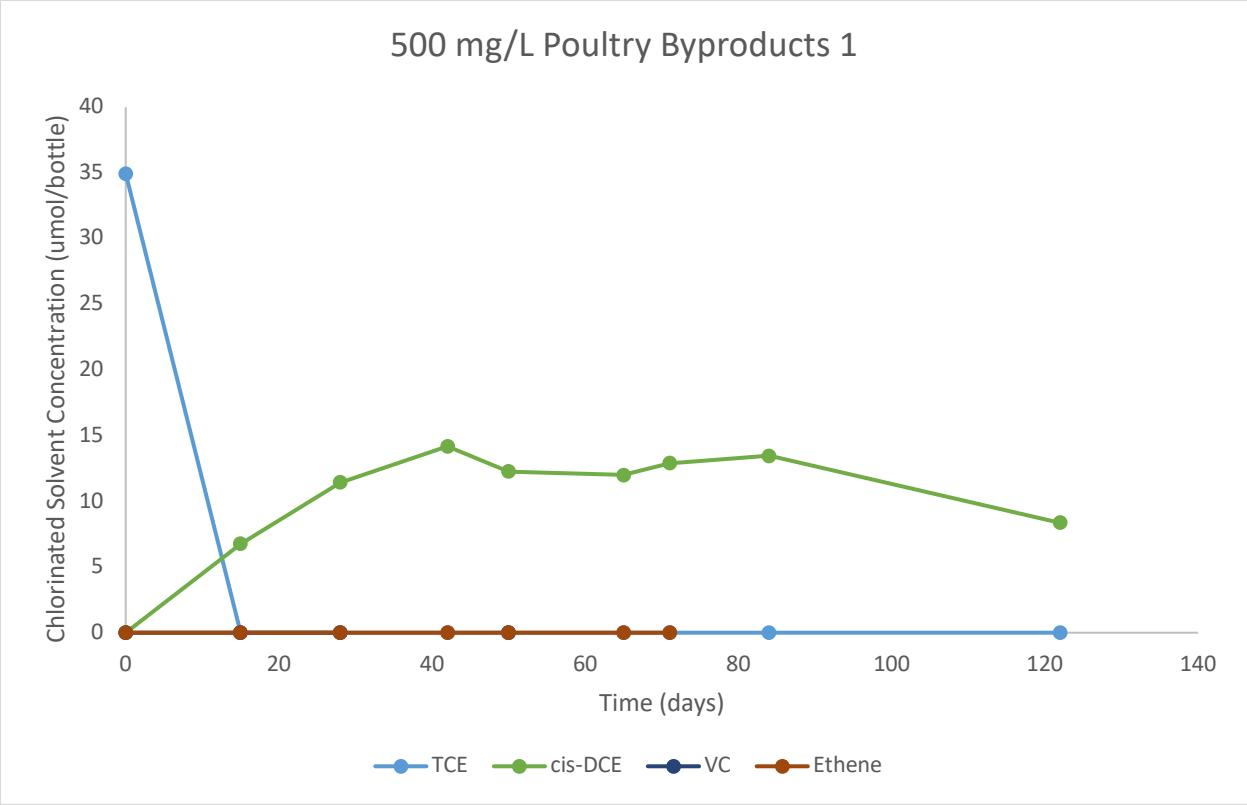
Appendix Figure 196. 500 mg/L PNM dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



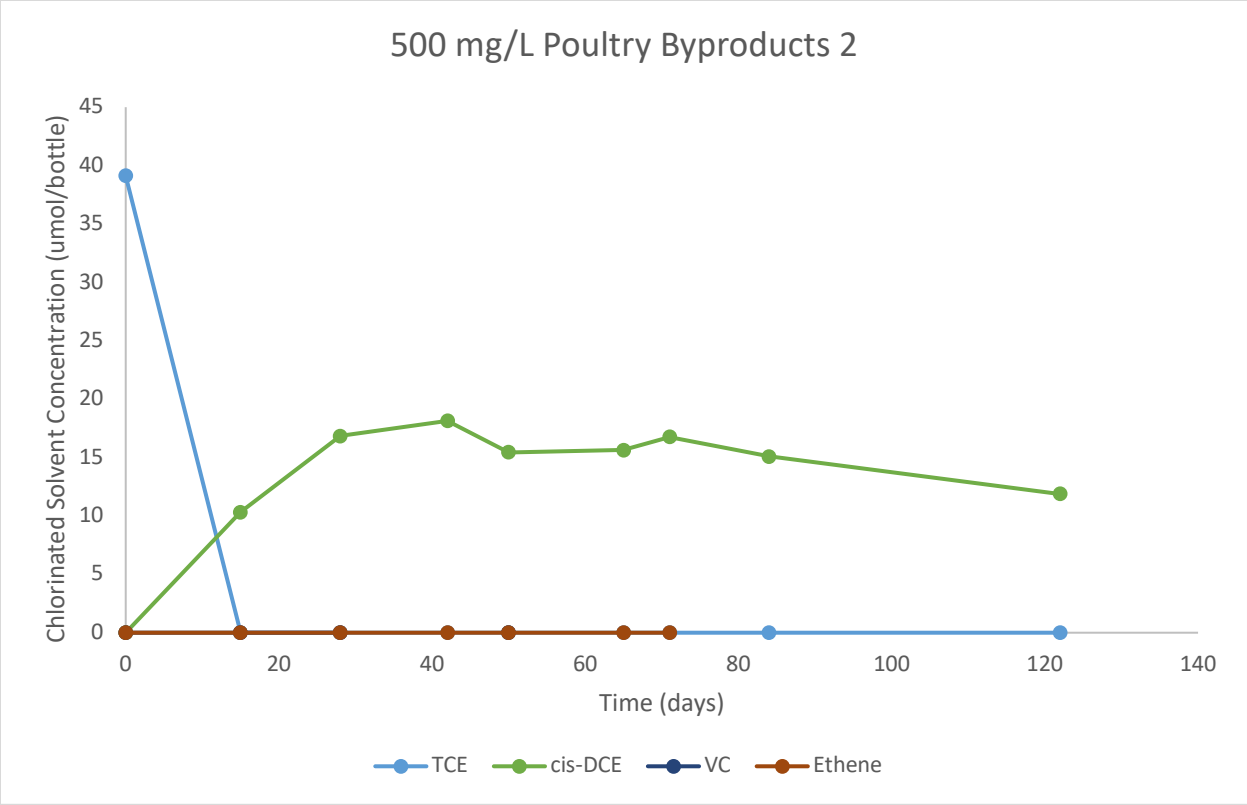
Appendix Figure 197. 500 mg/L PNM dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



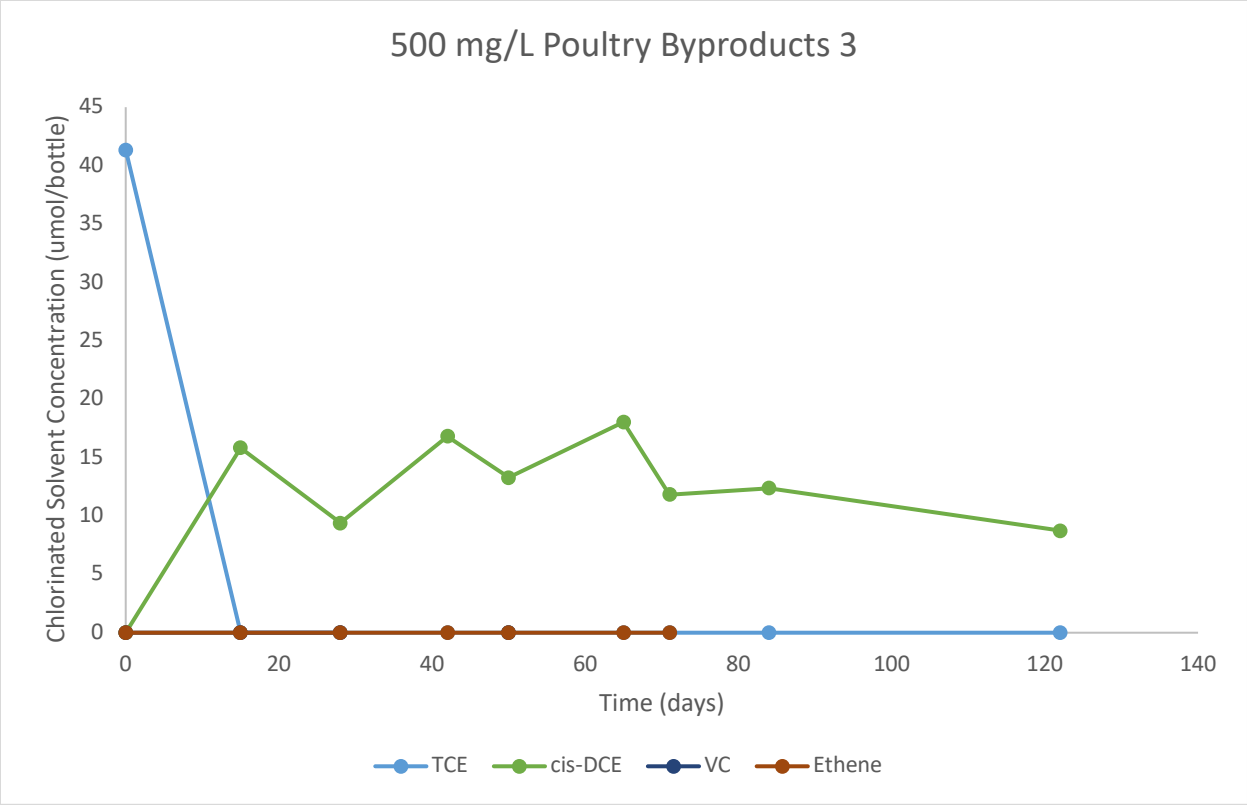
Appendix Figure 198. 500 mg/L PNM dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



Appendix Figure 199. 500 mg/L Poultry Byproducts dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



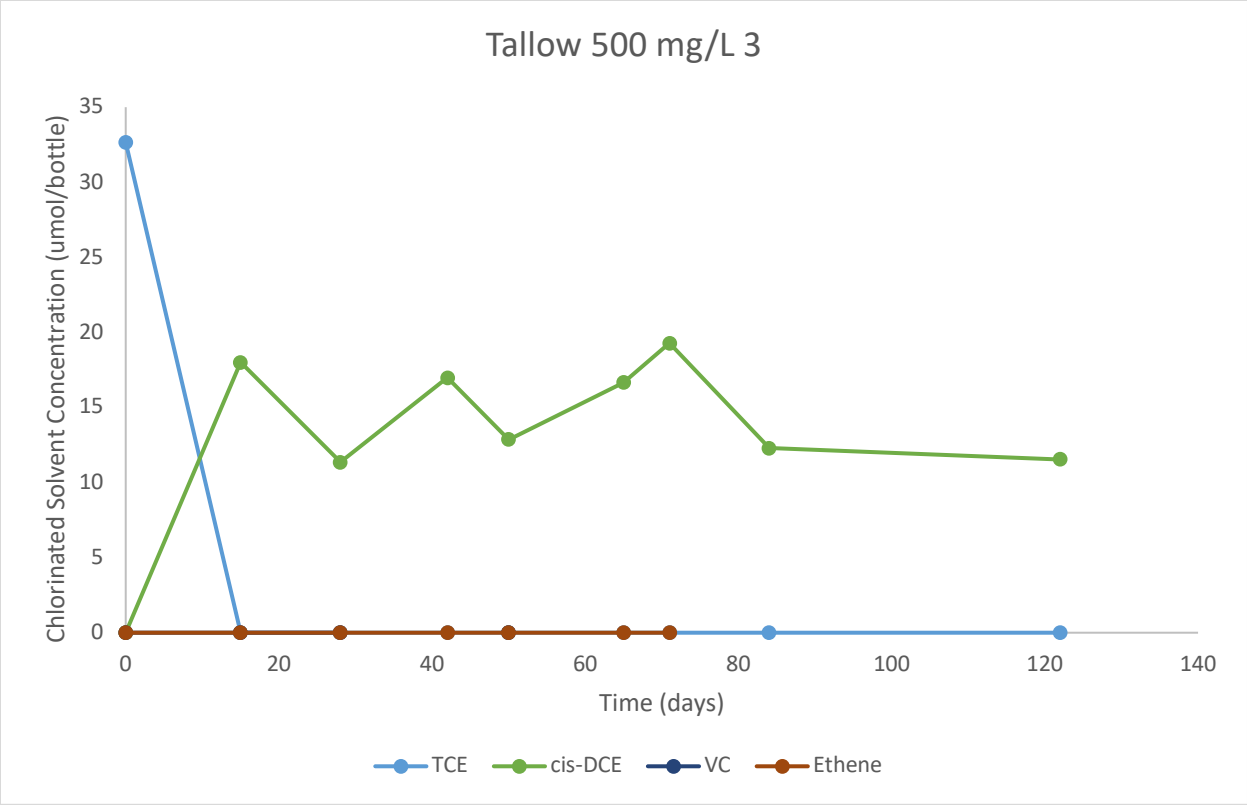
Appendix Figure 200. 500 mg/L Poultry Byproducts dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



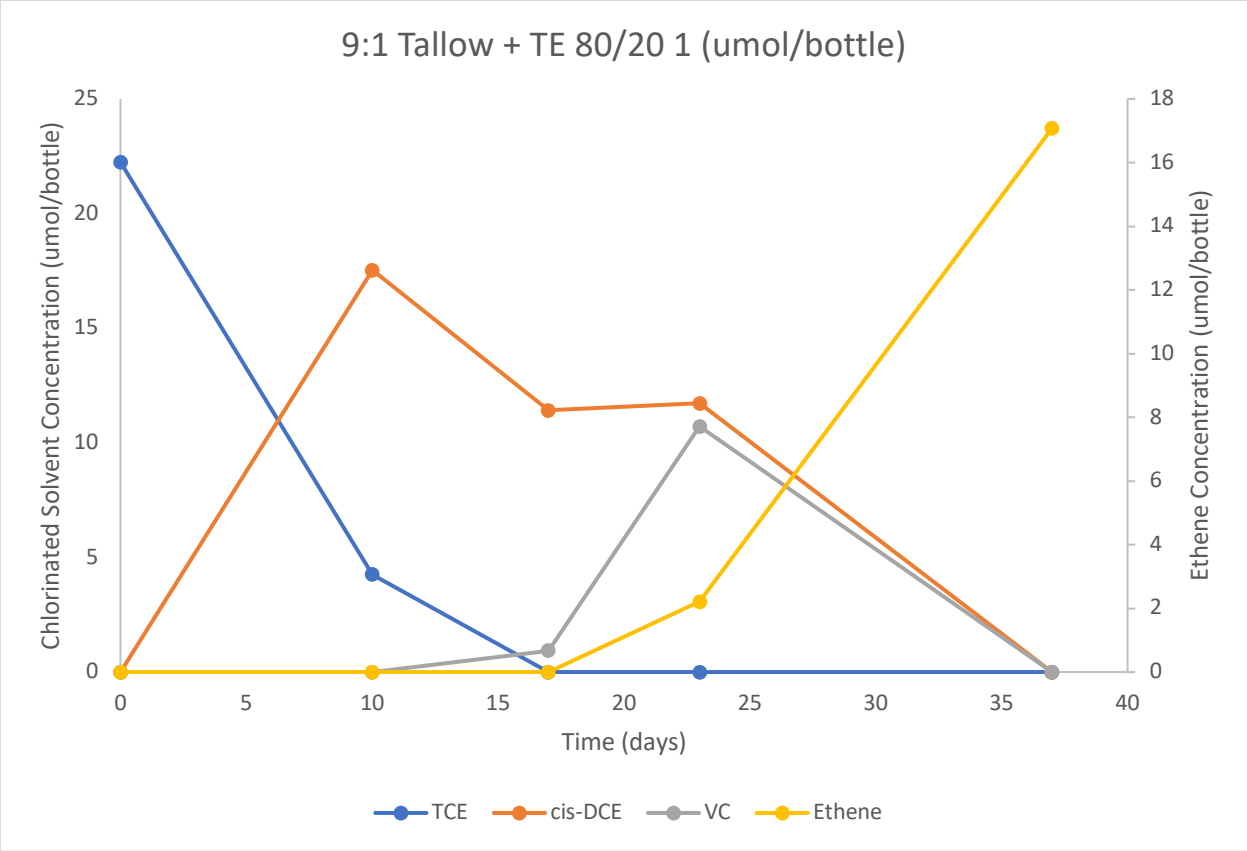
Appendix Figure 201. 500 mg/L Poultry Byproducts dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.

Appendix Figure 202. 500 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.

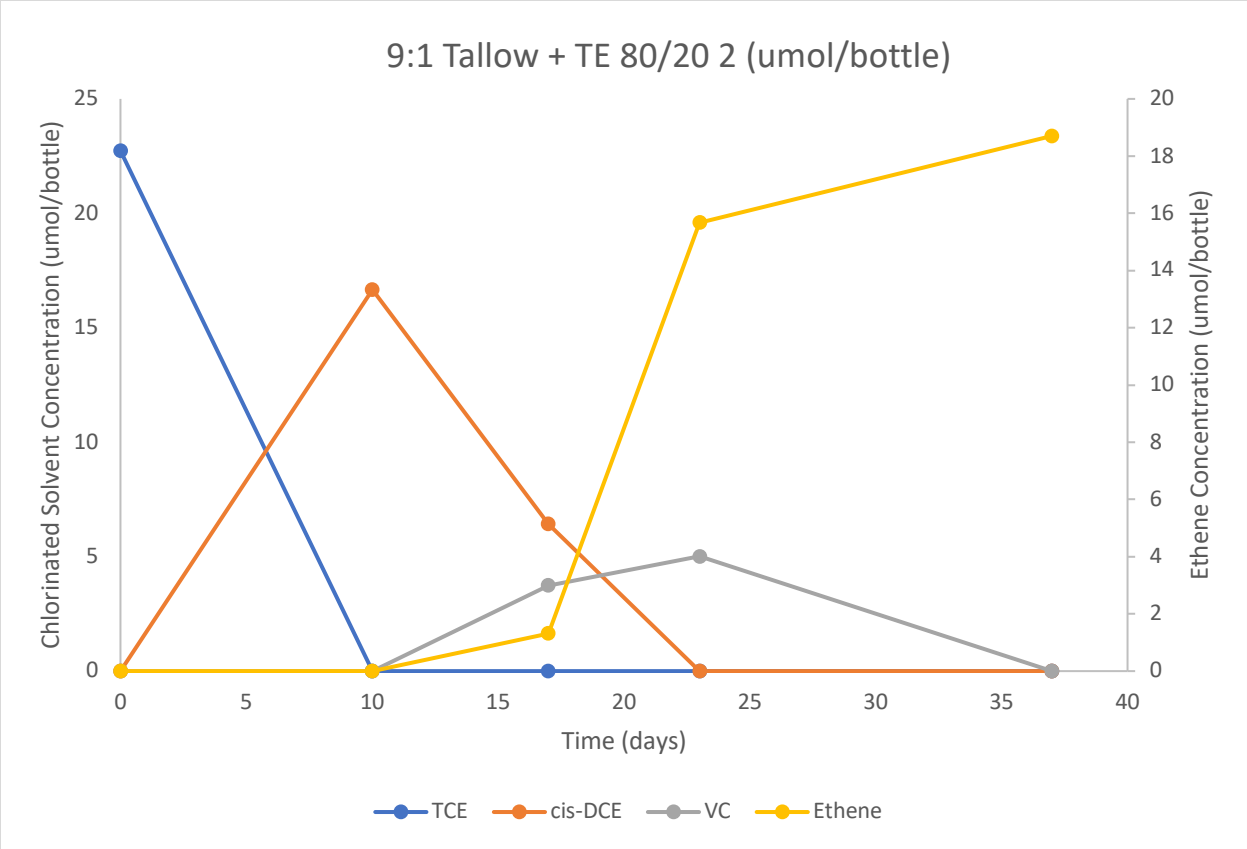
Appendix Figure 203. 500 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



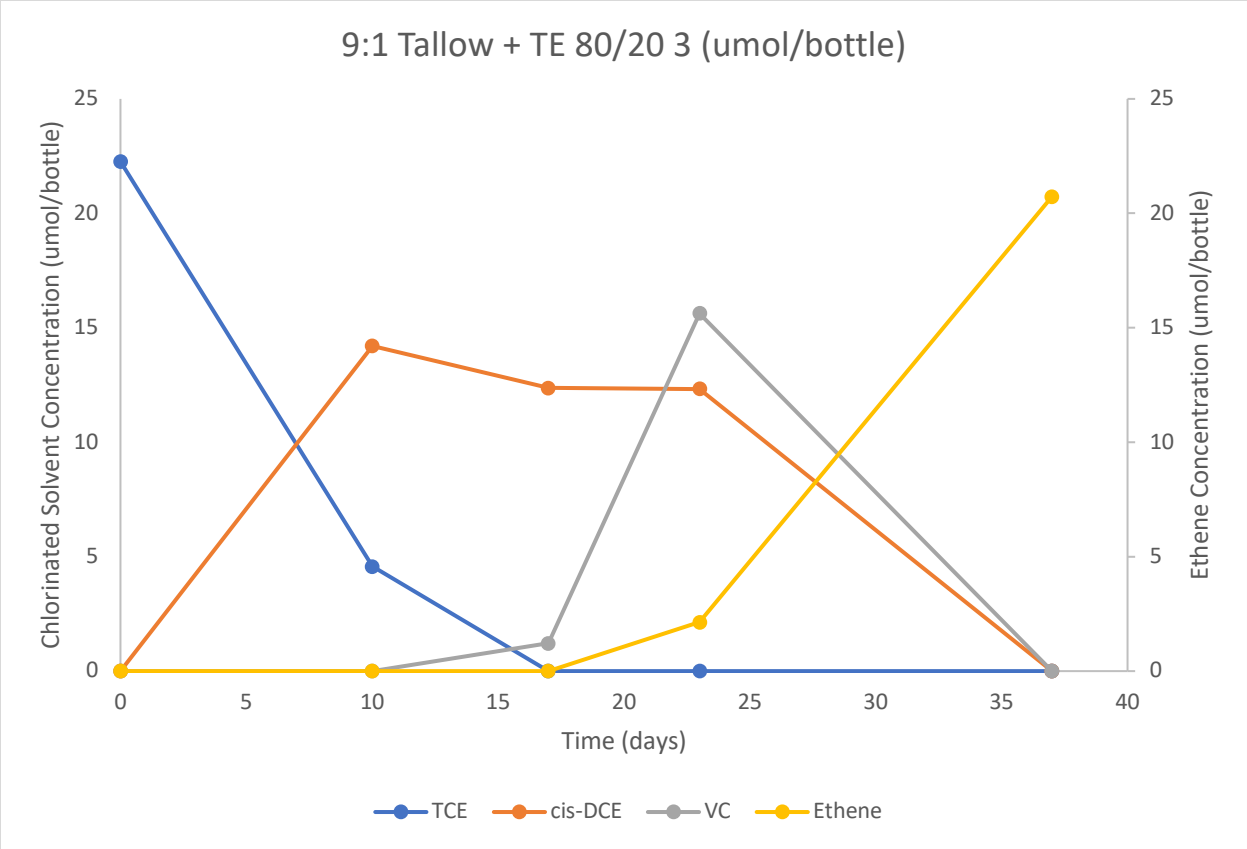
Appendix Figure 204. 500 mg/L Tallow dosed control bottle. Chlorinated solvent concentration over time in co-product mixture optimization experiment with soil collected from Easley, South Carolina.



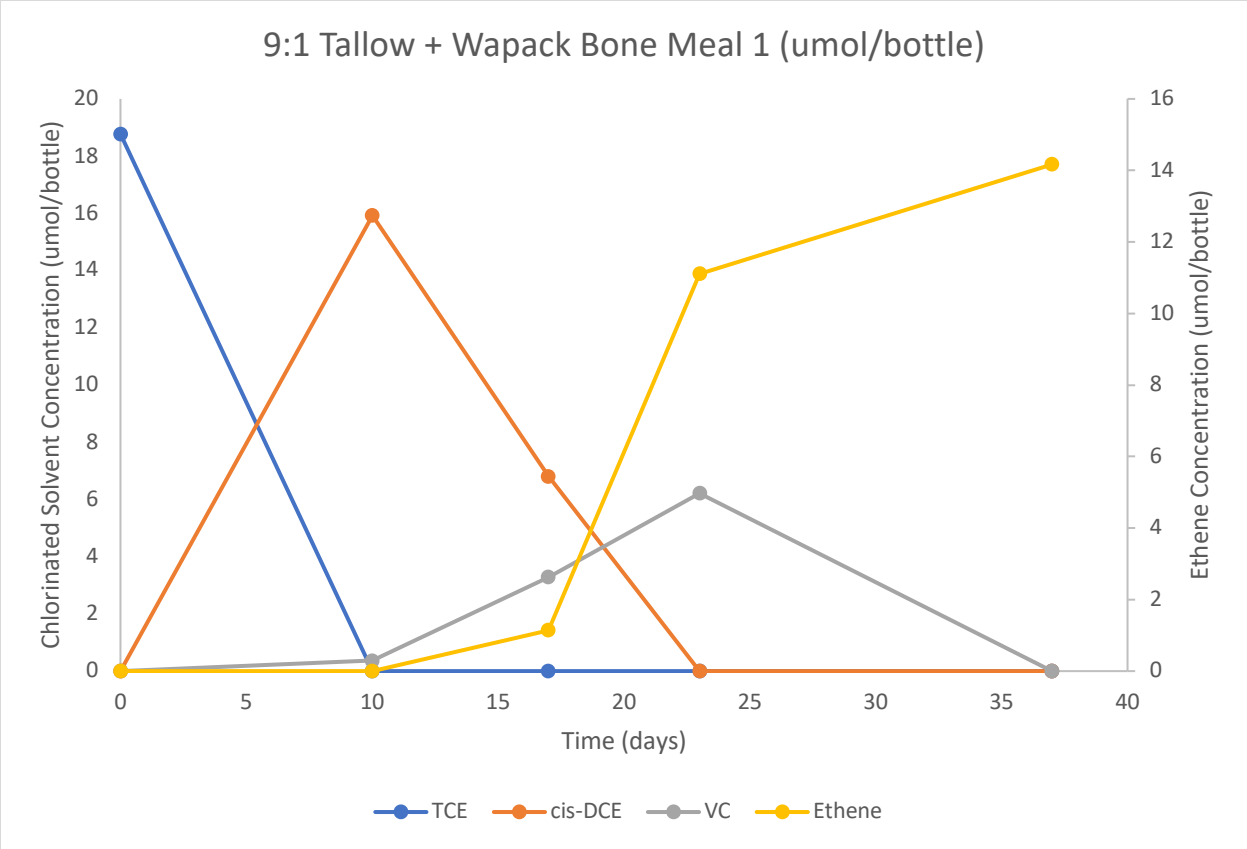
Appendix Figure 205. 500 mg/L 9:1 Tallow: TE 80/20 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



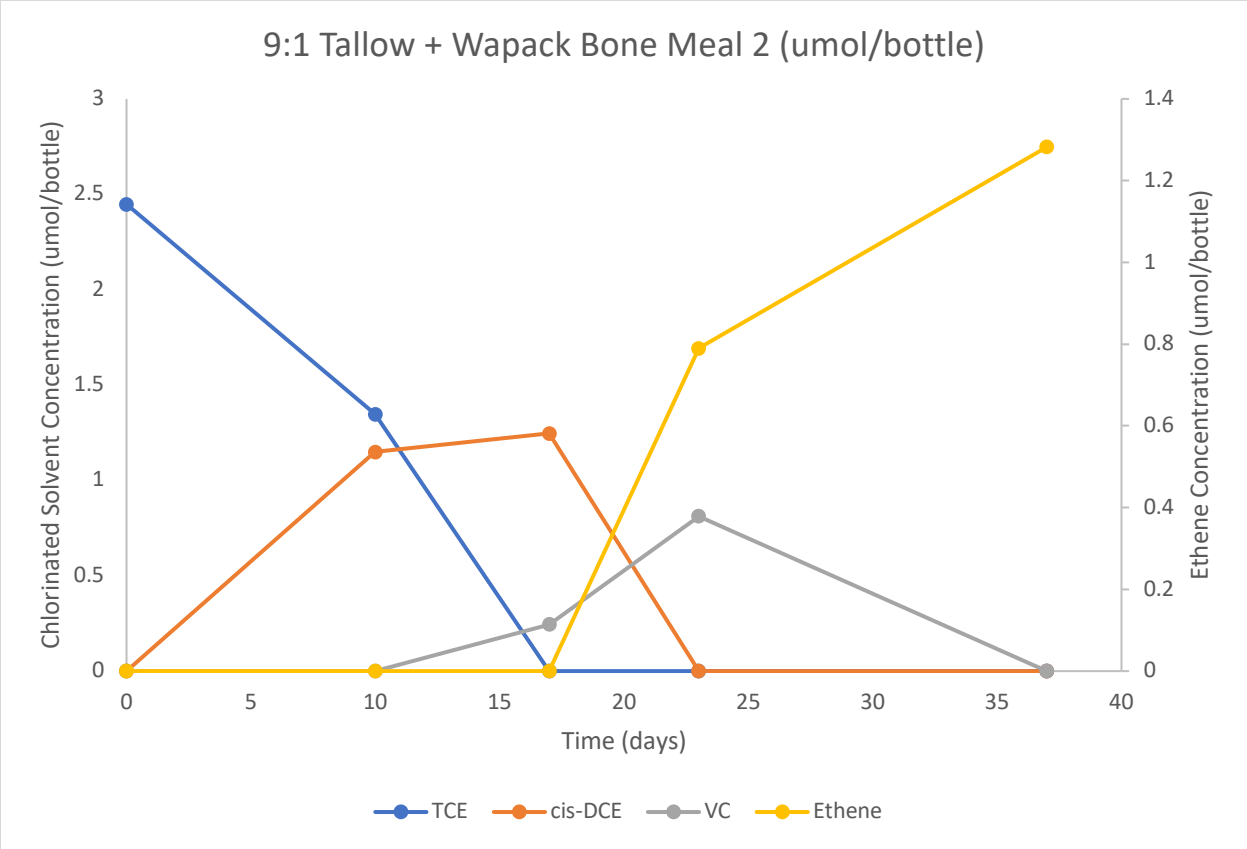
Appendix Figure 206. 500 mg/L 9:1 Tallow: TE 80/20 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



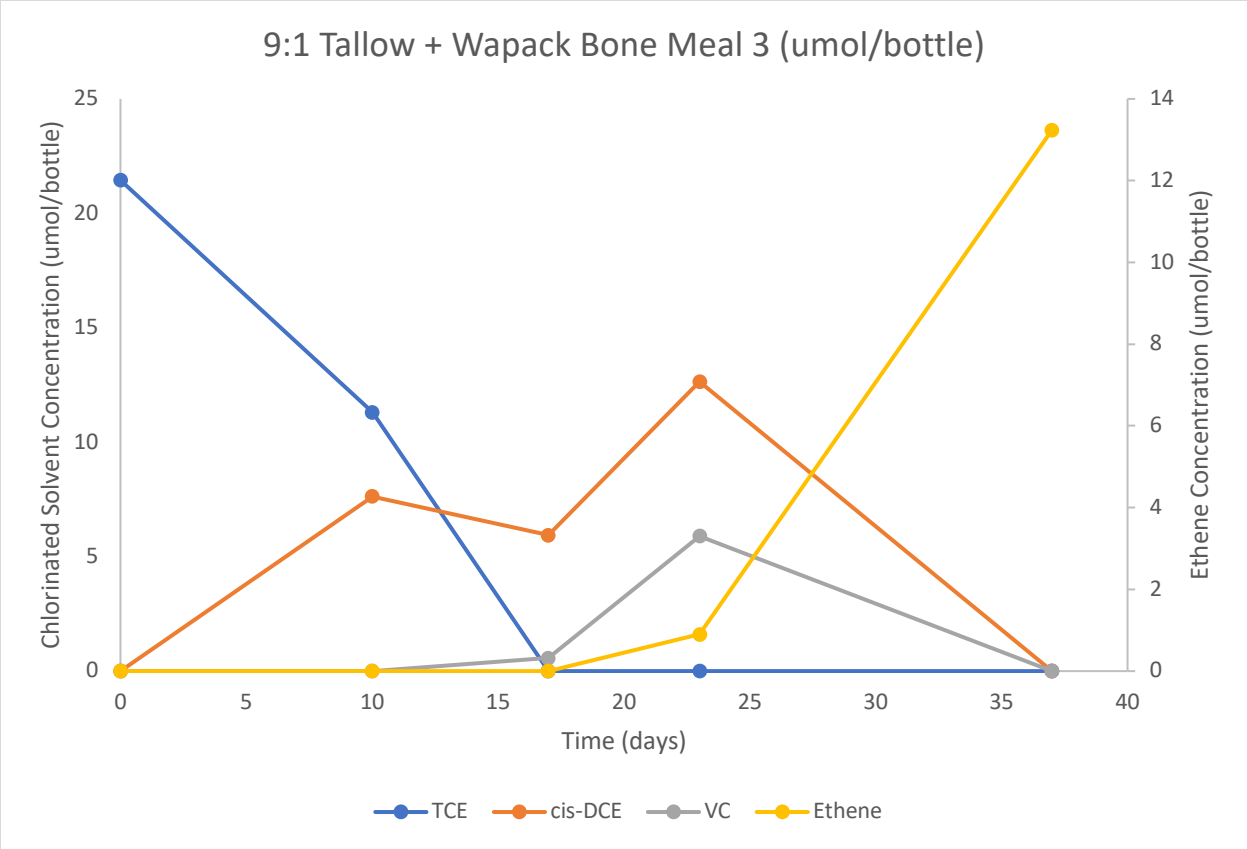
Appendix Figure 207. 500 mg/L 9:1 Tallow: TE 80/20 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



Appendix Figure 208. 500 mg/L 9:1 Tallow: Wapack Bone Meal dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



Appendix Figure 209. 500 mg/L 9:1 Tallow: Wapack Bone Meal dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

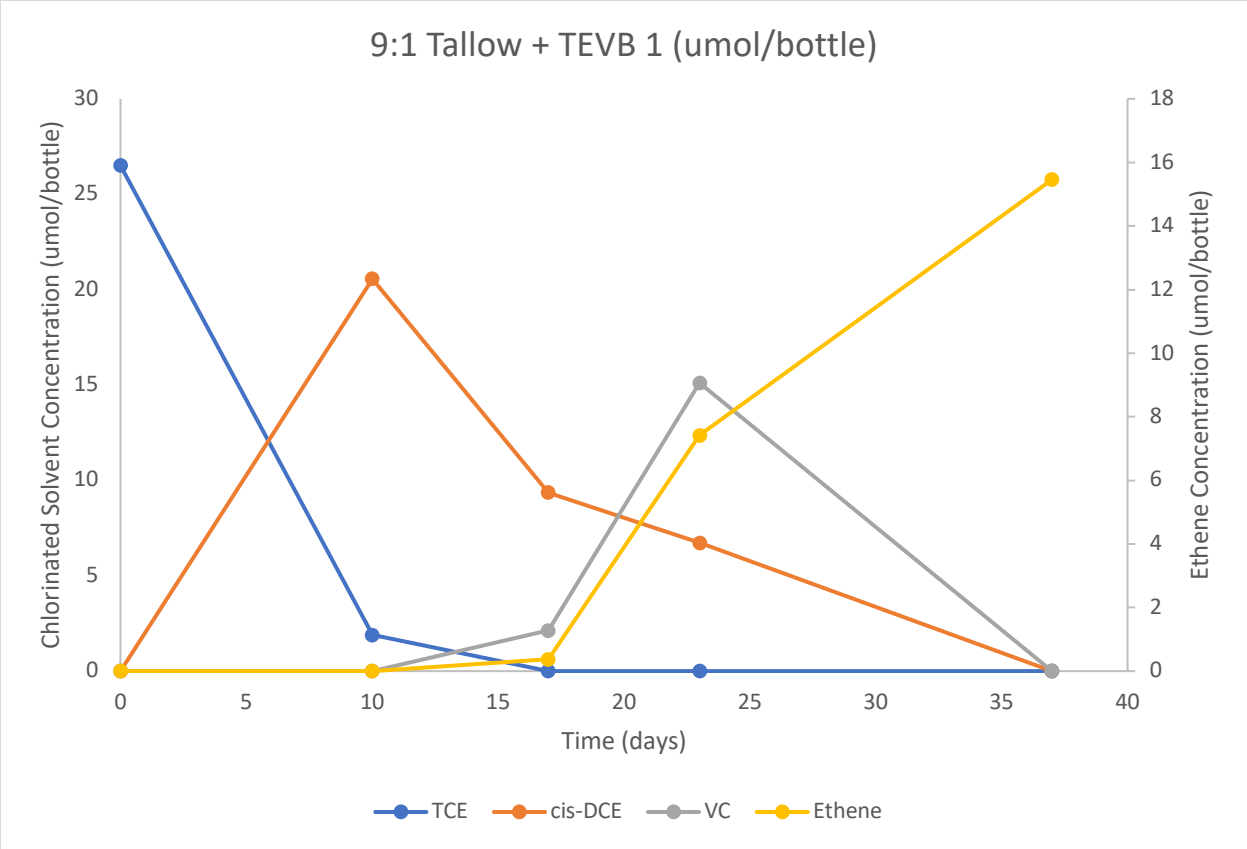


Appendix Figure 210. 500 mg/L 9:1 Tallow: Wapack Bone Meal dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

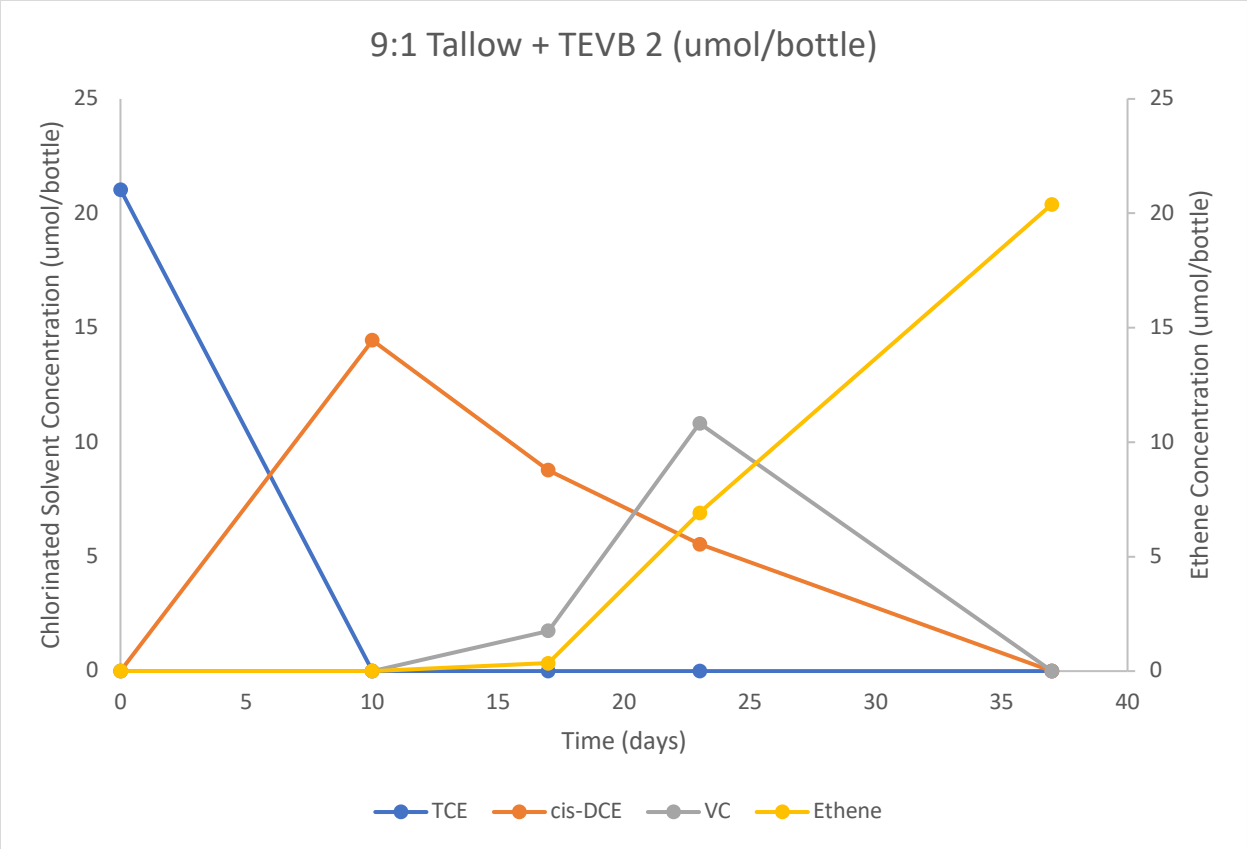
Appendix Figure 211. 500 mg/L 9:1 Tallow: LoPro 2 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

Appendix Figure 212. 500 mg/L 9:1 Tallow: LoPro 2 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

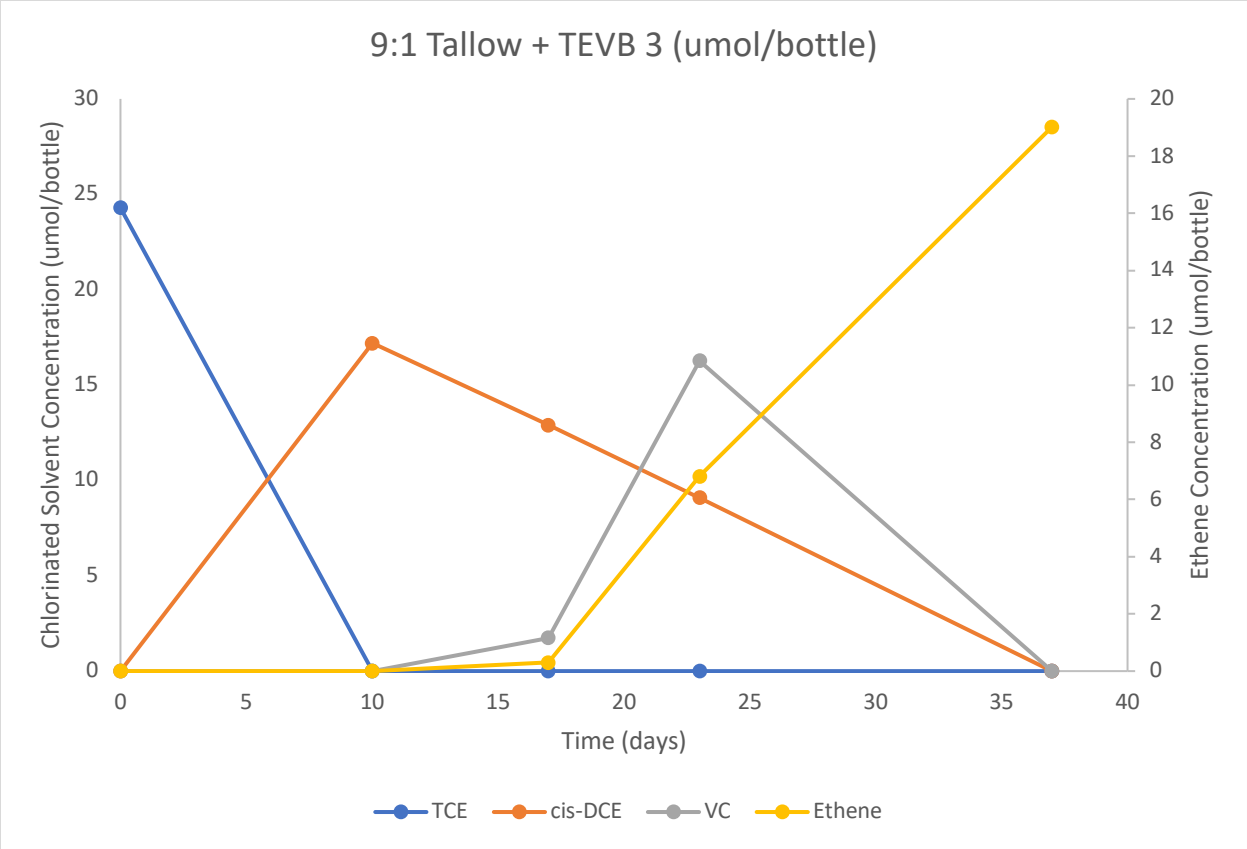
Appendix Figure 213. 500 mg/L 9:1 Tallow: LoPro 2 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



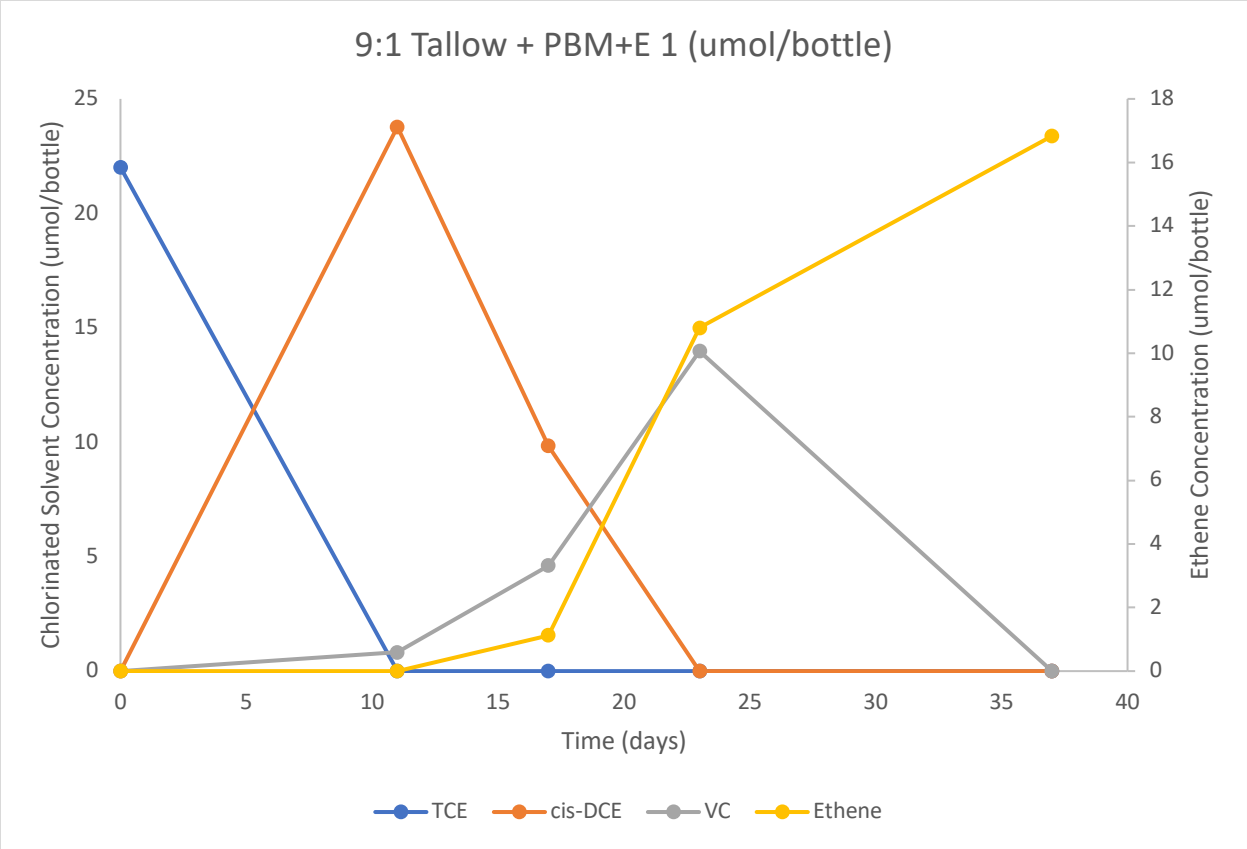
Appendix Figure 214. 500 mg/L 9:1 Tallow: TEVB dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



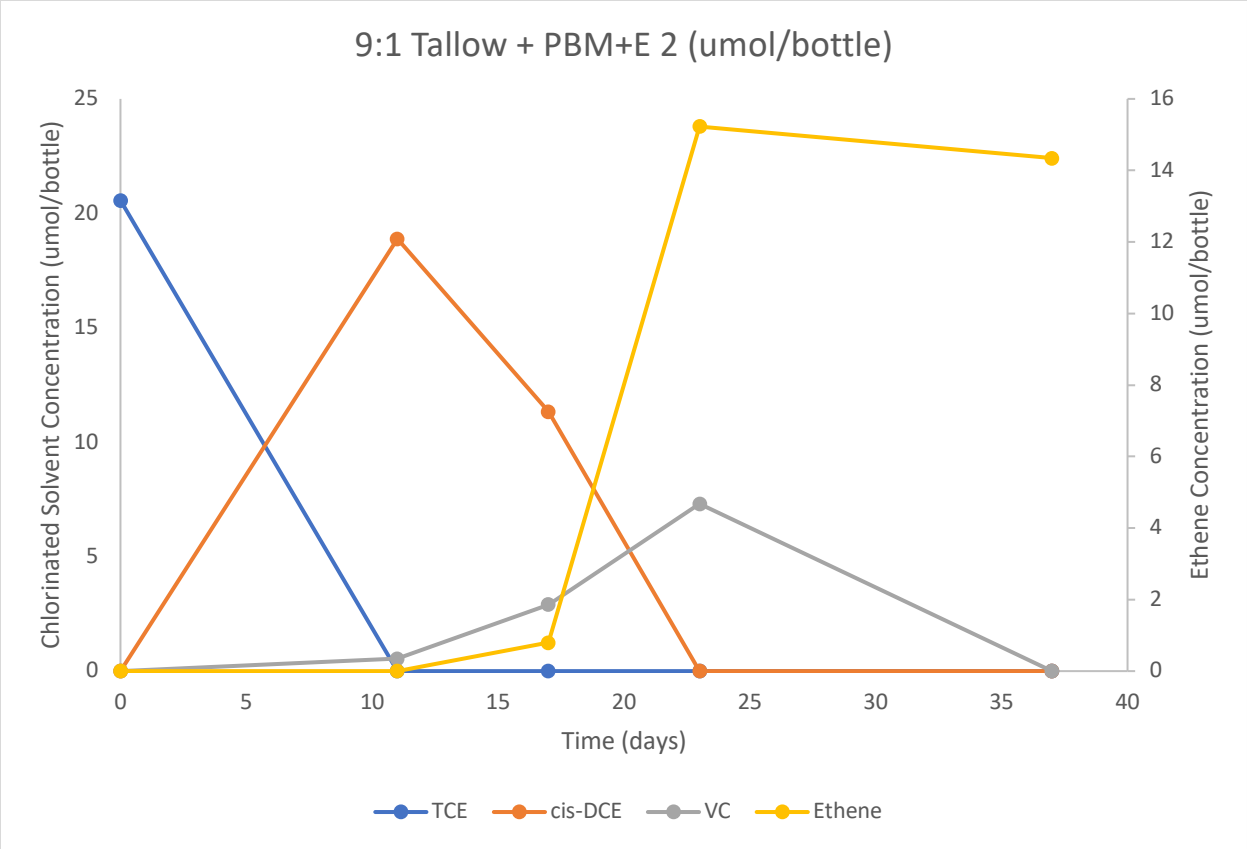
Appendix Figure 215. 500 mg/L 9:1 Tallow: TEVB dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



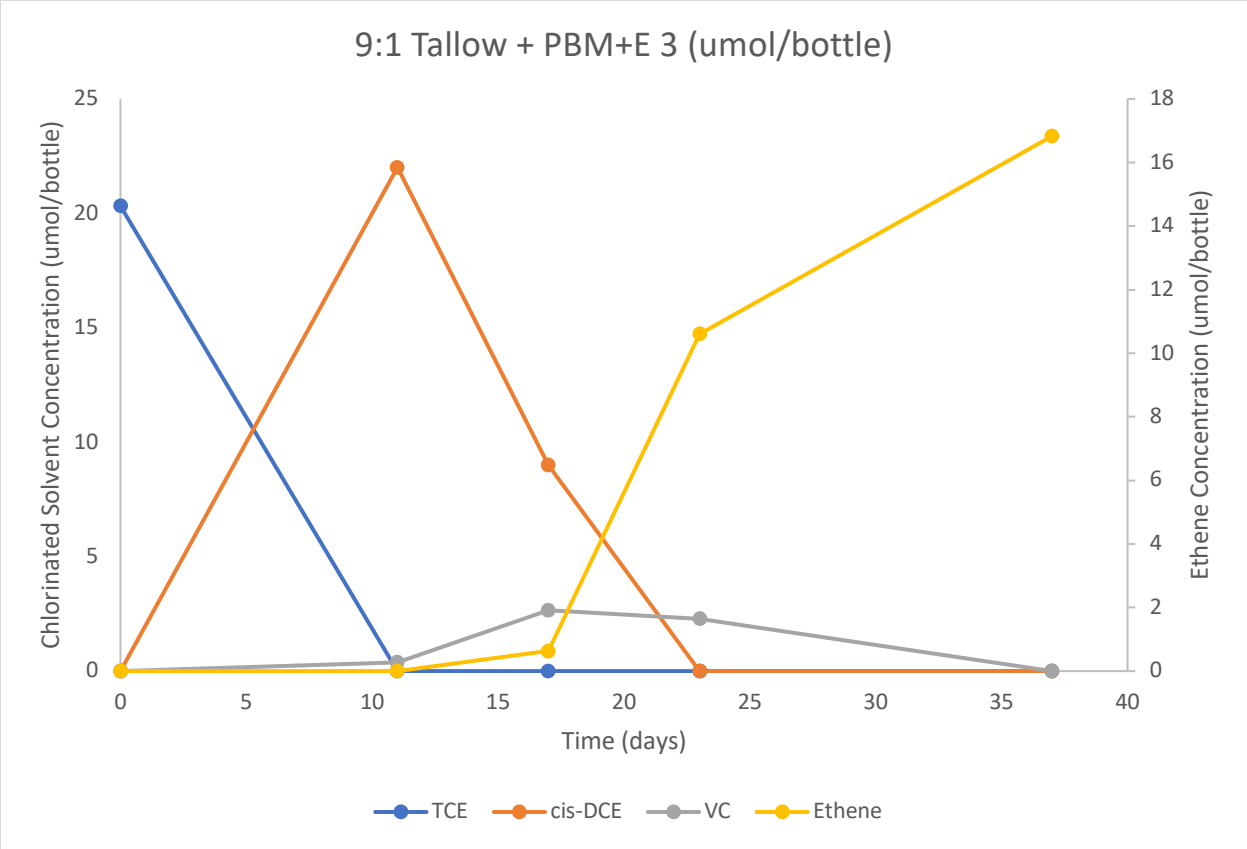
Appendix Figure 216. 500 mg/L 9:1 Tallow: TEVB dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



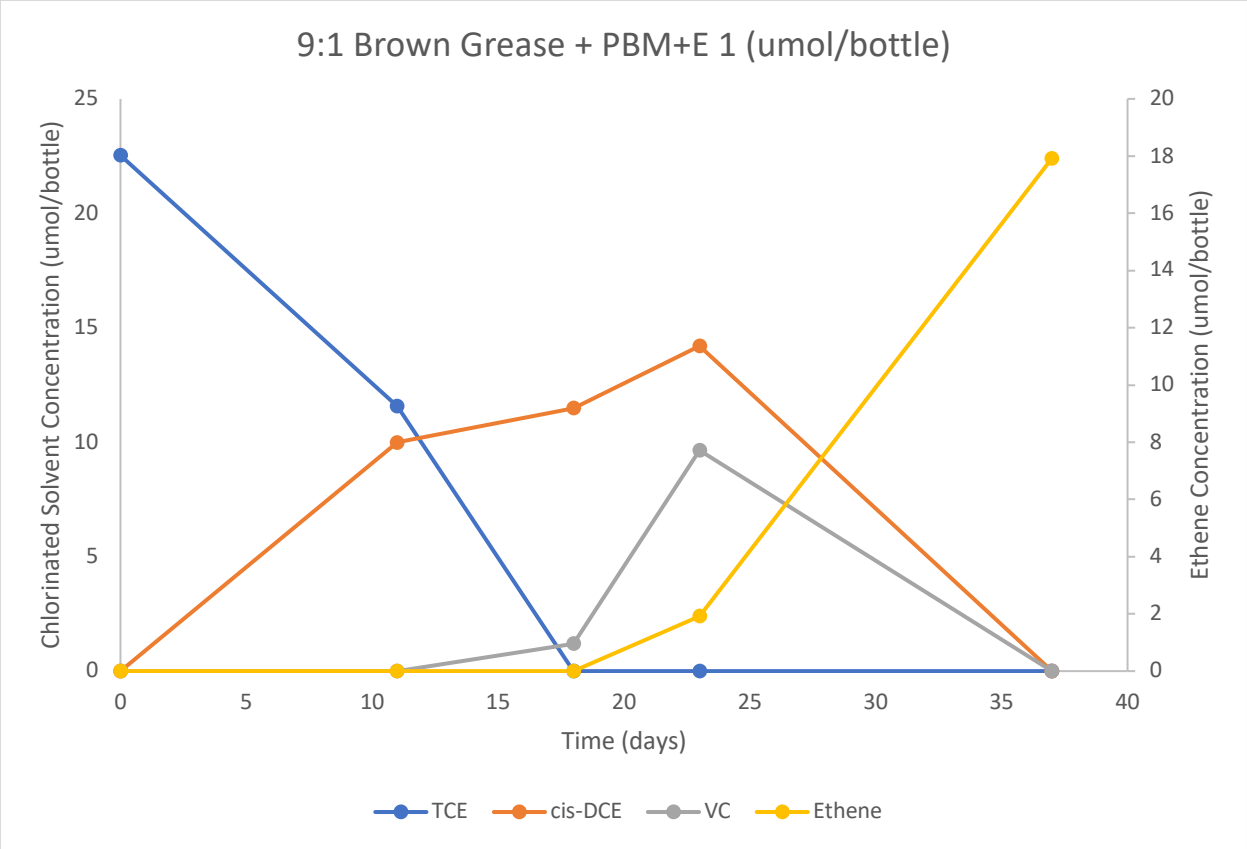
Appendix Figure 217. 500 mg/L 9:1 Tallow: PBM+E dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



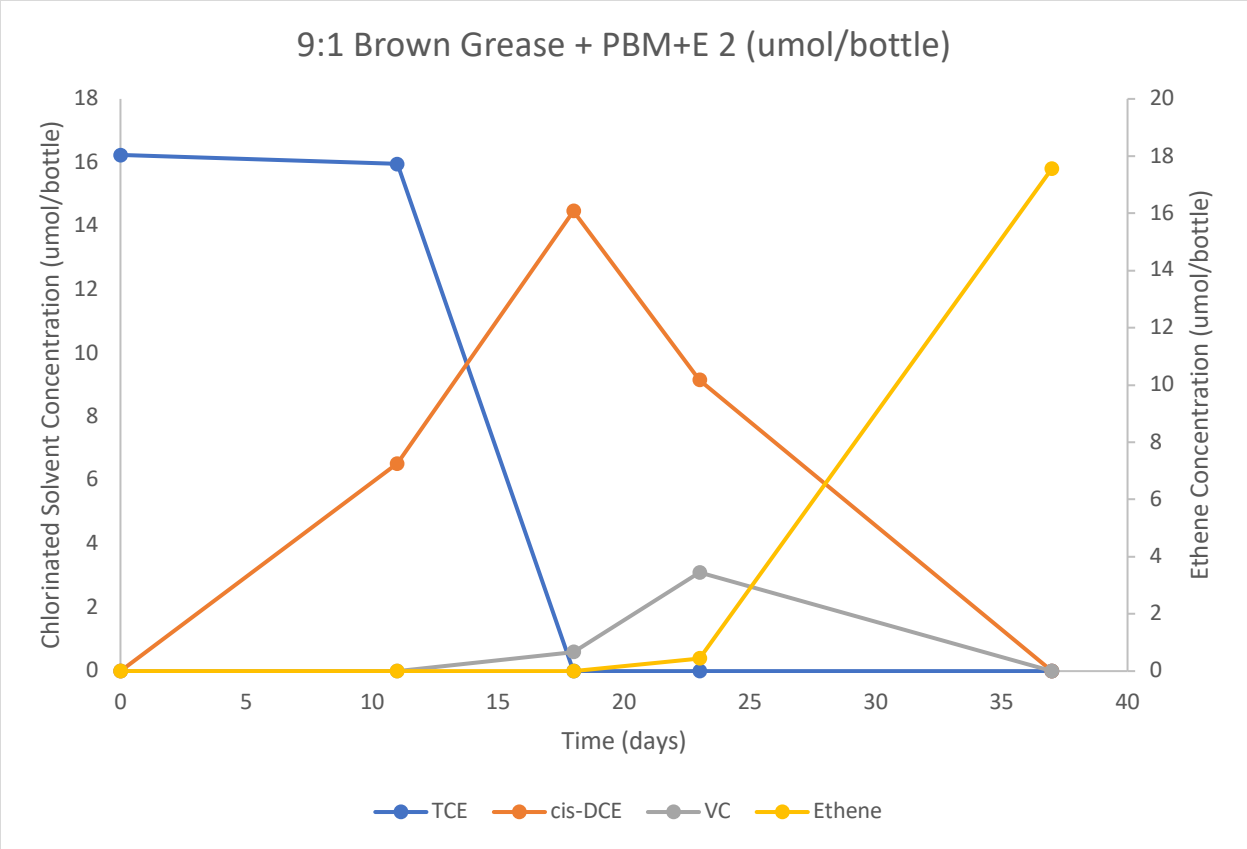
Appendix Figure 218. 500 mg/L 9:1 Tallow: PBM+E dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



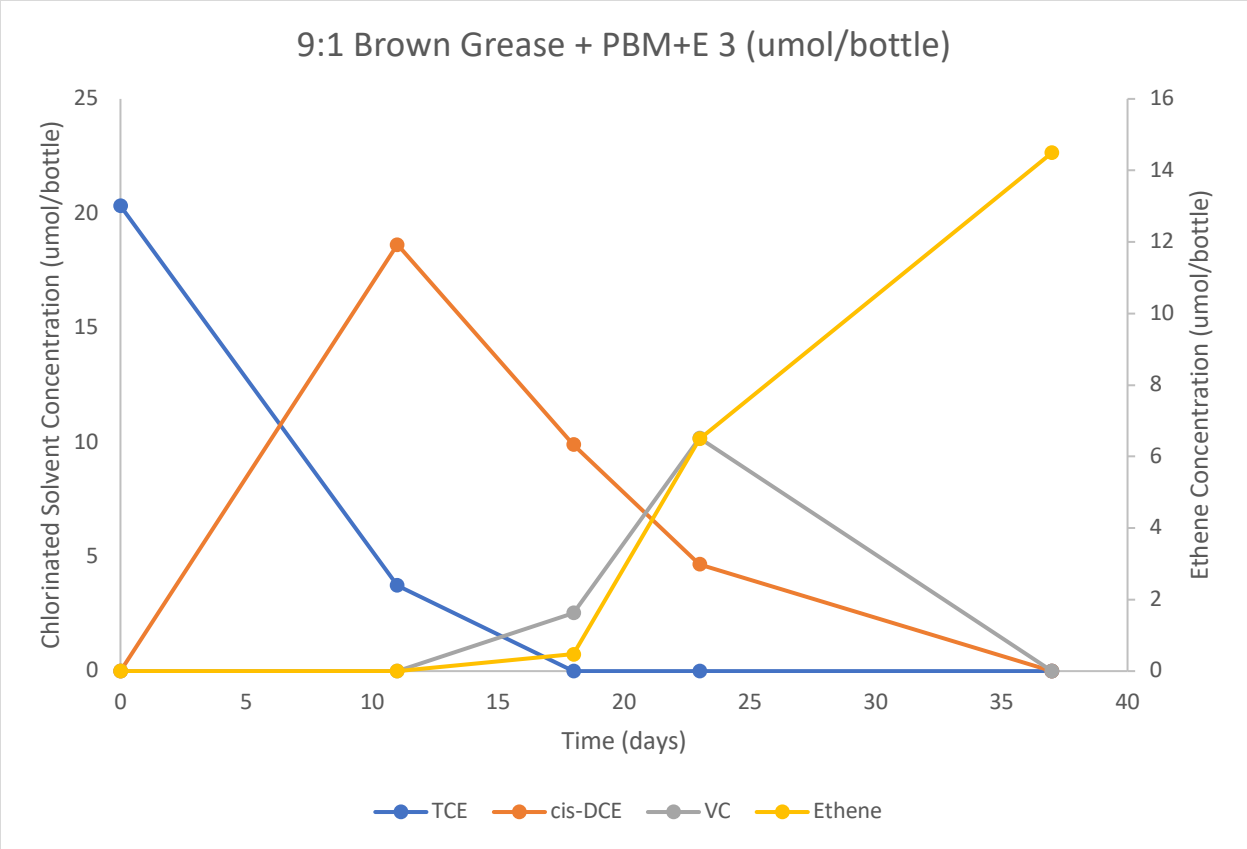
Appendix Figure 219. 500 mg/L 9:1 Tallow: PBM+E dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



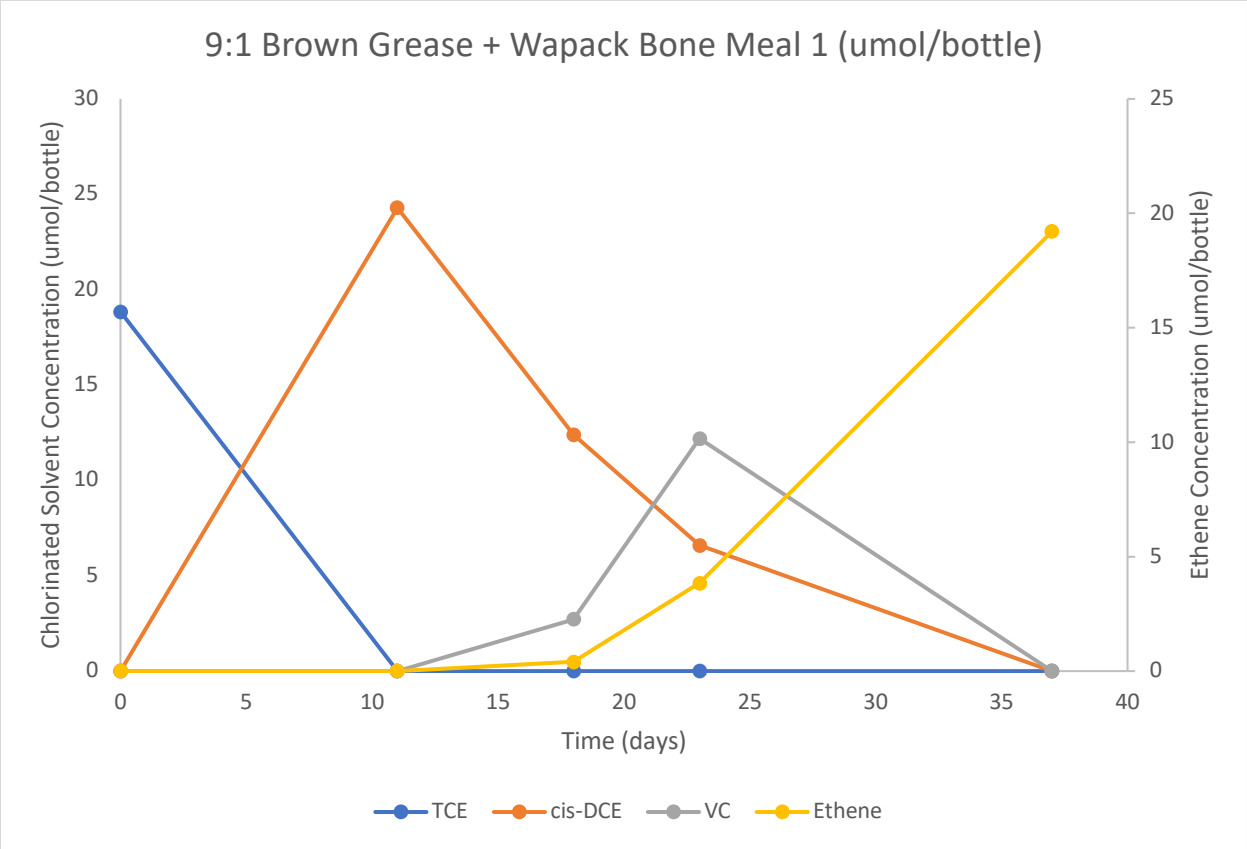
Appendix Figure 220. 500 mg/L 9:1 Brown Grease: PBM+E dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



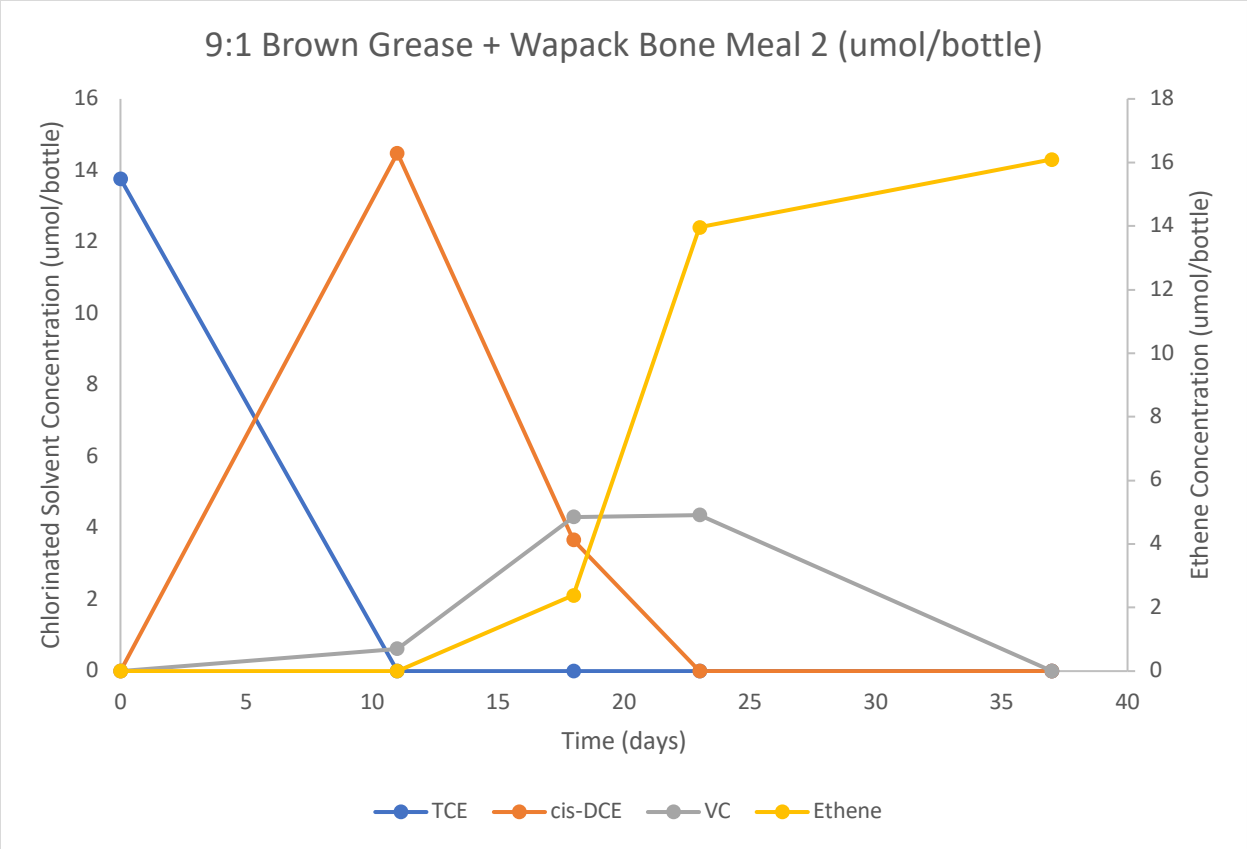
Appendix Figure 221. 500 mg/L 9:1 Brown Grease: PBM+E dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



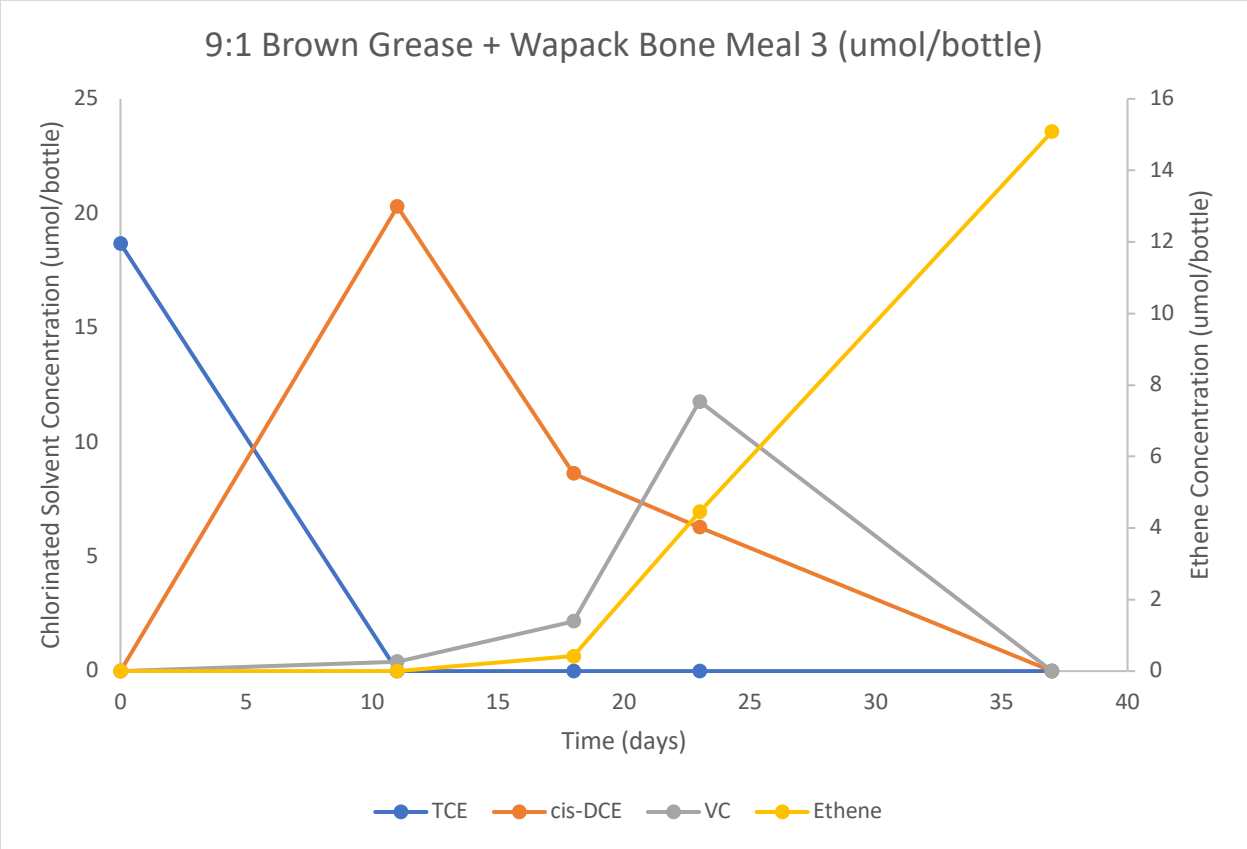
Appendix Figure 222. 500 mg/L 9:1 Brown Grease: PBM+E dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



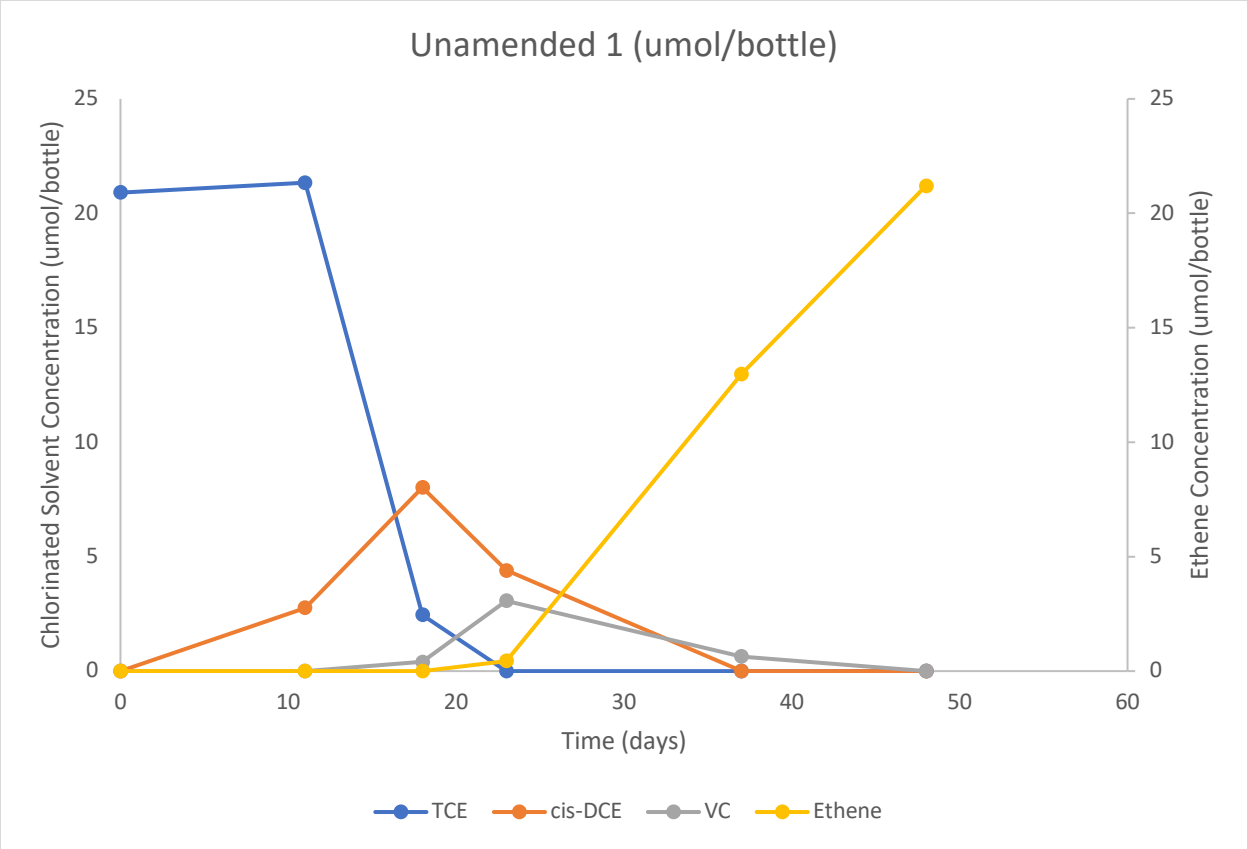
Appendix Figure 223. 500 mg/L 9:1 Brown Grease: Wapack Bone Meal dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



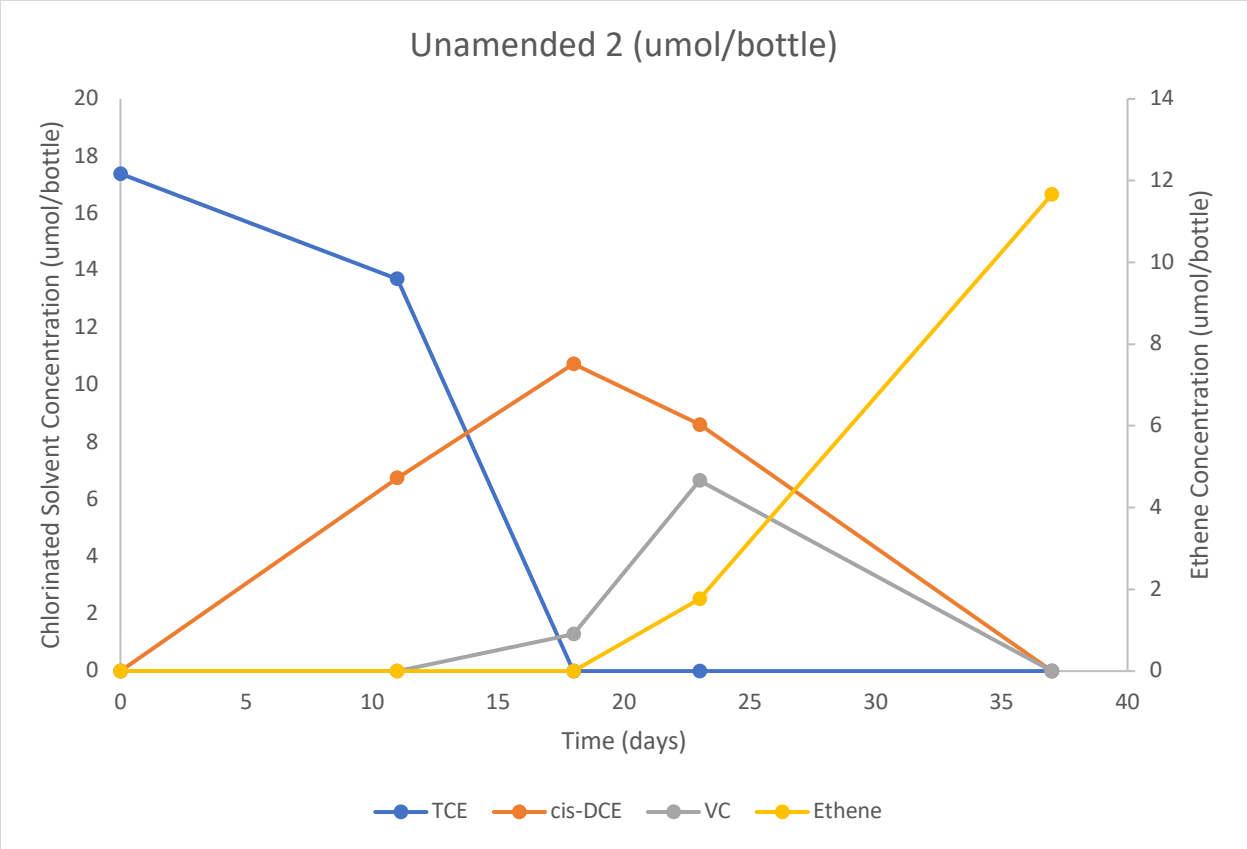
Appendix Figure 224. 500 mg/L 9:1 Brown Grease: Wapack Bone Meal dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



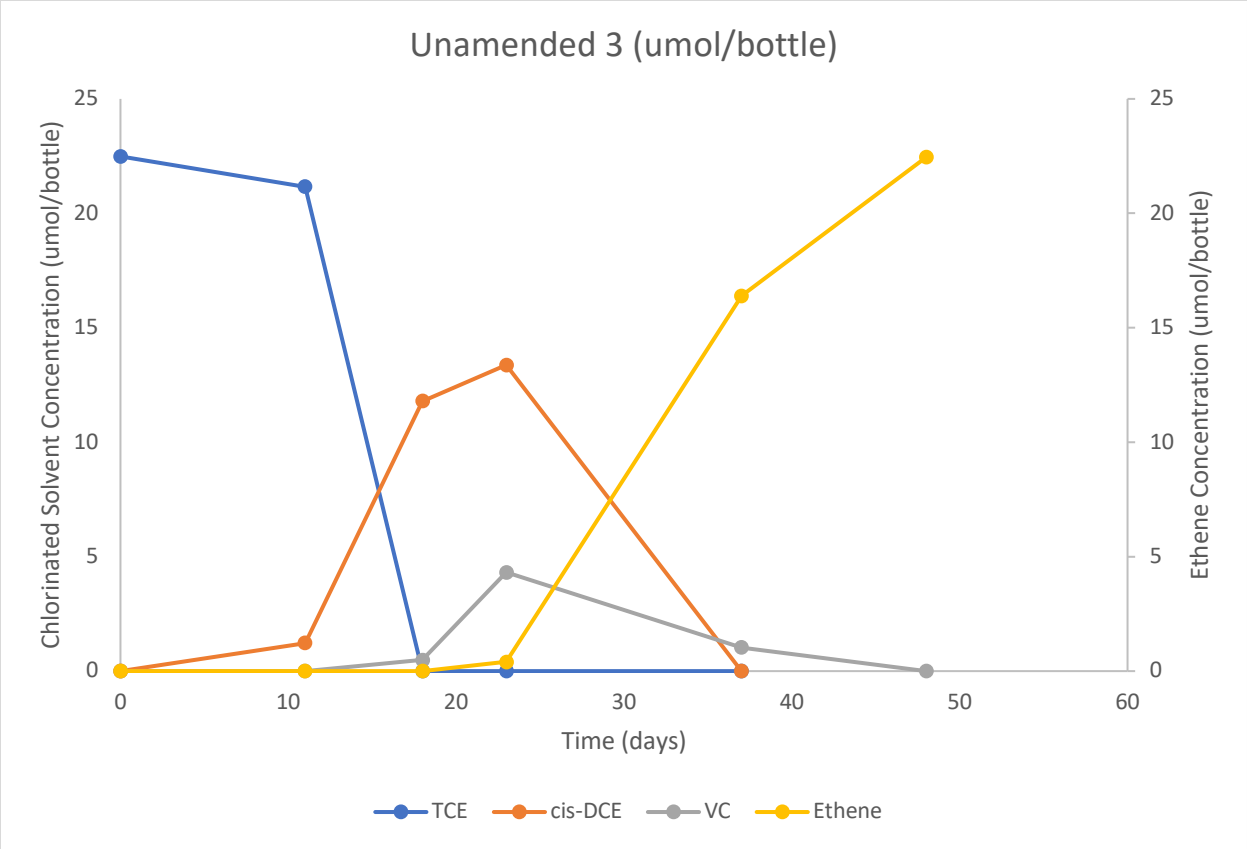
Appendix Figure 225. 500 mg/L 9:1 Brown Grease: Wapack Bone Meal dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



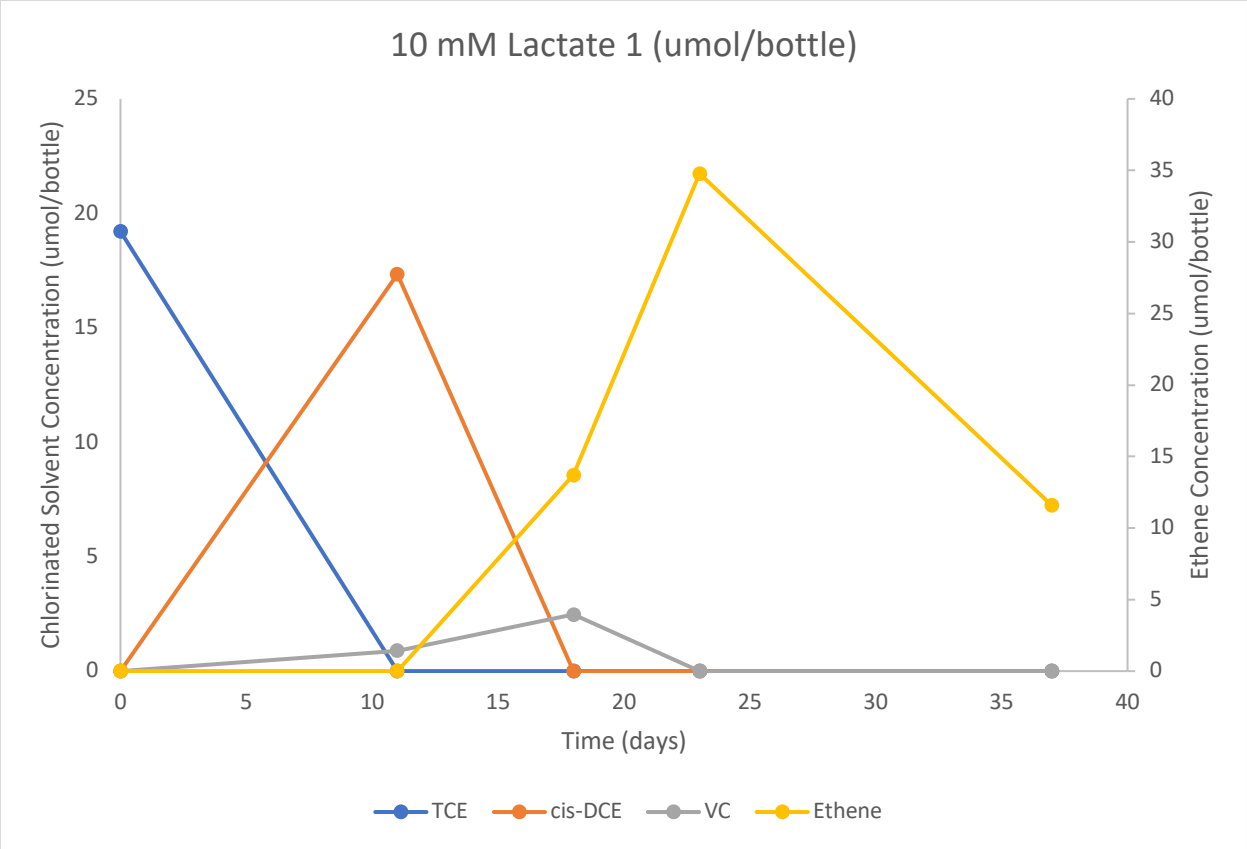
Appendix Figure 226. Unamended dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



Appendix Figure 227. Unamended dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

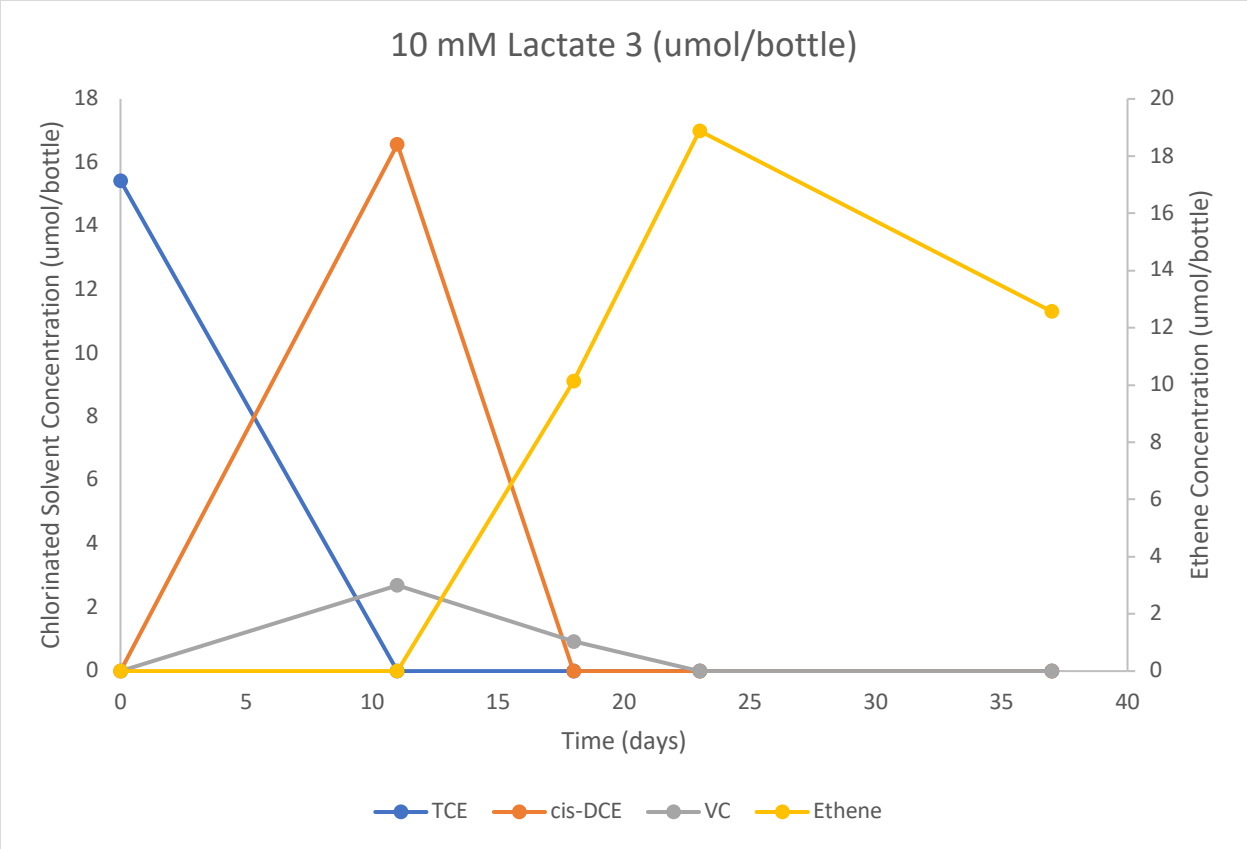


Appendix Figure 228. Unamended dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

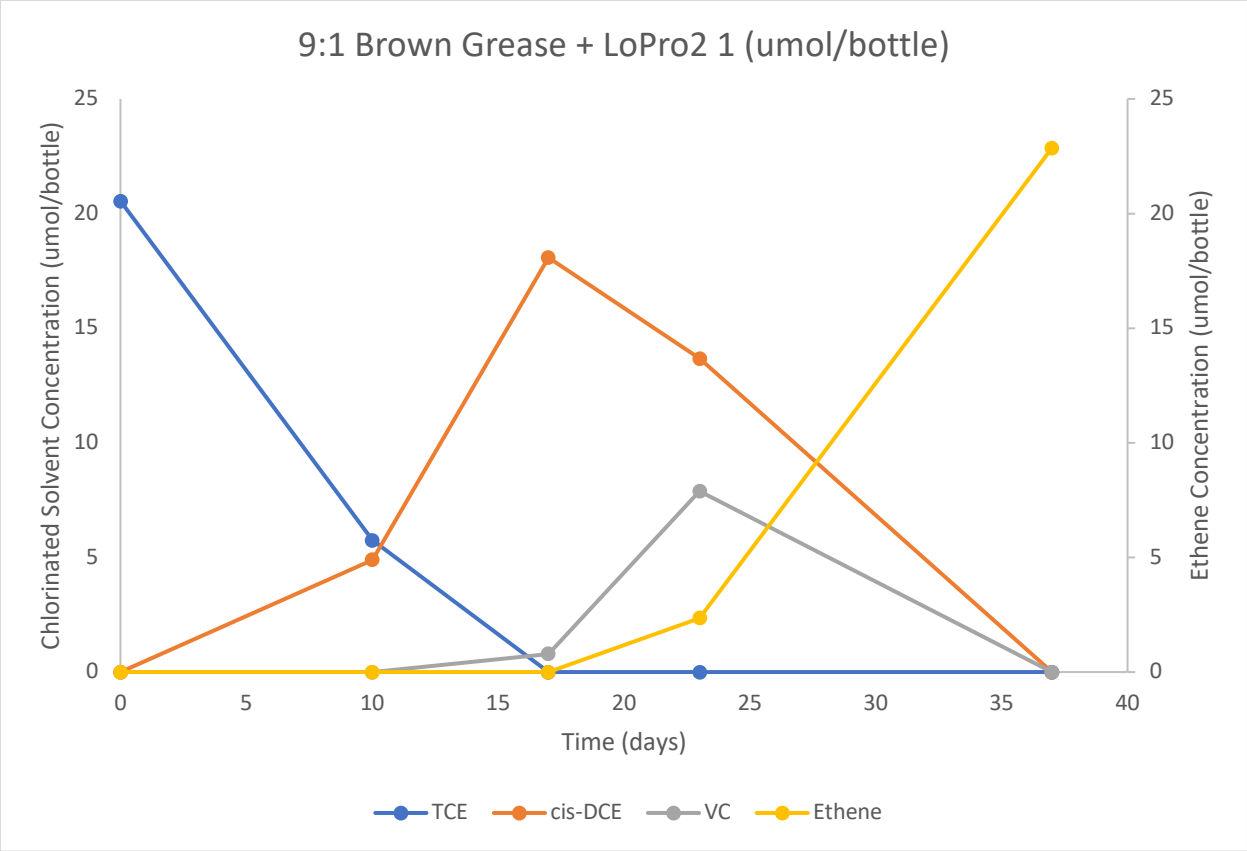


Appendix Figure 229. 10 mM Lactate dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

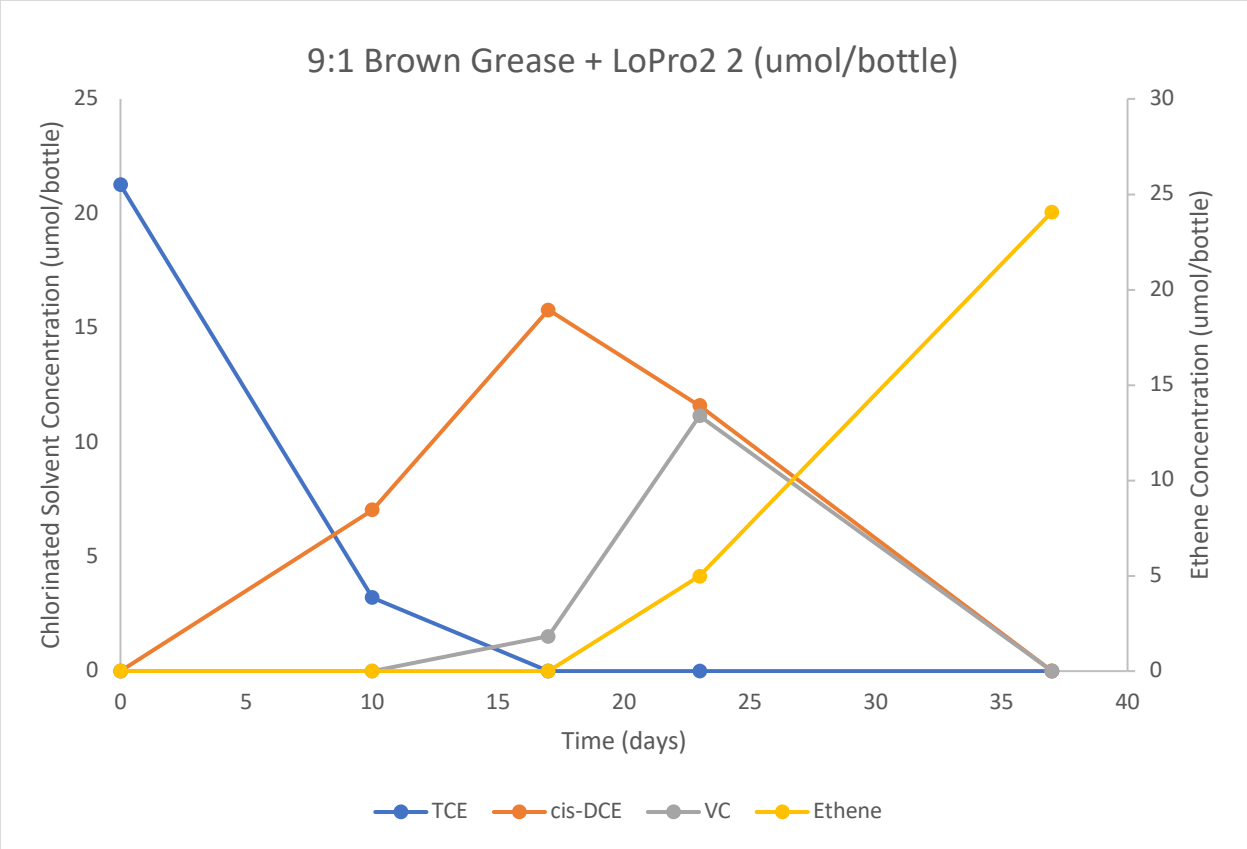
Appendix Figure 230. 10 mM Lactate dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



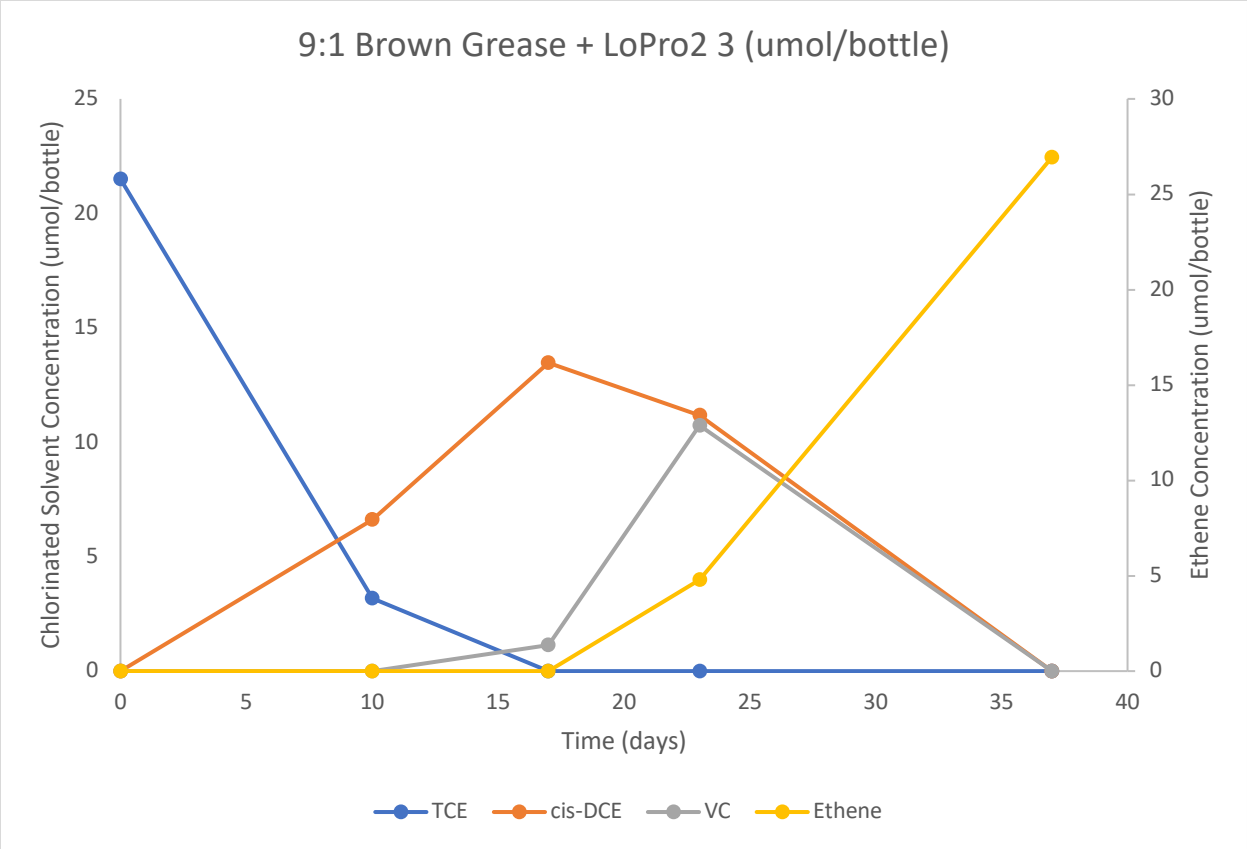
Appendix Figure 231. 10 mM Lactate dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



Appendix Figure 232. 500 mg/L Brown Grease + LoPro2 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

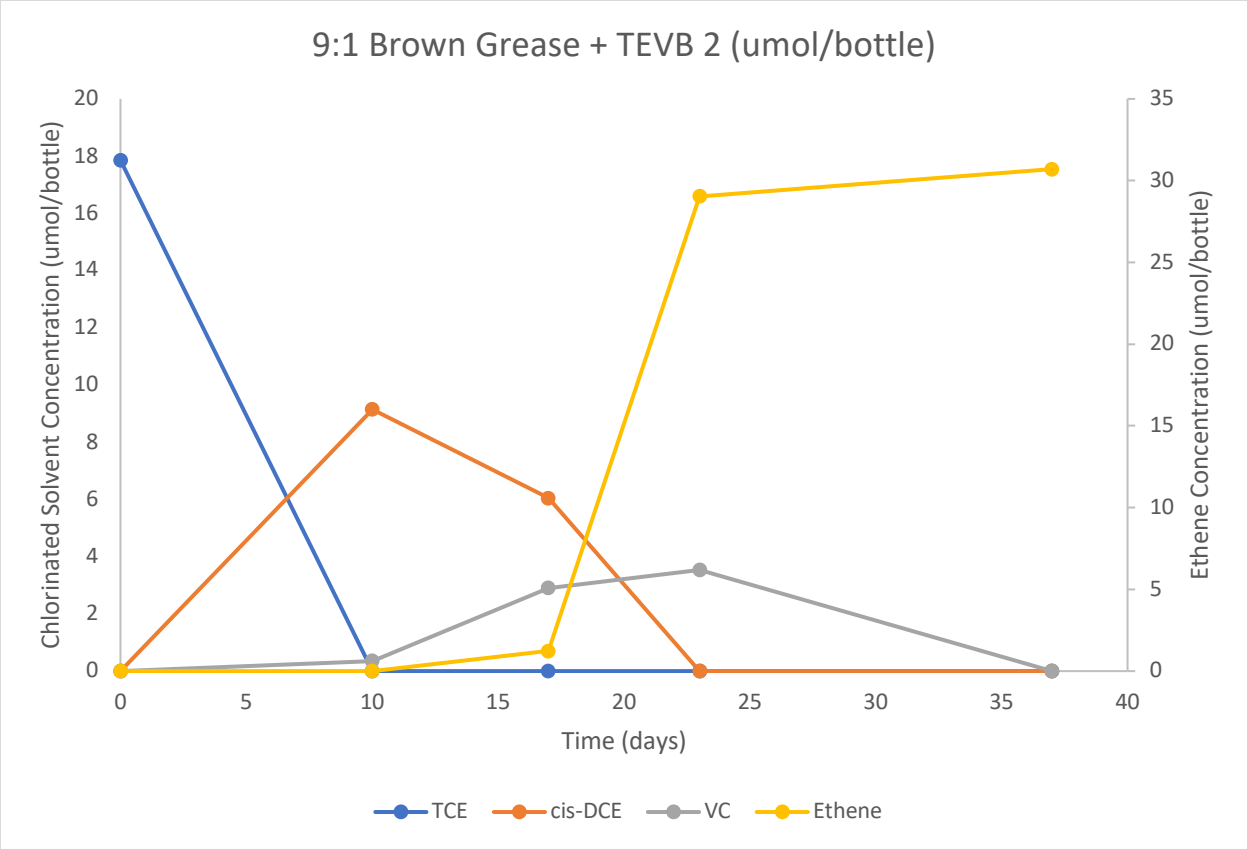


Appendix Figure 233. 500 mg/L Brown Grease + LoPro2 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



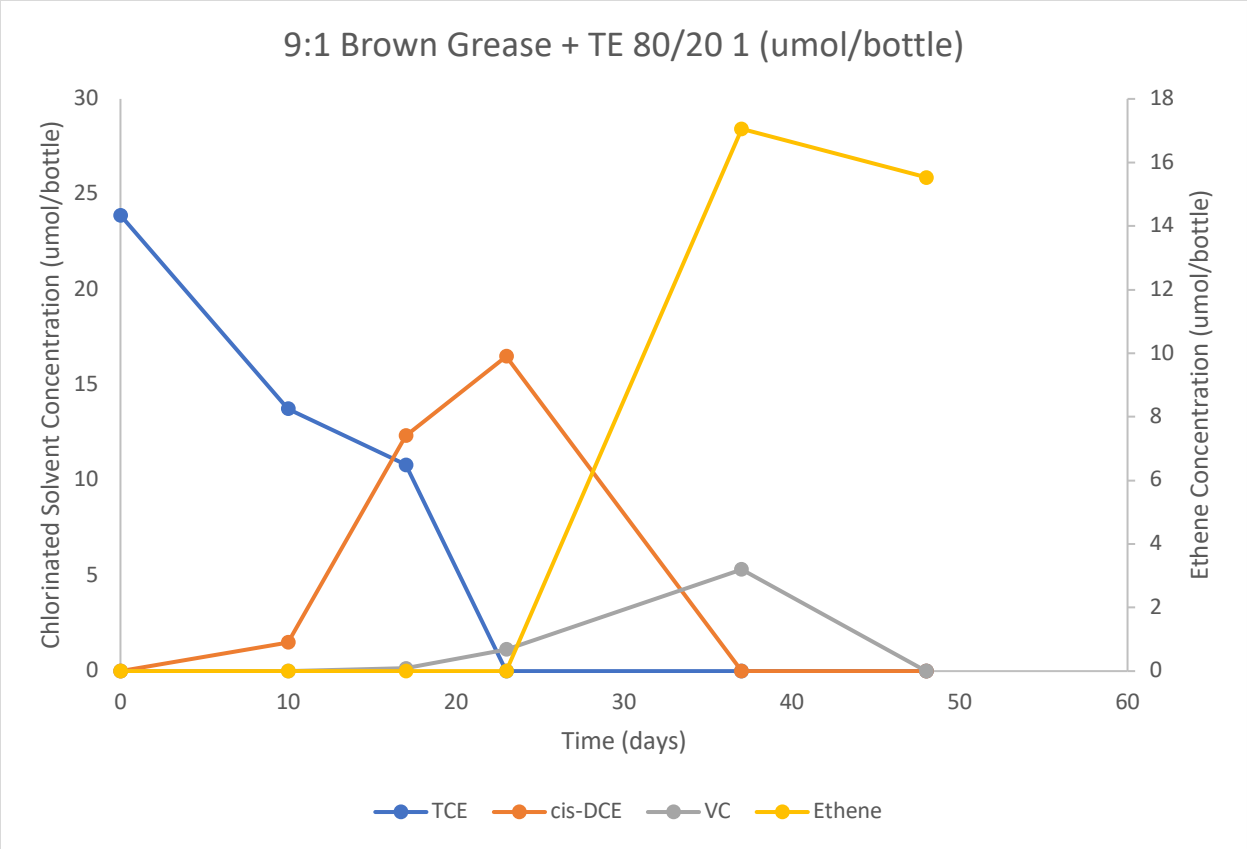
Appendix Figure 234. 500 mg/L Brown Grease + LoPro2 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

Appendix Figure 235. 500 mg/L Brown Grease + TEVB dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



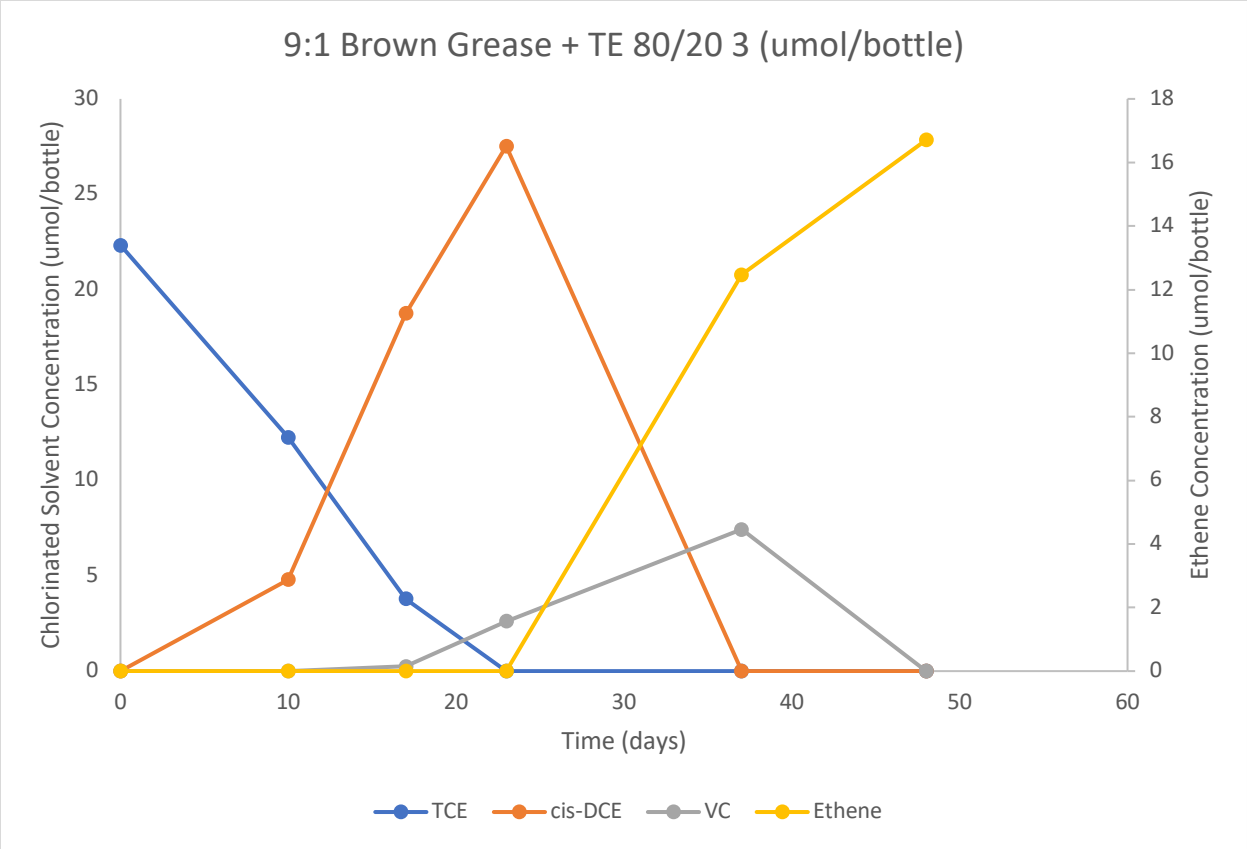
Appendix Figure 236. 500 mg/L Brown Grease + TEVB dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

Appendix Figure 237. 500 mg/L Brown Grease + TEVB dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

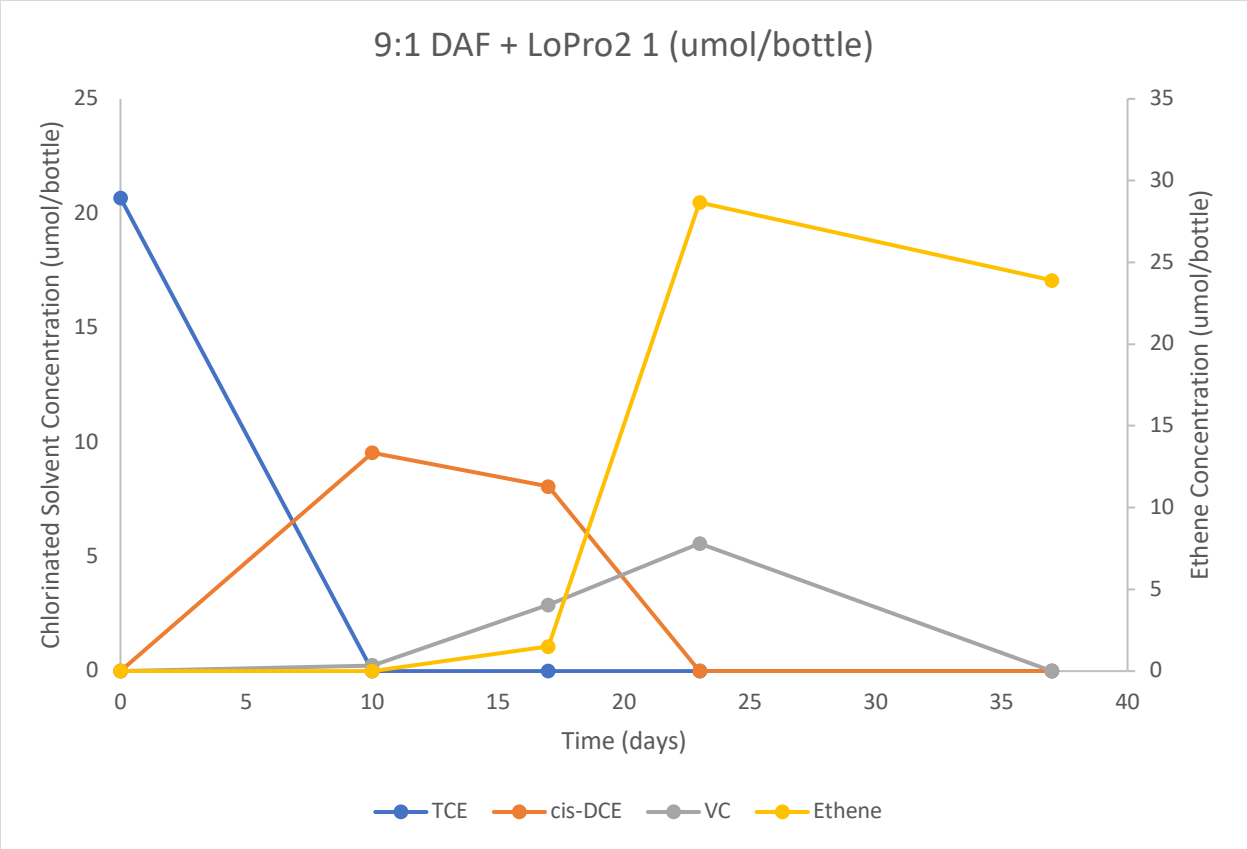


Appendix Figure 238. 500 mg/L Brown Grease + TE 80/20 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

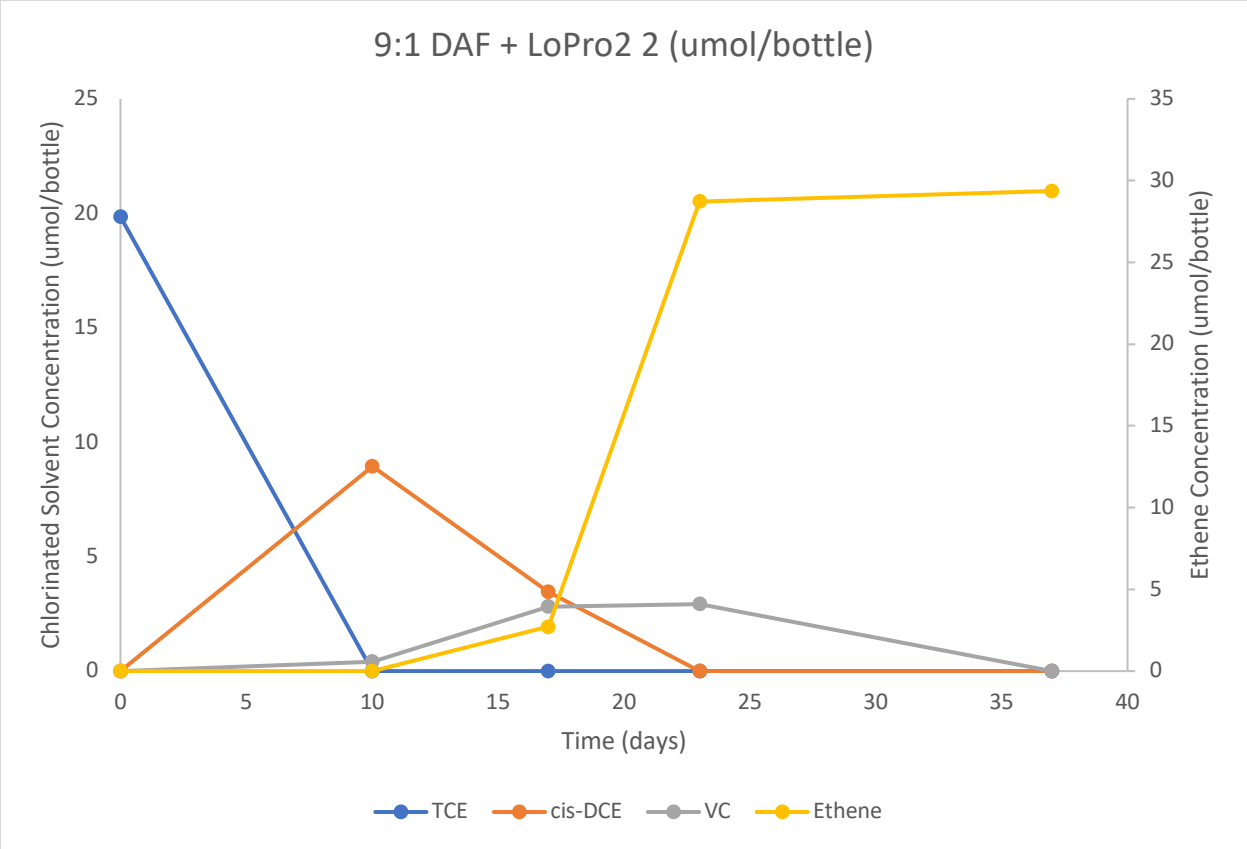
Appendix Figure 239. 500 mg/L Brown Grease + TE 80/20 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



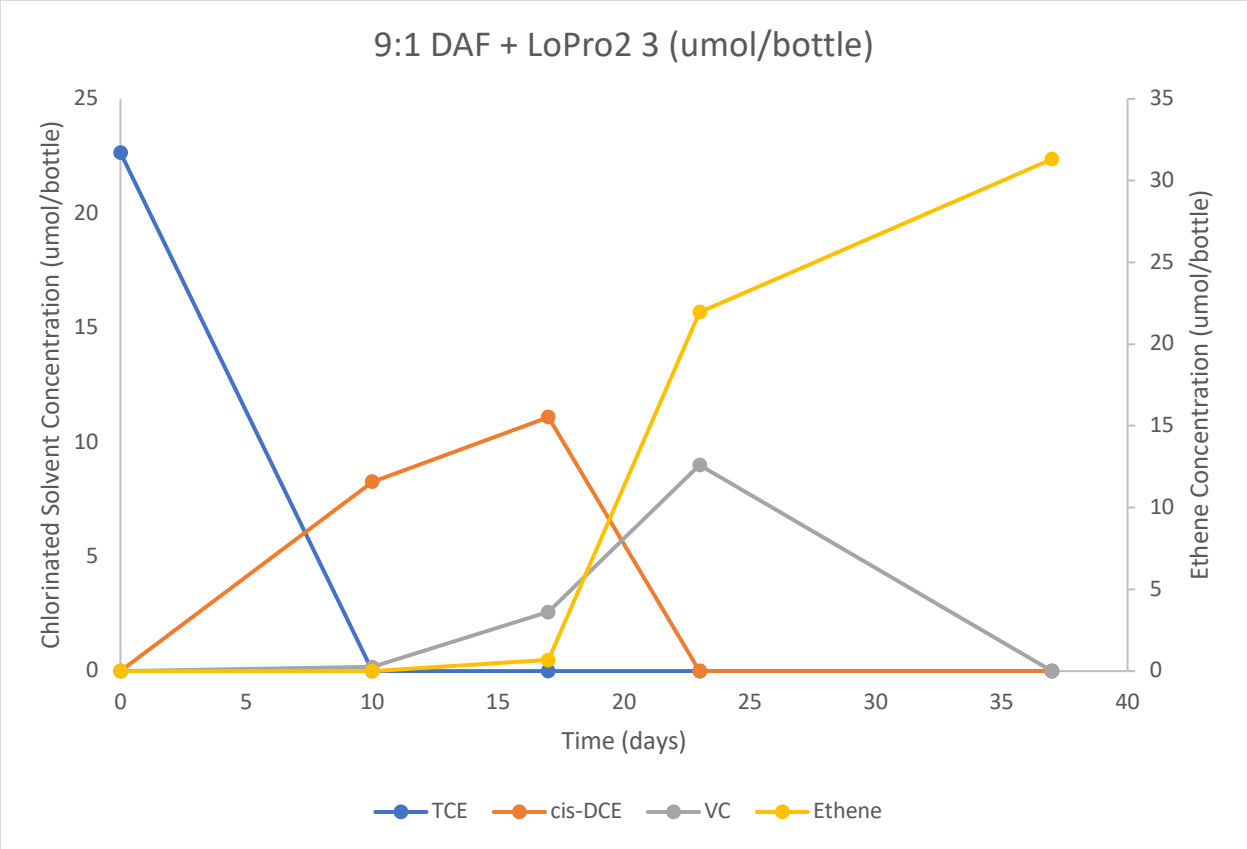
Appendix Figure 240. 500 mg/L Brown Grease + TE 80/20 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



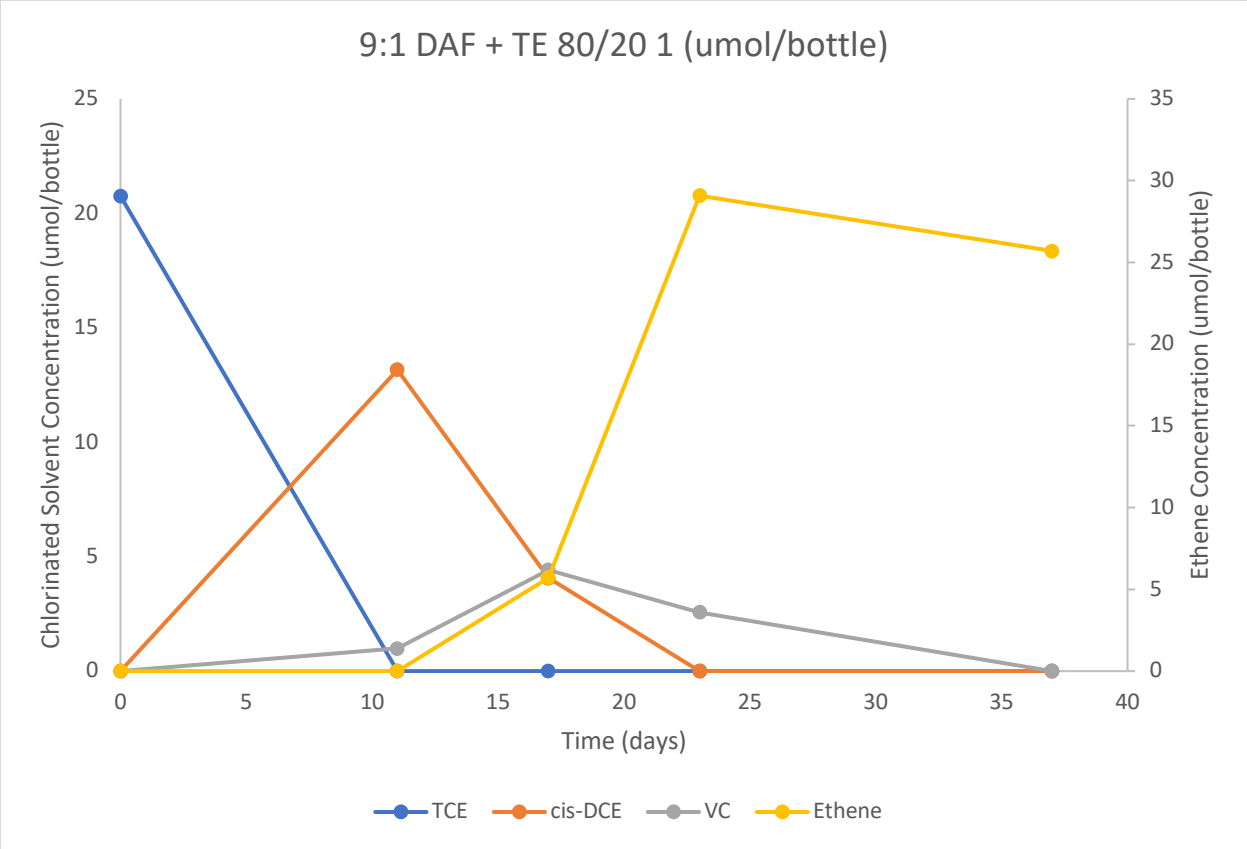
Appendix Figure 241. 500 mg/L DAF + LoPro2 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



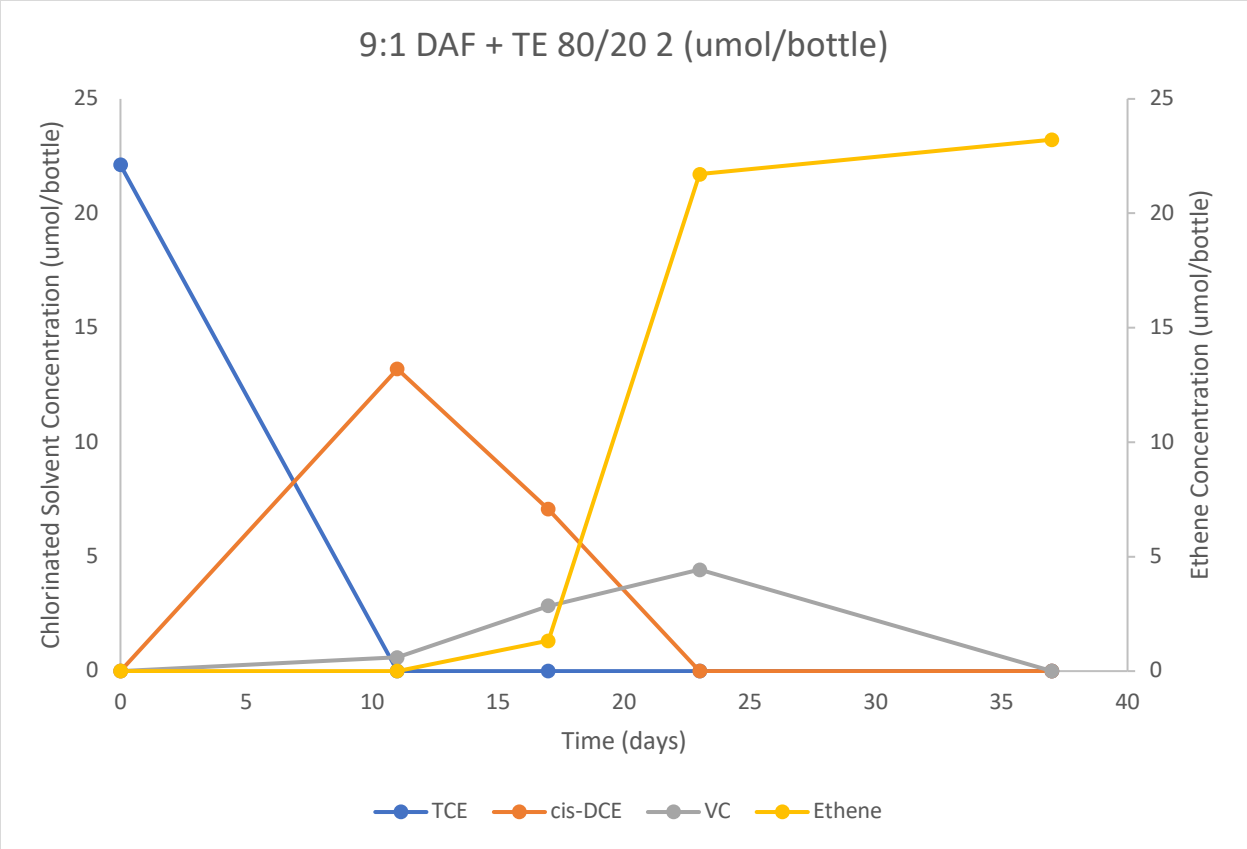
Appendix Figure 242. 500 mg/L DAF + LoPro2 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



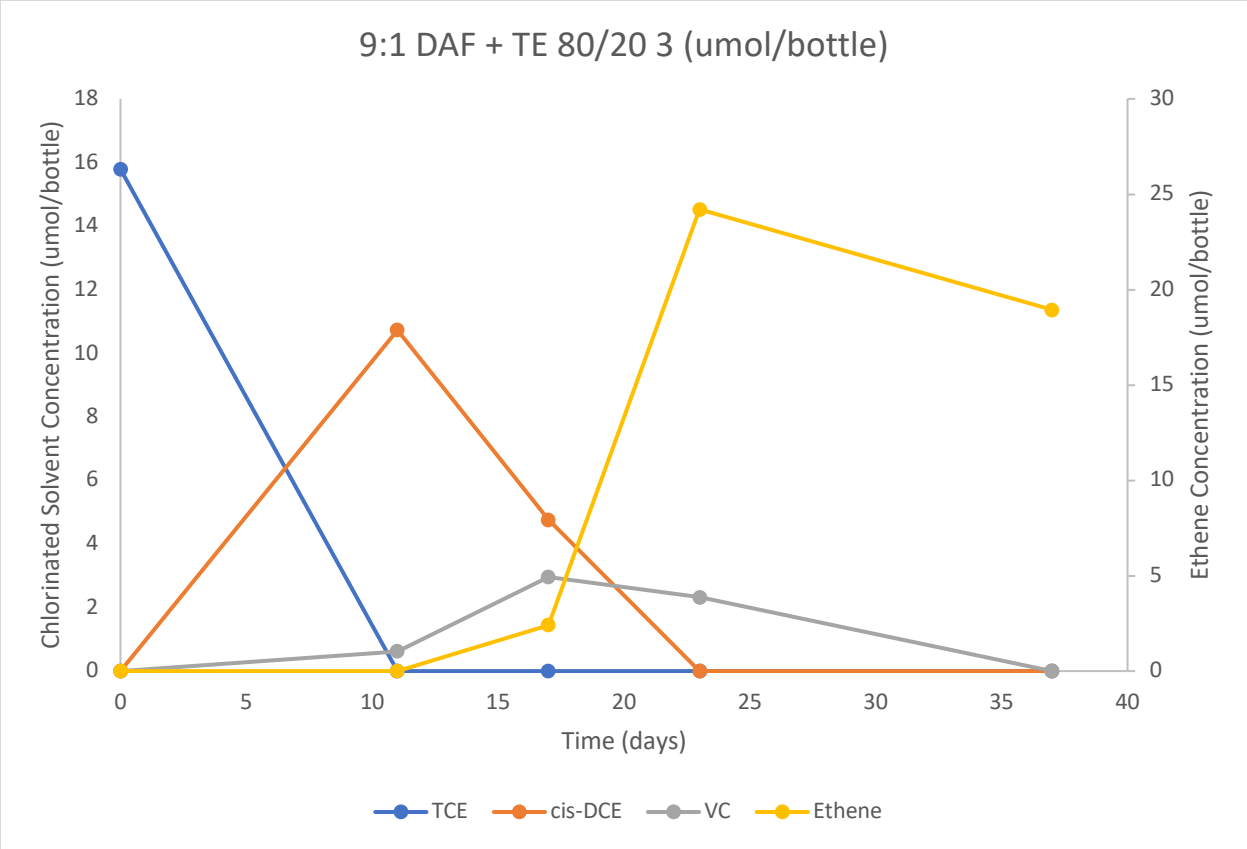
Appendix Figure 243. 500 mg/L DAF + LoPro2 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



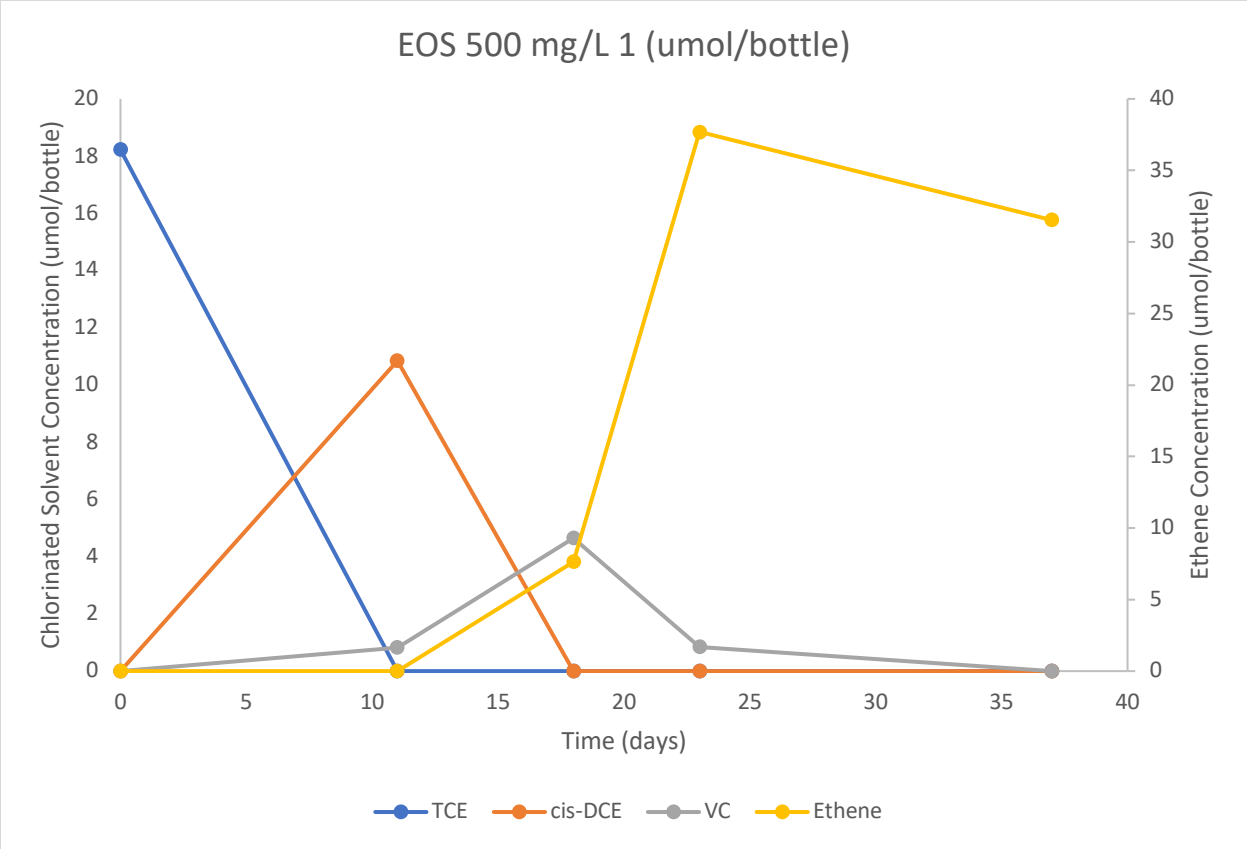
Appendix Figure 244. 500 mg/L DAF + TE 80/20 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



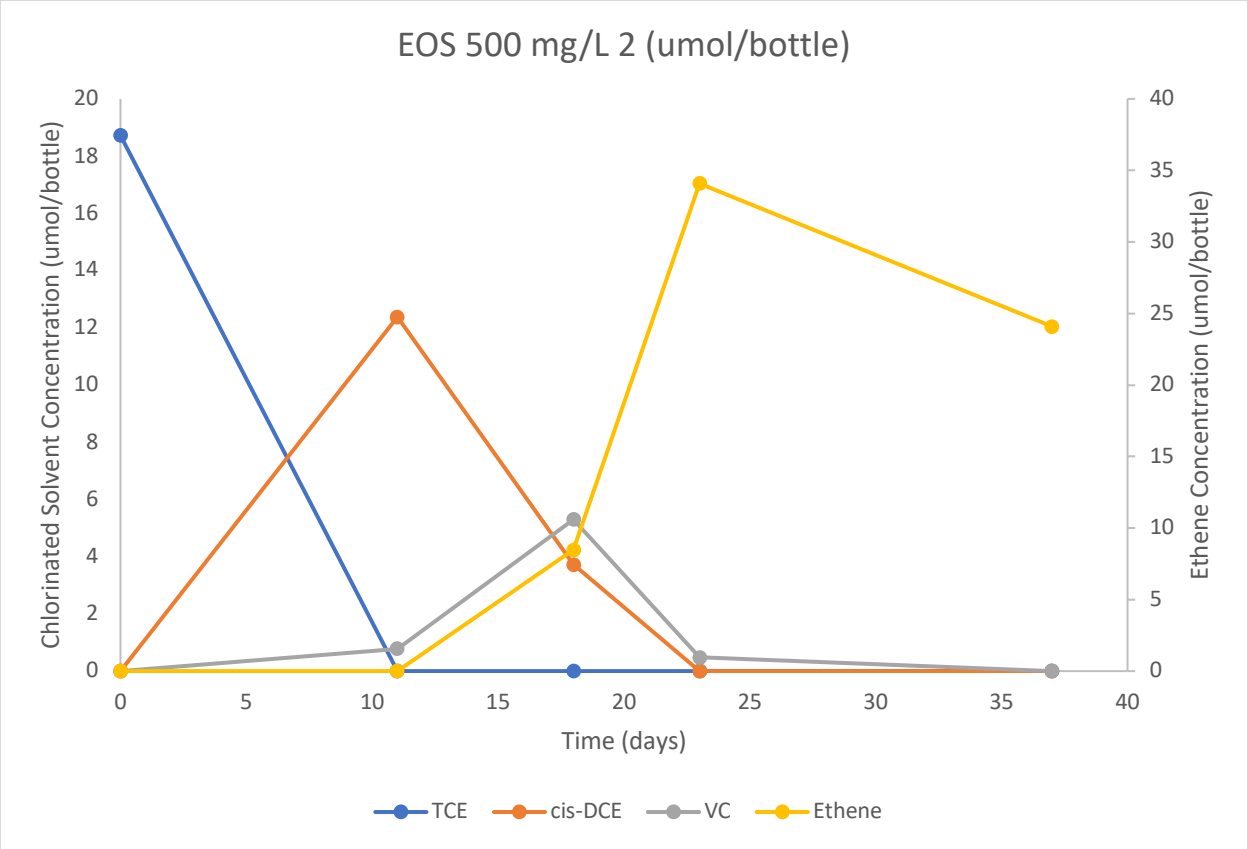
Appendix Figure 245. 500 mg/L DAF + TE 80/20 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



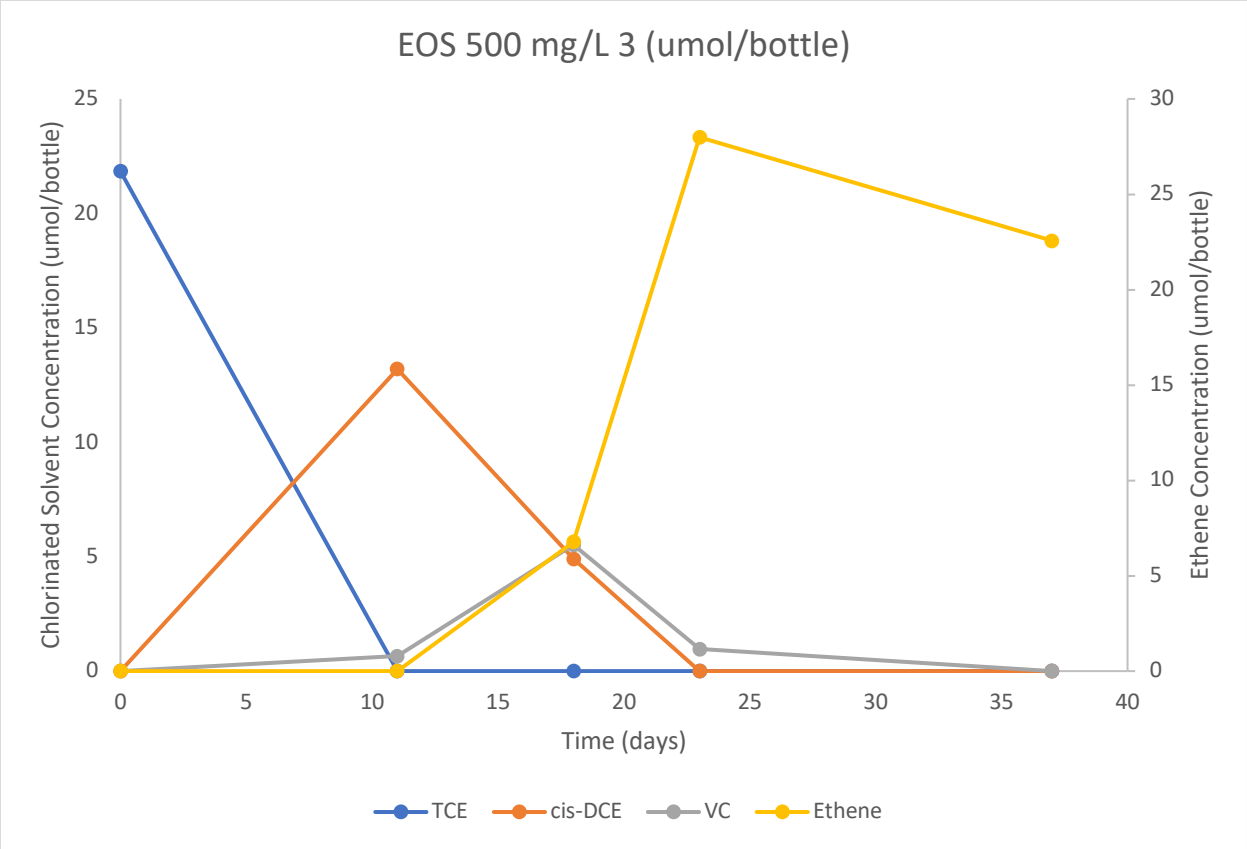
Appendix Figure 246. 500 mg/L DAF + TE 80/20 dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



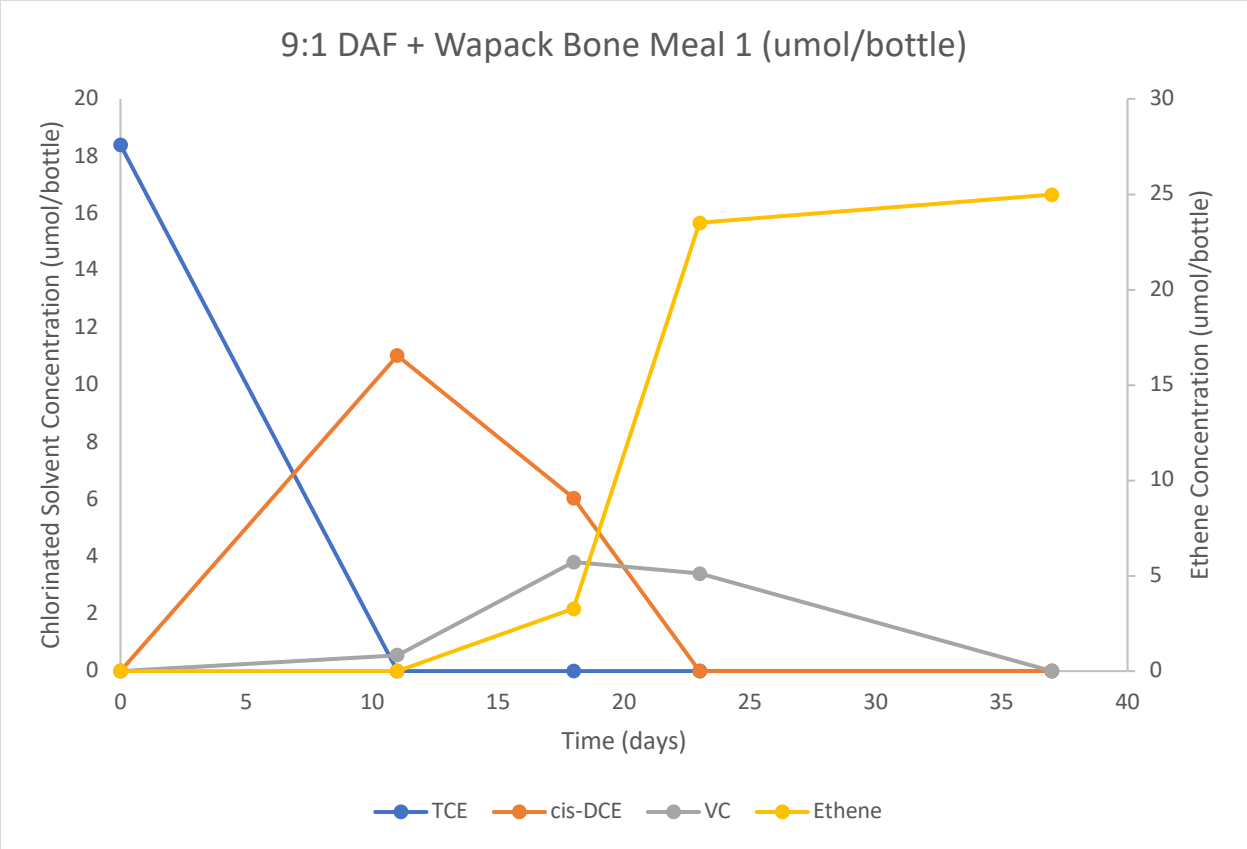
Appendix Figure 247. 500 mg/L EOS dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



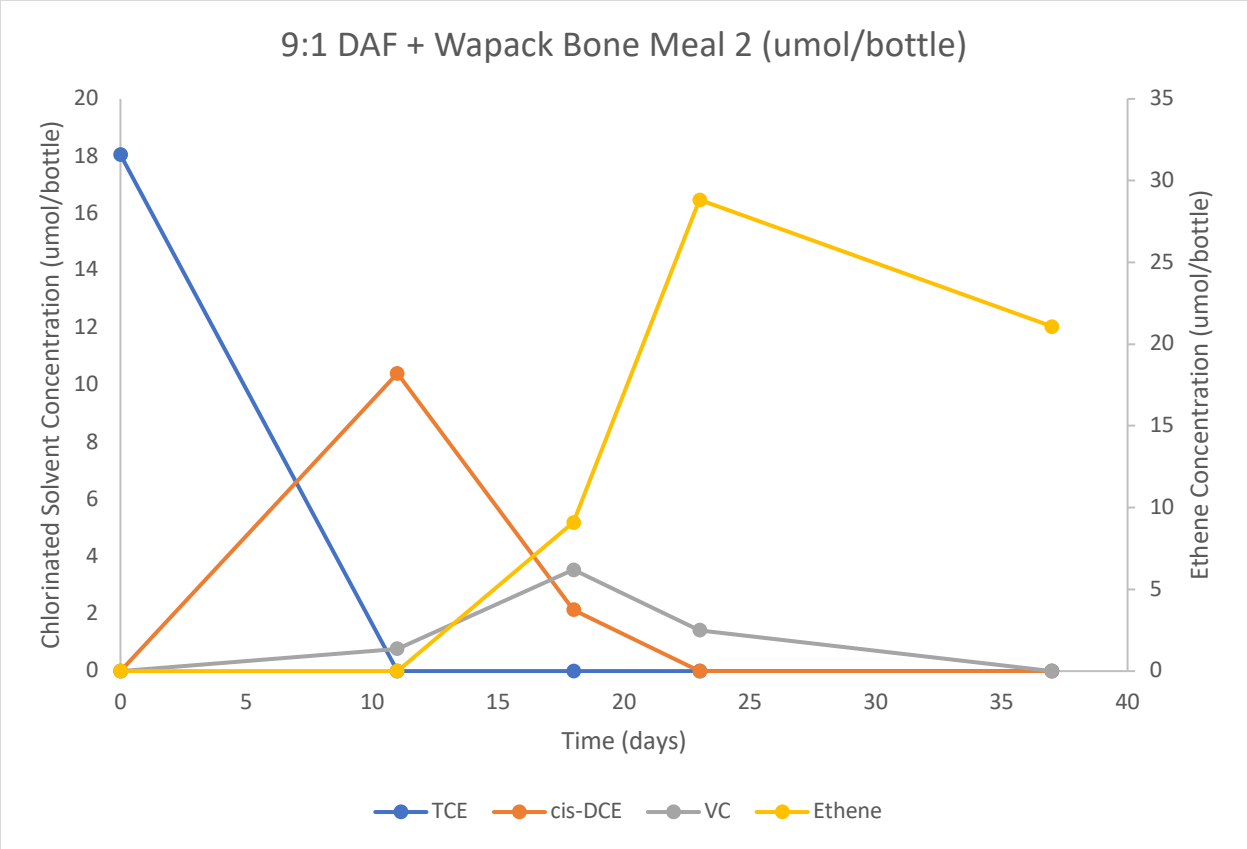
Appendix Figure 248. 500 mg/L EOS dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



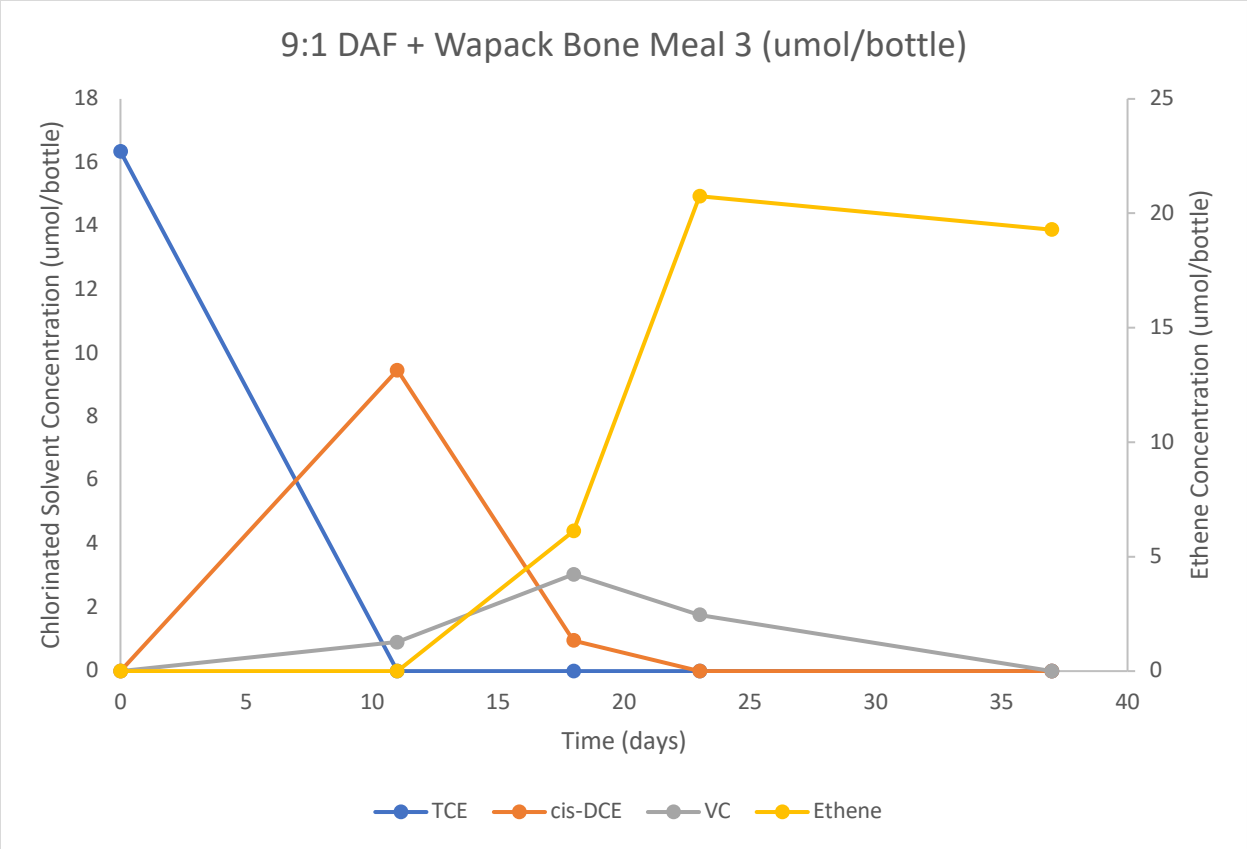
Appendix Figure 249. 500 mg/L EOS dosed control bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



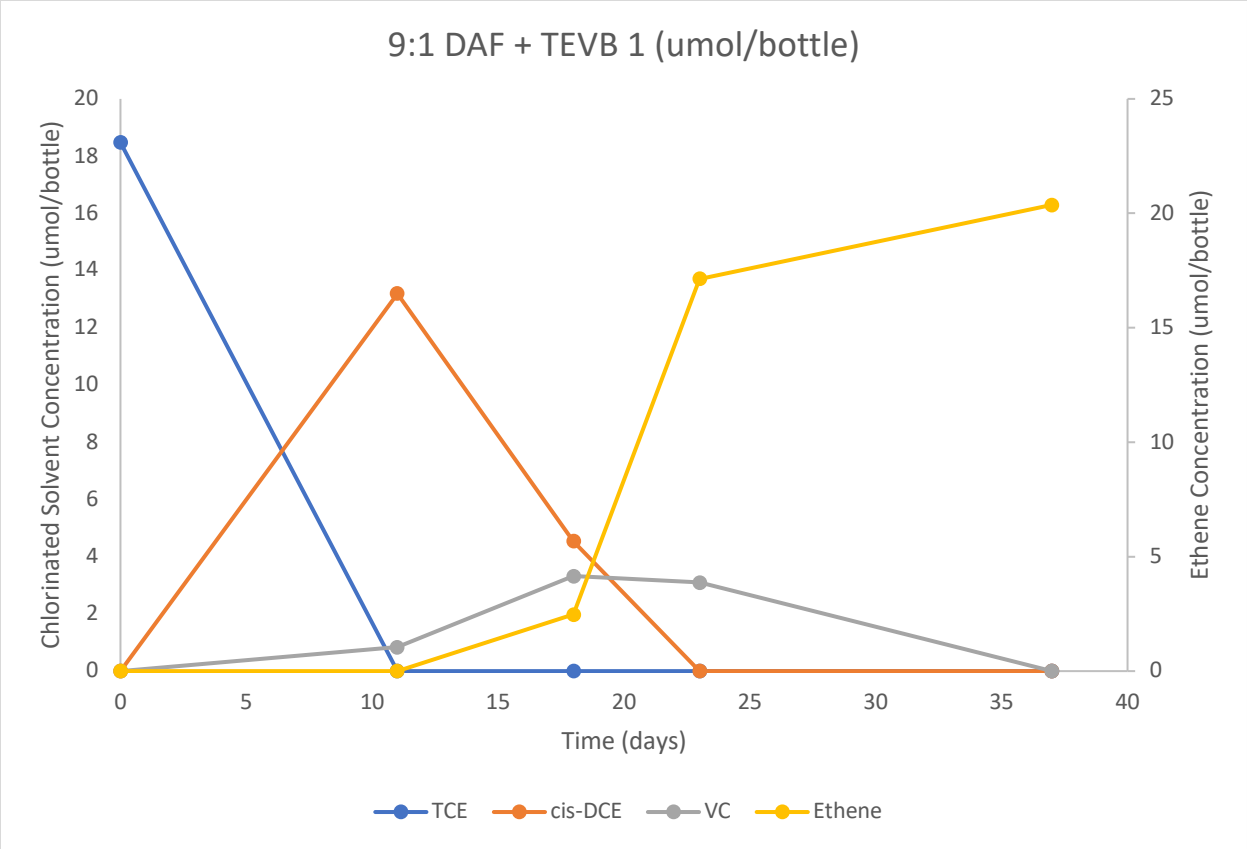
Appendix Figure 250. 500 mg/L 9:1 DAF: Wapack Bone Meal dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



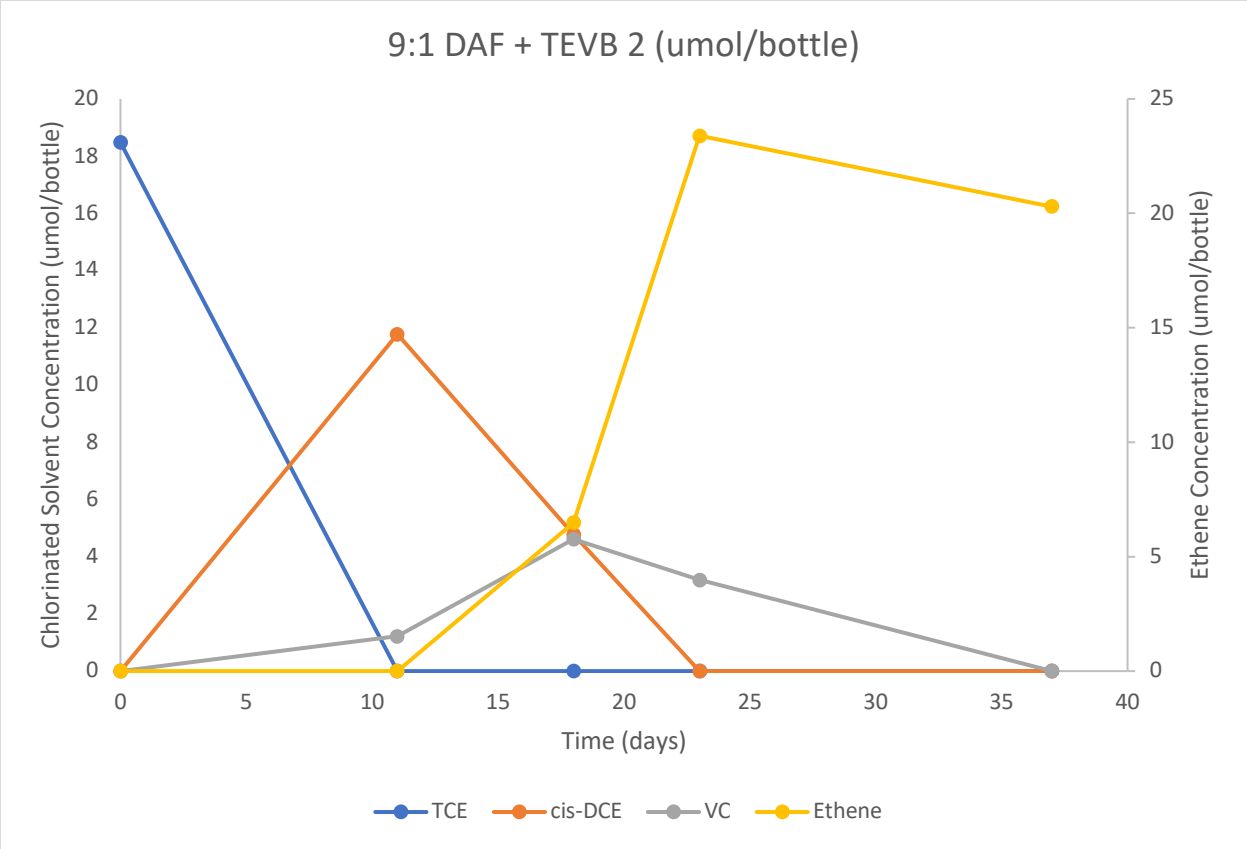
Appendix Figure 251. 500 mg/L 9:1 DAF: Wapack Bone Meal dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



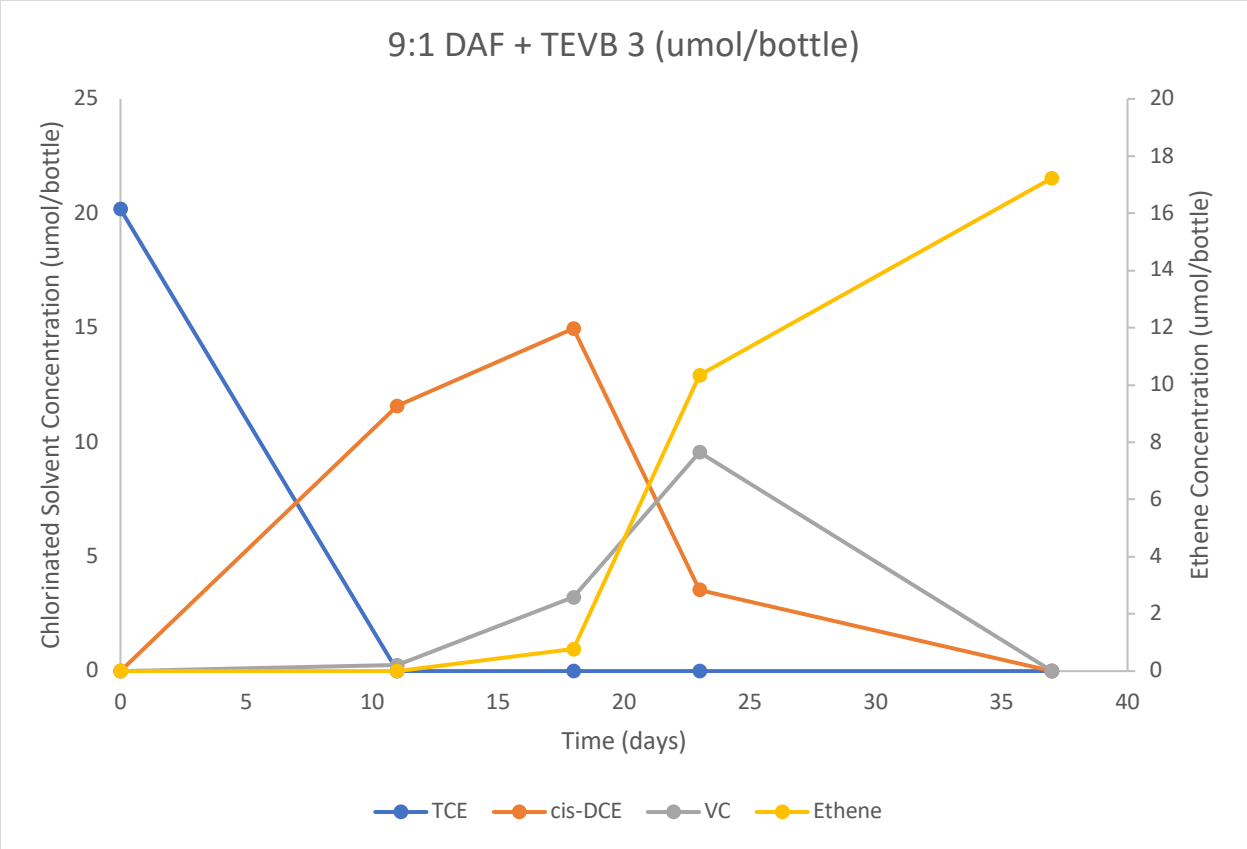
Appendix Figure 252. 500 mg/L 9:1 DAF: Wapack Bone Meal dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



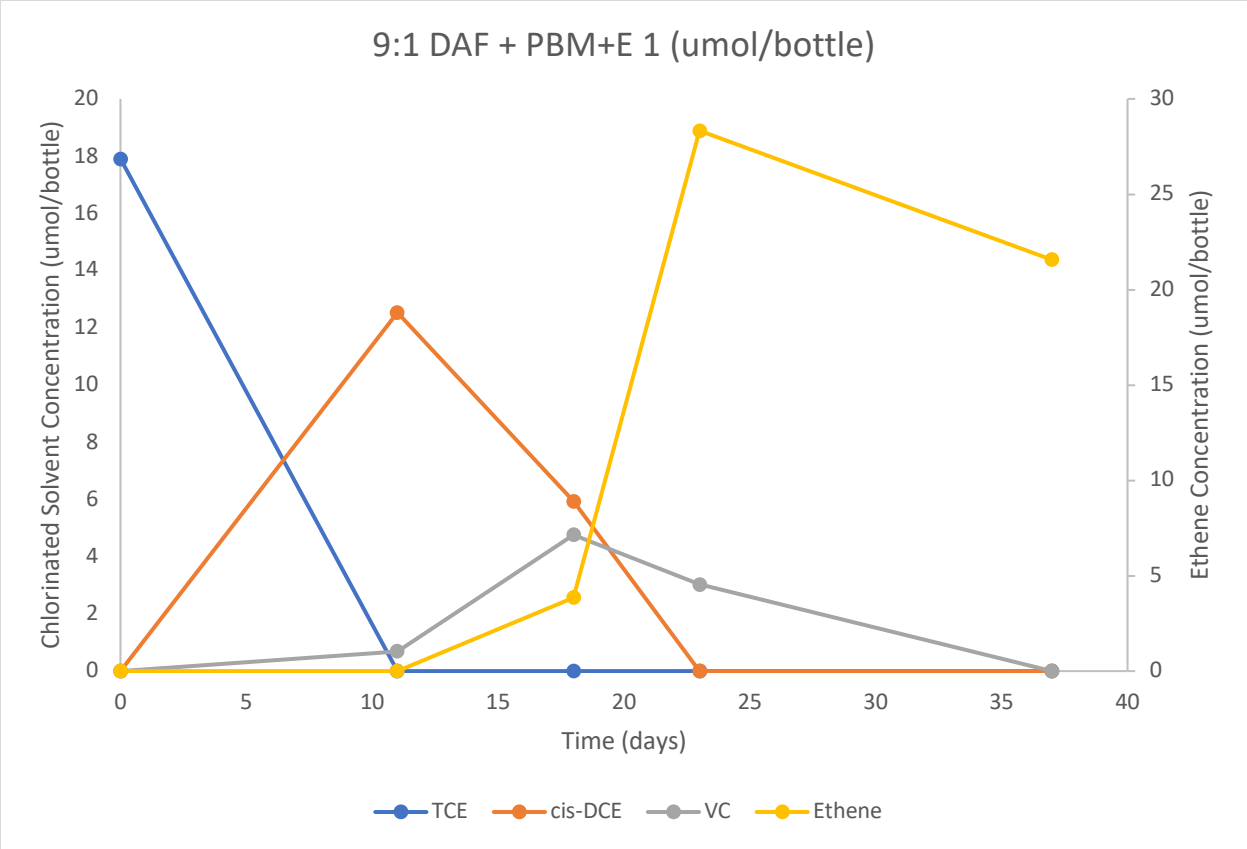
Appendix Figure 253. 500 mg/L 9:1 DAF: TEVB dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



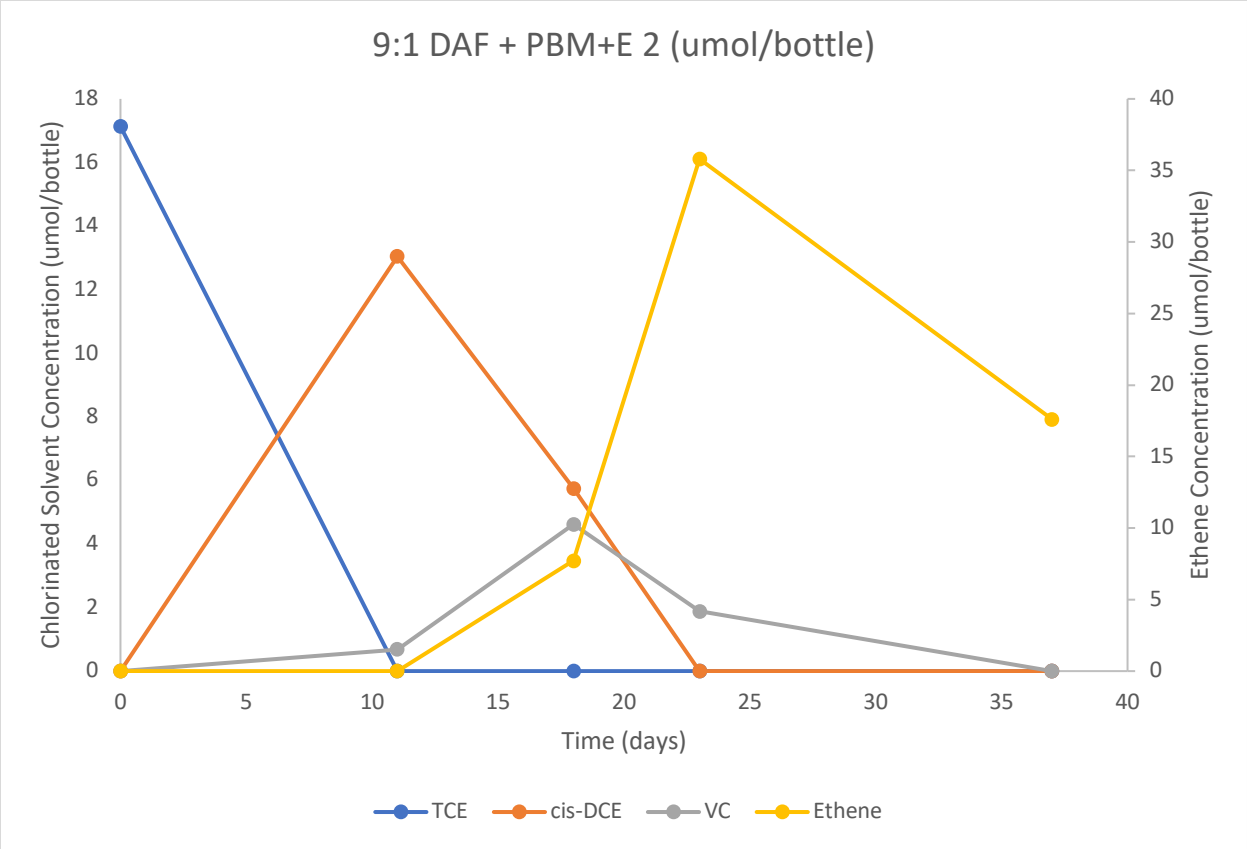
Appendix Figure 254. 500 mg/L 9:1 DAF: TEVB dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



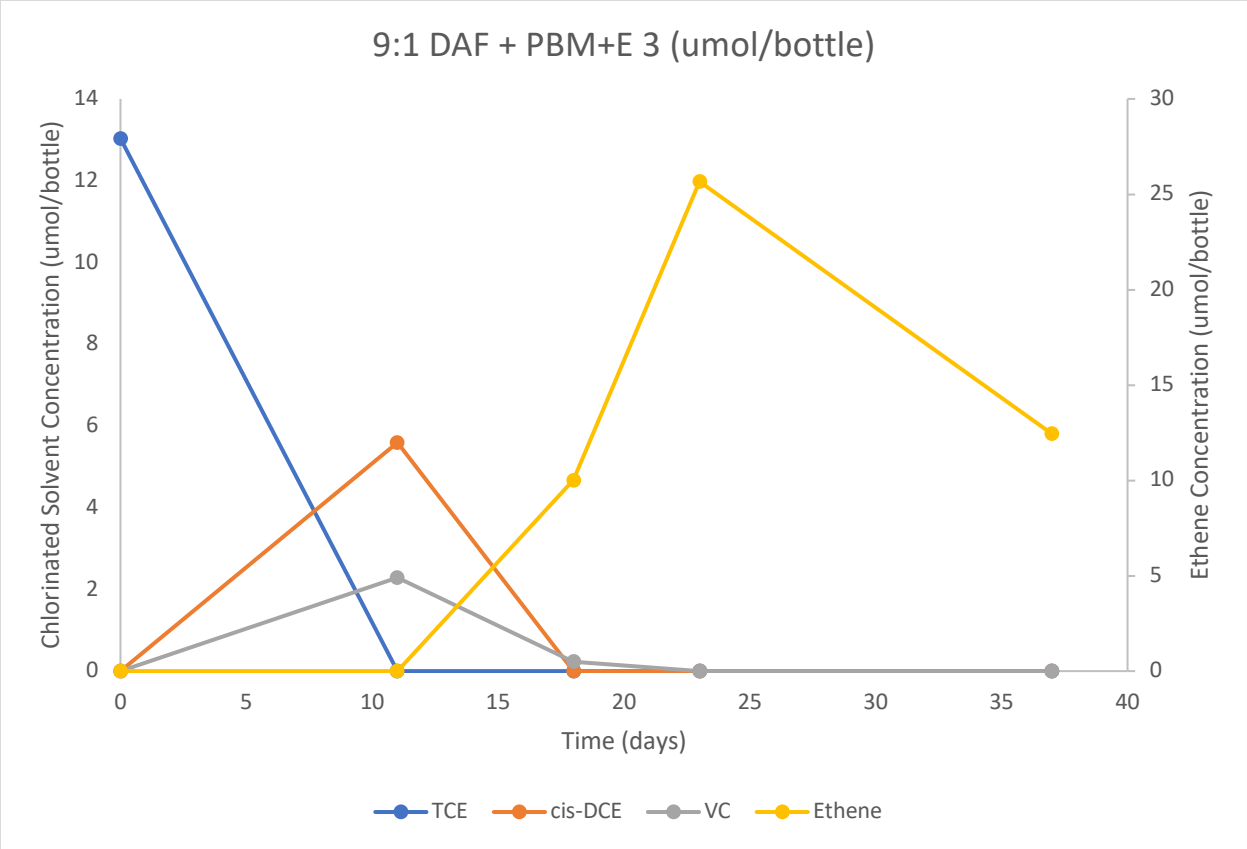
Appendix Figure 255. 500 mg/L 9:1 DAF: TEVB dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



Appendix Figure 256. 500 mg/L 9:1 DAF: PBM+E dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



Appendix Figure 257. 500 mg/L 9:1 DAF: PBM+E dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.



Appendix Figure 258. 500 mg/L 9:1 DAF: PBM+E dosed bottle. Chlorinated solvent concentration over time in co-product ratio optimization experiment with soil collected from Easley, South Carolina.

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