MICROCOSM STUDY OF NATURAL ATTENUATION, BIOSTIMULATION, AND BIOAUGMENTATION OF SOILS CONTAMINATED WITH PCBS, DIOXINS, PAHS, AND PETROLEUM HYDROCARBONS

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ABSTRACT

Microcosm Study of Natural Attenuation, Biostimulation, and Bioaugmentation of Soils Contaminated with PCBs, Dioxins, PAHs, and Petroleum Hydrocarbons

Mackenzie L. Billings

The potential for bioremediation of weathered petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), dioxins, and polychlorinated biphenyls (PCBs) was assessed using laboratory-scale microcosms with contaminated soils from the Santa Susana Field Laboratory (SSFL) in southern California. These contaminants of interest (COIs) have persisted in these soils for over 40 years in some cases. The objective of this United States Department of Energy (DOE)-funded study was to determine the potential of natural attenuation, *in-situ* biostimulation, and/or bioaugmentation remediation methods to reduce COI concentrations in soil and estimate potential biodegradation rates of COIs in SSFL soils.

Several types of soil microcosms were established: one set of microcosms was run without amendments to estimate natural attenuation rates at the site; biostimulation was tested by addition of nitrogen and phosphorus, rice hulls, and/or biosurfactant (soya lecithin), another set was augmented with the white-rot fungus *Phanerochaete chrysosporium*, and gamma-irradiated microcosms served as sterilized controls. Soil samples were collected and analyzed for dioxins, PCBs, PAHs, and extractable fuel hydrocarbons (EFH) after 0, 4, and 8 months of incubation. Soil contamination in the microcosms initially consisted of primarily heavily chlorinated dioxins and PCBs, longer-chain petroleum hydrocarbons (21-40 equivalent carbon chain length), and PAHs with 4-6 aromatic rings.

Small decreases in PAH, PCB, and dioxin soil concentrations were observed, but these decreases were not statistically significant over the time period of the microcosm experiments. EFH concentrations were inflated at the final sampling event, but they appeared to reduce for two of three soils tested at the second sampling (4 months). Because petroleum hydrocarbons were primarily longer-chain hydrocarbons in the C21 to C40 EFH range, it is likely that lighter hydrocarbons had been preferentially degraded, leaving the more recalcitrant longer-chain hydrocarbons in the soil. Larger PAHs (4-6 rings) comprise the majority of residual PAH soil contamination in the soils collected from the field site. These PAH concentrations did not decrease significantly during this 8-month long study; it is likely that these larger PAH compounds are somewhat recalcitrant and will take a long time to biodegrade. Similarly, little or no PCB biodegradation was observed, which is not surprising because the PCBs are heavily chlorinated, and bacterial biodegradation of these highly chlorinated compounds is reported to occur only under anaerobic conditions which were not observed in the field or in microcosms. Dioxin concentrations appeared to decrease in some cases, but these reductions were not statistically significant at the 95% confidence level. The primary dioxin congener present in soils was octachlorodibenzodioxin (OCDD), which is the heaviest-chlorinated dioxin congener. Like PCBs, this compound requires anaerobic conditions for reductive dechlorination, and these are not present at the site. Total dioxin concentrations decreased in the microcosms amended with *Phanerochaete chrysosporium*, although this decrease was not statistically significant due to variability of dioxin concentrations measured in the soil. No decrease in tetrachlorodibenzodioxin

(TCDD) toxicity equivalence (TEQ) was observed with *P. chrysosporium* bioaugmentation, and this parameter is important in terms of dioxin toxicity.

Soil vapor analyses performed at the site indicate highly aerobic soil conditions. To mimic site conditions as closely as possible, experimental microcosms were also maintained under aerobic conditions. Although fungi have been reported to degrade PCBs and dioxins under aerobic conditions, the microcosms augmented with *Phanerochaete chrysosporium* did not show statistically significant biodegradation of PCBs.

Contaminant sequestration in the soil may also have contributed to the lack of observed biodegradation because the COIs at this site are highly weathered. However, even microcosms augmented with a surfactant (soya lecithin), which would be expected to solubilize sequestered COIs, did not show significant biodegradation.

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GLOSSARY

2,3,7,8-TeCDD 2,3,7,8-Tetrachlorodiebnzo-p-dioxin

bgs beneath ground surface

AI North American Aviation's Atomic International

AOC Administrative Order on Consent

COI Contaminant of interest

DD/DF Dibenzodioxins/dibenzofurans

DOE United States Department of Energy

EPA Environmental Protection Agency

EFH Extractable fuel hydrocarbons

ft feet

Heptachlorodibenzo-p-dioxin (HpCDD)

NASA National Aeronautics and Space Administration

OCDD Octachlorodibenzodioxin

PCDD Polychlorinated dibenzo-p-dioxins

PCDF Polychlorinated dibenzofurans

PHCs petroleum hydrocarbons

PAHs polycyclic aromatic hydrocarbons

PCBs polychlorinated biphenyls

SSFL Santa Susana Field Laboratory

STIG Soil Treatability Interest Group

TCDD TEQ Tetrachlorodibenzodioxin toxicity equivalence

TEF Toxic Equivalent Factor

w/w weight by weight

1.0 INTRODUCTION

Santa Susana Field Laboratory (SSFL) is a historic rocket fuel, nuclear reactor, and liquid metals testing site. The Department of Energy (DOE) is one of three parties (Boeing, DOE, and the National Aeronautics and Space Administration, or NASA) responsible for mitigating soil contamination resulting from historic SSFL activities. Contamination includes dioxins, herbicides, metals, petroleum hydrocarbons (PHCs), polycyclic aromatic hydrocarbons (PAHs), perchlorate, pesticides, PCBs, and radionuclides. In 2010, the OE signed an Administrative Order on Consent (AOC) with the California Environmental Protection Agency that requires DOE to reduce contamination levels to background levels specified in a Chemical Look-Up Table (Look-Up Table) provided in a May 21, 2013 technical memorandum by the Department of Toxic Substances Control.

Sandia recommended five soil remediation technologies to assess in future studies: bioremediation, natural attenuation, phytoremediation, soil partitioning, and mercury volatilization. For the bioremediation study, Sandia recommended the following treatment study tasks: determine what biota/microbiota are currently present in Area IV soils; the rate of biologic degradation, if any, for the various contaminants in the affected soils; what nutrients/additives can be used to stimulate/increase native biota/microbiota degradation rates (i.e. biostimulation); and what non-native biota/microbiota could be used to degrade existing contaminants without interfering with native biota.

Following the recommendation of Sandia National Laboratories, this study investigated the rates of biologic degradation of dioxins, PAHs, PCBs, and PHCs observed in laboratory microcosm experiments. Natural attenuation rates were

investigated by incubating two different soils from the site without amendments. Biostimulation was tested on another soil from the site through nutrient, biosurfactant, and bulking agent amendment of soils. Bioaugmentation was explored by amending one set of microcosms with the white-rot fungi *Phanerochaete chrysosporium*, which has been shown to facilitate biodegradation of PCBs and dioxins under aerobic conditions. To observe changes in soil concentrations due to abiotic factors, control microcosms were sterilized using Cobalt-60 gamma irradiation.

Site conditions and soil quality assessments provide indispensable information that can shed light on the biodegradability limitations of contaminants at a given site. These data can be used in conjunction with microcosm sampling data to determine whether or not biodegradation of contaminants is occurring at a given site. Soil temperature and gas data were collected and mimicked during microcosm incubation.

Three different soils were collected from the site, homogenized, and placed in 4-L glass microcosms with amendments. Microcosms consisted of 4-L glass jars sealed with Teflon-lined lids, soil at 15% moisture, and soil amendments. The microcosms were incubated at temperatures representative of the field site under aerobic conditions. Soils were sampled at 0, 126, and 244 days after experiment startup to observe any changes in soil contaminant concentrations. A companion study characterized the microbial communities in SSFL soils and revealed that SSFL soils contain significant populations of microbes that can degrade PHCs aerobically (Croyle 2014). Several strains of fungi were identified which have been reported to mediate cometabolic biodegradation of PAHs, PCBs, and dioxins, but bacteria associated with biodegradation of these compounds were not detected (Croyle 2014).

2.0 BACKGROUND

2.1 Site Background

SSFL was established in 1947 for liquid propulsion rocket engine testing by both the Department of Defense and NASA for the manned-space program. The portion of the site that is of interest in this study, Area IV, was designated for energy research in 1954 by North American Aviation's Atomics International (AI). A 90-acre subarea of Area IV was leased to the Atomic Energy Commission and then to DOE for other research including nuclear energy. This 90-acre subarea came to be known as the Energy Technology Engineering Center (ETEC).

Several chemicals were used to support the research conducted at Area IV, including PCBs in electrical components and hydraulic fluids, fuels to run auxiliary generators and heat water for steam, solvents to clean components, metals such as mercury for energy transfer applications, and silver for photograph development. Waste from transformers, storage tanks, drums in storage areas, and leach fields was combusted onsite which released PCBs, metals, fuels and lubricants, and solvents. These combustion activities and the 2005 Topanga Wildfire also resulted in the generation of dioxins and furans.

The DOE led some of the research conducted in Area IV, and they are now responsible for addressing soil and groundwater contamination resulting from historic research activities. The most recently published estimate of SSFL soil volume with contaminants at levels exceeding the DTSC's Look Up Table (LUT) values is approximately 1,070,220 cubic yards (Collins, Sherwin, and Hambrick 2013).

This bioremediation study was performed in conjunction with natural attenuation, phytoremediation, soil partitioning, and mercury volatilization studies to determine the course of action to best minimize the amount of contaminated requiring excavation and transport to proper disposal. Eventually, DOE would like to turn this site into a park. Although there are several types of contaminants at the site, those addressed in this study include PAHs, PCBs, petroleum hydrocarbons, and dioxins. Groundwater contamination was not addressed in this study.

2.2 Site Contamination Characterization

Extensive site assessment indicates that contaminant concentrations in soil span a wide range (Table 1).

Table 1: Historic Area IV contaminant concentrations vary widely across the site.

Contaminant Type	Contaminant	Low Concentration	High Concentration
TPH (ppm)	Heavy lube oil	170	82,000
	Diesel (31-40 carbons)	5.9	5,100
	Diesel (20-30 carbons)	31	1,300
	Gasoline	3	6.6
	Kerosene (15-20 carbons)	0.44	350
SVOC/PAH (ppb)	SVOC/PAH	6.3	351,600
Dioxins (TCDD TEQ, ppt)	Dioxins	2.68	650
PCBs (ppb)	Aroclor 1242	392	
	Aroclor 1248	34	24,000,000
	Aroclor 1254	19	9,100
	Aroclor 1260	4.2	49,000

There are significantly higher concentrations of longer equivalent carbon chain hydrocarbons than their shorter counterparts (Table 1). This indicates that lighter hydrocarbons have mostly degraded (a preferential substrate to microorganisms). The longer equivalent carbon chain hydrocarbons that are left behind are highly weathered

and likely bound to soil particles, reducing their bioavailability (Smith et al. 2007).

Most of the site's PAH contamination is comprised of compounds with 4-6 aromatic rings (Appendix C, Bar Graphs of Individual PAH Compounds in Soils A, B, and C, illustrates this point). This fact agrees with the majority of papers cited in literature which indicate that PAH degradability becomes more difficult as the number of aromatic rings increases.

PCB contamination consists primarily of heavily chlorinated Aroclor mixtures (Aroclors 1254, 1260, and 5460). These Aroclors are 54%, 60%, and 59% chlorine by weight, respectively. These heavily chlorinated PCB mixtures' dominant presence at the site compared to their lighter chlorinated counterparts and the site's aerobic soil gas data support the well-cited literature hypothesis that more heavily chlorinated PCBs require anaerobic conditions to degrade to lighter-chlorinated compounds. Initial site data indicates that lesser-chlorinated PCBs either were not used at the site or have been aerobically degraded (Appendix D, Bar Graphs of Aroclor Concentrations in Soils A, B, and C), and more heavily chlorinated PCBs remain in soil because of the aerobic conditions. It is unlikely that the site will achieve anaerobic conditions because of the low rainfall in Simi Valley (13.8 inches) (*Simi Valley, CA Weather*) and the soil characteristics. In addition, groundwater at the site is being pumped and treated, eliminating the potential for saturated conditions.

The majority of contamination at the site is composed of the octachlorodibenzodioxin (OCDD) congener, which is the most heavily chlorinated dioxin. The next most common dioxin is 1,2,3,4,6,7,8 heptachlorodibenzo-p-dioxin (HpCDF), but it is present at levels less than 10% of OCDD concentrations soils used in

these experiments (Appendix B, Bar Graphs of Individual Dioxin Congeners in Soils A, B, and C). These two compounds have a fairly low toxic equivalent factor (TEF): OCDD's TEF is 0.0003, and HpCDD's is 0.01 (EPA 2013a). Clearly, individual compounds' TEF and the resulting dioxin toxicity equivalence (TEQ) must be understood when assessing mitigation of site contamination.

2.3 Contaminants

2.3.1 Petroleum Hydrocarbons

Hydrocarbon contaminants are present in the environment in two main forms: aliphatics and aromatics. Aliphatics may be saturated (alkanes), unsaturated (alkenes and/or alkynes), or may form cyclic ring structures. Hydrocarbons containing one or more aromatic ring structures are referred to as aromatic hydrocarbons; some of these are more readily degraded by indigenous microbes than others (Tyagi, da Fonseca, and de Carvalho 2011). Alkanes are typically quickly degraded, while polycyclic aromatic hydrocarbons are very recalcitrant (Van Hamme, Singh, and Ward 2003). Reported efficiencies of biodegradation for soil fungi and bacteria and marine bacteria vary (Table 2):

Table 2: Minimum and maximum biodegradation rates reported for soil and marine organisms

Organism type	Minimum reported biodegradation (%)	Reference	Maximum reported biodegradation (%)	Reference
Soil fungi	6	(Jones, Knight, and Byron 1970)	82	(Pinholt, Struwe, and Kjoller 1979)
Soil bacteria	0.13	(Jones, Knight, and Byron 1970)	50	(Pinholt, Struwe, and Kjoller 1979)
Marine bacteria	0.003	(Hollaway, Faw, and Sizemore 1980)	100	(Mulkins Phillips and Stewart 1974)

It is clear that reported degradation rates vary widely. In addition, because hydrocarbon mixtures in soil and water are complex, mixed populations with broad enzymatic capacities are needed for their degradation (Das and Chandran 2010). Fortunately, several bacteria are known to feed exclusively on hydrocarbons (Yakimov, Timmis, and Golyshin 2007). In particular, *Gordonia, Brevibacterium, Aeromicrobiom, Dietzia, Burkholderia,* and *Mycobacterium* were identified as potential organisms for hydrocarbon degradation when isolated from petroleum-contaminated soil (Chaillan, Fleche, and Bury et al. 2004).

Petroleum hydrocarbon degradation rates are dependent on several environmental factors (Brusseau 1998). A compound's structure and biodegradability are two of the most prominent considerations when assessing remedial options (Das and Chandran 2010). Temperature also plays an important role, affecting pollutant chemistry and microbial physiology and diversity (Das and Chandran 2010). Typically, biodegradation rates decrease as temperature decreases (Das and Chandran 2010). Bartha, Bossert, and Cooney (Bartha and Bossert 1984; Cooney 1984) showed that the highest degradation rates occur at 30-40°C in soil, 20-30°C in some freshwater environments, and 15-20°C in marine environments. In addition, nutrient availability (especially nitrogen, phosphorus,

and even sometimes iron) is essential for hydrocarbon degradation (Cooney 1984). If degradation is nutrient-limited, biodegradation may be impeded. However, excessive nutrients can also be detrimental to degradation (Chaillan et al. 2006). In fact, high NPK levels' detrimental effects on biodegradation are well-cited (Oudot, Merlin, and Pinvidic 1998; Chaineau et al. 2005; Carmichael and Pfaender 1997).

Aerobic conditions offer the most rapid and complete degradation of petroleum

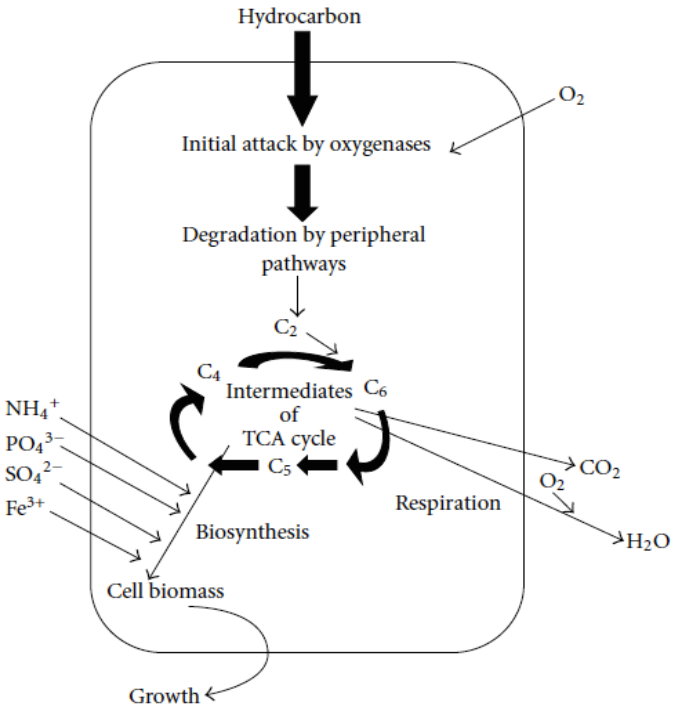

Figure 1: Major hydrocarbon biodegradation pathway (Fritsche and Hofrichter 2000)

hydrocarbons (Das and Chandran 2010). The main mechanism by which hydrocarbons are aerobically degraded is straightforward (Figure 1).

2.3.2 Polycyclic Aromatic Hydrocarbons

PAHs are just one class of aromatic hydrocarbons that contain two or more fused aromatic rings arranged in linear, angular, or cluster formations (Cerniglia 1992). In

general, PAHs are relatively stable, recalcitrant in soils, and notoriously more difficult to degrade than several other organic compounds (Seo, Keum, and Li 2009) They are not easily removed using soil remediation methods that are traditionally used to clean soils contaminated with volatile compounds (Pitter and Chudoba 1990). As the molecular weight of PAHs increases, aqueous solubility and volatility decrease, and PAH recalcitrance increases as a result. There are 16 PAHs identified by the U.S. EPA as priority pollutants, some of which are possible or probable carcinogens (EPA 2013b).

According to Ouvrard et al., a contaminant's availability is the primary factor determining its biodegradability (2013). They conducted a 100-month study assessing the capacity of PAHs to naturally attenuate in loamy sand, loam to sandy loam, sandy clay loam, and sandy loam. Soil type used in this study is significant because these soil types are prevalent at the SSFL site. PAH concentrations in soil ranged from 380 mg/kg to 2,077 mg/kg, and contamination at the site was predominantly 3 and 4 aromatic-ringed compounds typical of weathered contamination from coke origin. Study findings indicate that natural attenuation can be used to remediate PAH-contaminated soils while increasing or preserving soil fertility and biological functions. This suggests that SSFL's soils may be amenable using natural attenuation.

Another factor worth considering when assessing contaminant biodegradability is soil organic carbon content. In fact, PAH compounds' fate and transport in the environment is largely limited by their tendency to sorb to organic carbon. Dissolved organic carbon and water PAH concentrations appeared to be the most relevant factors in PAH degradation rates in one study (Ouvrard et al. 2013). This is likely because the organic composition of soils at a site may act as a long-term PAH sink (Doick and

Semple 2004). Soil organic carbon content should be considered when assessing PAH transport and degradation in the environment.

PAHs are degraded by at least two mechanisms: one uses the cytochrome P-450 system, and the other uses soluble extra-cellular lignin catabolism enzymes (Yadav, Doddapaneni, and Subramanian 2006). These enzymes include lignin peroxidase, manganese peroxidase (Steffen 2003), and laccase (Andreoni et al. 2004). Cometabolism is essential for biodegradation of some high-molecular-weight PAHs that are not used as a sole carbon or energy source. For example, benzo[*a*]pyrene is mineralized by microbial cultures when pyrene, oil, or oil fractions are used as a co-substrate (Baboshin and Golovleva 2012). In addition, a study conducted by Hwang and Cutright indicated pyrene biodegradation was enhanced due to cometabolism in the presence of phenanthrene (Sangchul Hwang and Cutright 2004). In 2001, Yuan et al. also found that phenanthrene enhanced the biodegradation of anthracene, fluorine, and pyrene (Yuan et al. 2001). Boldrin et al. reported that fluorine, a compound that could not be used as a sole carbon source, was cometabolically degraded with other PAHs present as growth substrates (Boldrin, Tiehm, and Fritzsche 1993).

Unlike eukaryotes, bacteria can utilize PAHs as a sole carbon and energy source (Johnsen, Wick, and Harms 2005). Typically, aerobic bacterial systems facilitate dioxegynase-catalyzed oxidation of arenes. Early byproducts created by a multicomponent enzyme system include vicinal *cis*-dihydrodiols that are cleaved by intra or extradiol ring-cleaving dioxygenases through either an *ortho*- or *meta*-cleavage pathway. Central intermediates include protocatechuates and catechols, and they are

converted to tricarboxylic acid cycle intermediates (Cerniglia 1992; Eaton and Chapman 1992; Gibson and Parales 2000).

2.3.3 Polychlorinated Biphenyls

The term PCBs encompasses 209 possible PCB congeners with anywhere from 2-10 chlorine atoms bonded to a biphenyl molecule (Center for Disease Control). PCBs were historically manufactured to be inert, stable, flame-resistant, and oxidation-resistant products and used as coolants and dielectric fluids in electrical equipment. They are hydrophobic and partition to organic particles in the environment. Because of these properties, currents and wind can carry PCBs long distances from their original sources. PCBs' chemical properties made them useful in the electrical industry, but their stability also made them compounds termed persistent organic pollutants by the Environmental Protection Agency (Environmental Protection Agency 2014). They were manufactured and sold as Aroclor mixtures primarily by Monsanto Corporation from 1933 to 1977. Aroclor mixtures are identified by a 4-digit numbering code: the first two digits indicate the mixture type, and the last two digits indicate the approximate chlorine content by weight percent. They were banned in the United States in 1979 and globally in 2001 as their environmental and health effects were better understood (Center for Disease Control).

Because of their significant health risk, cost-effective and sustainable methods of *in-situ* PCBs remediation have long been sought after (Fagervold et al. 2011). Highly chlorinated PCBs like those in Aroclors resist aerobic degradation and must first be partially dechlorinated by anaerobic microbes (Kjellerup et al. 2012).

2.3.3.1 Reductive Dechlorination

Anaerobic dechlorination was first observed as a change in congener patterns downstream of a capacitor plant that released Aroclor 1242 into the Hudson River (Kjellerup et al. 2012). Since then, it has been shown to occur in the environment before aerobic degradation of lesser chlorinated PCB congeners (Waller et al. 2005). During reductive dechlorination, preferential removal of chlorines proceeds from *para* to *meta* to *ortho* position (Tiedje et al. 1993). Over time, this order of preferential degradation leaves a larger proportion of PCBs with chlorines in the *ortho* position. Anaerobic *Dehalococcoides* bacteria have been shown to degrade heavily chlorinated Aroclor 1260; in fact, one study found that the *Dehalococcoides* population nearly doubled in magnitude its presence (Bedard, Ritalahti, and Loffler 2007). Unfortunately, it is unlinkely that *Dehalococcoides* populations do or will ever thrive in SSFL soils under current conditions. Results from two soil gas sampling events suggest that the site is aerobic which would prevent proliferation of anaerobic microbes.

2.3.3.2 Aerobic Oxidative Processes

After anaerobic dechlorination, aerobic degradation of lightly chlorinated PCB occurs. During this process, PCBs are converted to chlorobenzoic acids. Indigenous bacteria can degrade the chlorobenzoic acids, producing carbon dioxide, water, chloride, and biomass (Field and Sierra-Alvarez 2008b).

2.3.3.3 Combining Anaerobic and Aerobic Processes

Some studies have explored the coupling of anaerobic and aerobic PCB dechlorination to accelerate PCB degradation. One such study indicated that a PCB-contaminated sediment in an anaerobic PCB dehalorespiring enrichment that was

transferred into an aerobic culture containing *Burkholderia xenovorans* LB400 effectively degraded Aroclors by as much as 70% (Payne, May, and Sowers 2011). In theory, alternating between anaerobic and aerobic conditions to achieve complete PCB dechlorination is ideal, but all anaerobic-aerobic studies have been conducted in closed microcosms that do not accurately represent *in-situ* conditions (Kjellerup et al. 2012). Soil gas data presented in the Results section 4.1.1 (Site Conditions, Soil Gas Composition) indicates that SSFL is overwhelmingly aerobic and is unlikely to resemble these fluctuating conditions.

2.3.4 Dioxins

Dioxins are introduced to the environment by both natural and industrial processes (i.e. forest fires, waste incineration, and chlorinated phenol production). Chlorinated dioxins are naturally formed through catalysis of the coupling of chlorophenols into dioxins by enzymes such as peroxidase (Oberg and Rappe 1992; Wittsiepe et al. 2000). The term 'chlorinated dioxins' encompasses two families of tricyclic, planar, aromatic compounds. One family is comprised of 75 congeners and is referred to as polychlorinated dibenzo-p-dioxins (PCDD), and the other, polychlorinated dibenzofurans (PCDF), is comprised of 135 congeners. PCDD/Fs are stable, have low volatility, are very hydrophobic, and their low bioavailability is the main reason they persist in the environment. They are quite prone to adsorption onto soils and sediments and bioaccumulation in organisms (Field and Sierra-Alvarez 2008a).

Toxicity of dioxin congeners varies. Those with chlorine atoms in the 2, 3, 7, and 8 positions, such as 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin (2378-TeCDD), are highly toxic to mammals and other organisms (Landers and Bunce 1991; Pohjanvirta and

Tuomisto 1994; Boening 1998). Because only isomers with chlorine groups in the 2, 3, 7, 8 positions are considered toxic to higher organisms, only 17 PCDDs and 10 PCDFs are toxicologically significant (Field and Sierra-Alvarez 2008a).

Studies have produced conflicting results regarding dioxins' biodegradation in soil. The overwhelming consensus is that biodegradation is most often successful for monochloro- or dichloro-congeners which collectively account for 84% of the reported cases of aerobic bacterial chlorinated dioxin degradation (Field and Sierra-Alvarez 2008a). Another microcosm study reported 37-44% reduction of 2,3,7,8-TeCDD when at initial concentrations ranging from 1-100 ppm (Kearney, Woolson, and Ellingto 1972). On a more pessimistic note, one 260-day study indicated no dioxin degradation in soil (Wilson et al. 1997).

In aerobic environments, microbes can aerobically metabolize dioxin by cleaving its aromatic rings. Non-chlorinated and monochlorinated dibenzofurans and dibenzo-p-dioxins can serve as the sole carbon and energy sources for some aerobic bacteria that can completely mineralize the non-chlorinated aryl ring (Wilkes et al. 1996). *Pseudomonas* and *Sphingomonas* have been shown to be the most efficient PCDD oxidizers (Field and Sierra-Alvarez 2008a).

In contrast, di- to tetra-chlorinated congeners are attacked co-metabolically during growth of bacteria on another utilizable substrate. Often, this cometabolism results in accumulation of salicyclic acid or chlorocatechols as intermediates (Habe et al. 2001; Hong et al. 2002). This accumulation can be avoided if the compounds are converted through co-cultivation with a chlorosalicylate-degrading bacteria such as *Burkholderia*

that can degrade the chlorosalicylate excreted by known PCDD/F degraders (Arfmann, Timmis, and Wittich 1997).

Unfortunately, not all dioxins are accessible by bacteria. PCDD/F congeners with greater than five chlorine atoms are most often inaccessible by aerobic bacteria (Urbaniak 2013). This may be due to several factors including low bioavailability, steric hindrance of angular and ring-cleaving dioxygenase by multiple chlorine substituents, and limited active catalytic site space (Wilkes et al. 1996).

Although no single organism has yet to be identified as capable of degrading all dioxins, Fagervold et al. (2011) hypothesized that collaborated actions of different aerobic microbial groups like fungi and bacterial communities that partake in angular hydroxylation and degrade chlorinated monoaromatic compounds can ultimately break down highly chlorinated dioxins. This publication also stated that anaerobic reductive dehalogenation is the only known biological process able to convert PCDD/Fs and speculated that anaerobic bacteria can remove halogen atoms from di- to octachlorinated PCDD/Fs through co-metabolic bacterial activity with unspecific enzymes. Dehalorespiration, is one process in which PCDD/Fs can serve as a terminal electron acceptor.

2.3.4.1 Reductive Dechlorination

Highly chlorinated dioxins can be microbially degraded through anaerobic reductive dechlorination (Johnson et al. 2008). During anaerobic reductive dechlorination, a chlorine atom is removed and replaced with a hydrogen atom. *Dehalococcoides* save energy during dechlorination by using chlorinated compounds as terminal electron acceptors. The rate of dechlorination depends on the degree of

chlorination; as the number of chlorines increases, the dechlorination rate decreases. Complete dechlorination by bacteria has yet to be observed (Johnson et al. 2008).

2.3.4.2 Angular Dioxygenation

Once dibenzo-p-dioxin and dibenzofuran are dechlorinated, they may be degraded aerobically via angular dioxygenation (Johnson et al. 2008). Angular dioxygenase catalyzes dibenzo-p-dioxin and dibenzofuran degradation by oxidizing one oxygen-bonded carbon and its adjacent carbon. Dibenzofuran and dibenzo-p-dioxin are spontaneously converted to 2,2',3-Trihydroxybiphenyl and 2,2',3-Trihydroxydiphenyl ether, respectively (Nojiri, Habe, and Omori 2001). Dibenzofurans are then cleaved at the *meta* position and converted to salicylic acid or 2-Hydroxypenta-2,4-dienoic acid via hydrolysis. For dibenzo-p-dioxins, angular dioxygenation may be followed by either *meta* or *ortho* cleavage followed by spontaneous conversion to either a catechol or 2-pyrone-6-carboxylate (Nojiri, Habe, and Omori 2001). If degradation proceeds to completion, compounds react with one or more enzymes, are eventually metabolized by aerobic respiration, and produce cell biomass, carbon dioxide, and water.

2.4 Bioremediation Technologies

2.4.1 Monitored Natural Attenuation

Monitored natural attenuation (MNA) is used to monitor or test the progress of natural attenuation processes that can degrade contaminants in soil and groundwater. It is useful if degradation rates are fast enough to protect both human health and the environment (US EPA 2013).

In some cases, natural attenuation is as effective as more complex bioremediation technologies. Couto et al. conducted a study in 2010 that showed natural attenuation was as efficient as bioaugmentation, surfactant addition, and nutrient supplementation at remediating turbine oil-contaminated soils (Couto, Monteiro, and Vasconcelos 2010). Soil aeration did not have a significant effect on biodegradation rates either. Couto et al. contributed this to the fact that the petroleum hydrocarbon contamination was old, and native microorganisms were able to efficiently degrade the contaminants present. This is promising for SSFL because site contamination is decades old and native microbes may already be able to degrade the contaminants present.

A companion study characterized SSFL's microbial communities consist of significant populations of microbes that can aerobically degrade PHCs (Croyle 2014). No bacteria associated with biodegradation of PAHs, PCBs, and dioxins were detected, but several strains of fungi reported to mediate cometabolic biodegradation of these compounds were identified (Croyle 2014).

2.4.2 Biostimulation

The term biostimulation umbrellas several remedial technologies used to enhance biodegradation in the field by supplementing soils with growth substrates/co-substrates. Popular biostimulation agents include bulking agents, nutrient supplementation, halogenated priming compounds (halopriming), and surfactants (Rastegarzadeh, Nelson, and Ririe 2006; Richardson et al. 2012; Harkness et al. 1993; Couto, Monteiro, and Vasconcelos 2010; Krumins et al. 2009; Lawniczak, Marecik, and Chrzanowski 2013; Mukherjee and Das 2010; Mulligan, Yong, and Gibbs 2001; Neu 1996; P. K. S. M. Rahman and Gakpe 2008; Rust and Wildes 2008; Fava et al. 2004; Kobayashi et al. 2012;

Llado et al. 2013; Providenti et al. 1995; Tiehm et al. 1997a; Soeder et al. 1996; Rodriguez-Escales et al. 2013; Aronstein and Paterek 1995; Yong-lei et al. 2011; Viisimaa et al. 2013; Inakollu, Hung, and Shreve 2004; Whang et al. 2009; K. S. M. Rahman et al. 2002; Gorna et al. 2011).

Addition of bulking agents promotes aeration of soils (Rastegarzadeh, Nelson, and Ririe 2006). One such bulking agent is rice hulls. For example, Rastergarzadeh et al. added rice hulls at 10% w/w 1:1 mixture of soil:drill cuttings. Unamended soils experienced biodegradation of TPH to 91% from 24% degradation without rice hulls 4 months.

Nutrient supplementation can be a very effective stimulation method when biodegradation of contaminants is nutrient-limited. A review of the literature indicated that nutrient supplementation effectively enhances biodegradation of PCBs (lightly chlorinated congeners), petroleum hydrocarbons, and PAHs (Harkness et al. 1993; Couto, Monteiro, and Vasconcelos 2010; Richardson et al. 2012). However, even if a carbon source is readily available, microbial growth may be inhibited by limited microelement availability (Lawniczak, Marecik, and Chrzanowski 2013).

Halopriming, a method by which halogenated compounds are added to soils already contaminated with halogenated compounds, has been shown to improve bioremediation of PCBs. Through addition of pentachloronitrobenzene to PCB-contaminated soils, concentrations of lesser-chlorinated PCB congeners (2-4 chlorines per biphenyl) increased by 20 ± 1.9% after 415 days of incubation (Krumins et al. 2009).

2.4.3 Bioaugmentation

Bioaugmentation involves the addition of microorganisms known to biodegrade one or more of the contaminants of concern (COCs) present at a site. Several microorgansims have been cited in the literature as known degraders of compounds at SSFL. More specifically, several species of white-rot fungi have been shown to degrade multiple contaminants found at the site. White-rot fungi are a promising class of fungi that have been shown to degrade the recalcitrant compounds found at SSFL. For example, Takada et al. conducted the first study of its kind in which results indicated that a microorganism, *Phanerochaete sordida* substantially degraded both tetra- to octa-chlorodibenzo-p-dioxins (PCDDs) and tetra- to octa-chlorodibenzofurans (PCDFs) (1996). Dechlorination of molecules chlorinated at 2-, 3-, 7-, and 8-positions was significant: tetrachloro and hexachloro PCDDs were degraded at approximately 40% and 76%, respectively; tetrachloro and hexachloro PCDFs were degraded at 45% and 70%, respectively. *Pleurotus ostreatus*, another white-rot fungus, degraded PCBs in a study using wood chip as the primary fungus growth substrate (Zeddel et al.1993). After five weeks, a PCB-congener mixture of primarily tri- and tetra-chlorinated biphenyls at 2500 ppm was degraded more than 95%. Penta- and hexa-chlorobiphenyls were found to be degradable by 50%, and the only congener resistant to degradation was 2,2',4,2',5,5'-hexachlorobiphenyl. Unfortunately, the same study indicated that *Phanerochaete chrysosporium* was unable to degrade any PCBs except mono- and di-chlorobiphenyl at atmospheric oxygen levels.

Fungi show promise in their abilities to degrade SSFL contaminants, but bacteria have also been shown to degrade PCBs. *In-situ* treatment of PCB-contaminated soils has

not been shown to be successful in many studies, but a few promising study indicates that it may be possible through bioaugmentation with dehalogenating organisms. One study concluded that a critical cell mass was required for reductive dechlorination of Aroclor 1260; study authors proposed that low populations of dehalorespiring bacteria might be the root cause of insubstantial PCB degradation in the environment (Bedard, Ritalahti, and Loffler 2007). Another study indicated that bioaugmentation with *D. ethenogenes* and stimulation with haloprimers pentachloronitrobenzene and tetrachlorobenzene effectively accelerated PCB degradation, while stimulation with electron donors did not (Krumins et al. 2009).

Total penta-chlorinated and higher chlorinated PCBs were reduced by 56% by mass in open mesocosms containing weathered Aroclor 1260 at 1.3 ppm (Payne, May, and Sowers 2011). This was done through augmentation with *D. chlorocoercia* DF1. *D. chlorocoercia* was sustained within the local microflora population within 120 days of initial inoculation, meaning that initial bioaugmentation may lead to self-sustaining a remedial method in the field.

One study indicated that the collaborated use of the bacteria *Sphingomonas sp.* and *Pseudomonas sp.* increased degradation rates of PCBs to exceed those of the organisms individually, and degradation of more highly chlorinated PCBs was enhanced (Yong-lei et al. 2011).

Consideration should be taken prior to amending soils with foreign microorganisms, though. One study showed that antagonistic effects were observed for native soil microbiota when PAH-contaminated soils were augmented with non-native white-rot fungi (Llado et al. 2013).

Bioaugmentation can also be used to accelerate degradation of dioxins in soil. In particular, white-rot fungi have been shown to degrade several low to highly chlorinated dibenzo-p-dioxins (Takada et al. 1996). Takada et al. compared the percent degradation of tetra- to octa-chlorinated dibenzo-p-dioxins and dibenzofurans by glucose-supplemented *P. chrysosporium* and *P. sordida*. Glucose-supplemented *P. chrysosporium* consistently degraded all congeners but 2, 3, 7, 8, TeCDF more efficiently than *P. sordida* at rates ranging from 27.3 to 64.9% over 7 days. *P. sordida*'s degradation rates of the same contaminants ranged from 14.2 to 50.4% in the same time period. *P. sordida*'s ability to degrade tetra- and octa-chlorinated dibenzo-p-dioxins was supported by identification of a corresponding metabolite from the contaminants. This is significant for environmental contamination because it typically consists of multiple dioxin congeners. Takada et al. also stated that both *P. sordida* and *P. chrysosporium* showed no structural dependence for PCDD/F degradation and that it may be a free-radical process with little specificity. Degradation by the free-radical process may be more favorable in the presence of the oxygen molecule on PCDD/Fs: unlike the little specificity outlined in Takada et al.'s article outlining PCDD/F degradation, Yadav et al. showed in 1995 that PCB (biphenyl molecules lack the oxygen molecules that dioxins and furans contain) degradation becomes more difficult with increasing number of chlorine substitutions around the biphenyl nucleus.

A review conducted by Habe et al. indicates that 32-100% of mono- to tri-chloro-dibenzodioxins/dibenzofurans (DD/DF) at concentrations of 1 – 10 ppm in artificially contaminated soils were degraded in one week by bacterial strains added to soils (Habe et

al. 2001). Actual contaminated soils that were inoculated with dioxin-degrading bacteria resulted in 8.3-10% removal of dioxins after the same incubation time.

The success of bioaugmentation in degrading petroleum hydrocarbons has also been fairly successful. Although one study indicated that biostimulation was more effective than bioaugmentation (Abdulsalam et al. 2011). Again, bioaugmentation proved the most effective remediation method for diesel-contaminated soil in a study using *Rhodococcus sp. EH831* (Lee, Kang, and Cho 2011). In another study, bioaugmentation resulted in biodegradation rates two to four times higher than intrinsic biodegradation rates (Malina and Zawierucha 2007). In this study, application of indigenous bacteria resulted in more efficient degradation than that of an exogenous culture.

Bioaugmentation has produced mixed results for PAH degradation as well. In one study, bioaugmentation increased biodegradation of pyrene and phenanthrene by 68% and 86%, respectively, in aged soils compared to biostimulation (S. Hwang and Cutright 2002). Another study indicated that native soil microbiota hampered augmented microorganisms' growth in petroleum hydrocarbon and high-molecular weight PAH-contaminated soil (Llado et al. 2013).

2.4.4 Surfactant Addition

Surfactants are molecules that can increase bioavailability of hydrophobic and/or recalcitrant compounds that are embedded in the soil matrix. They work by increasing compounds' solubility in the aqueous phase (Lawniczak, Marecik, and Chrzanowski 2013; Inakollu, Hung, and Shreve 2004; Whang et al. 2009). They may also change cell membrane properties and increase microbial adherence, increasing the likelihood of

direct substrate uptake when two immiscible phases are present (Neu 1996; Franzetti et al. 2009). As amphiphilic compounds, surfactants tend to deposit at the oil/water interface (Lawniczak, Marecik, and Chrzanowski 2013). The hydrophobic and lipopholic components of biosurfactant molecules are easily distinguishable and vital to their contribution to bioremediation.

Both synthetic (petrochemical) and natural (oleochemical) surfactant sources are available. Primary petrochemical surfactant feedstocks are crude oil derivatives such as ethylene and benzene. Typical oleochemical surfactant feedstocks are seed oils (palm, soybean, and coconut oils), but plant carbohydrates and animal fats may be used as well. There are four types of surfactants available: anionic, nonionic, cationic, and amphoteric. The largest group, anionic surfactants, has superior wetting and emulsifying properties and tends to be constituted of higher-foaming materials (Rust and Wildes 2008). Nonionic surfactants are known to be the least toxic. Amphoteric surfactants behave as either mild cationic or anionic surfactants depending on pH (Rust and Wildes 2008).

Biosurfactants are known to rival their synthetic counterparts' efficiency while being more biodegradable and less toxic to contaminant-degrading microorganisms (Lawniczak, Marecik, and Chrzanowski 2013). They may either be added to soils externally (most common) or produced on-site. For on-site production, soils must either contain or be augmented with microorganisms capable of biosurfactant production (Lawniczak, Marecik, and Chrzanowski 2013).

Some types of biosurfactants have become more popular than others. For example, rhamnolipids often serve as a model biosurfactant for experiments (Rahman et al. 2002). Use of rhamnolipid surfactants has accelerated degradation of petroleum

hydrocarbons (Inakollu, Hung, and Shreve 2004). It is important to note that Inakollu et al.'s study indicated that the use of biosurfactants enhanced biodegradation of all hydrocarbons except phenanthrene and naphthalene, perhaps because surfactant solubilization is influenced by contaminant molecular size and structure.

The largest volume of soy-based surfactants is constituted by soy lecithin, an anionic surfactant (Rust and Wildes 2008). It has been shown to improve biodegradation of both PCBs and PAH (Fava et al. 2004; Soeder et al. 1996).

Perhaps the most important considerations to take into account when applying biosurfactants for bioremediation of contaminants include bio-compatibility between the pollutants, microorganisms, and biosurfactants. Native microflora may also impact *in-situ* biosurfactant treatment. Rhamnolipids can sometimes be biodegraded preferentially over contaminants (Chrzanowski et al. 2012). For example, Lin et al. (2011) showed initial enhanced biodegradation diesel oil through addition of biosurfactants, but the biodegradation rate in latter stages of the study was similar to that in the absence of biosurfactants. In this study, hydrocarbon availability was likely the limiting factor in the beginning of the degradation process. Degradation in the later stage was likely limited by desorption and mass transfer of hydrocarbon in the soil matrix (Lin et al. 2011), or they may simply serve as an alternative carbon source (an undesired outcome if metabolized before target contaminants). One way to solve this issue is to apply microorganisms that do not preferentially degrade biosurfactants, a trait commonly observed in biosurfactant producers (Providenti et al. 1995).

Biological and chemical surfactants are very promising remedial amendments for PCB-contaminated soils: addition of biological and chemical surfactants resulted in 47-

50% PCB removal in one study (Viisimaa et al. 2013), biosurfactant amendment reduced concentrations of hexa- to nona-chlorinated congeners by 10-20% in another study (with no significant change in overall PCB concentrations) , and the biosurfactant soya lecithin, specifically, resulted in 40% degradation of all PCBs in one year (Federici et al. 2012).

Literature review yielded no published studies in which biosurfactant was used for remediation of soils contaminated with dioxins.

Surfactants have also been confirmed to enhance mobilization and biodegradation of PAHs in soils (Tiehm et al. 1997b). Some nonionic surfactants were able to enhance degradation of naphthalene and phenanthrene as observed by Aronstein et al (1991).

Before surfactants are applied in the field, several factors must be considered: cost, effectiveness at low concentrations (generally less than 3%), low toxicity, low adsorption to soil, low soil dispersion, and low surface tension. All of these factors shold be considered prior to surfactant selection (Mulligan, Yong, and Gibbs 2001).

2.4.5 Combined Treatments

Biostimulation and bioaugmentation can be combined with each other and other technologies to successfully accelerate contaminant degradation even more than for one treatment alone. For example, one study assessed both bioaugmentation and biostimulation (with 1,2,3,4-tetrachlorobenzene and 2',3',4'-trichloroacetophenone) to accelerate dechlorination of PCDDs (Bedard, Ritalahti, and Loffler 2007). Using denaturing gradient gel electrophoresis, this study found that sites with more contamination were associated with more indigenous dechlorinators. Interestingly, biostimulation and bioaugmentation did not greatly enhance dechlorination at heavily contaminated sites, but it did at less contaminated sites. Another study indicated that the

combination of biostimulation and bioaugmentation in a silty-loam soil with 60,600 mg kg^{-1} of a complex mixture of TPH (comprised of 40% aliphatic hydrocarbons and 21% PAHs) was more effective than biostimulation alone (Mancera-López et al. 2008). In this study, *Rhizopus sp.*, *Penicillium funiculosum* and *Aspergillus sydowii* resulted in 36%, 30% and 17% more PAH compared to biostimulation alone, respectively. Another 120-day study indicated that a combined treatment using biostimulation, biosurfactant, and bioaugmentation resulted in the highest hydrocarbon degradation rate of the five treatments assessed (biostimulation, biosurfactant addition, bioaugmentation, natural attenuation, and the combined treatment) (Bento et al. 2005). Similar results were obtained in another study where bioaugmentation combined with nutrient and surfactant amendments resulted in 50% TPH degradation, while natural attenuation resulted in just 30% TPH degradation (Couto, Monteiro, and Vasconcelos 2010).

3.0 METHODS

3.1 Soil Sampling Site Selection and Prescreening Soil Collection

Soils used in the microcosm study were collected from SSFL on January 16, 2014. To choose soil collection locations, historical COI concentration data was analyzed with the following considerations in mind:

- Soils needed to be contaminated with moderate COI concentrations, meaning contaminant concentrations fell within a range determined using best professional judgment (Table 3):
- Soils needed to have minimal concentrations of metals to prevent potential toxicity to microbes, and
- Ideally, all soil collection sites would be in historic site drainages to maximize soil homogeneity. Two of the three sampling locations were within historic drainages (Drainage East of 4015 Field and 17th Street Pond and Drainage).

Table 3: Total target soil contaminant concentrations

Contaminant	Total concentration
EFH	44,000 mg/kg
PAHs	300,000 µg/kg
PCBs	500,000 µg/kg
Dioxins	100,000,000 ng/kg

Once potential soil collection sites were identified, the sites were prescreened for total organic vapors using a calibrated photoionization detector. Background readings were recorded prior to the start of sampling, and additional readings were taken during

sampling. Collection sites were also prescreened for residual radiation using a MicroR gamma detector and Dual Phosphor Alpha Scintillator (alpha/beta detector). Gamma, alpha, and beta measurements were collected approximately 0.5-1 inch above the ground surface of the sample area. Measurements were taken for at least one minute. Once sites were determined to be free of radiation, pre-screening soil samples were also collected to ensure that treatability study samples were not taken from soils with COI concentrations exceeding federal or state regulatory levels for hazardous wastes and to compare actual soil concentrations to target concentrations. Soil sample collection was conducted by Hazardous Waste Operations and Emergency Response (HAZWOPER)-certified field personnel per 29 CFR 1910.120. Once soil samples were collected and analyzed, data was analyzed to determine whether or not contaminant concentrations at the selected locations met the aforementioned criteria. Based on analysis of prescreening soil samples, COI concentrations were lower than target values, so other locations were selected for soil collection.

3.2 Bulk Soil Sample Collection

During soil collection, 68 kg of soil was collected from historic sampling sites 5C_DG-516, 5C_DG-755, and PUBS1044. Soils were collected using stainless steel shovels and placed in Teflon-lined 5-gallon buckets for transport to Cal Poly (Figures 2 and 3).

A total of 68 kg of soil was collected from the following locations (Figure 4):

- 52 kg were collected from 4-5.5 feet (ft) beneath ground surface (bgs) at 5C_DG-516 (“Soil A”),
- 8 kg were collected from 1-4 ft bgs at PUBS1044 (“Soil B”), and

- 8 kg from 1-4 ft bgs at 5C_DG-755 (“Soil C”).

Soil gas data and soil temperature were collected from the site in the summer of 2014. Soil properties including total organic carbon (TOC), total nitrogen, pH, and moisture were also measured and recorded during the first and second microcosm sampling events.

Figure 2: Stainless steel shovels and bulk soil collection buckets (Teflon liners not shown)

Figure 3: Organic vapor and radiation levels were monitored throughout sample collection

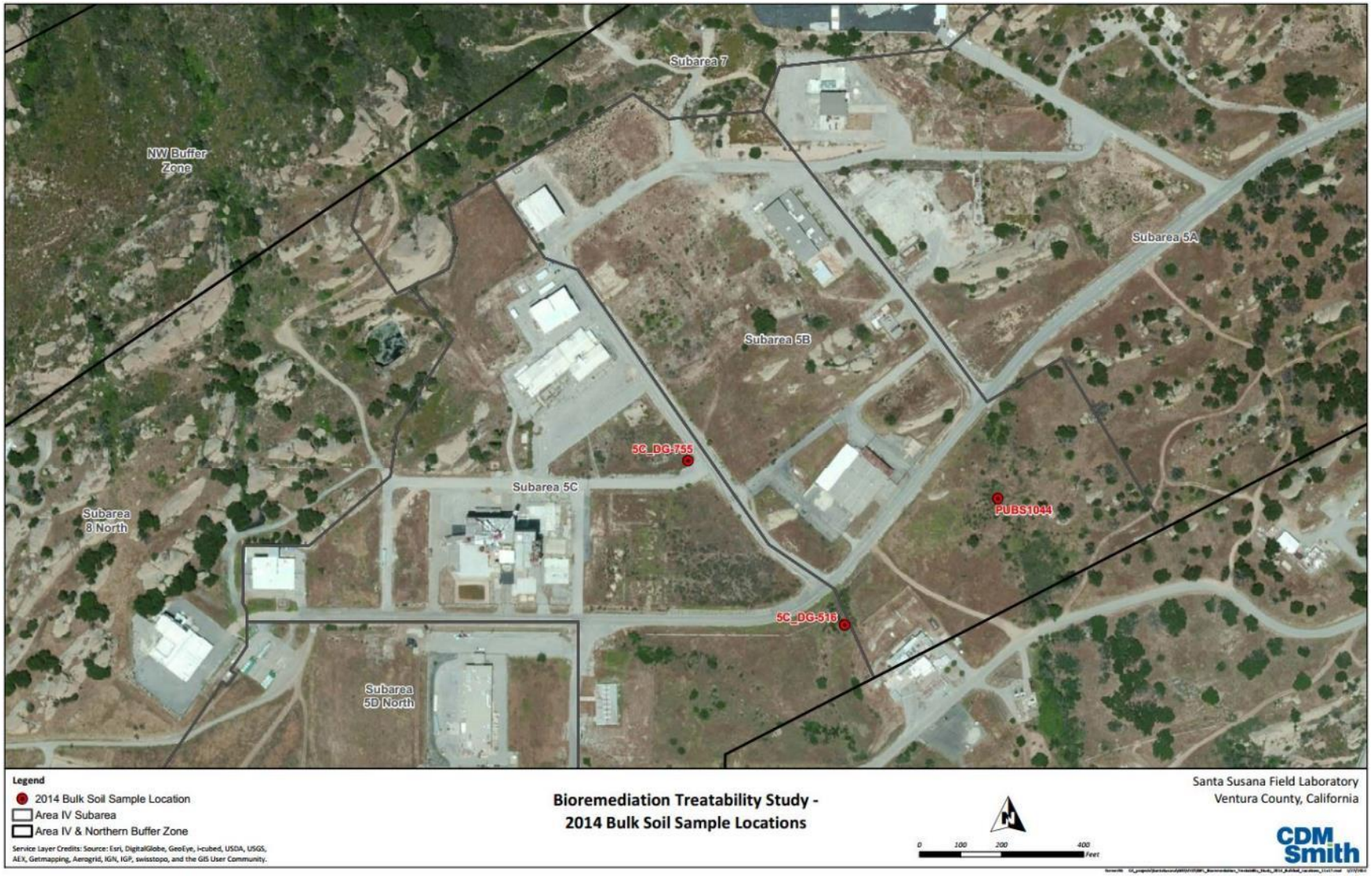

Figure 4: Bulk Soil Sample Collection Locations

3.3 Soil Processing

Soils collected from the aforementioned locations were sieved through a No. 4 sieve (4.76 mm) (Figure 5). After sieving, soil was homogenized in 5-gallon increments in an acid-washed (10% weight by weight, w/w, HNO_3 solution followed by triple-rinsing with DI water) 10-gallon UNS S30400 stainless steel drum. Soils were rolled in a well-ventilated area for five minutes and replaced in their respective Teflon-lined 5-gallon buckets. The drum was rinsed and air-dried between uses.

Figure 5: Soil sieving

After sieving and homogenization, soil moisture of soils from all three sampling sites was determined using ASTM International Method D2216 (*ASTM Standard D2216, "Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass"* 2010). Soil samples were placed in a clean, dry, labeled container. A balance was used to determine the mass of the moist soil and container. This value was recorded. The moist soil was then placed in a drying oven at 105° overnight. Once dry, the soil was removed from the oven and reweighed using the same balance. This oven-dried mass was recorded and used to determine the water content of the sample. Water content was used to determine the amount of water required to amend soils to 15% w/w water content.

3.4 Microcosm Preparation

In total, 45 4-L Fisher Scientific™ glass jars and the Teflon™-lined lids to be used in the experiment were acid washed in a 10% w/w nitric acid solution composed of nitric acid and milli-Q water. The 45 jars and lids were then triple rinsed in milliQ water and air dried.

Following soil homogenization (outlined above), 1.4 kilograms (kg) of soil was placed in each 4-L acid-washed glass jar. Amendments were added to microcosms as described in Table 4 and thoroughly mixed using a stainless steel spatula.

Amendments were added to each microcosm as shown in Table 3, and the moisture content was adjusted to 15%. Based on results of soil moisture testing, moisture content was adjusted to the desired water content of 15% w/w. After moisture and amendments were added to each microcosm, they were thoroughly mixed with a stainless steel trowel, sealed with a Teflon-lined lid, and shaken to evenly distribute soil.

Five of the microcosms containing soil from collection location 5C_DG-516 and milliQ water (for 15% moisture) were transported to Sterigenics, a sterilization facility, located in Gilroy, California. Microcosms were dosed with 25 kilograys using Cobalt-60 irradiation to ensure adequate sterilization (Abo-El-Seoud et al. 2004).

Table 4: Microcosm soil locations and sampling frequency (5 replicates per Microcosm ID)

Microcosm ID	Description	Amendments	Abbreviation	Amount Amendment Added	Sterile?	Collection Location	Sampling Times
A1	Fertilized	Nutrient solution	NUTRIENT	0.1g KH_2PO_4 0.015g $MgSO_4 \cdot 7H2O$ 0.02g $CaCl_2 \cdot 2H_2O$ 0.29g $NaNO_3$	No	5C_DG-516	0, 4, 8 mos.
A2	Surfactant	Soya lecithin	SURFACT	1.5% w/w	No	5C_DG-516	0, 4, 8 mos.
A3	Bulking agent	Rice hulls	RICEHULL	10% w/w	No	5C_DG-516	0, 4, 8 mos.
A4	Bioaugmented	Rice hulls, Nutrient solution, Malt extract, *P. chrysosporium*	BIOAUGM	10% w/w rice hulls 0.1g KH_2PO_4 0.015g $MgSO_4 \cdot 7H2O$ 0.02g $CaCl_2 \cdot 2H_2O$ 0.29g $NaNO_3$ 0.15g malt extract *P. chrysosporium*	No	5C_DG-516	0, 4, 8 mos.
A5	Combined Amendments	Rice hulls, Nutrient solution, Malt extract, *P. chrysosporium*, Soya lecithin	COMB	10% w/w rice hulls 0.1g KH_2PO_4 0.015g $MgSO_4 \cdot 7H2O$ 0.02g $CaCl_2 \cdot 2H_2O$ 0.29g $NaNO_3$ 0.15g malt extract *P. chrysosporium* 1.5% soya lecithin	No	5C_DG-516	0, 4, 8 mos.
A6	Unamended A	None	UNAMENDA	None	No`	5C_DG-516	0, 4, 8 mos.
A7	Sterilized	Gamma irradiation	STERILE	25 kilograys of gamma irradiation	Yes	5C_DG-516	0 and 8 mos.
B6	Unamended B	None	UNAMENDB	None	No	PUBS1044	0, 4, 8 mos.
C6	Unamended C	None	UNAMENDC	None	No	5C_DG-755	0, 4, 8 mos.

3.5 Microcosm Incubation

Microcosms were incubated in a U-Line stainless steel cabinet lined with polyisocyanurate foam board insulation. Temperature was kept constant in this cabinet using a temperature-controlled water bath with tubing routed throughout the shelving. Microcosm temperature was measured and recorded weekly using a HDE high accuracy non-contact Fluke infrared IR thermometer gun with laser sight. Soil temperature was also measured and recorded directly with a standard thermometer in an extra microcosm that contained no amendments. This temperature reading confirmed that the infrared thermometer's measurements were representative of actual soil temperature.

3.6 Sample Collection and Analysis

Samples were collected from each microcosm at experiment startup and 126 and

Figure 6: Soil sample processing: labeling and completing the chain of custodv

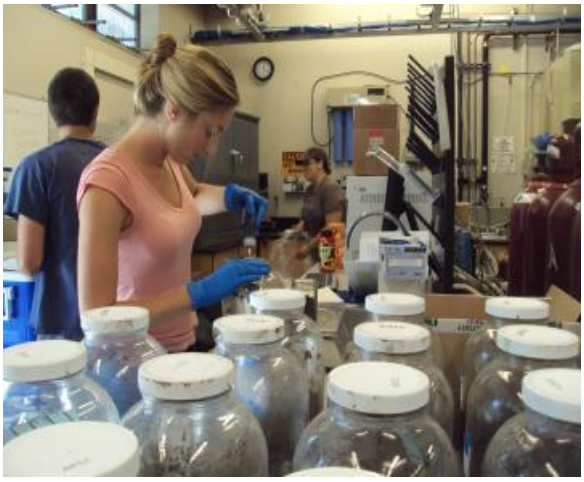

Figure 7: Soil sample collection

244 days after the start of incubation (Figures 6 and 7). Sampling was conducted using a stainless steel shovel that was washed with Alconox and triple-rinsed with ASTM Type II Water (reagent grade water defined by American Standards for Testing and Measurements that is used in the final rinse of surfaces of contaminated equipment) between microcosm types. Table 3 describes experimental design and sampling frequency. All non-disposable sampling equipment used was decontaminated using a decontamination line that progressed from "dirty" to"clean" (equipment entered the decontamination line as dirty and exited as clean). The line consisted of three buckets: one for scrubbing Alconox solution on the equipment with a stiff bristle brush (to remove particulate matter and surface films), one for rinsing off dirt and Alconox with ASTM Type II Water. Equipment was not set down between decontamination and sample collection. If there was a break in sampling, equipment was decontaminated prior to resuming sampling activities. Any equipment that was not reusable was stored for disposal after all sampling activities were complete. At the end of sampling activities, all laboratory-derived waste was collected, labeled as such, and transported back to SSFL for proper disposal.

Samples were transported to EMAX and Lancaster laboratories for analysis using analytical methods listed in Table 4.

Table 5: Analytical methods used for soil sample analysis

Analyte	Analytical Methods for Soil	Laboratory (sampling date)
PCBs	EPA Method 8082A Gas Chromatograph/Electron Capture Detector	EMAX (0, 126 days) Lancaster (244 days)
Dioxins	EPA Method 1613B Gas Chromatograph/High Resolution Mass Spectroscopy	Lancaster (0, 126, 244 days)
PAHs	EPA Method 8270C/D SIM Gas Chromatograph/High Resolution Mass Spectroscopy	EMAX (0, 126 days) Lancaster (244 days)
TPH	EPA Method 8015B/C/D Gas Chromatograph/Flame Ionization Detector	EMAX (0, 126 days) Lancaster (244 days)
Metals	EPA Method 6010C/6020A/7471B Inductively Coupled Plasma-Atomic Emission Spectrometry, Inductively Coupled Plasma-Mass Spectrometry Mercury in Solid or Semisolid Waste (Manual Cold-Vapor Technique)	EMAX (0, 126 days)
Mercury	Cold vapor atomic absorption spectroscopy EPA Method 7471B	EMAX (0, 126 days)
Percent Moisture	ASTM D2216 Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass	Lancaster (0, 126, 244 days)
Nitrogen	ASTM D5373 Standard Test Methods for Determination of Carbon, Hydrogen and Nitrogen in Analysis Samples of Coal and Carbon in Analysis Samples of Coal and Coke	Lancaster (0, 126 days)
Organic Carbon	SM 5310B Total Organic Carbon	Lancaster (0, 126 days

3.7 Data Analysis

Following sample collection and soil analysis, the resulting data were checked for quality control by CDM personnel. Statistical analyses were performed using Minitab. Average, standard deviation, and standard error of contaminant concentrations (both

summations of individual compounds within a contaminant type and individual compounds) were calculated. Any lab data with a "U" qualifier was assumed to be nondetect, and the chemical concentration was assumed to be zero.

3.8 Statistical Analysis

Statistical analysis of data included a general linear model with the response variable being either chemical concentration, log(concentration), or the square root of concentration. The log(concentration) and square root of concentration were calculated in an attempt to normalize data if fanning of residuals was observed. The general linear model used for this analysis analyzed the statistical significance of treatment's effect on contaminant concentration at the three different sampling events. Residual plots provided a helpful visual representation of data normality. The general linear model was used to compare three different sets of data:

- Effect of treatment on changes in contaminant concentrations in soil A
- Effect of gamma irradiation on changes in contaminant concentrations in soil A (using only beginning and end time points to include gamma irradiated samples were not analyzed at the sampling midpoint), and
- Effect of different soil type (A, B, or C) on changes in contaminant concentrations over time.

4.0 RESULTS AND DISCUSSION

This chapter describes first the site conditions (Section 4.1) and then the results of the microcosm experiments (Section 4.2). Characterization of the soil collected for the microcosms is described in the beginning of Section 4.2 (4.2.1).

4.1 Site Conditions

4.1.1 Soil Gas Composition

Soil gas data collected in June and July of 2014 indicate that average oxygen concentrations at 1-foot intervals in soil vapor ranged from 10.1% to 20.0%, and the lowest average concentration was detected at 20-21 feet below ground surface (bgs) (Table 5; raw data is presented in Appendix L). The fact that oxygen is available as a terminal electron acceptor down to the deepest sampling point (20 ft bgs) indicates that aerobic conditions prevail and it is unlikely that there are any anaerobic subsurface conditions at the test sites. There could however be small anaerobic zones on soil particles, but it is unlikely that conditions are favorable for much reductive dehalogenation of chlorinated compounds present at the site.

The maximum carbon dioxide concentration (6.3%) was detected at 20 ft bgs. The high carbon dioxide concentrations are an indicator of extensive biological respiration – either of contaminants or natural organic material.

Table 6: June 2014 Soil Gas Data

Depth Interval (ft bgs)	Carbon Dioxide (%)		Oxygen (%)	
	Average	Standard Deviation	Average	Standard Deviation
5-6	1.8	2.4	18.3	3.5
6-7	2.0	1.5	16.9	5.0
7-8	2.1	1.4	17.4	3.9
8-9	1.5	1.4	18.4	1.2
9-10	2.9	2.5	17.2	3.3
10-11	3.0	3.2	15.5	6.2
11-12	2.5	1.7	17.5	1.6
12-13	3.2	2.2	13.9	8.1
13-14	1.2	1.6	18.4	1.5
14-15*	1.0	N/A	15.9	N/A
15-16	4.0	4.5	14.5	6.9
16-17*	1.6	N/A	19.0	N/A
17-18*	0.0	N/A	20.0	N/A
18-19	2.4	1.1	16.6	0.1
19-20*	4.6	N/A	16.2	N/A
20-21	6.3	3.8	10.1	7.7
*only one measurement taken at this depth interval				

4.1.2 Soil Temperature

Site soil temperatures were measured in May and June of 2014. Overall average site temperature was 30ºC with a standard deviation of 7ºC (Table 6). These temperature data were collected in summer months. Soil temperature varied greatly with vegetative cover because of shading and also follow a logical trend of decreasing temperature with increasing depth.

4.2 Microcosms

4.2.1 Characterization of Soils used for Microcosms

Soil pH, TOC, total nitrogen, and moisture content were all measured during February and June microcosm sampling events in 2014. Due to budget constraints, these soil parameters were not analyzed during the final sampling event in October.

4.2.1.1 Soil pH

The pH of the microcosm soils was within the range of 5.8-7.4 (Table 7 and Figure 8). Two microcosm sets (A2 and A5) had an initial pH outside of the EPA's specified acceptable pH region for optimal bioremediation (6-8). These two microcosm types included soya lecithin as an amendment which may have caused the reduced pH. This indicates that soy lecithin could have an adverse effect on initial degradation. Over time, though, the pH in soy lecithin-amended microcosms increased to within the acceptable range (Figure 8). This suggests that soya lecithin was degraded over time; it is likely that it was preferentially degraded before other compounds.

Table 7: Soil Temperature Data (Summer 2014)

Location ID	Depth (ft)	Time	Temp (degrees C)	Date
STS-18_CB_A	0	8:15	23	6/2/2014
STS-06_PG_C	0	8:28	23	6/4/2014
STS-01_BE_D	0	8:47	26	6/2/2014
STS-04_MF_B	0	9:33	26	6/3/2014
STS-17_NM_C	0	9:45	26	6/4/2014
STS-02_LS_B	0	10:22	30	6/3/2014
STS-04_MF_D	0	10:55	29	6/2/2014
STS-01_BE_C	0	11:35	31	6/4/2014
STS-23_YS_C	0	12:50	34	6/3/2014
STS-06_PG_D	0	13:40	37	6/2/2014
Average			**29**	
Standard Deviation			**5**	
STS_35_NG_C	0.1	7:30	22	5/28/2014
STS_08_SM_CC	0.1	8:10	22	5/29/2014
STS-01_BE_A	0.1	8:30	23	5/29/2014
STS_17_NM_BB	0.1	8:45	24	5/28/2014
STS-23_YS_D	0.1	8:50	25	5/30/2014
STS-18_CB_D	0.1	9:35	27	5/30/2014
STS_08_SM_D	0.1	9:36	35	6/2/2014
STS_08_SM_BB	0.1	9:50	28	5/28/2014
STS_35_NG_A	0.1	10:30	26	5/27/2014
STS-23_YS_A	0.1	10:50	37	5/29/2014
STS-02_LS_D	0.1	11:00	30	5/30/2014
STS-17_NM_D	0.1	12:15	49	5/30/2014
STS-02_LS_C	0.1	12:40	35	5/28/2014
STS_35_NG_B	0.1	13:30	37	5/27/2014
STS-06_PG_B	0.1	14:15	44	5/29/2014
STS_35_MG_D	0.1	14:25	36	5/28/2014
Average			**31**	
Standard Deviation			**8**	
STS-18_CB_A	1.5	8:15	24	6/3/2014
STS-01_BE_D	1.5	8:47	27	6/2/2014
STS-23_YS_D	1.5	8:50	30	5/29/2014
STS-23_YS_A	1.5	10:50	29	5/29/2014
STS-04_MF_D	1.5	10:55	25	6/2/2014
Average			**27**	
Standard Deviation			**3**	
Overall Average			**30**	
Overall Standard Deviation			**7**	

Table 8: Microcosm Soil pH

	Average		Standard Deviation		Standard Error	
Microcosm Type	0 days	126 days	0 days	126 days	0 days	126 days
nutrient	6.53	6.28	0.04	0.06	0.02	0.03
soya lecithin	5.87	6.31	0.03	0.19	0.01	0.08
rice hulls	6.60	6.24	0.07	0.17	0.03	0.08
nutrients+ rice hulls+ *P. chrysosporium*	6.44	6.35	0.06	0.18	0.03	0.08
nutrients+ soya lecithin+ rice hulls+ *P. chrysosporium*	6.03	6.18	0.03	0.09	0.01	0.04
unamended site A	6.64	6.30	0.03	0.02	0.01	0.01
unamended site B	6.84	6.68	0.03	0.05	0.01	0.02
unamended site C	7.35	7.33	0.05	0.05	0.02	0.02
gamma-irradiated unamended site A	6.676	N/A	0.038471	N/A	0.017205	N/A

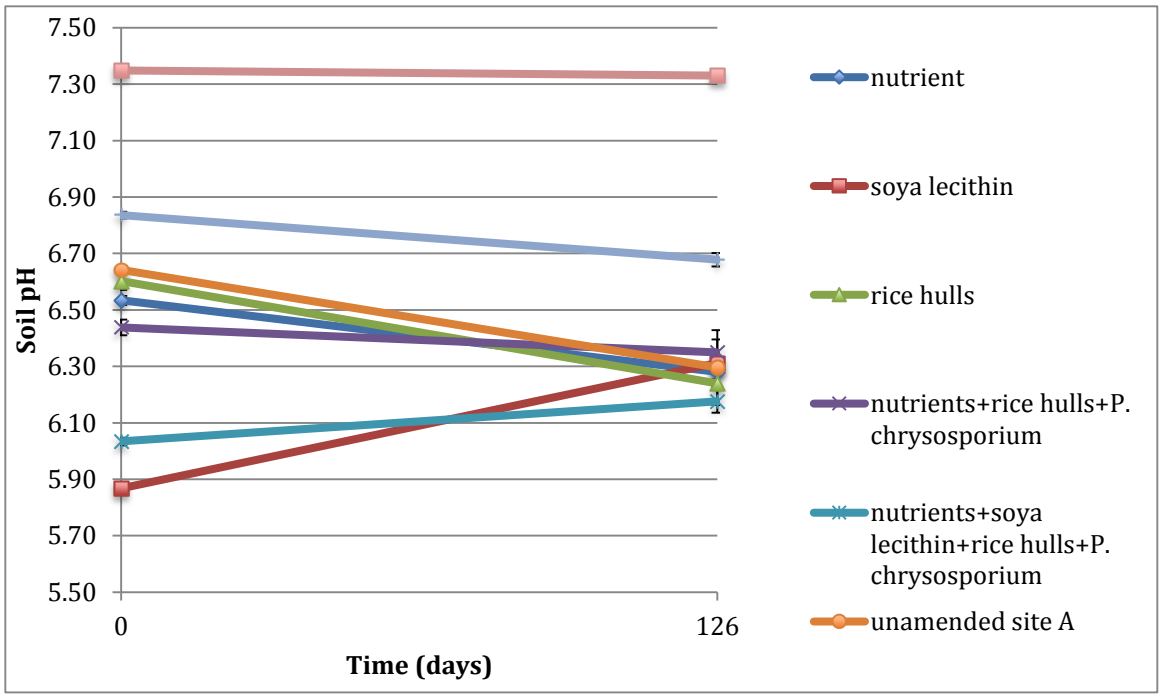

Figure 8: Soil pH in microcosms during incubation

4.2.1.2 Soil TOC

TOC concentrations in microcosm soils varied for the different microcosm sets (Table 15 and Figure 69, Appendix I). The initial TOC in Site B soils was much greater than that in Site A and Site C soils. TOC decreased slightly in almost all of the microcosms suggesting some biodegradation, but there was a large amount of variability, particularly during the initial sampling event and for both sampling events in the unamended Site B soils.

4.2.1.3 Soil Nitrogen

Total nitrogen concentrations in the microcosm soils varied significantly among microcosm sets (Table 16 and Figure 69, Appendix I). During incubation, nitrogen concentrations eitherremained unchanged or slightly increased. This indicates that there were sufficient nitrogen nutrients in the soil, and contaminant degradation was not nitrogen-limited. Phosphorus concentrations were not measured, so it is not known if phosphate was limiting biodegradation.

4.2.1.4 Soil Moisture

Target experimental soil moisture in the microcosms was 15% based on previous research (Rastegarzadeh, Nelson, and Ririe 2006). As data from previous sampling events was received and analyzed, soil moisture was adjusted in an attempt to meet the target 15%. As a result, soil moisture was maintained between a minimum of 9% and a maximum of 17% throughout the experiment (Table 14, Appendix I). Moisture content can be a limiting factor in biodegradation (“In Situ Biological Treatment”); however, lower moisture content is likely more representative of actual site conditions due to the

low rainfall at the site and the fact that stormwater is pumped, treated, and removed from the site.

4.2.1.5 Soil Contaminant Concentrations

Before this experiment was started, target soil contaminant concentrations were chosen using professional judgment (Table 3). Soil contaminant concentrations in microcosms were much lower than target concentrations (Appendix K). Total EFH was consistently lower than the target value (100 – 230 mg/kg, Appendix K). The cleanup goal for this site is 5.7 mg/kg of EFH (C15-C20), and all unamended microcosm soil concentrations were less than 250 mg/kg. PAH concentrations were also lower than target concentrations (ranging from 87 – 45,139 µg/kg). They were very low in Soils A and C, but still above the Look-Up Table value of 4.47 µg/kg TEQ for benzo(a)pyrene. PCB concentrations were lower than target values (37 – 328 µg/kg Aroclor 1260) and limited to the most heavily chlorinated mixtures. Heavily chlorinated Aroclors were present at similar levels in all three soils except for Aroclor 5460 in Soil C. Initial dioxin concentrations ranged from 0.026 – 0.116 mg/kg, which were also lower than the target concentration of 100 mg/kg. Maximum total concentration was observed in Soil A, and minimum total concentration was observed in Soil B.

4.2.2 Microcosm Incubation Temperature

Microcosm soil temperatures throughout the 244-day study averaged 27.4ºC with a standard deviation was 3.1ºC (Figure 9). This is slightly lower than the average site temperature observed in June and July, but presumably much higher than soil temperatures in the winter. This suggests that any biodegradation rates observed in microcosm data could be slightly elevated estimations of what could happen if a bioremediation technology were applied at the site year-round.

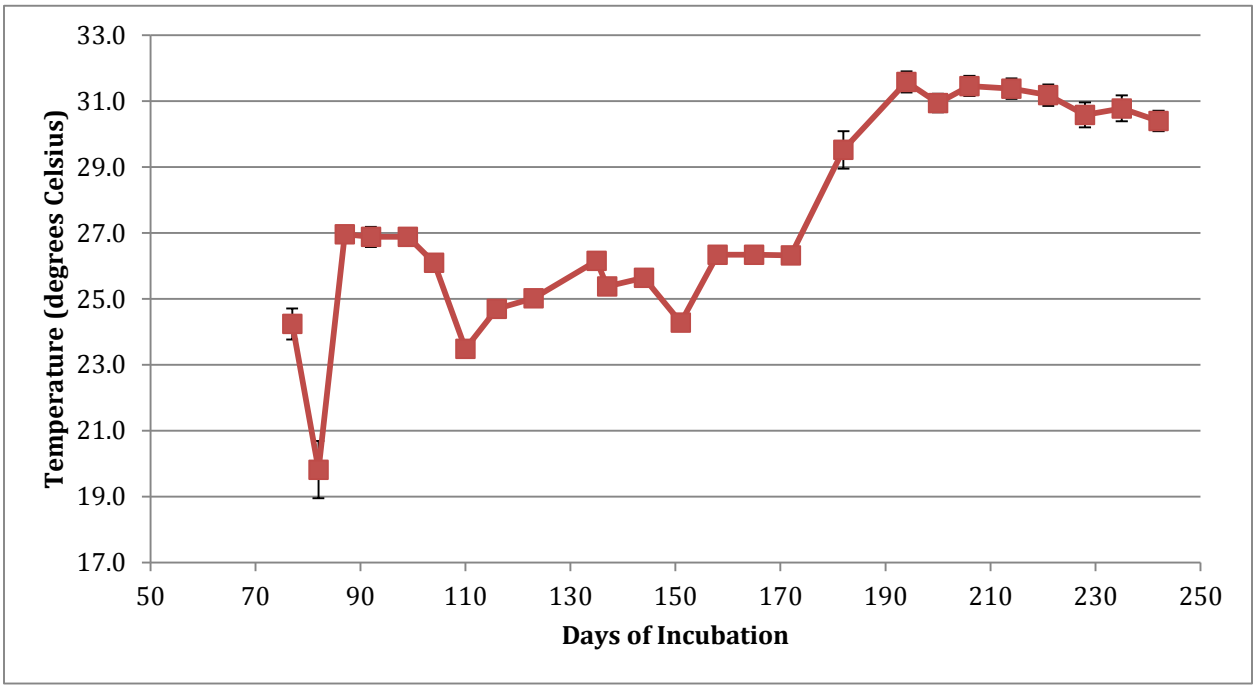

Figure 9: Microcosm incubator temperature during experiment

4.2.3 Contaminant Soil Concentrations in Microcosms During Incubation

The total concentration of each contaminant type (EFH, PAHs, PCBs, and dioxins) were calculated and the averages and standard errors were plotted as a function of time to examine overall trends in chemical concentrations (Figures 10-14). More detailed data for each individual chemical are also provided in tables and graphs in Appendices A – D.

All statistical software outputs are provided as Appendices H, I, and J, respectively: Statistical Analysis of Effect of Treatment on Changes in Contaminant Concentrations in Soil A, Statistical Analysis of Effect of Gamma Irradiation on Changes in Contaminant Concentrations in Soil A, and Statistical Analysis of Different Soil Type (A, B, or C) on Changes in Contaminant Concentrations over Time.

4.2.3.1 EFH

Some of the observed EFH concentrations in microcosms are much higher than that observed for the collected soil (Table 9, Figure 10, Appendix A, and Appendix K). Initial concentrations were elevated in microcosms containing soy lecithin because some of its organic compounds elute at the same time as petroleum hydrocarbons during gas chromatography. This EFH inflation appeared to dissipate at the second sampling event, but EFH concentrations for all microcosms were elevated at the final sampling event. EFH values at the start of the experiment were clearly inflated by soy lecithin amendment (Figure 10). Apparently, organic compounds in the soya lecithin volatilize in the gas chromatograph at the same time as equivalent carbon ranges of some petroleum hydrocarbons. These EFH-mimicking components of soya lecithin are most likely biodegraded before the second sampling event. Since the corresponding apparent EFH

concentrations were reduced substantially within 126 days, soil in these jars was not analyzed for EFH because of the interference by this amendment.

For the microcosms without soy lecithin interference, EFH concentrations were unchanged or decreased slightly during the first 126 days of incubation (Figure 10). Total EFH concentration appeared to increase substantially in all other microcosms at 244 days after the start of the experiment (Figure 10). This sudden increase was observed for both shorter equivalent carbon chains and longer equivalent carbon chains (Appendix A: Bar Graphs of EFH Equivalent Carbon Ranges). This increase in EFH concentration may have been a laboratory artifact since the Day 244 GC analyses were conducted by a different laboratory than the Day 0 and Day 126 analyses. For example, the two labs may have used different methods of integration or established a different baseline for integrating the chromatograms.

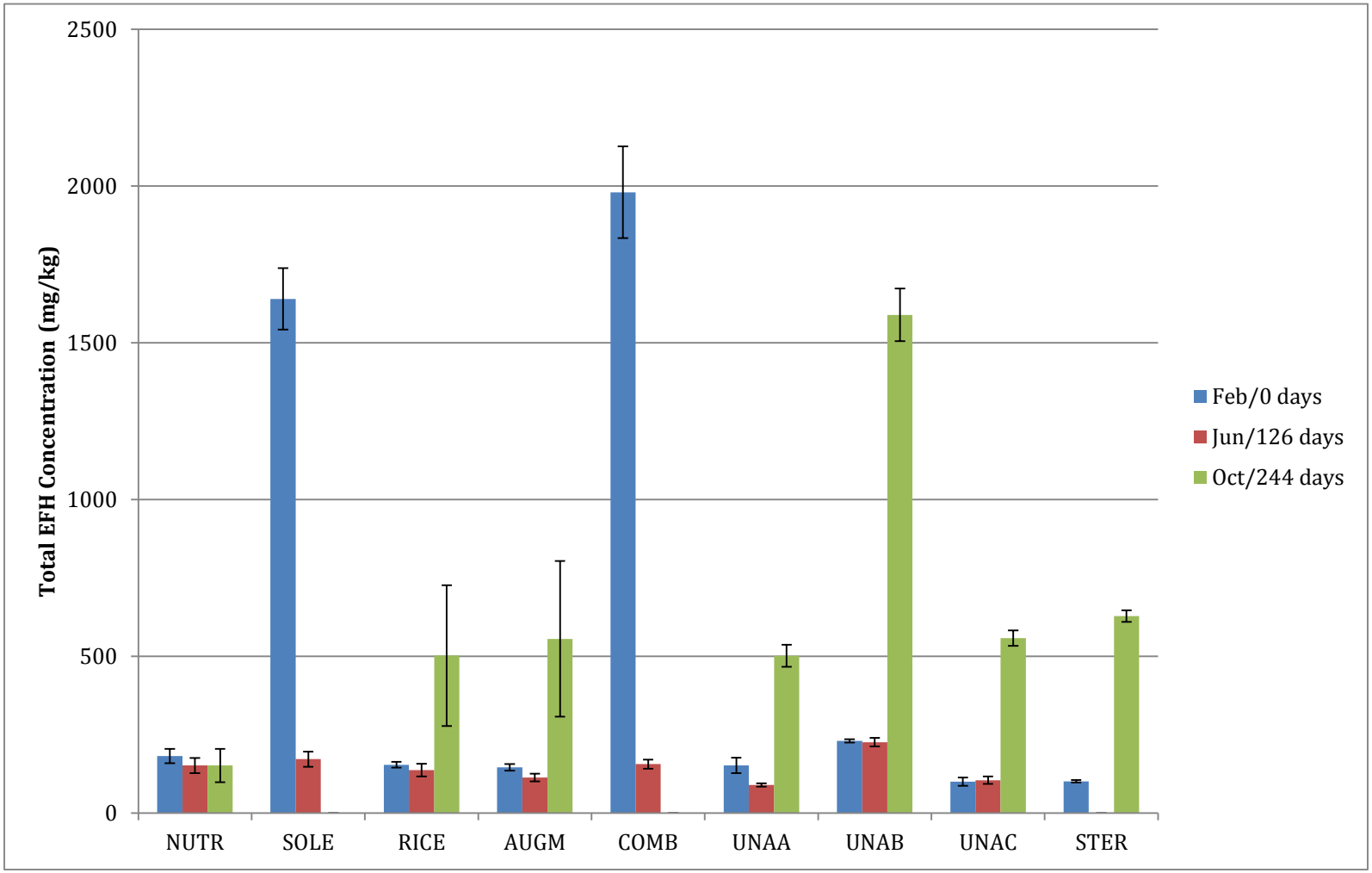

Figure 10: Total EFH concentration during microcosm incubation

4.2.3.2 PAHs

Total PAH concentrations were calculated by summing all of the various PAH concentrations, as shown in Appendix K (Table 21). Concentrations of individual PAHs are shown in Table 19, Appendix K. Initial PAH concentrations were much higher in unamended B soils than both A and C soils (Figures 11 and 12). This is likely because soil B was located in a drainage into which PAH-contaminated water likely flowed.

PAH concentrations decreased slightly in Soil B during microcosm incubation (Figure 11). However, no decreases in PAH concentrations were not statistically significant with a 95% confidence level (p-value of 0.296, Appendix F). For Soil C, total PAH concentrations also appeared to decrease dramatically, but the high variability of PAH concentrations measured (as indicated by the large error bars in Figure 12) led to no statistically significant change. For Soil A, total PAH concentration appeared to actually increase in several of the amended microcosms. This is undoubtedly due to the high variability of PAH concentrations measured.

The PAH contamination in these soils is largely comprised of compounds with 4-6 aromatic rings (Appendix C), and these are typically the most recalcitrant PAHs (Llado et al. 2013). Any degradation of lighter PAHs at the site is likely to have already occurred. If there were more PAHs with 1-3 aromatic rings in soil at one point in time, they have likely been preferentially degraded by microorganisms. Also, once PAHs adsorb onto soils, their biodegradation becomes difficult as their bioavailability is compromised. Residual contamination may be tightly adsorbed onto the soil matrix. However, surfactant addition to two sets of microcosms (SOLE and COMB) did not enhance PAH biodegradation (Figure 12).

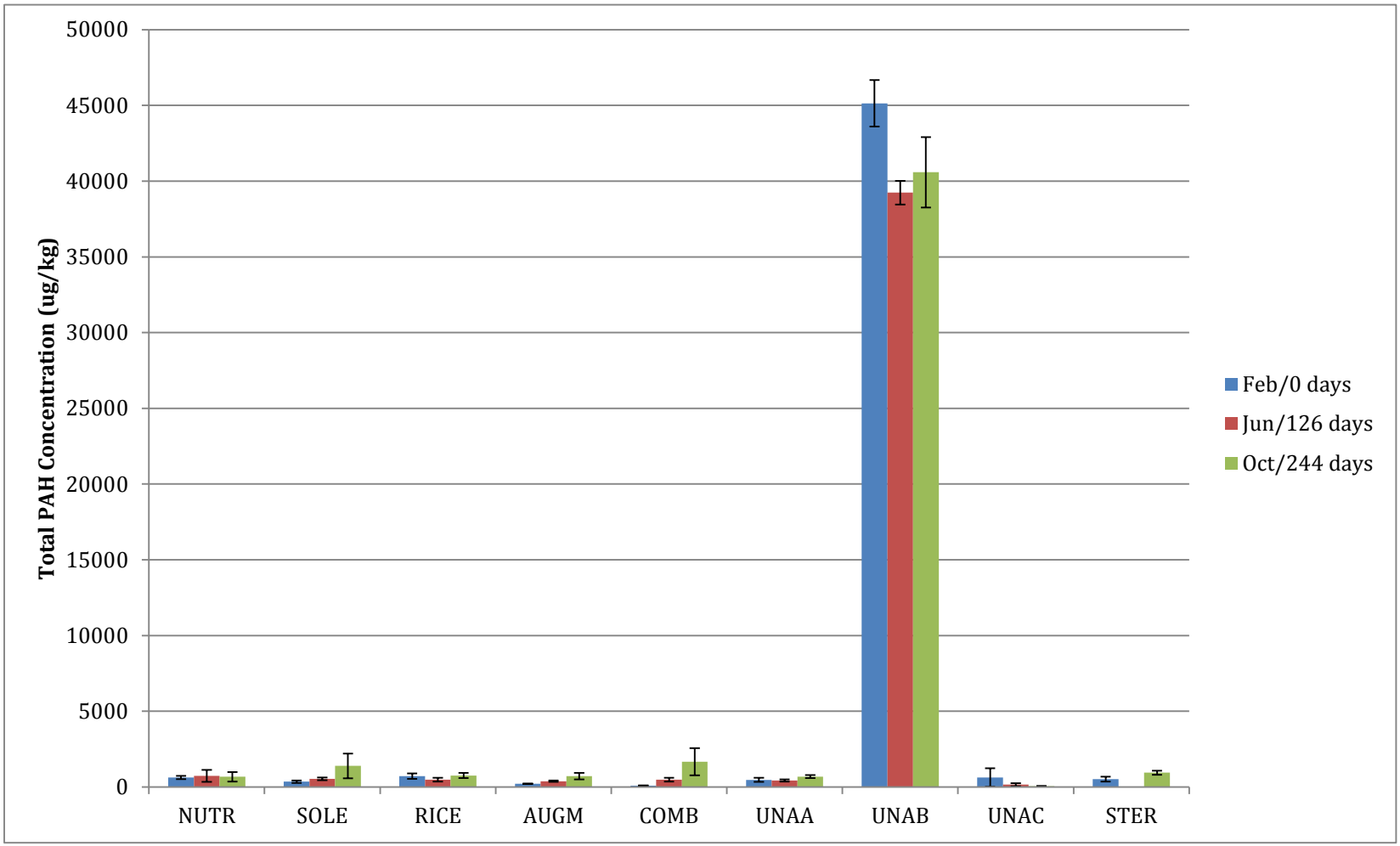

Figure 11: Total PAH concentration during microcosm incubation

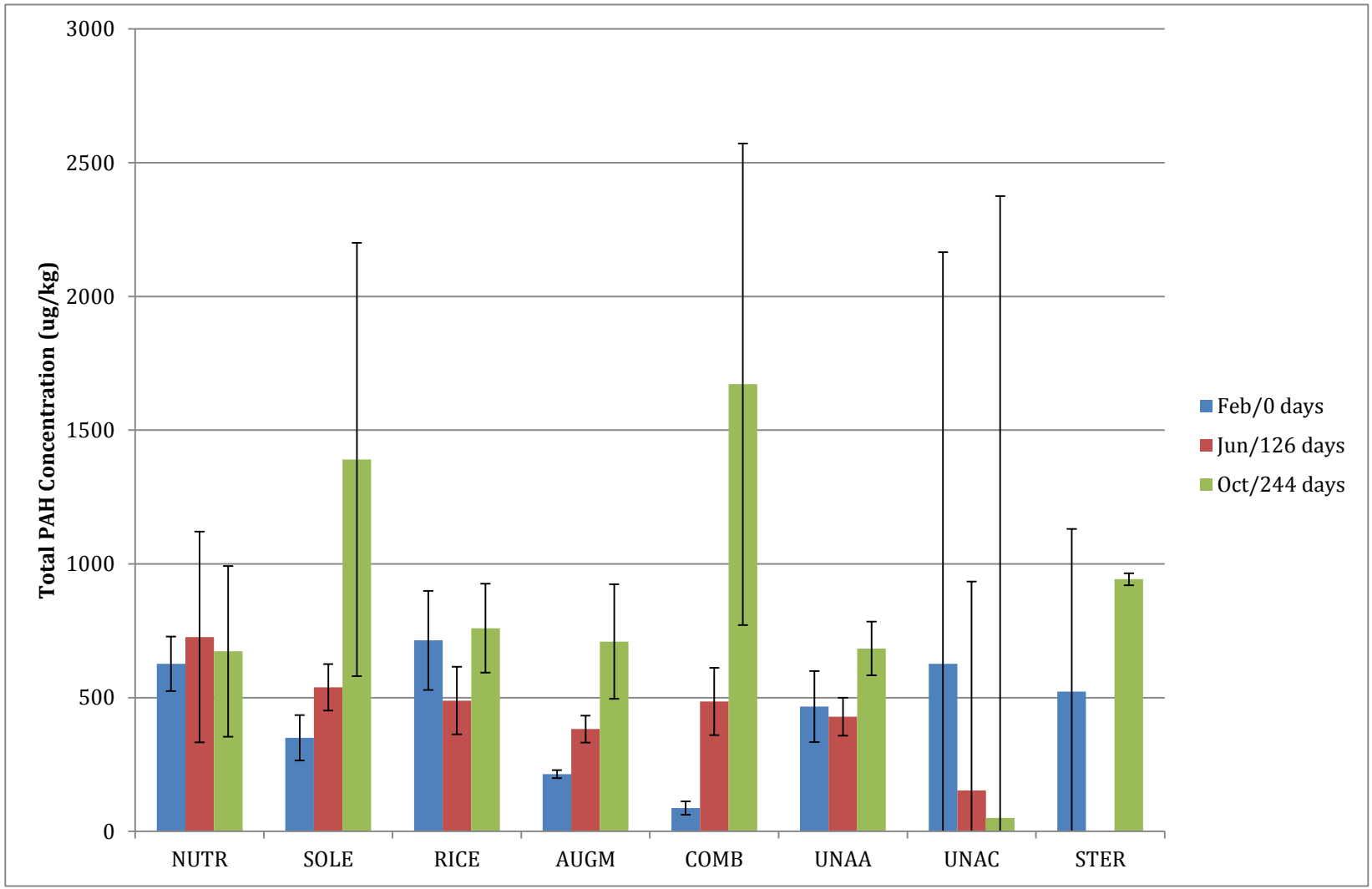

Figure 12: Total PAH concentration during microcosm incubation (A and C)

4.2.3.3 PCBs

Slight decreases in Aroclor 1260 concentrations were observed in all but one of the microcosms (Figure 13). However, none of these decreases were statistically significant at the 95% confidence interval. Also, a similar decrease in PCB concentration was observed for the sterilized control. One set of microcosms (unamended A6) exhibited an exceptionally high initial PCB concentration which was caused by one sample with a particularly high initial PCB concentration. The Aroclor 1260 concentration appeared to increase for Soil C, but again this change was not statistically significant. Concentrations appeared to decrease for the most part over time, though comparison of treatments indicated that no treatment resulted in greater reduction in concentration than another at the 95% confidence level (Appendices F – H).

The lack of significant PCB biodegradation may be because detectable Aroclors detected at the site are the heaviest percent chlorine that were produced (54-60% by weight). Lesser chlorinated PCBs with just 1-2 chlorines that have been to shown to degrade under aerobic conditions are only about 30% chlorine by weight, and it is likely that these compounds if present historically present at the site have already been degraded, and the more heavily chlorinated, recalcitrant compounds remain in the soil. The predominantly aerobic conditions at the site and in the microcosms make bacterially-mediated reductive dechlorination unlikely. Fungi such as *P. chrysosporium*, *Sphingomonas wittichii* have been shown to biodegrade PCBs under aerobic conditions, but in these experiments bioaugmentation with *P. chrysosporium* did not result in significantly more PCB degradation (Figures 3). Another possible limitation of PCB biodegradation is sequestration in the soil which limits bioavilability. However, even

addition of soy lecithin as a surfactant to release PCBs from the soil structure did not facilitate significant PCB degradation.

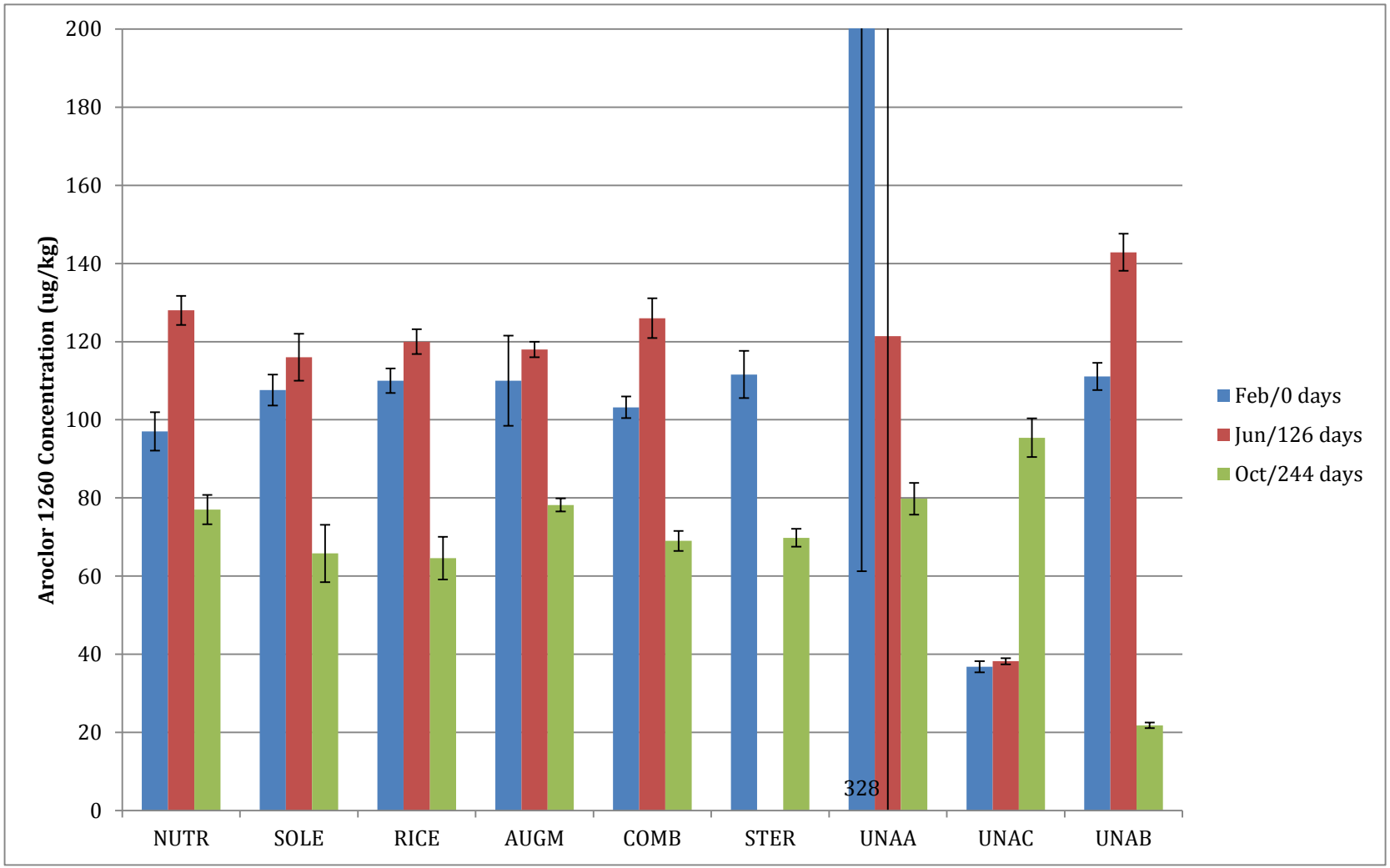

Figure 13: Aroclor 1260 concentration during microcosm incubation

4.2.3.4 Chlorinated Dioxins and TCDD TEQ

Total chlorinated dioxin concentration increased on average in Soils B and C and decreased on average in Soil A. Total chlorinated dioxin concentration decreased noticeably only in the microcosms with Soil A amended with the combination of nutrients, rice hulls, and *P. chrysosporium* (AUGM) (Figure 14; also see Appendix B for more detail). However, this decrease was not statistically significant with 95% confidence in any of three statistical tests run on these data (Appendices F-H). For the same amendments with soy lecithin also added (COMB), no such decrease was observed (Figure 14). It is not clear why soy lecithin would interfere with biodegradation, unless its biodegradation consumed some nutrient needed for biodegradation. The sterile control held a constant dioxin concentration (Figure 14).

The lack of significant observed dioxin biodegradation may be because the primary dioxin contaminant at the site is OCDD, which is the most heavily chlorinated dioxin congener. These highly chlorinated dioxins require anaerobic conditions to be bacterially dechlorinated, but site and experimental conditions were aerobic. Biodegradation under aerobic conditions may be possible with fungi such as *P. chrysosporium*, and indeed bioagumentation with this fungi appears to have aided dioxin biodegradtion, but again this observation was not statistically significant.

The dioxin source at the site could be from natural fires, or from anthropogenic sources. According to a paper citing congener profiles for anthropogenic sources of chlorinated DD/DFs, OCDD is the primary congener emitted from several industrial sources: municipal solid waste incineration with dry scrubbers and fabric filters for dioxin controls, industrial oil-fired boilers, industrial wood-fired boilers, unleaded

gasoline combustion, diesel fuel combustion, and from sewage sludge incineration (Cleverly et al. 1997). Burning of hazardous waste results in minor OCDD and OCDF stack emissions. However, savanna woodland and arid grassland fires also produce DD/DFs dominated by OCDD (MacDougall, Rillig, and Klironomos 2011). Savanna woodlands seem to resemble SSFL site conditions (a grassland ecosystem with trees spaced so that the canopy does not close, seasonal water availability, and in the transitional zone between forest and desert or grassland) suggesting that emissions from a wildfire at SSFL might have contributed to the OCDDs as well.

TCDD TEQ, an important measure of dioxin congeners' toxicity, did not appear to decrease for any of the treatments (Figure 15).

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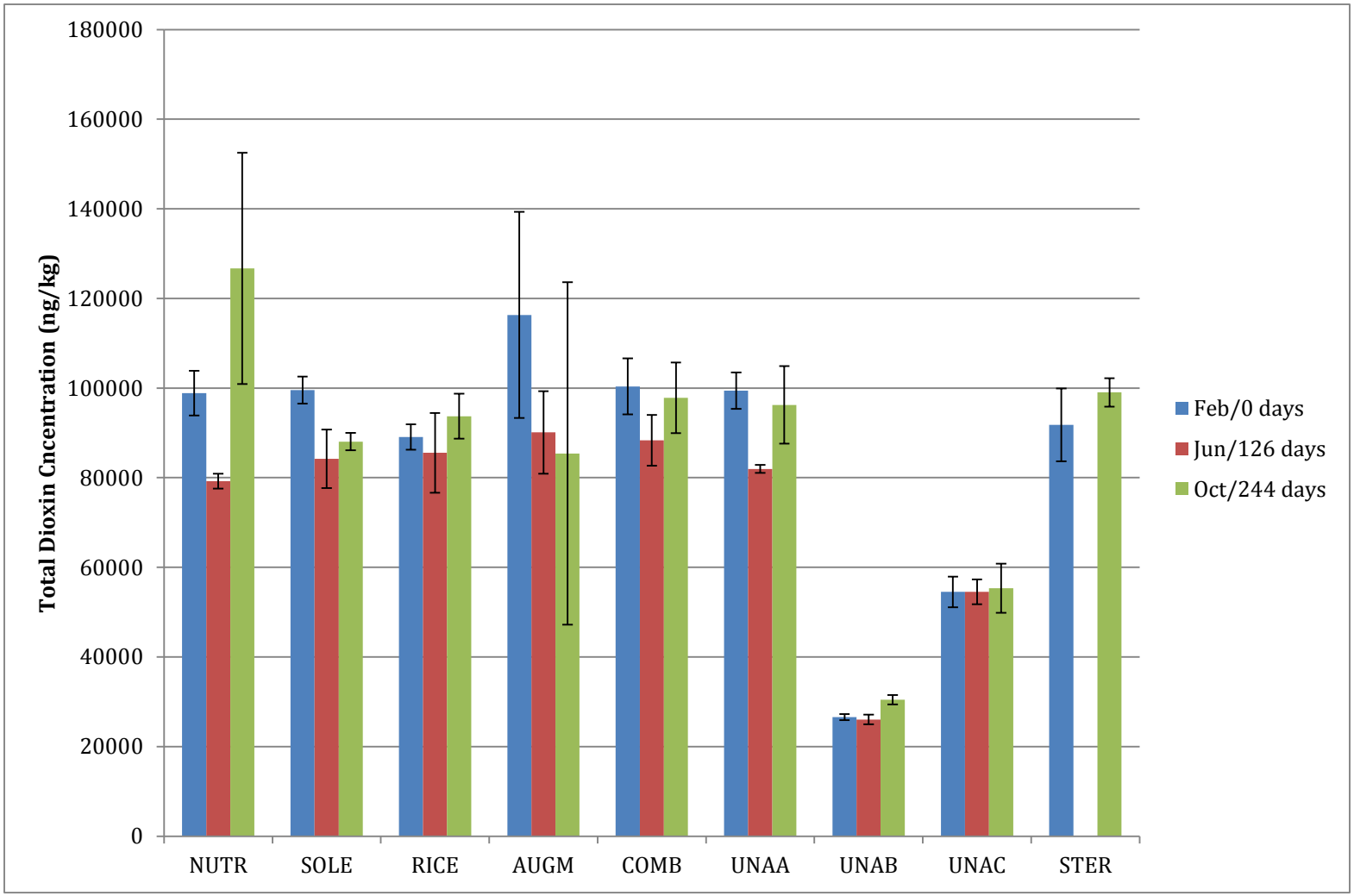

Figure 14: Total dioxin concentration during microcosm incubation

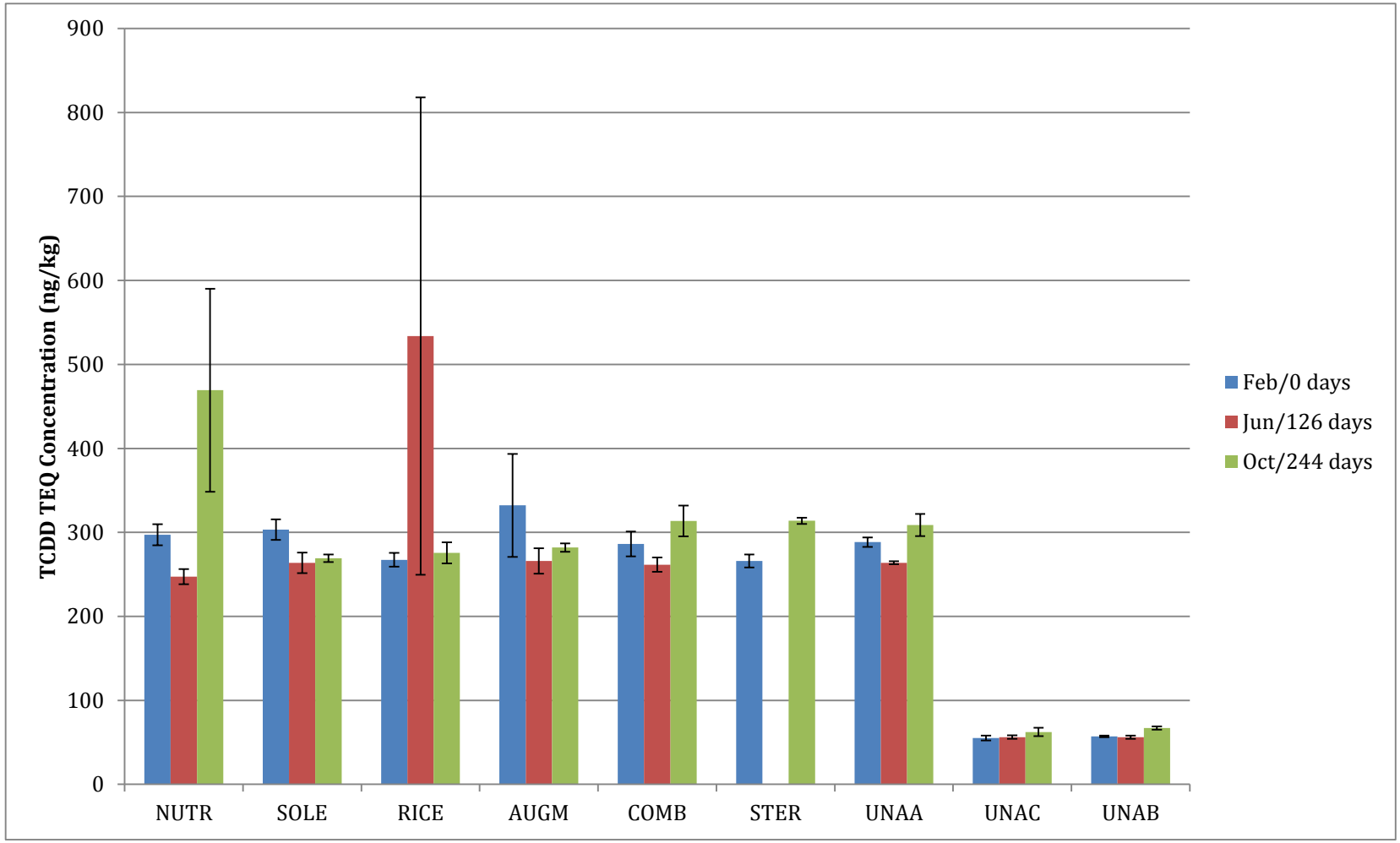

Figure 15: TCDD TEQ concentration during microcosm incubation

5.0 CONCLUSIONS AND RECOMMENDATIONS

Only slight decreases in PAH, PCB, and dioxin concentrations were observed over the 244-day soil microcosm experiment, and the difference in concentration reduction between treatments was not statistically significant with 95% confidence. Conclusions could not be made about petroleum hydrocarbon biodegradation because EFH measurements were compromised by the use of two different analytical labs for initial and final analyses. Natural attenuation rates of the COIs appear to be very slow, indicating that a long time would be required to reach acceptable COI concentrations. Amendments tested in this study for biostimulation and/or bioaugmentation (nutrients, soy lecithin, rice hulls, and *P. chrysosporium*) also did not result in statistically significant reductions in PAH, dioxin, or PCB concentrations in SSFL soils.

The lack of significant observed biodegradation is likely because the COIs in the site soil are highly weathered. Such weathering results in adsorption onto the soil matrix which can limit the bioavailability of contaminants. Also, after weathering, the forms of the COIs found in these soils are the more recalcitrant forms of these COIs. Weathered EFH is composed of longer equivalent carbon chains, PAH contamination is composed of compounds with 4-6 aromatic rings, the most abundant dioxin congener is OCDD, and the PCBs are comprised of the highly chlorinated Aroclor mixtures. Because of the site's aerobic conditions, it is unlikely that heavily chlorinated compounds will reductively dechlorinate over time. Heavier PAHs are also unlikely to biodegrade under these conditions. It is likely that organic carbon at the site acts as a long-term sink for PAH contamination.

It is difficult to determine a source of dioxins at the site. OCDD/Fs are generated by both forest fires and anthropogenic sources. Perhaps a study of the land surrounding SSFL that was also burned in the Topanga Wildfire might help to determine an appropriate background dioxin level to compare to SSFL soil chlorinated dioxin concentrations.

This experiment was short compared to the age of SSFL contamination. As stated in the introduction, some contaminants have persisted at the site for over 40 years, and a 244-day study may not accurately model COI degradation. However, some kinetic estimations were made using microcosm experiments (Appendix M). Assuming zero-order kinetics, contaminants may take less than a year to three years to reack Look-Up Table values. Assuming first-order kinetics, dioxins and PAHs may take up to 20-30 years to reach Look-Up Table values (Appendix M). This is a narrower range of time required to reach Look-Up Table values than that provided in the December Natural Attenuation Report.

Although this experiment did not result in significant bioremediation rates, it shed light on much information that can be used in future studies. First, soils should be adequately contaminated to observe degradation. In some cases, COI concentrations were too low to observe a decreasing trend due to soil variability. In addition, consistent experimental conditions are essential to minimize variability. Furthermore, methods should be kept consistent to prevent data anomalies and unexpected fluctuations in concentrations. All analyses should be performed by the same lab if at all possible, and integration techniques should be clearly delineated so methods can be reproduced.

In conclusion, this experiment indicated that natural attenuation and/or bioremediation of COIs at SSFL is likely to require extensive time. Although unfortunate, this is valuable information for moving forward to clean up the site and let the public embrace its natural beauty.

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APPENDICES

Appendix A: Bar Graphs of EFH Equivalent Carbon Ranges

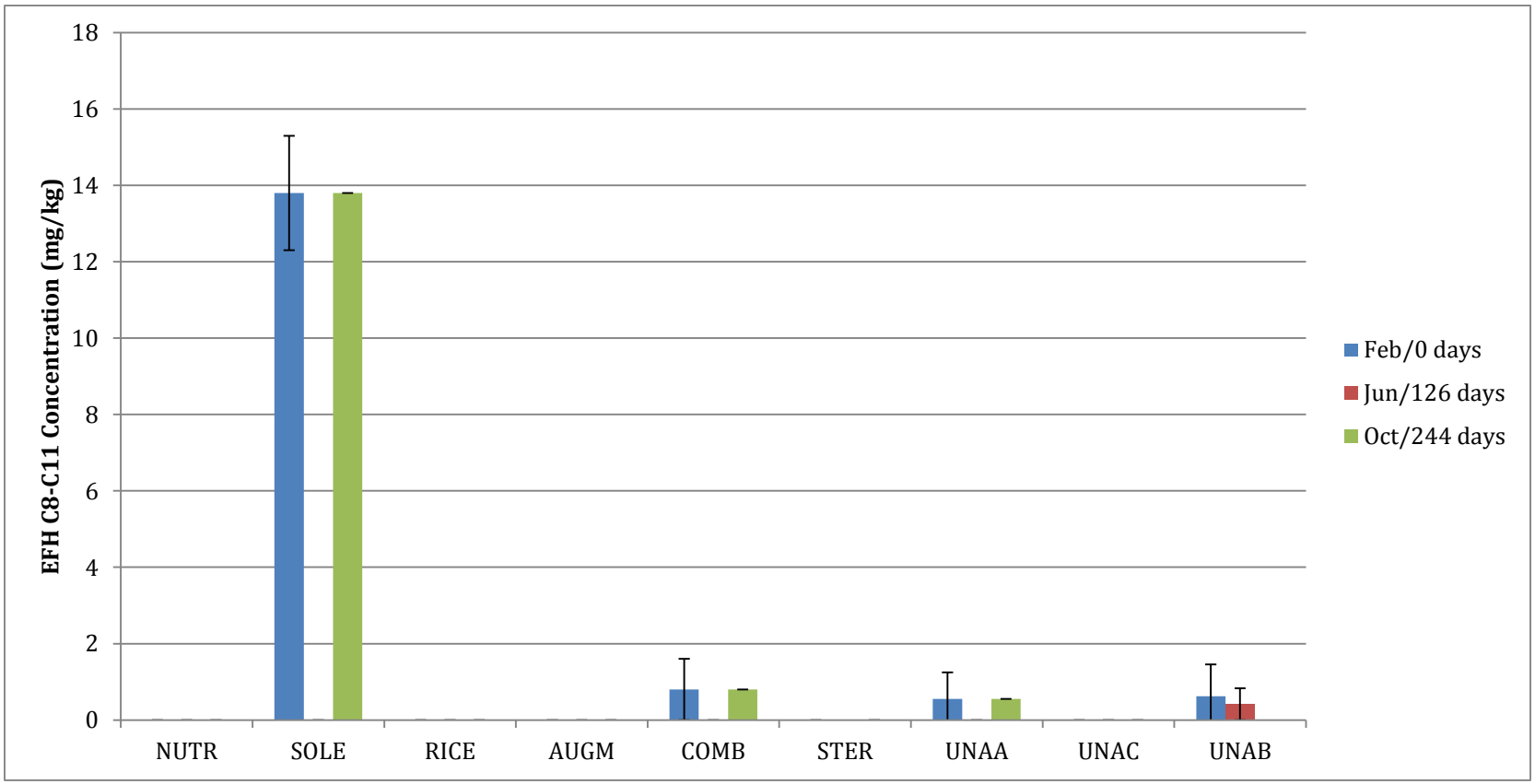


Figure 16: C8-C11 EFH equivalent carbon ranges during microcosm incubation

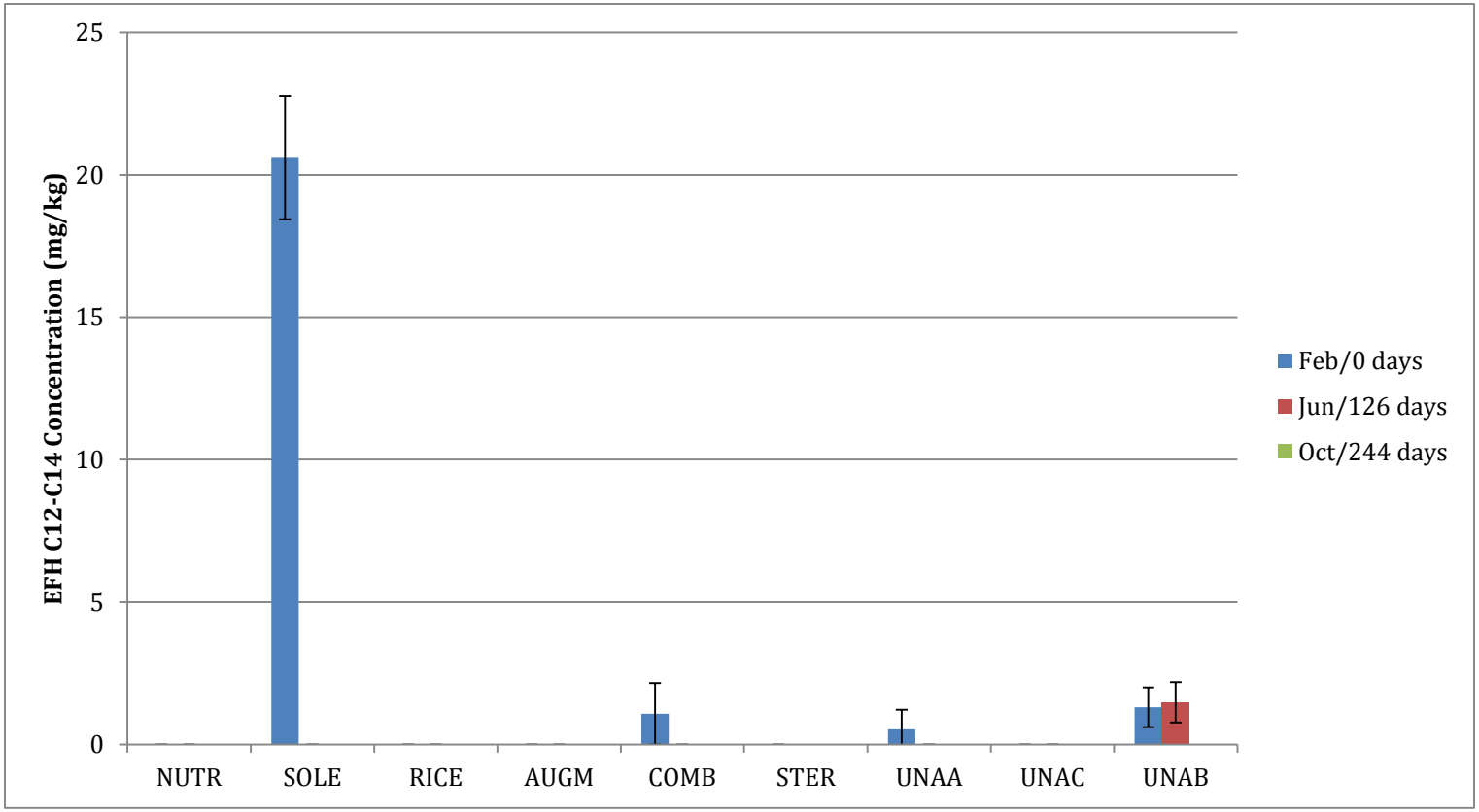


Figure 17: EFH C12-C14 concentrations during microcosm incubation

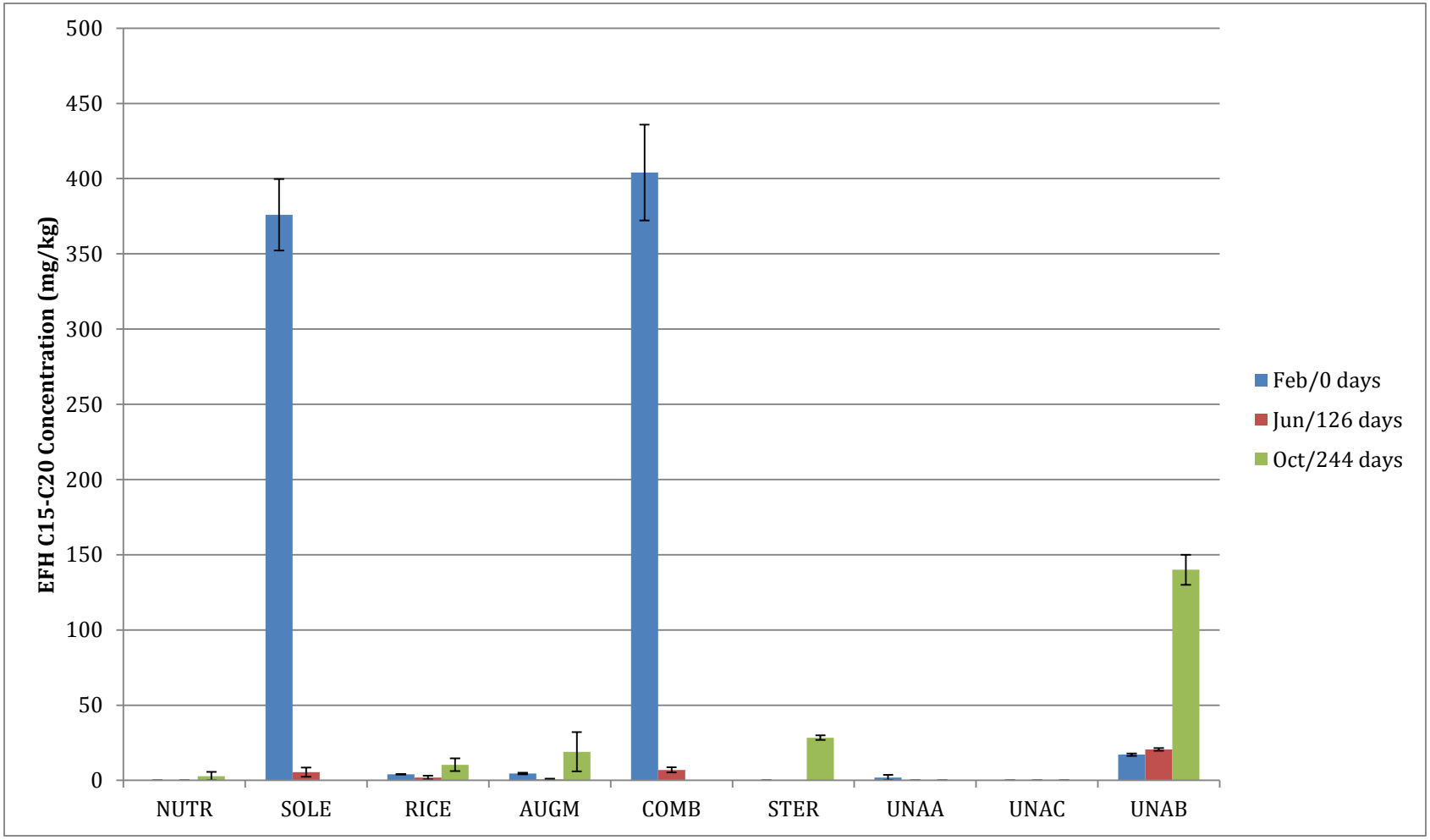


Figure 18: EFH C15-C20 concentrations during microcosm incubation

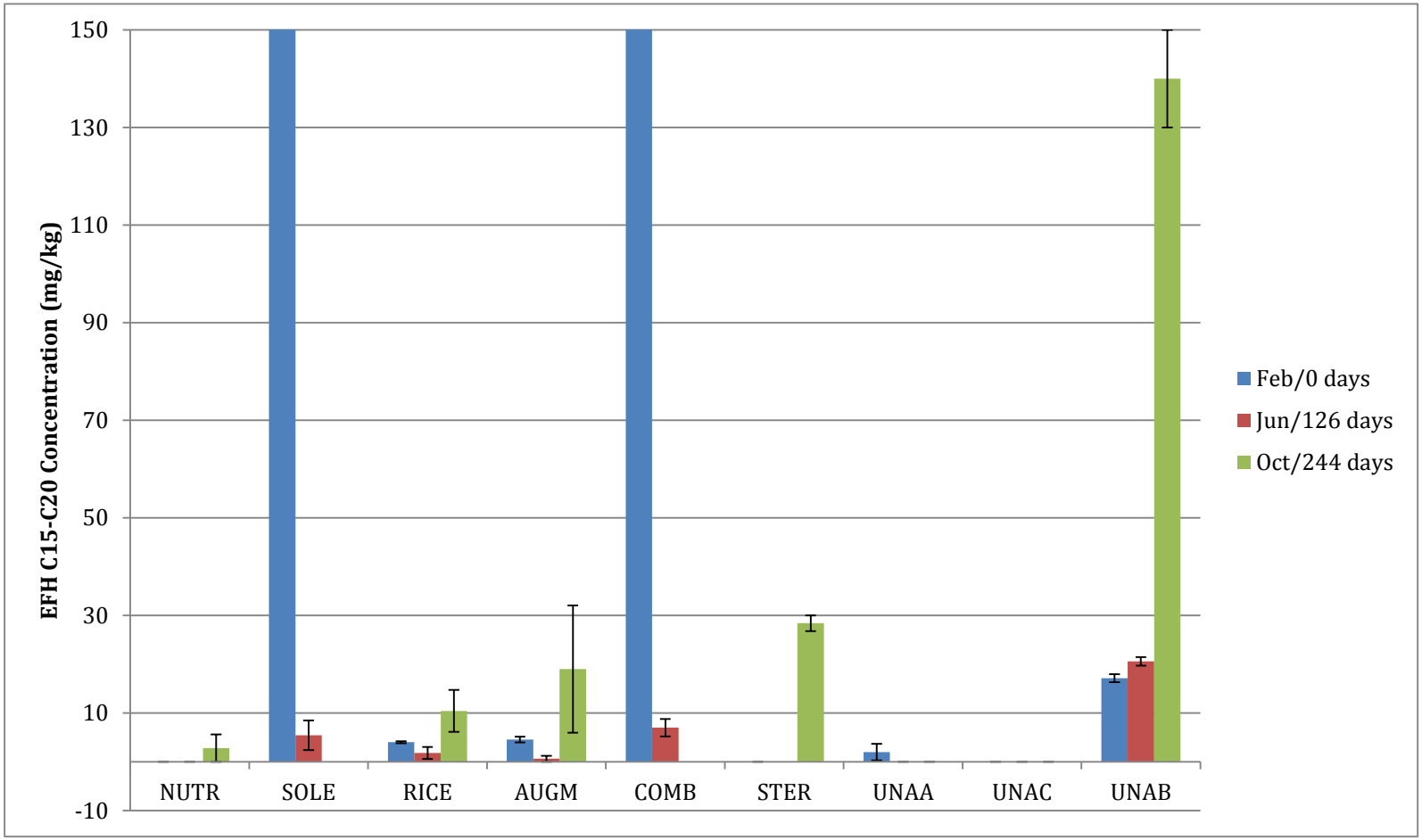


Figure 19: Truncated EFH C15-C20 concentrations during microcosm incubation

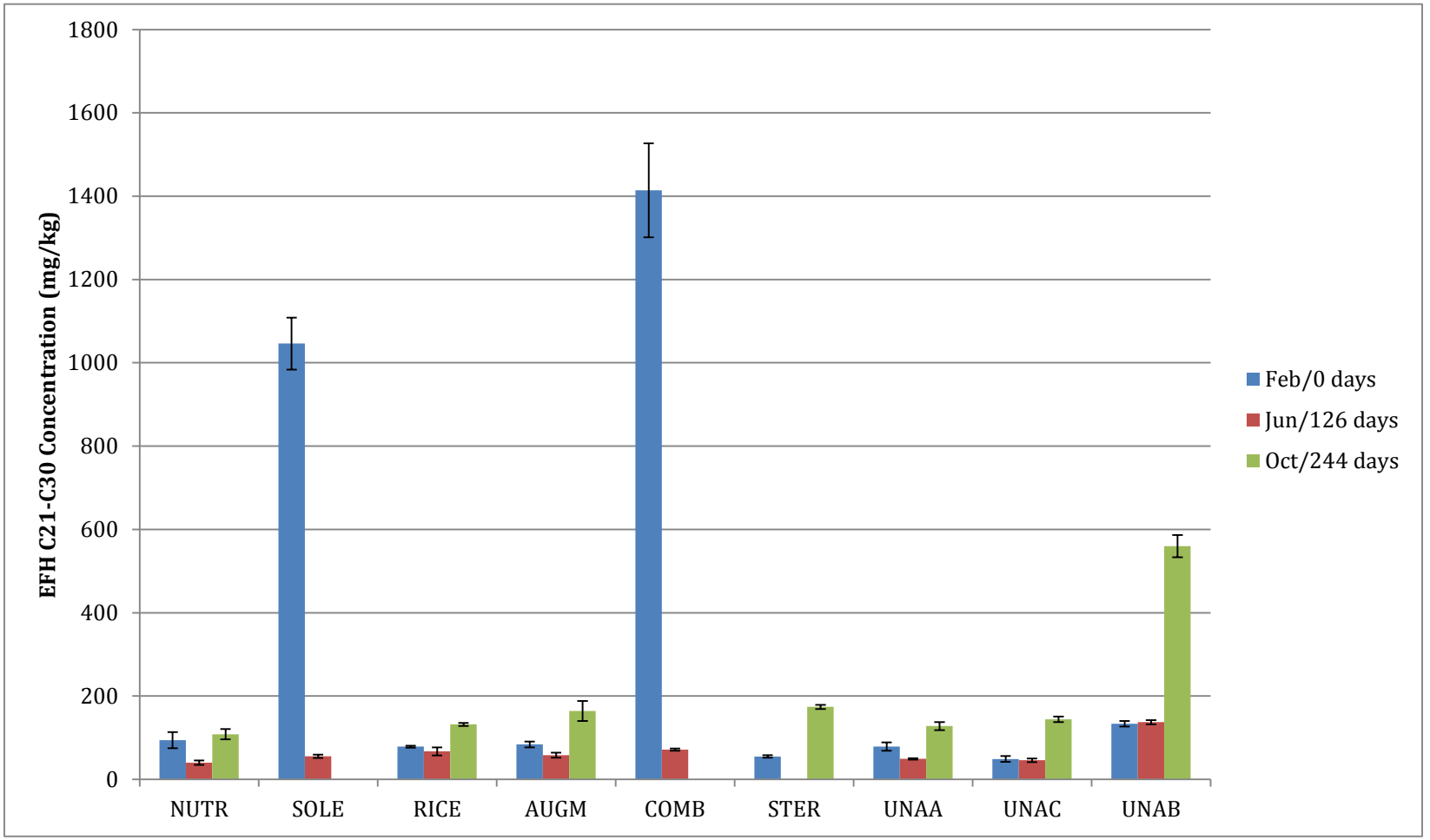


Figure 20: EFH C21-C30 concentrations during microcosm incubation

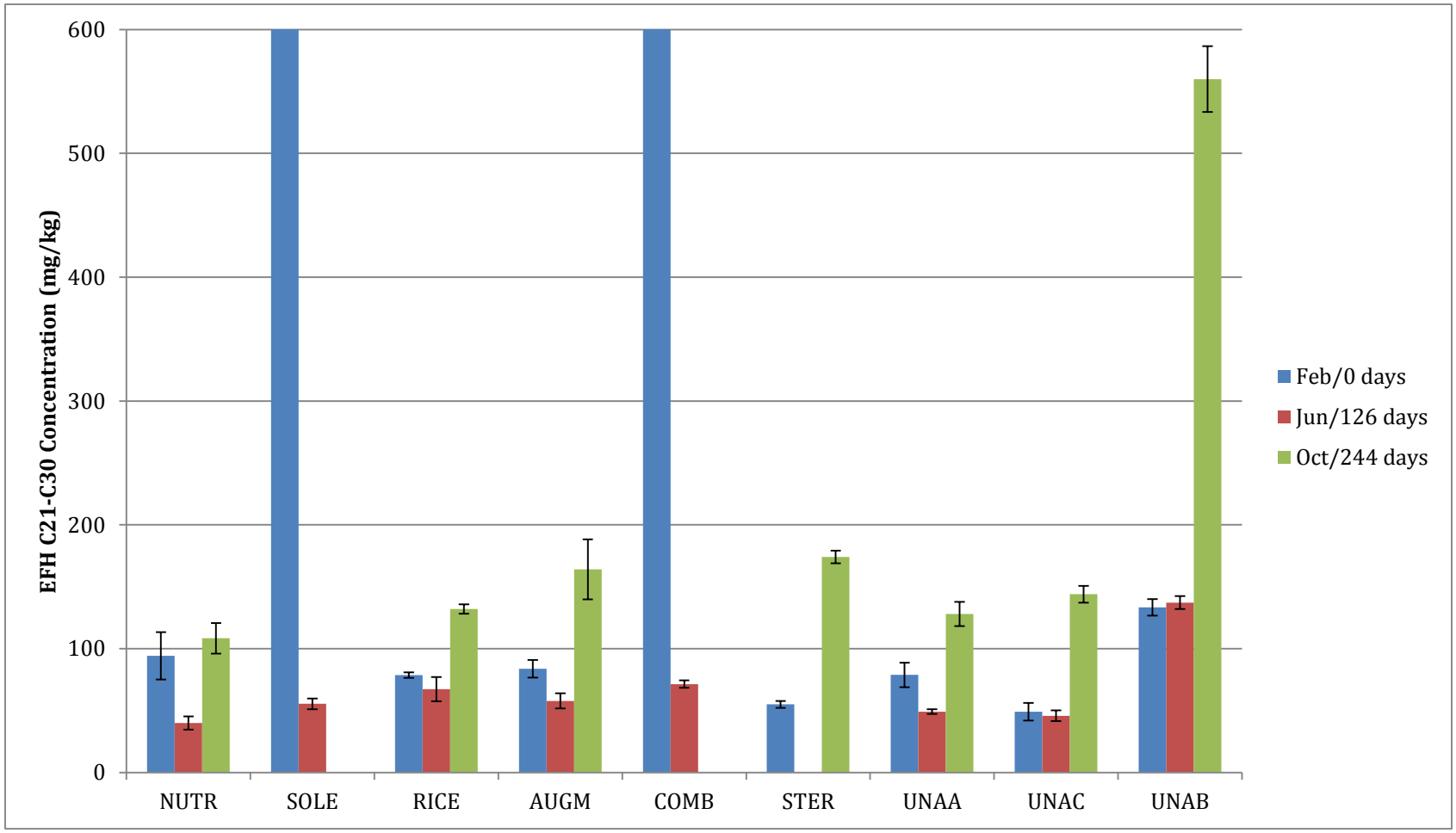


Figure 21: Truncated EFH C21-C30 concentrations during microcoms incubation

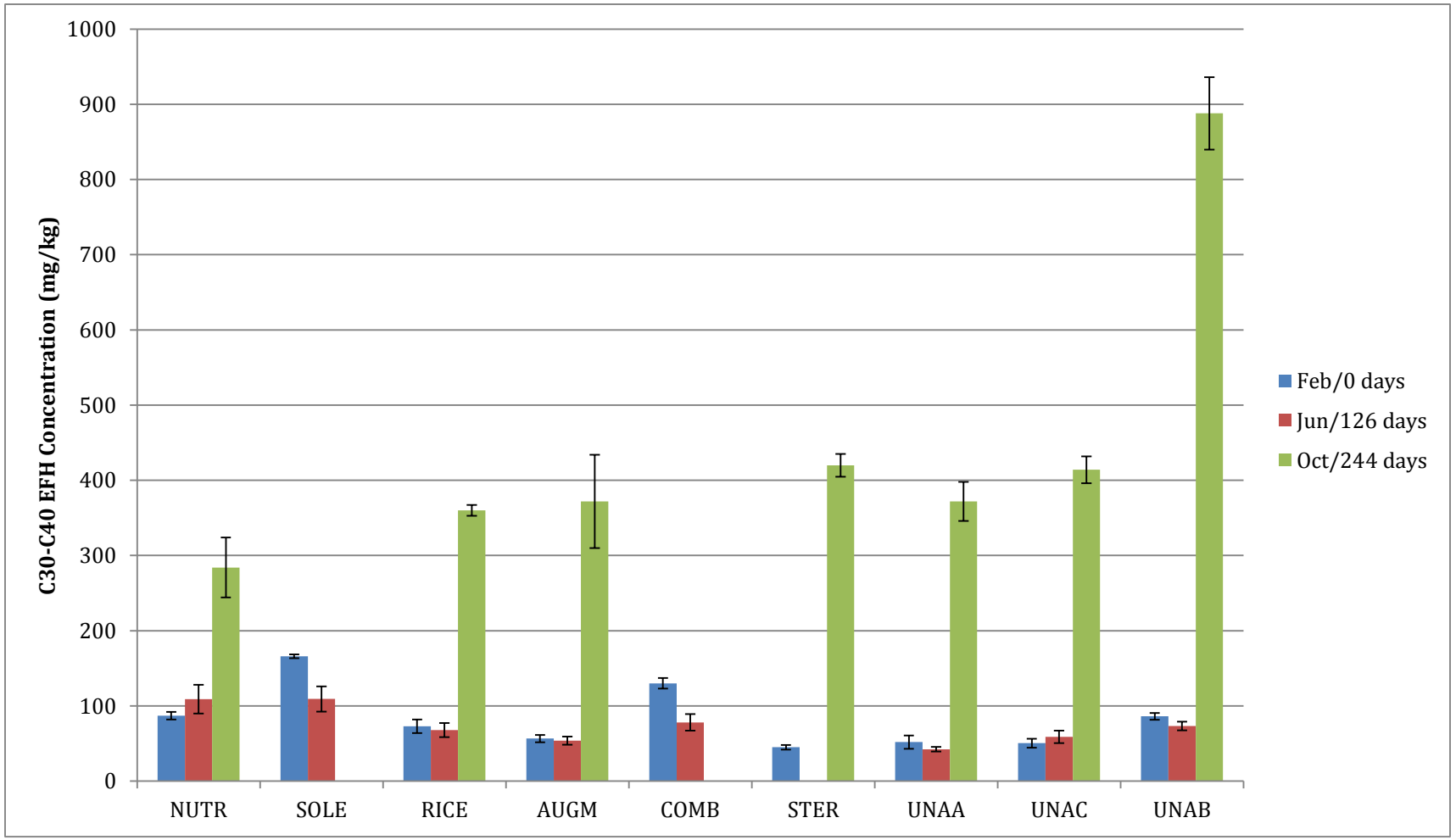


Figure 22: EFH C30-C40 concentrations during microcosm incubation

Appendix B: Bar Graphs of Individual Dioxin Congener Concentrations

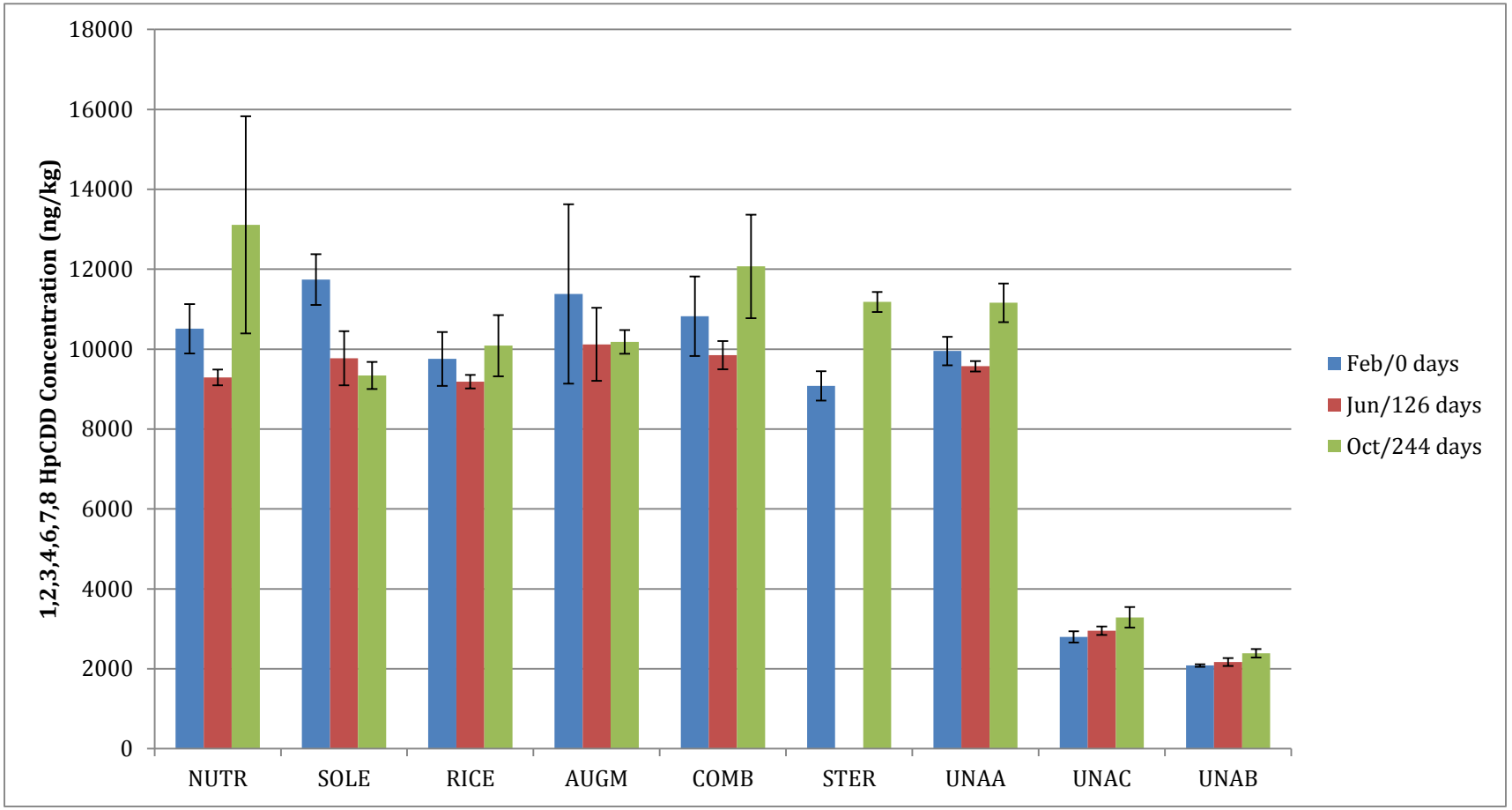


Figure 23: 1,2,3,4,6,7,8 HpCDD concentrations during microcosm incubation

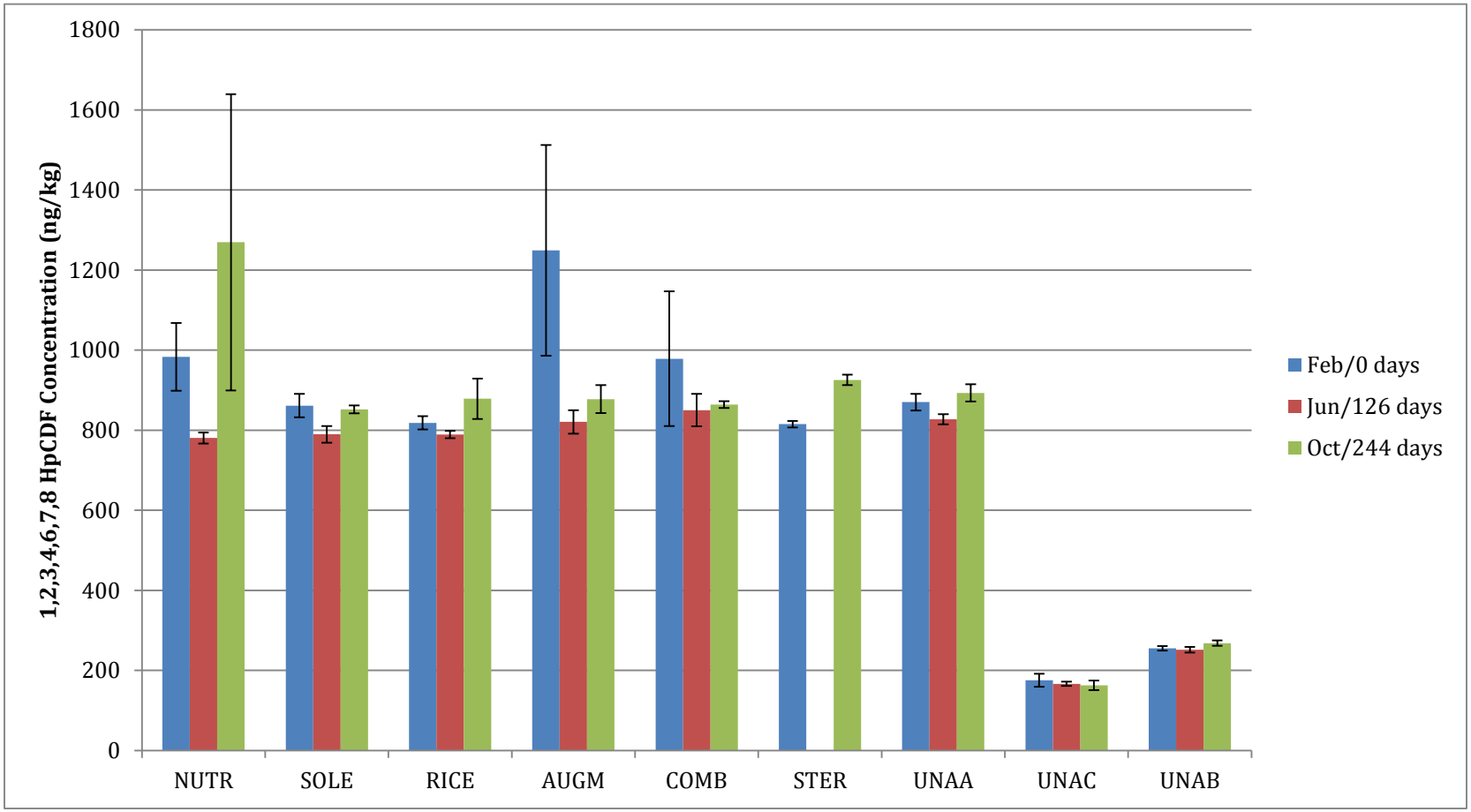


Figure 24: 1,2,3,4,6,7,8 HpCDF concentrations during microcosm incubation

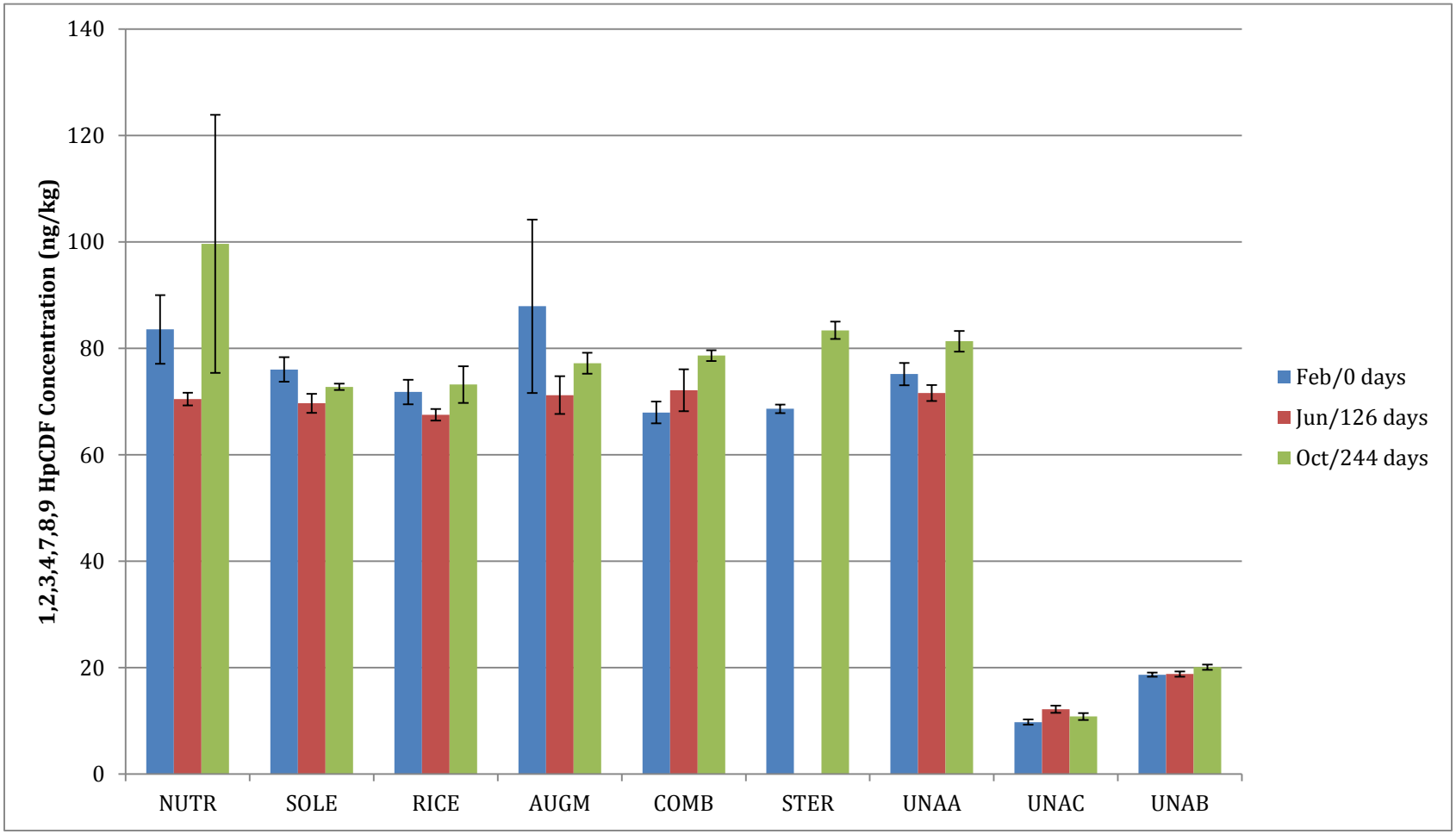


Figure 25: 1,2,3,4,7,8,9 HpCDF concentrations during microcosm incubation

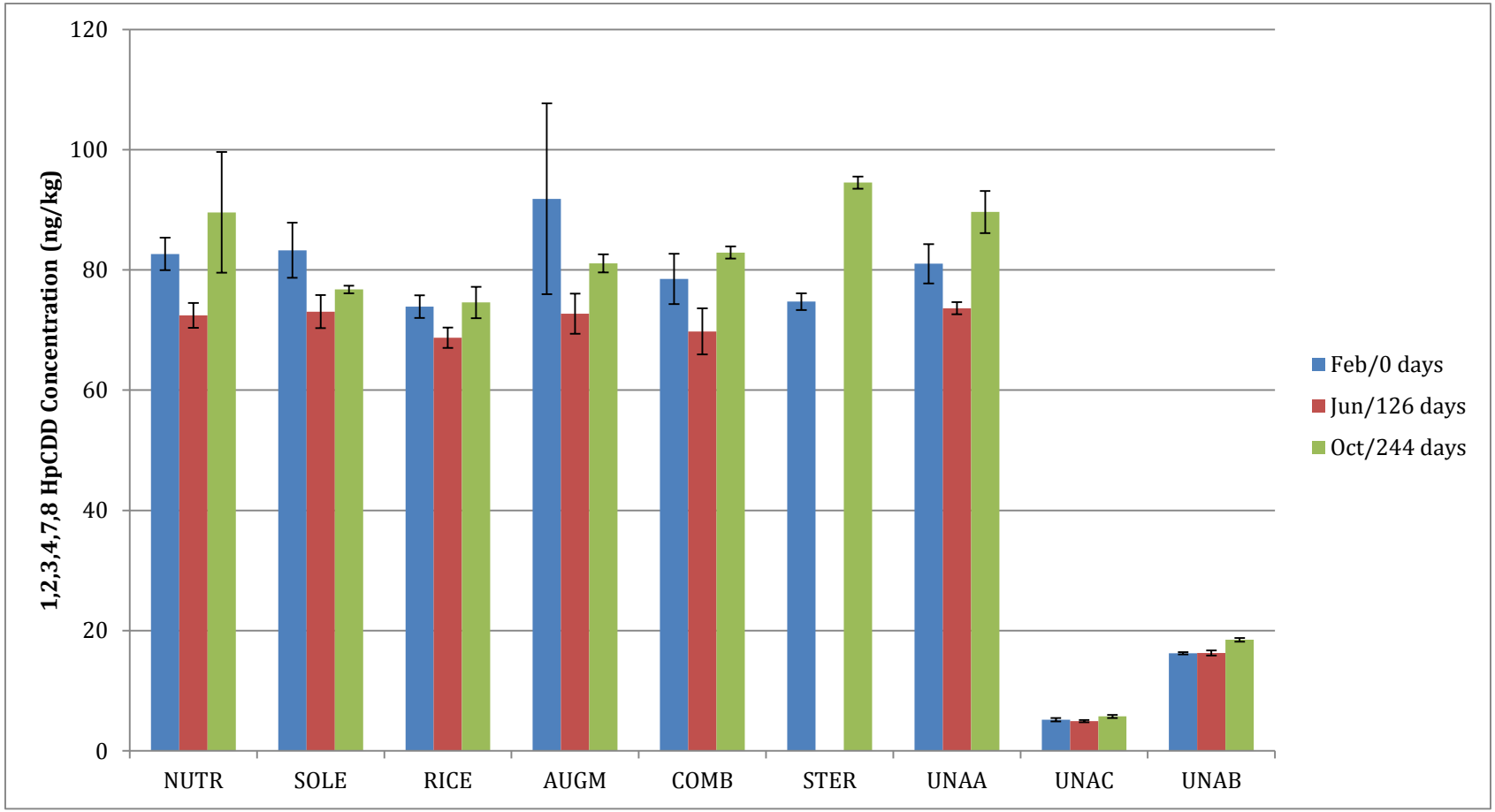


Figure 26: 1,2,3,4,7,8 HpCDD concentrations during microcosm incubation

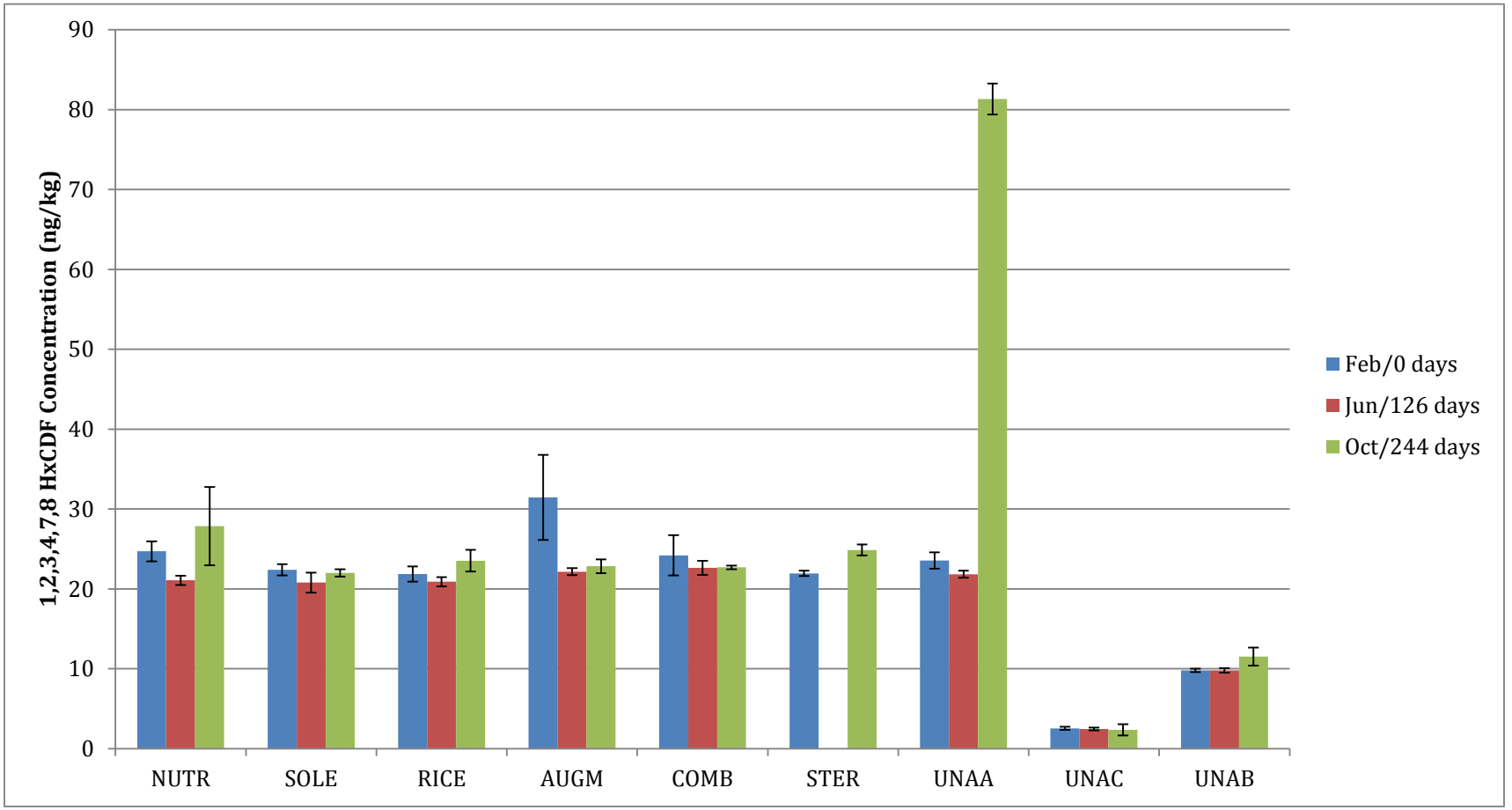


Figure 27: 1,2,3,4,7,8 HxCDF concentrations during microcosm incubation

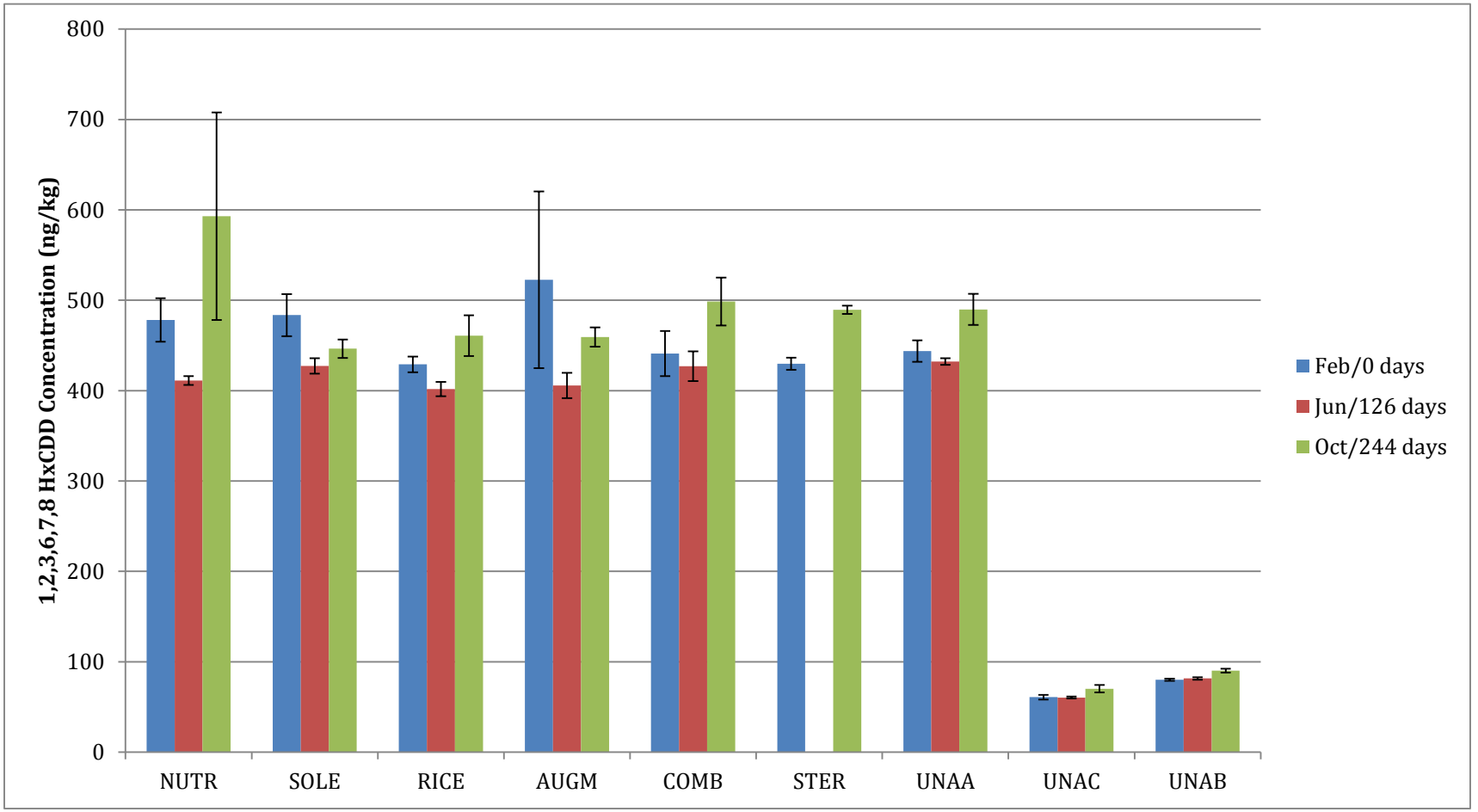


Figure 28: 1,2,3,6,7,8 HxCDD concentrations during microcosm incubation

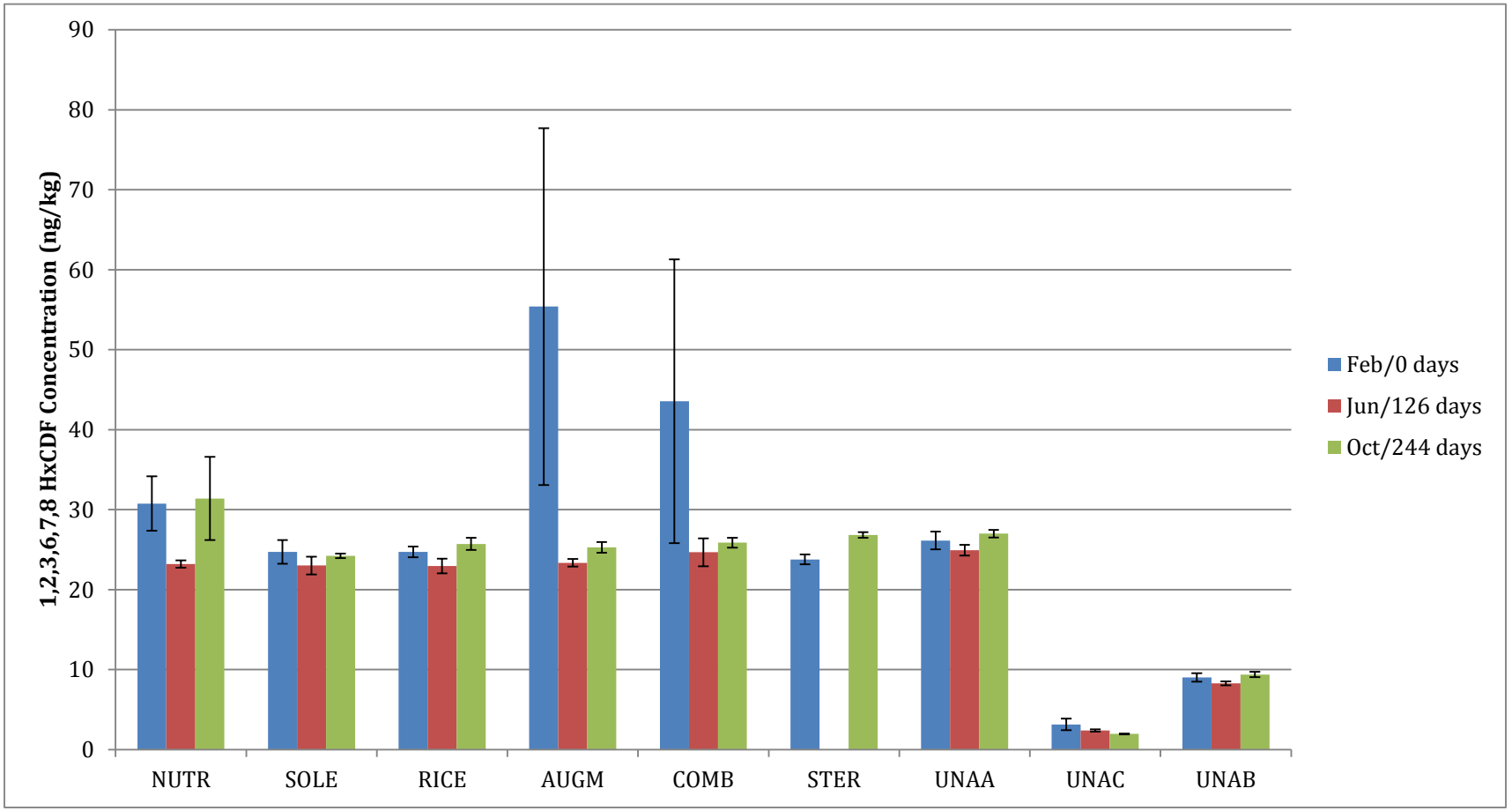


Figure 29: 1,2,3,6,7,8 HxCDF concentrations during microcosm incubation

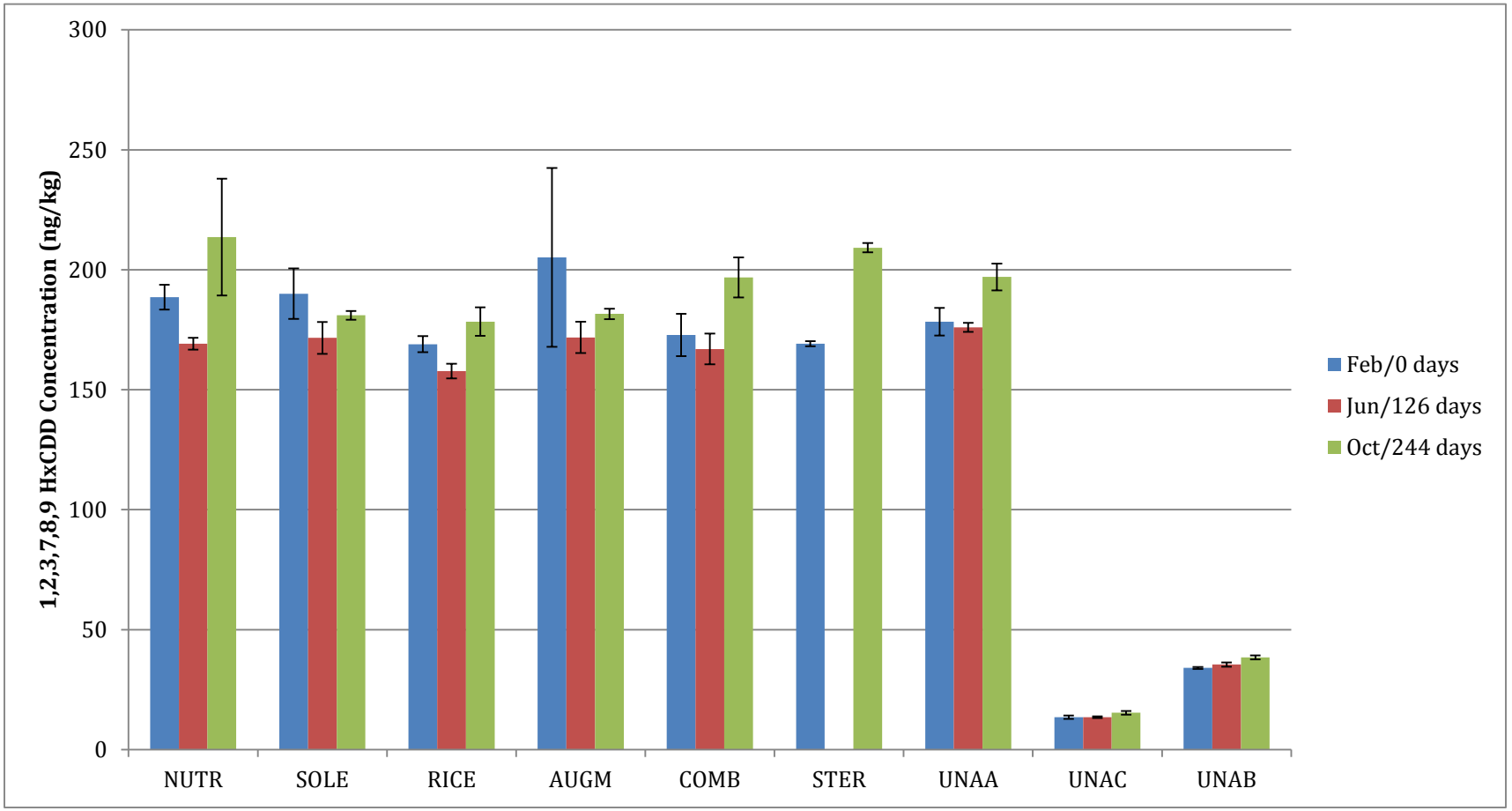


Figure 30: 1,2,3,7,8,9 HxCDD concentrations during microcosm incubation

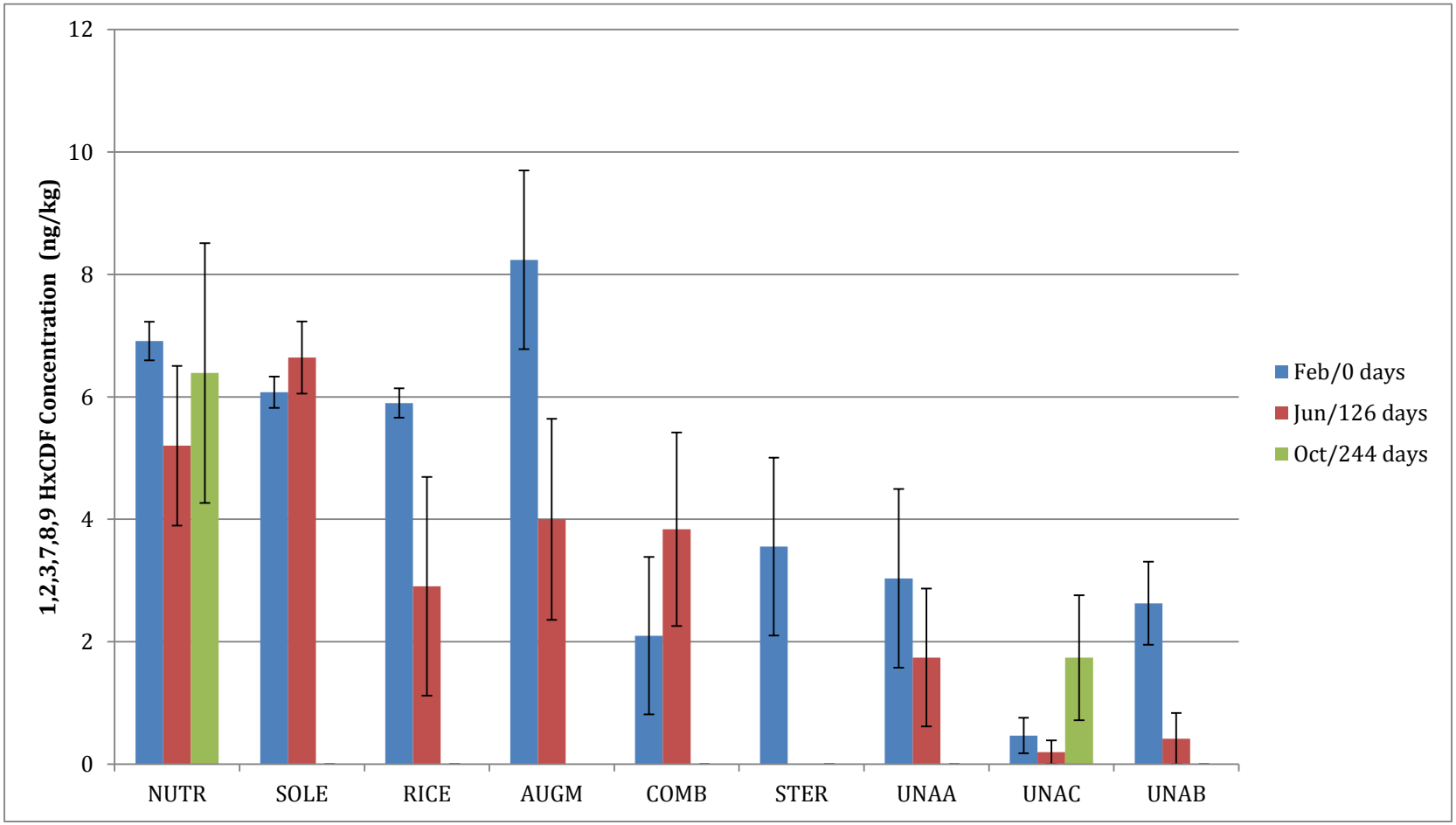


Figure 31: 1,2,3,7,8,9 HxCDF concentrations during microcosm incubation

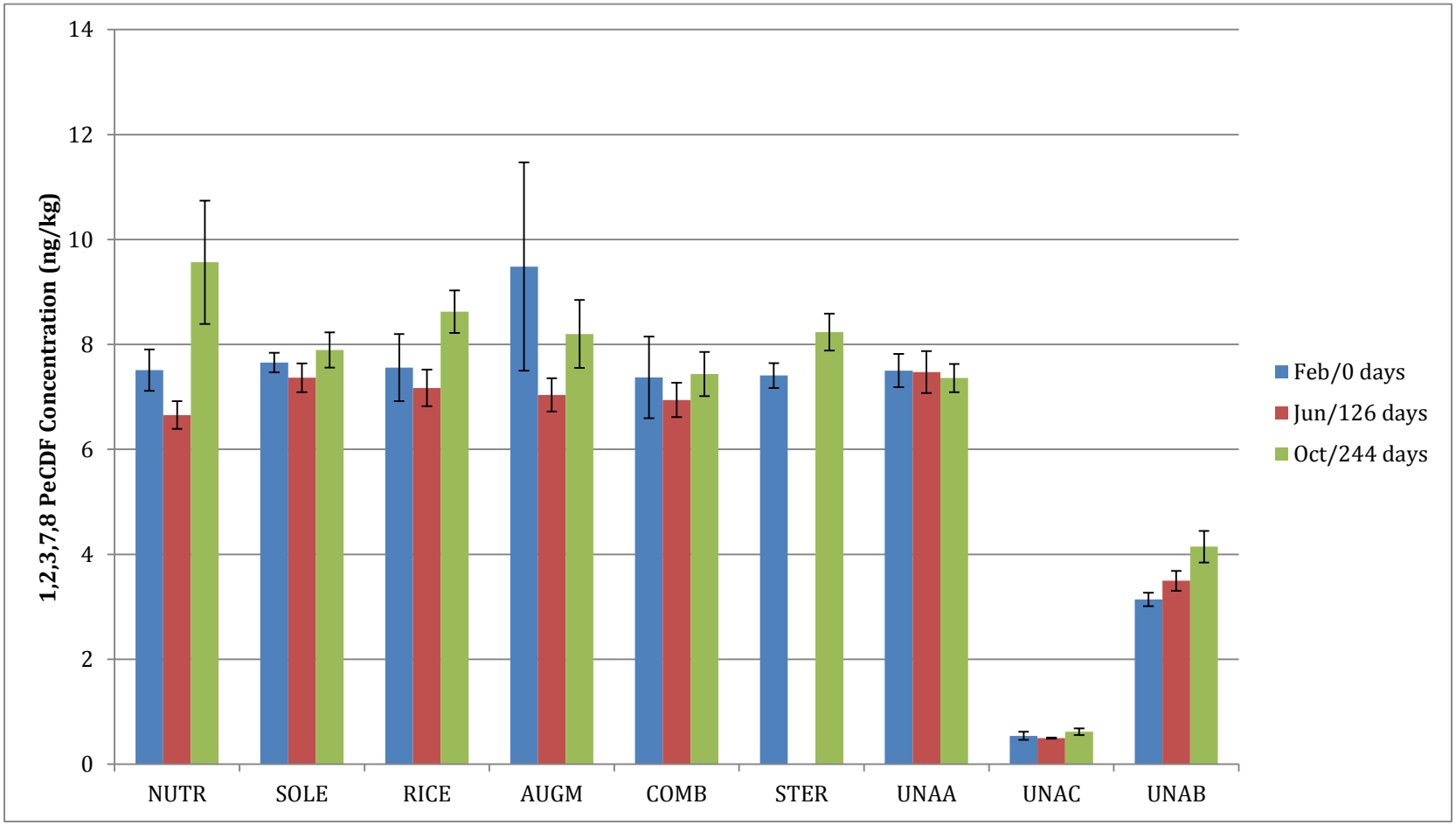


Figure 32: 1,2,3,7,8 PeCDF concentrations during microcosm incubation

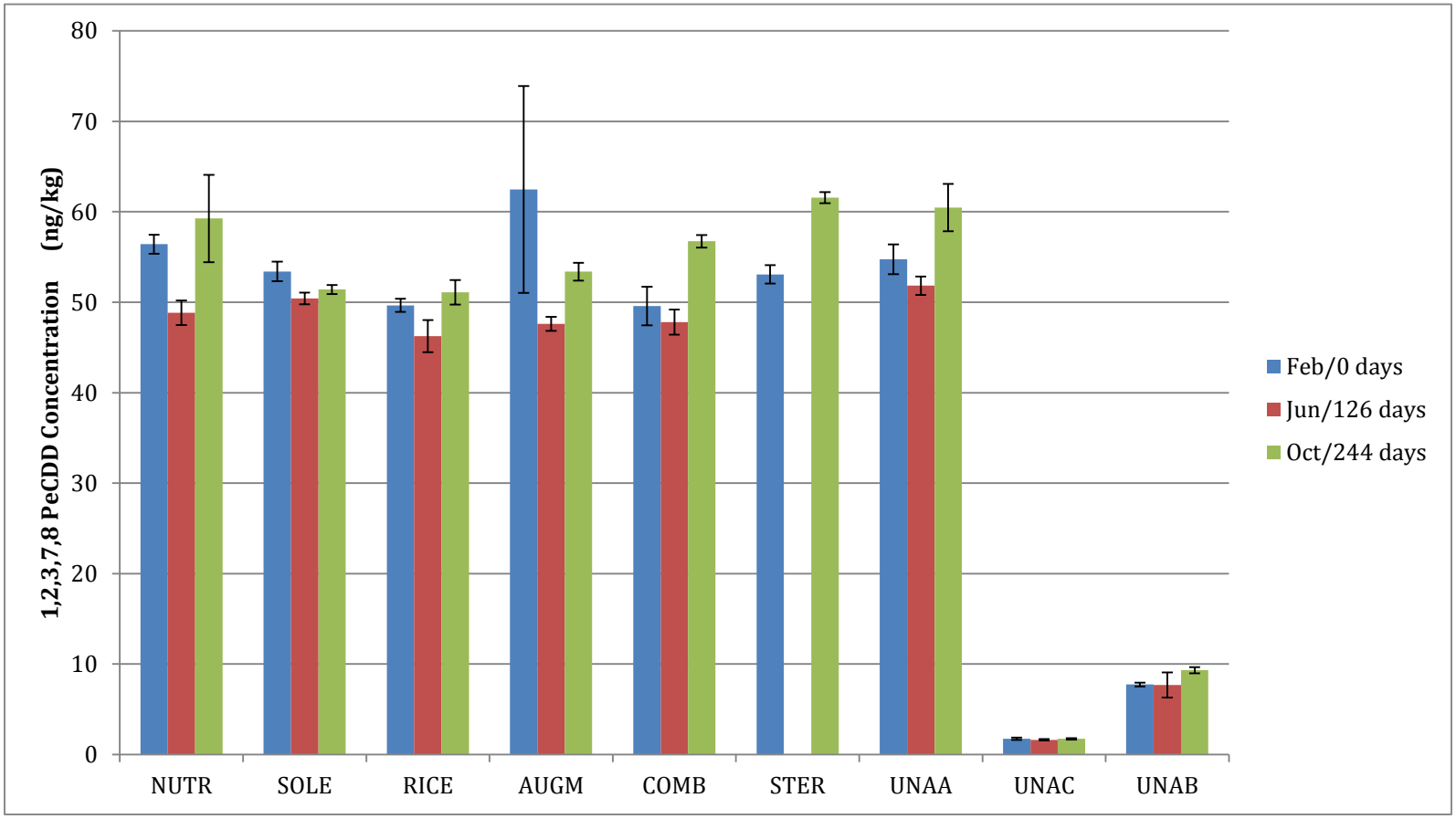


Figure 33: 1,2,3,7,8 PeCDD concentrations during microcosm incubation

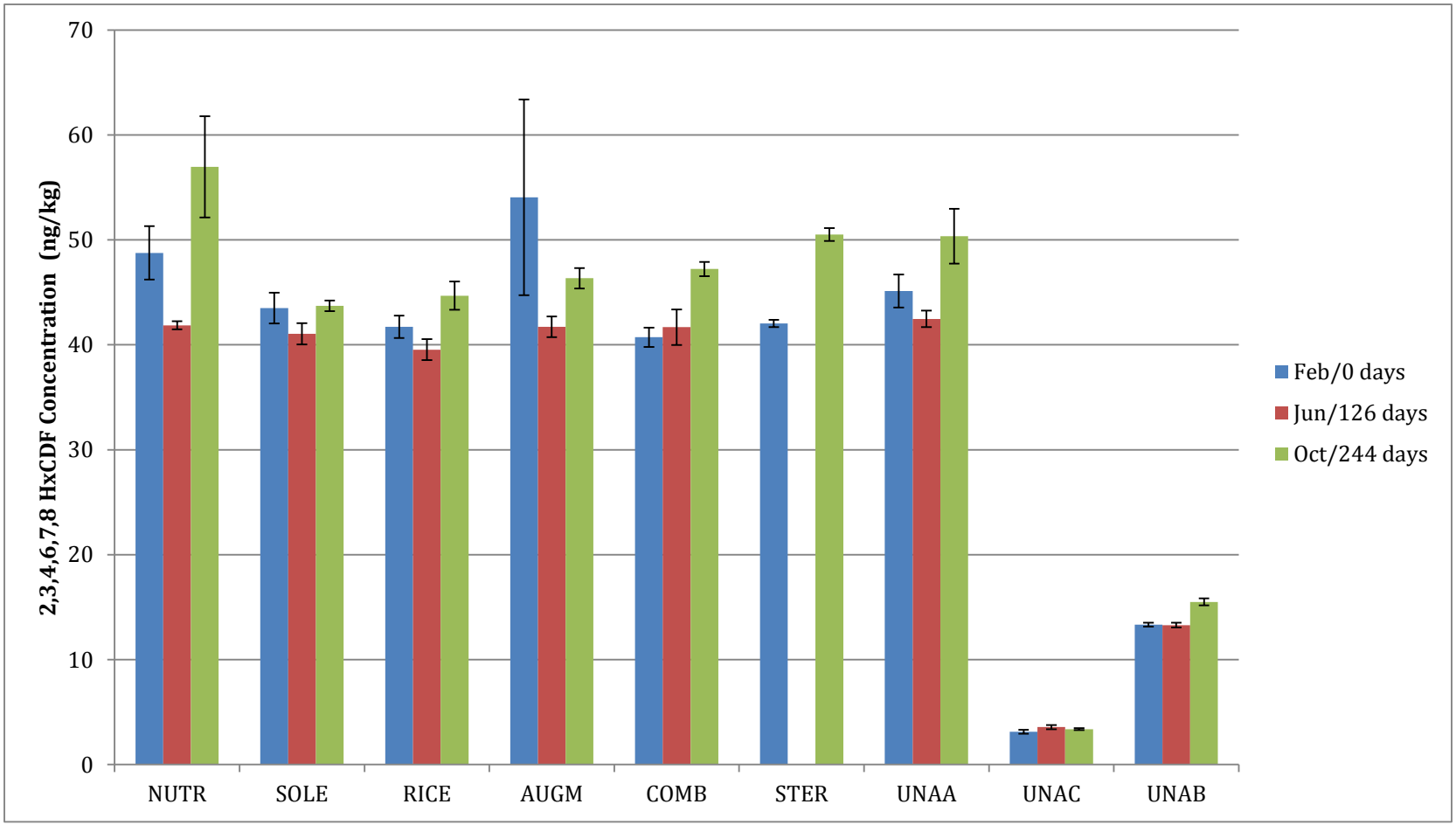


Figure 34: 2,3,4,6,7,8 HxCDF concentrations during microcosm incubation

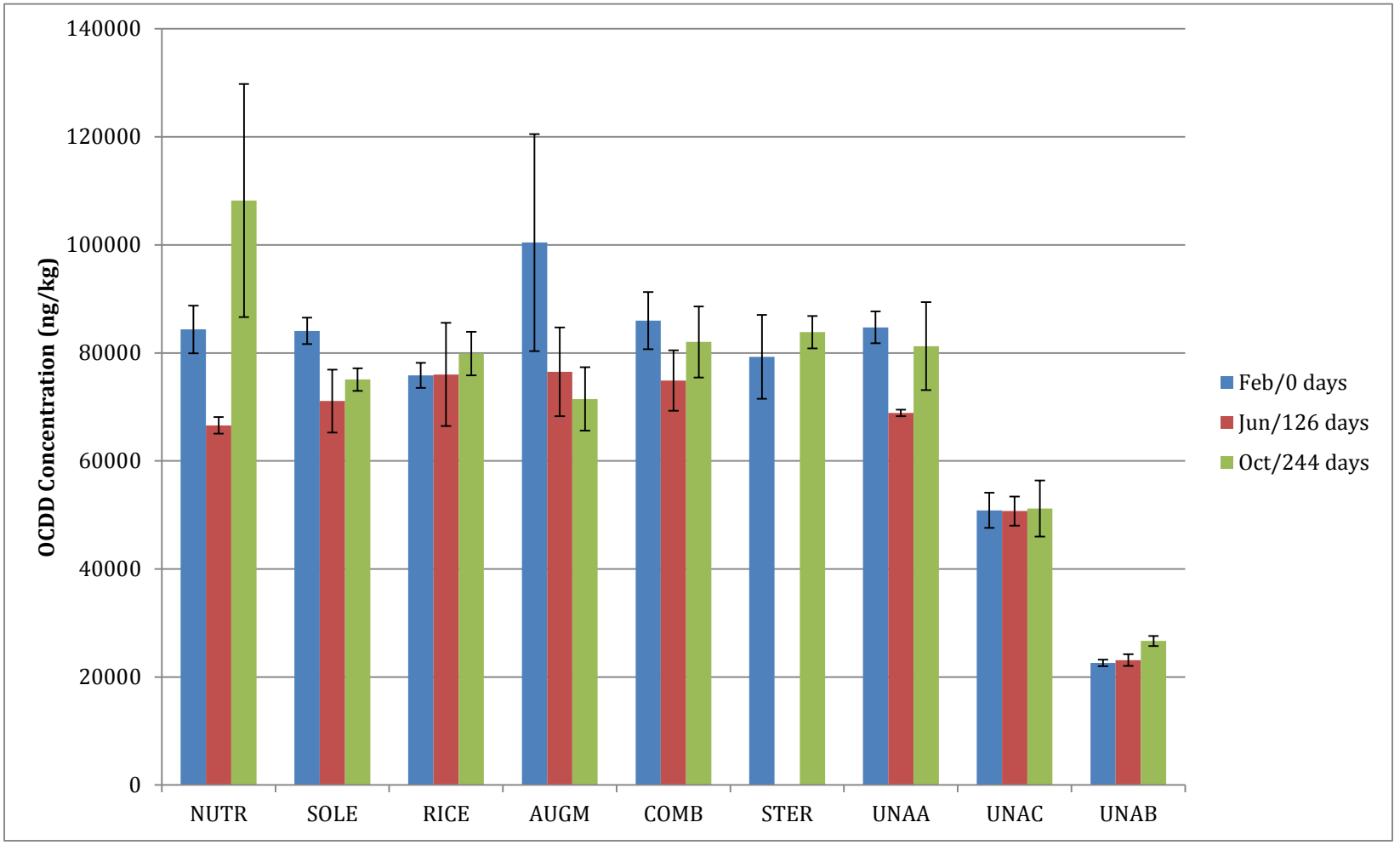


Figure 35: OCDD concentrations during microcosm incubation

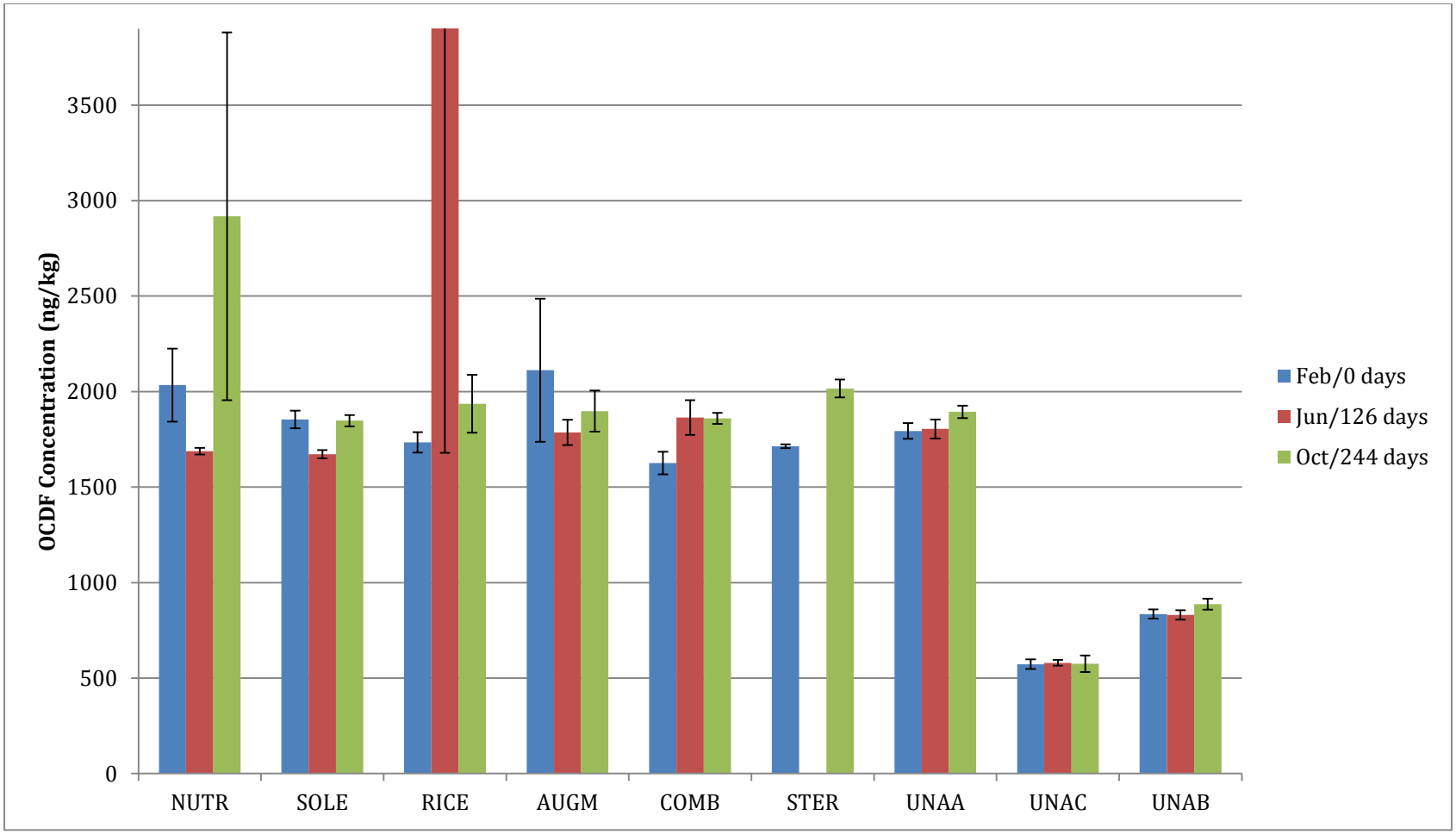


Figure 36: Truncated OCDF concentrations during microcosm incubation

Appendix C: Bar Graphs of Individual PAH Compound Concentrations

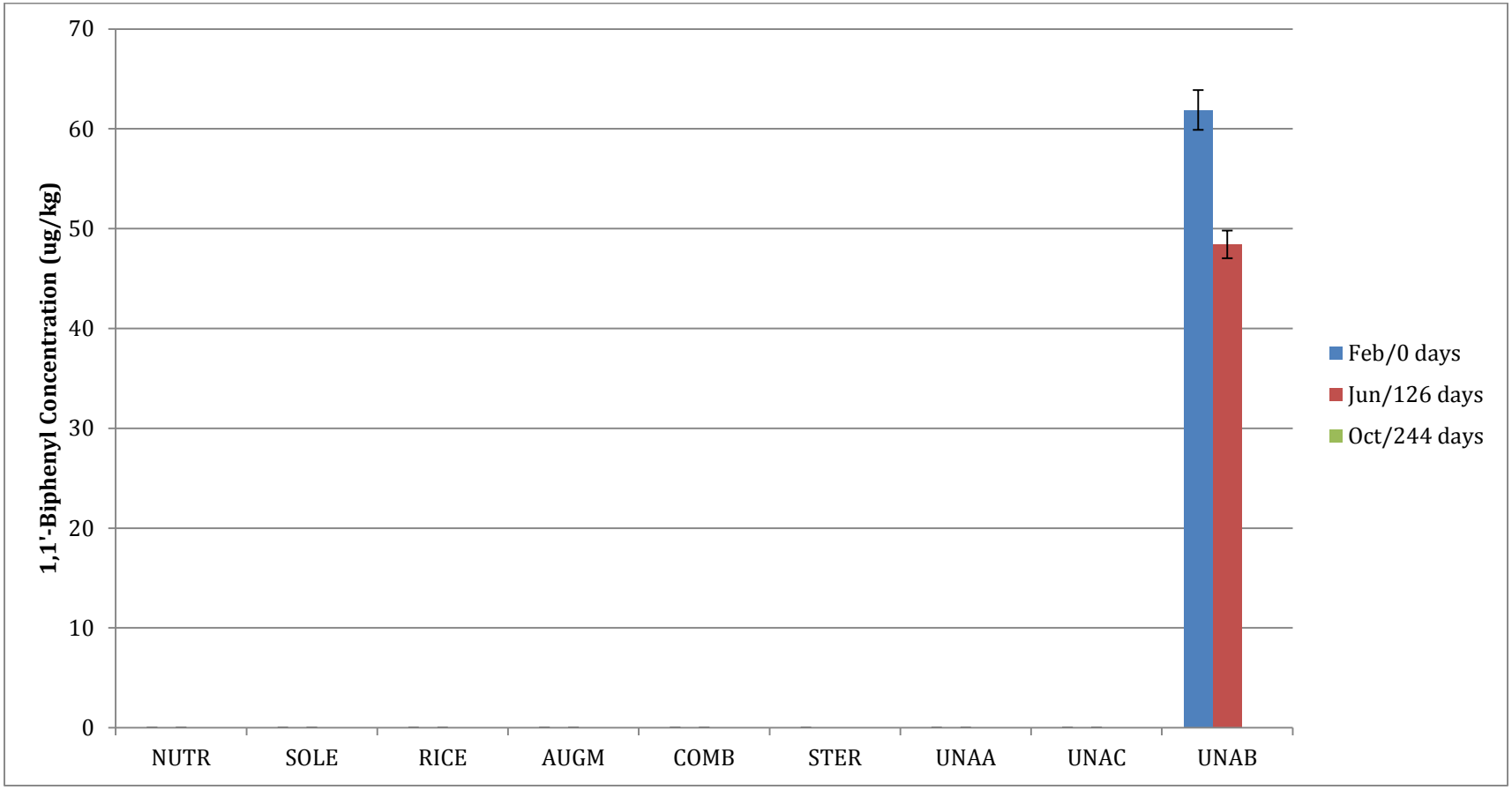


Figure 37: 1,1'-biphenyl concetrations during microcosm incubation

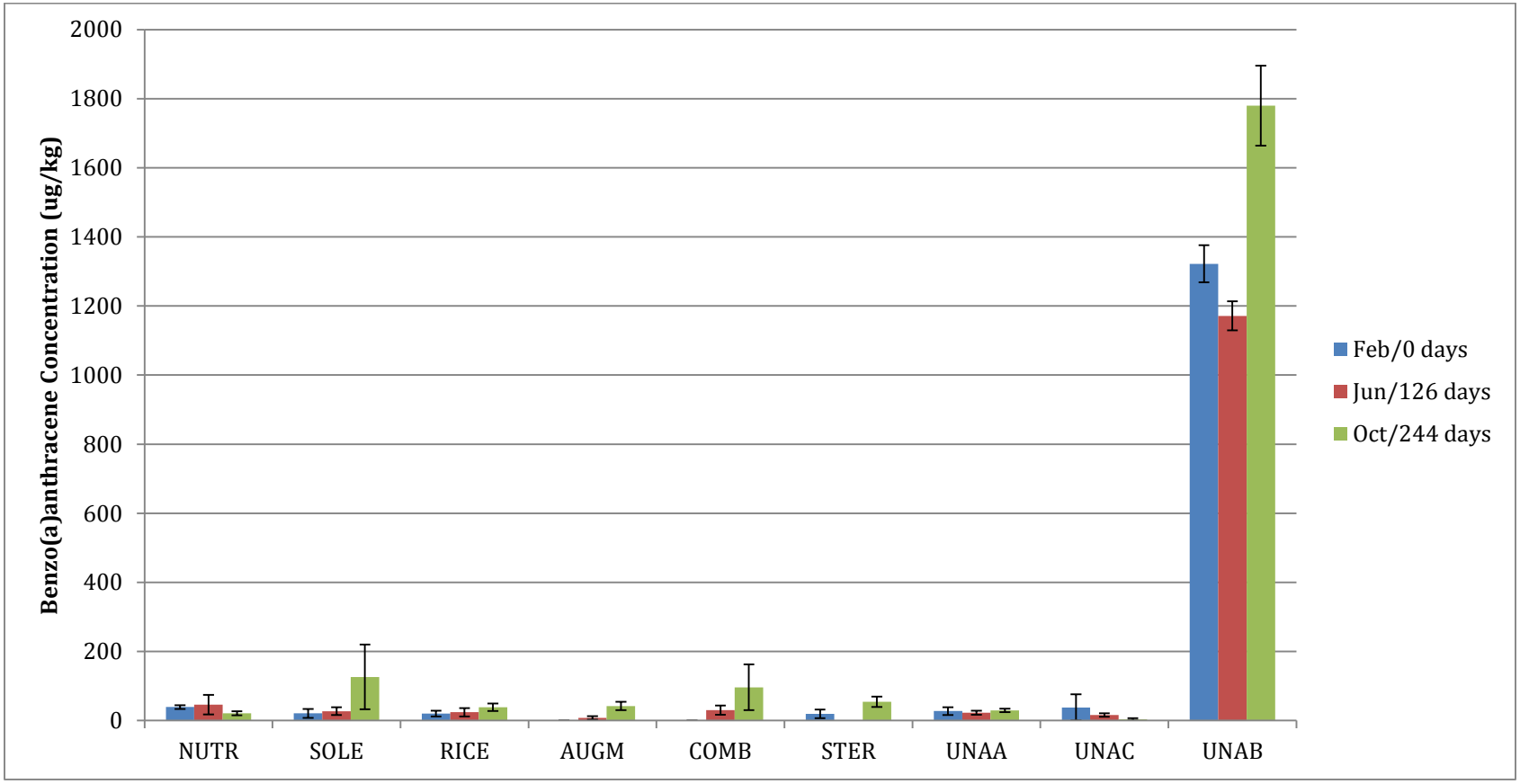


Figure 38: Benzo(a)anthracene concentrations during microcosm incubation (all soils)

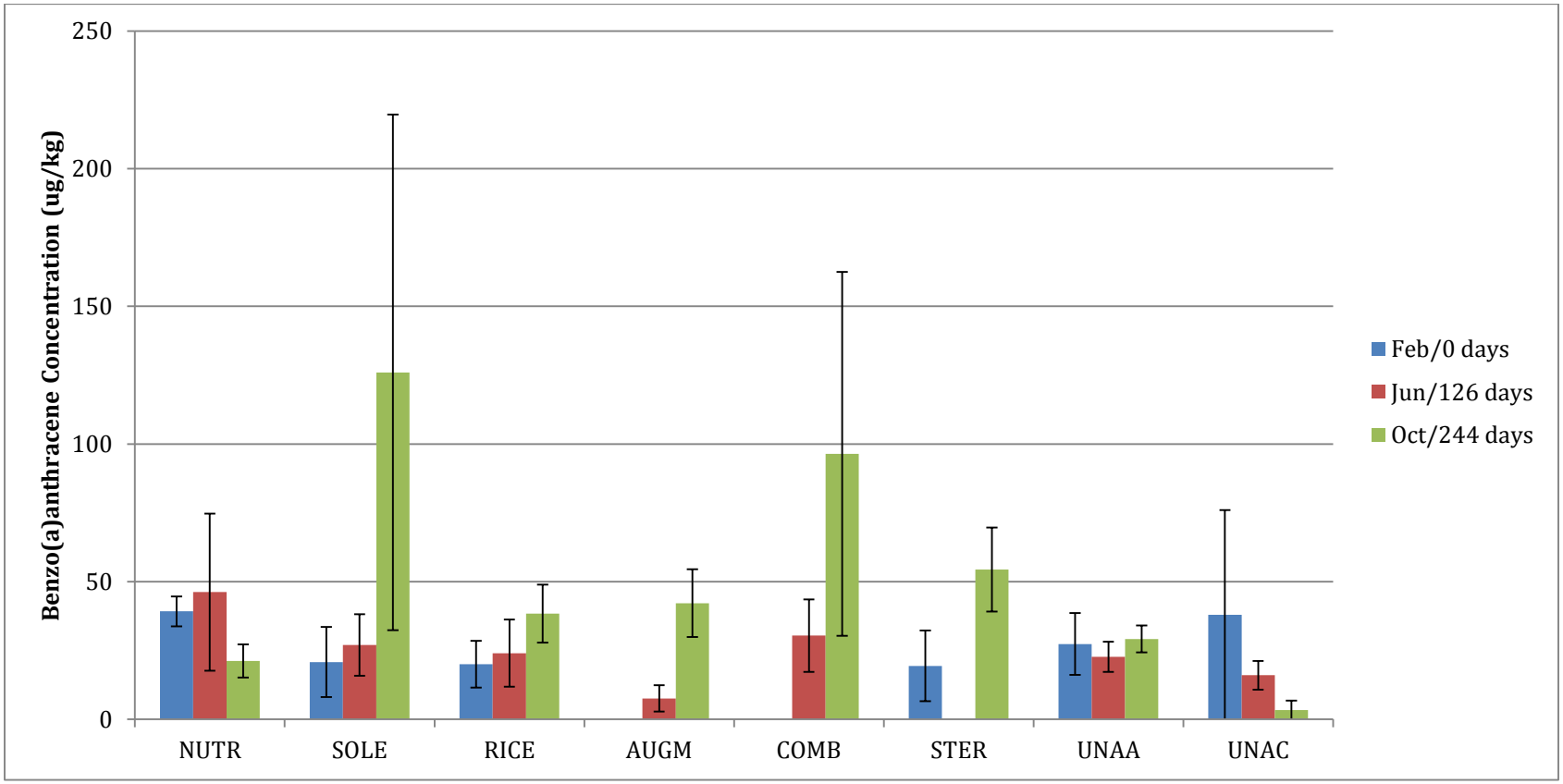


Figure 39: Benzo(a)anthracene during incubation (A and C)

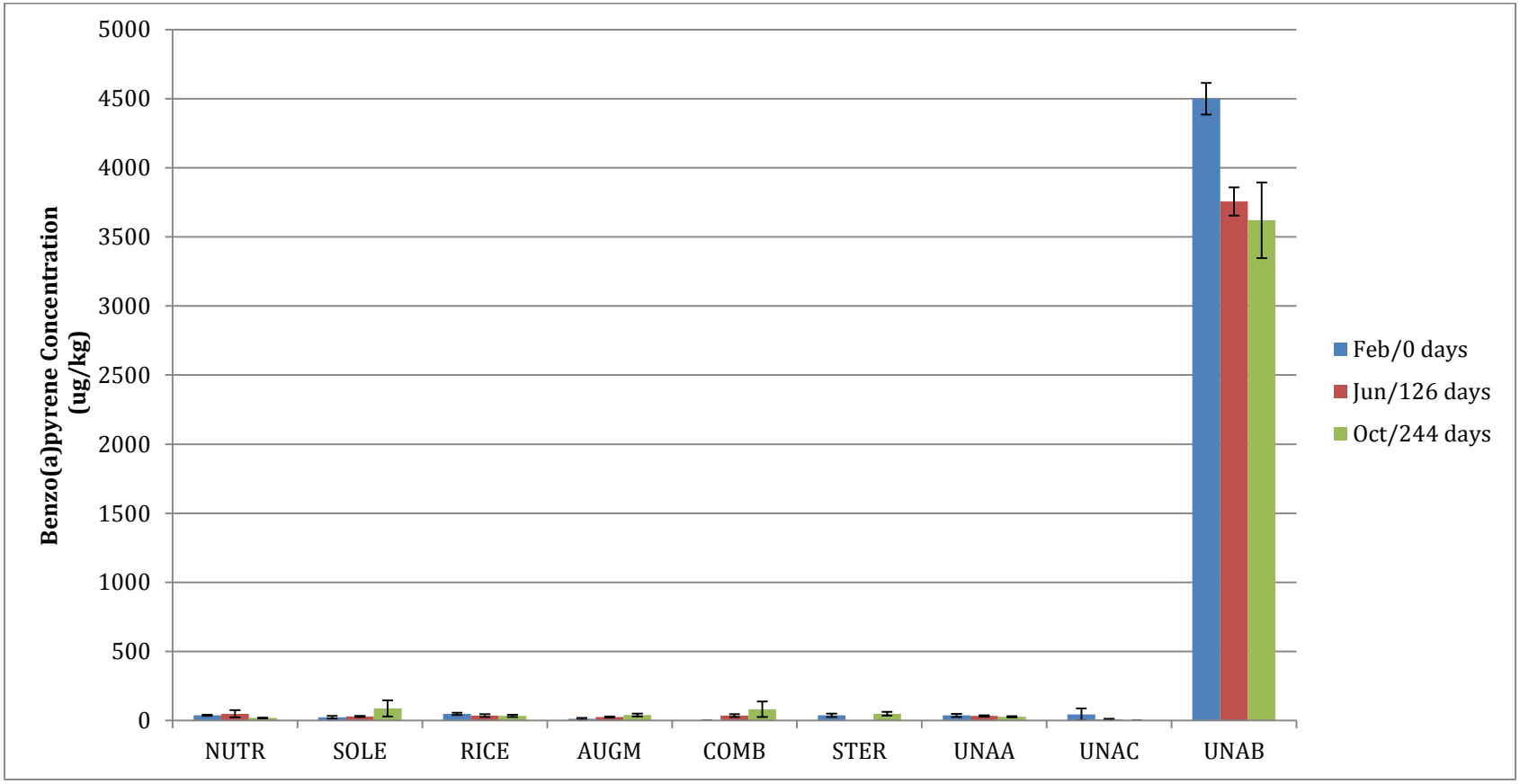


Figure 40: Benzo(a)pyrene concentrations during microcosm incubation (all soils)

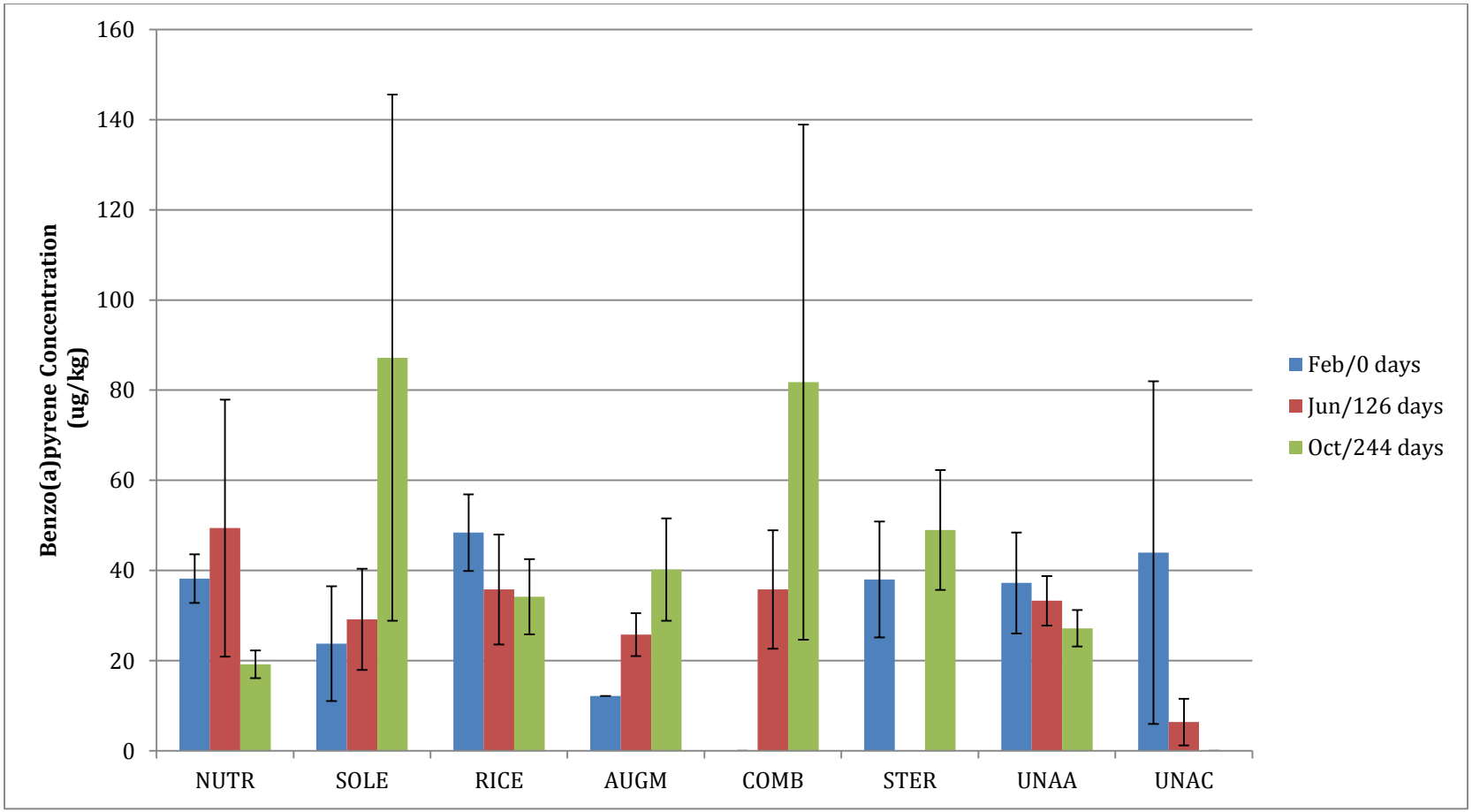


Figure 41: Benzo(a)pyrene concentrations during microcosm incubation (A and C)

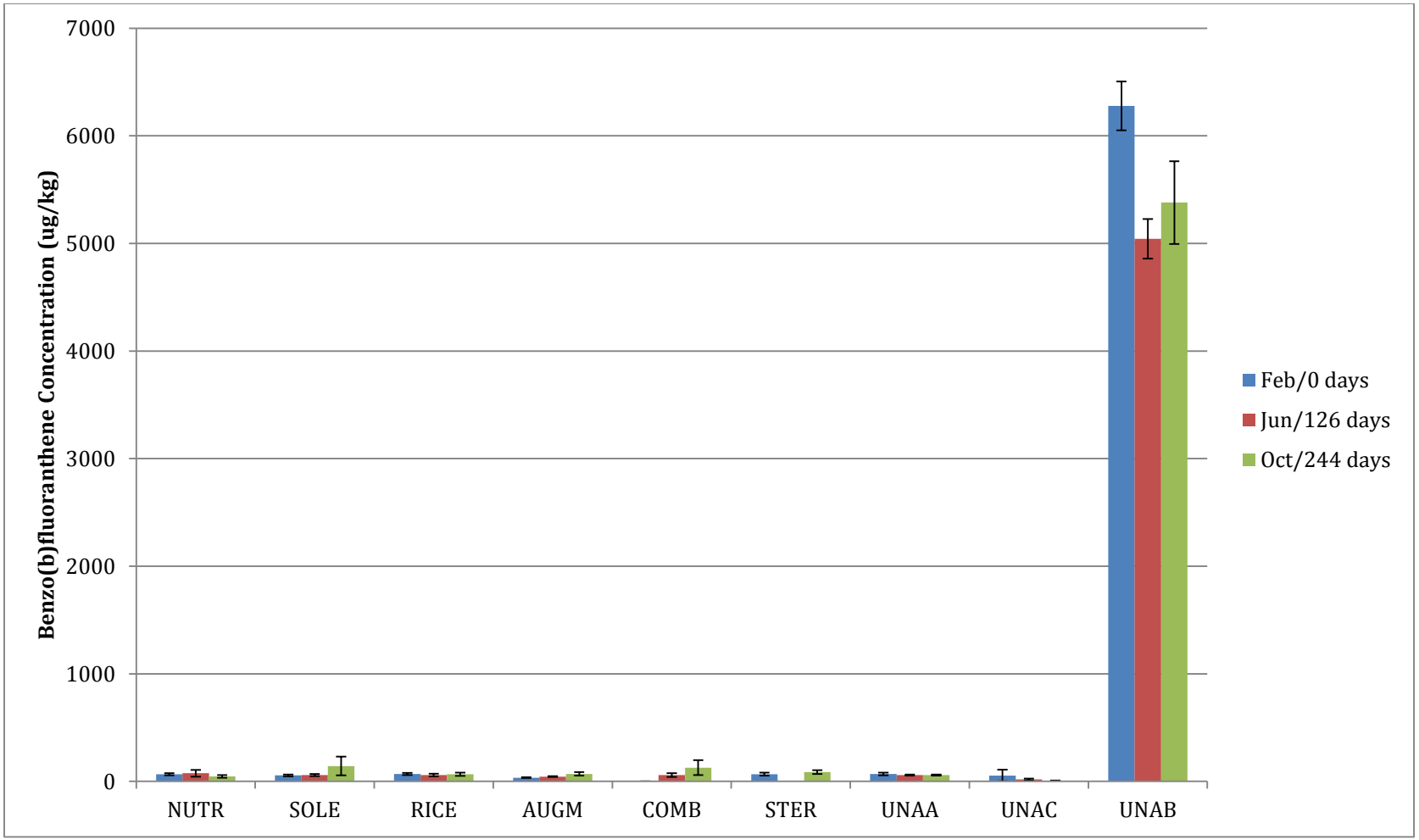


Figure 42: Benzo(b)fluoranthene concentrations during microcosm incubation (all soils)

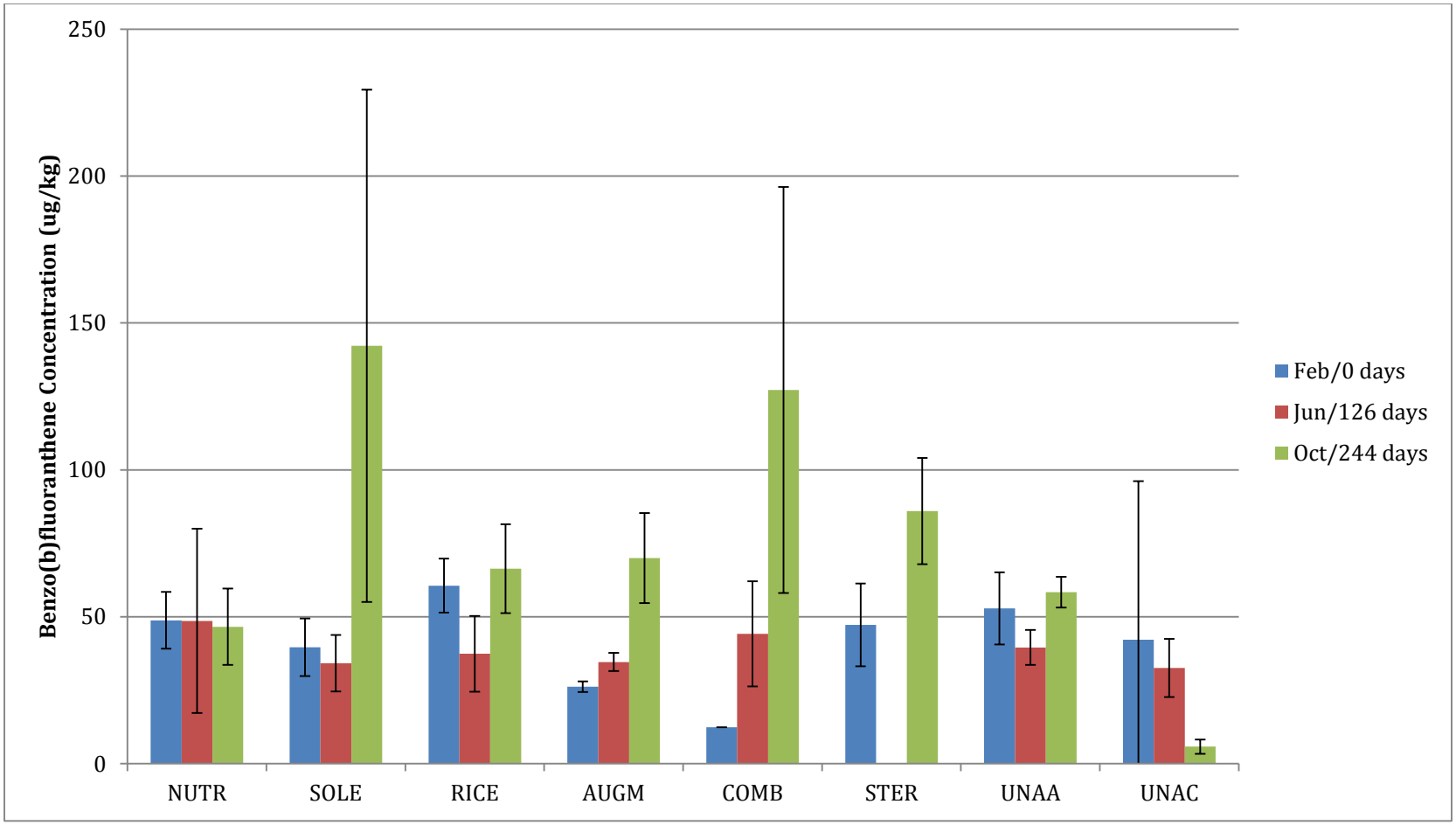


Figure 43: Benzo(b)fluoranthene concentrations during microcosm incubation (A and C)

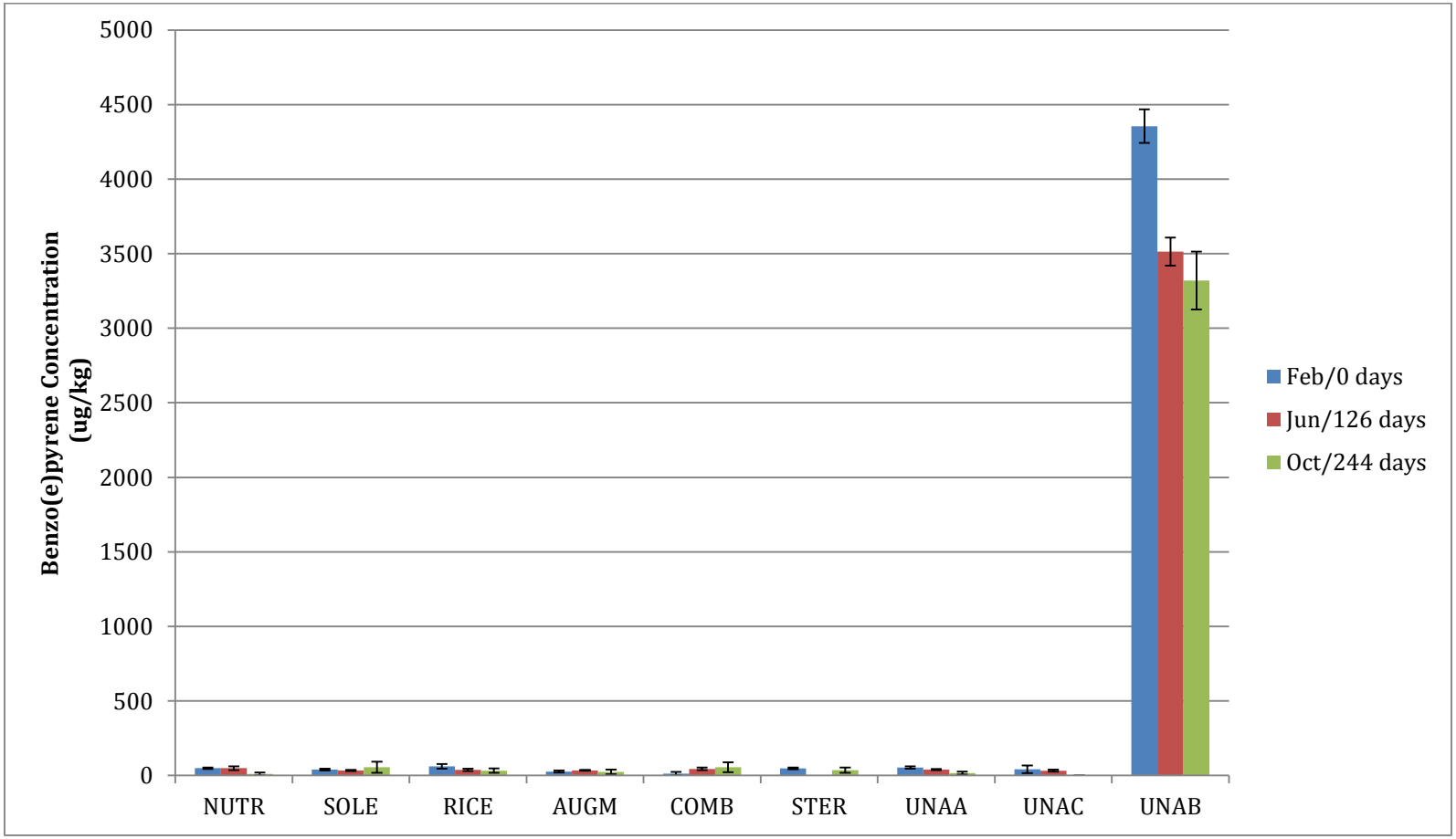


Figure 44: Benzo(e)pyrene concentrations during microcosm incubation (all soils)

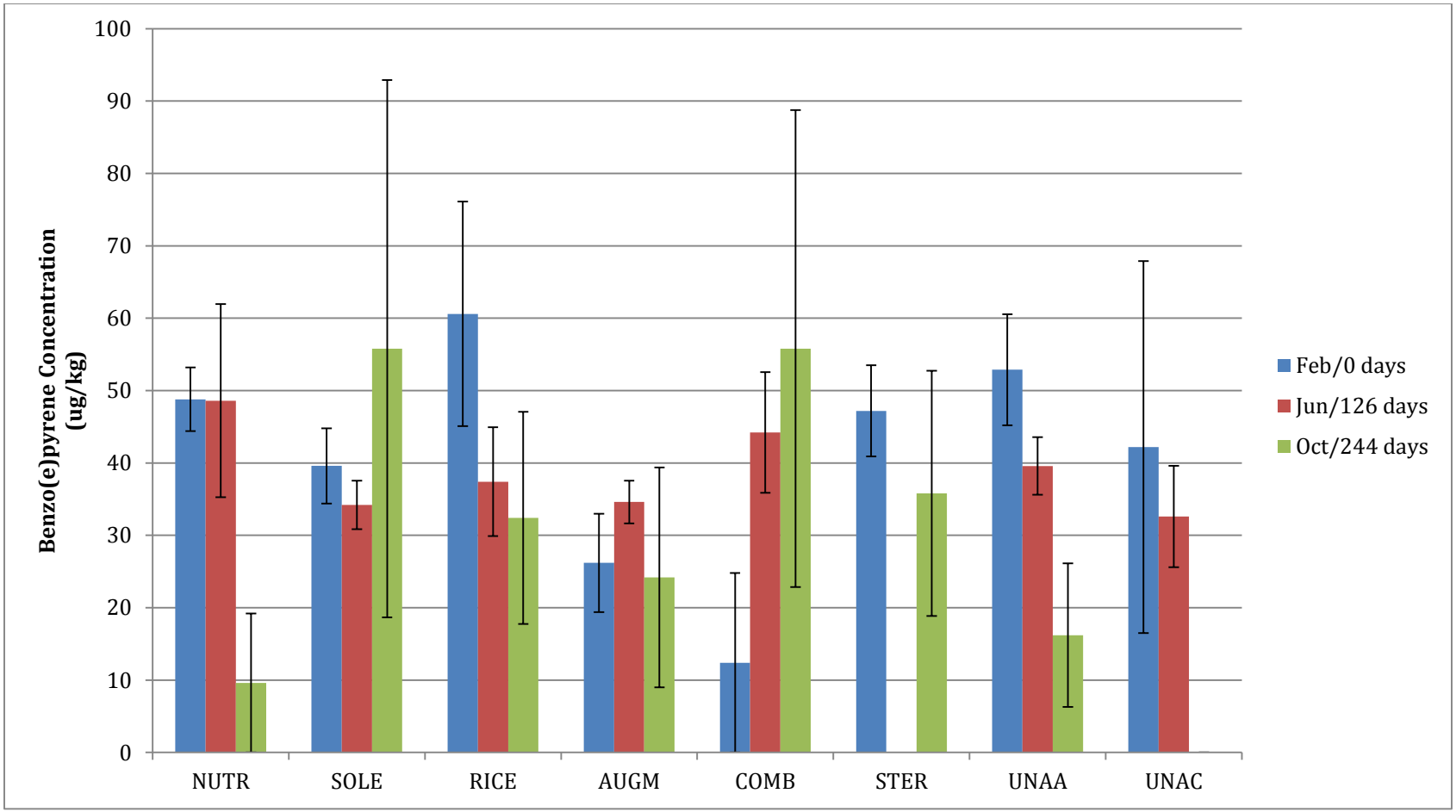


Figure 45: Benzo(e)pyrene concentrations during microcosm incubation (Soils A and C)

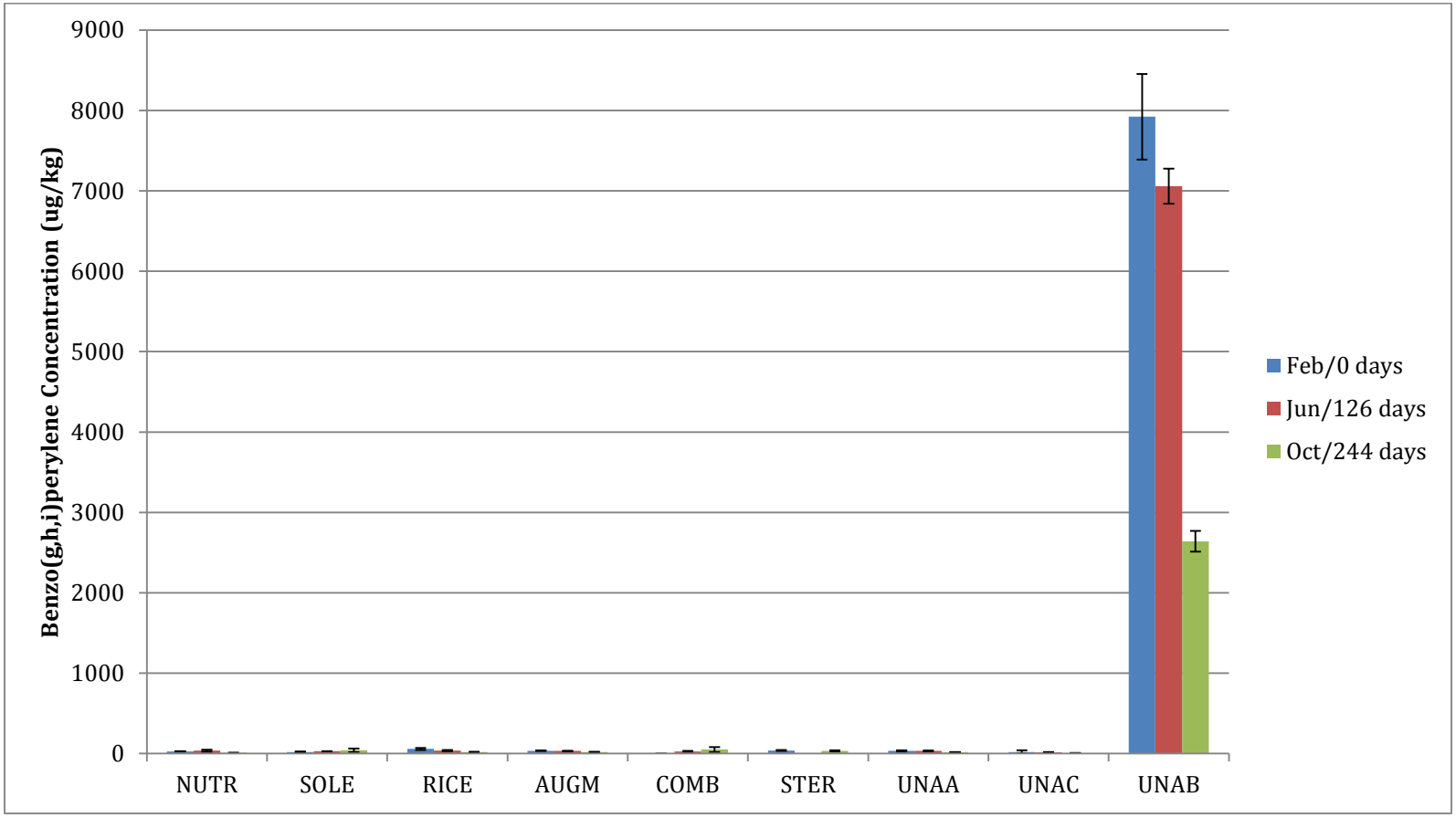


Figure 46: Benzo(g,h,i)perylene concentrations during microcosm incubation (all soils)

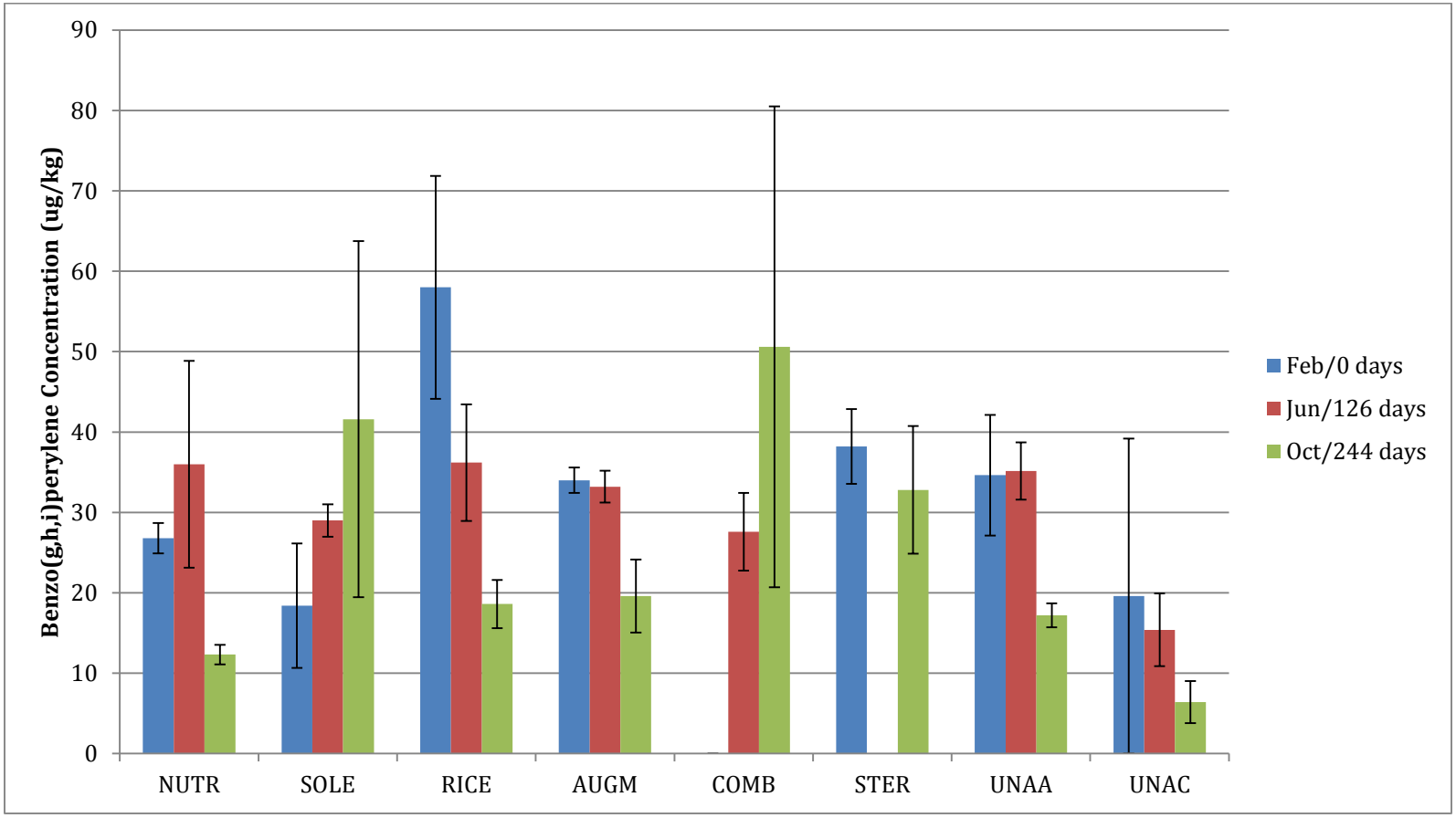


Figure 47: Benzo(g,h,i)perylene concentrations during microcosm incubation (A and C)

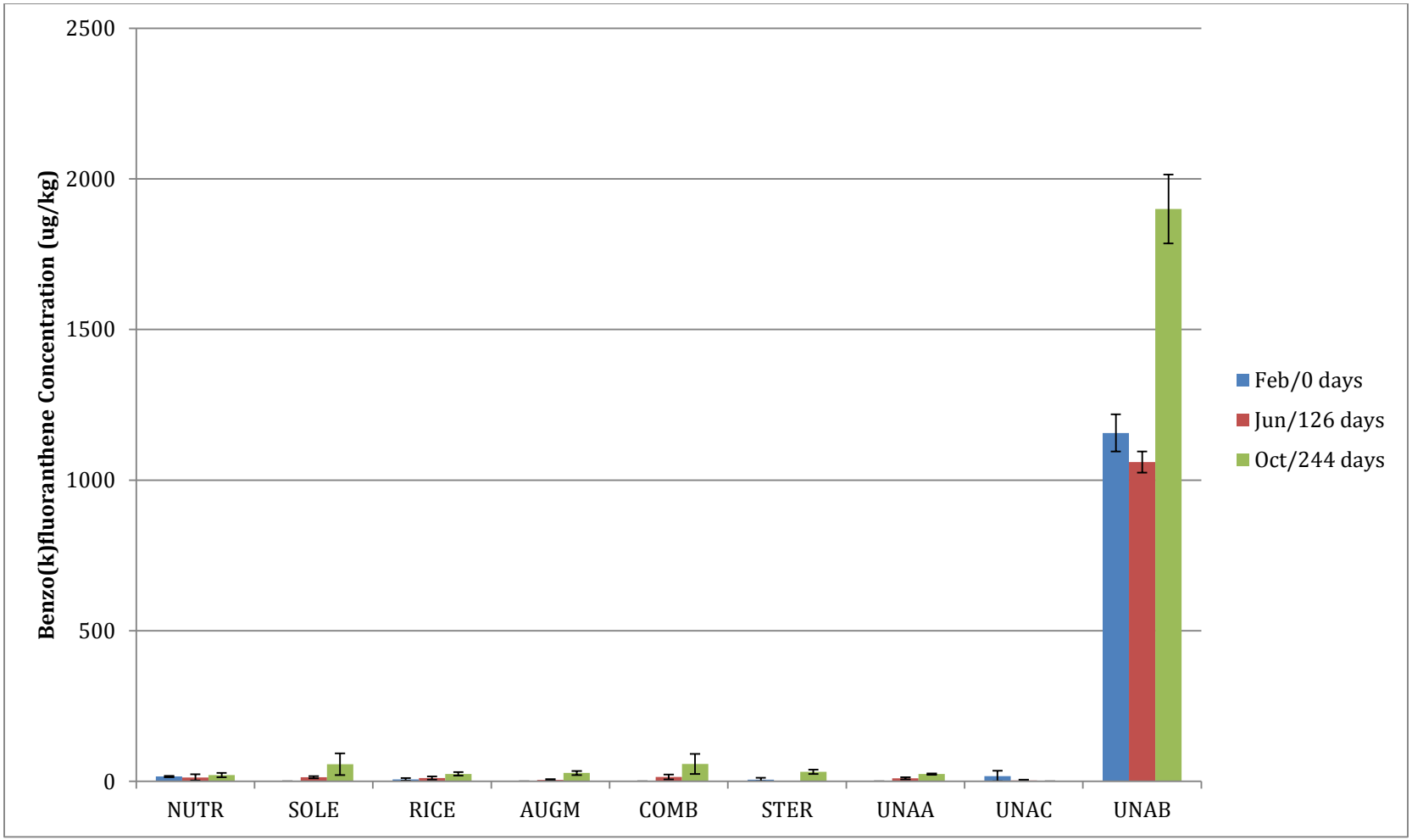


Figure 48: Benzo(k)fluoranthene concentrations during microcosm incubation (all soils)

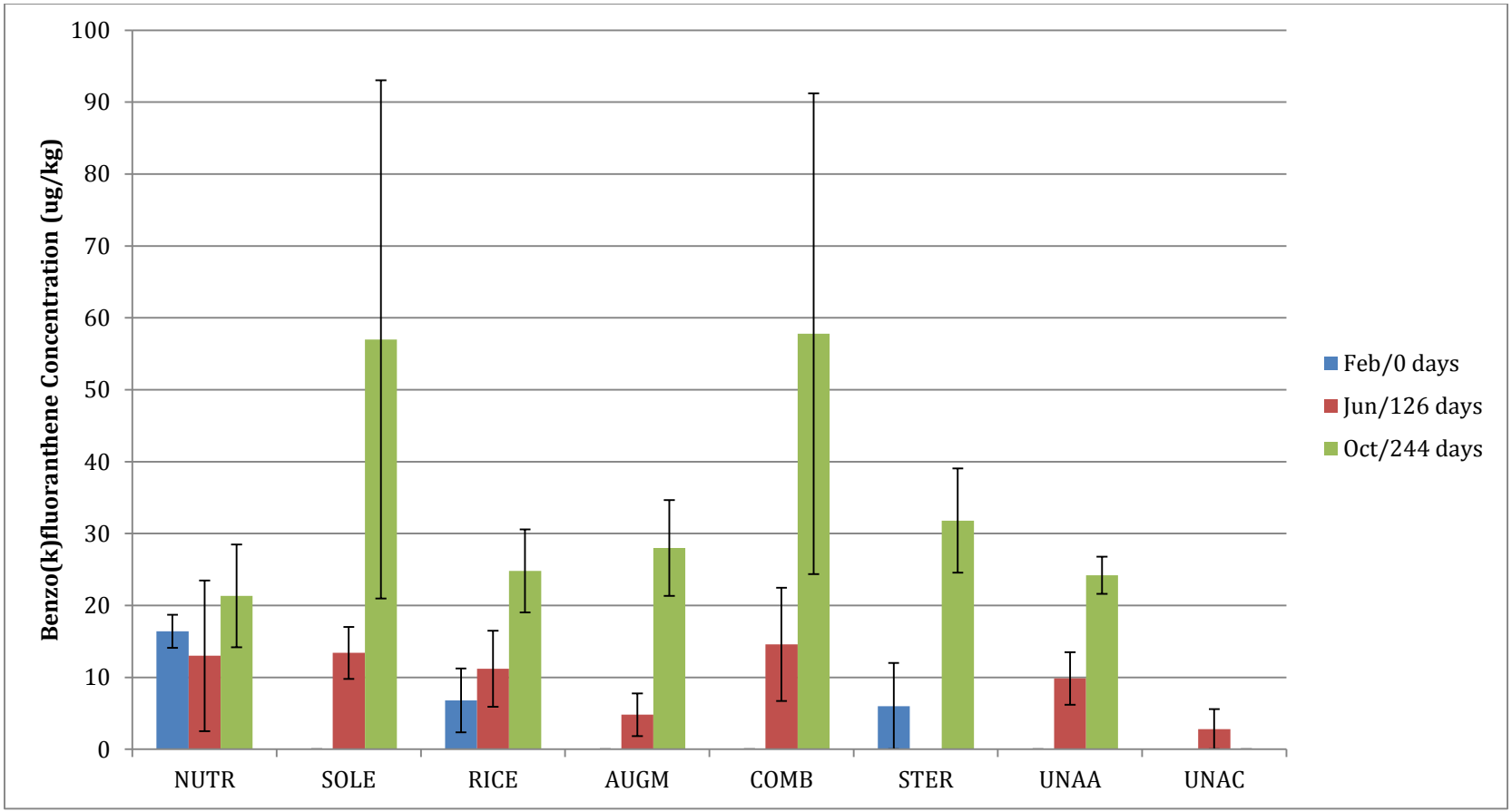


Figure 49: Benzo(k)fluoranthene concentrations during microcosm incubation (A and C)

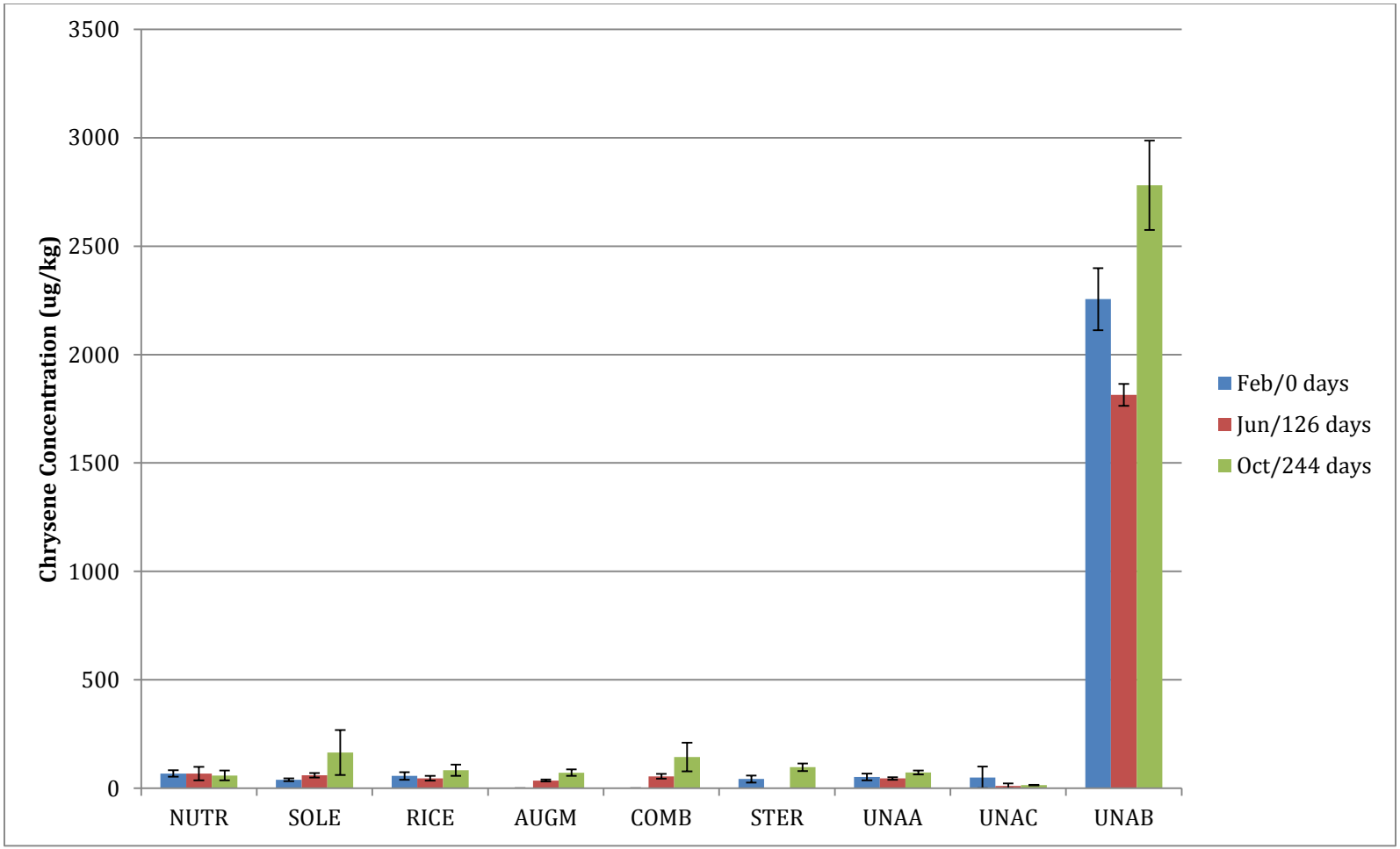


Figure 50: Chrysene concentrations during microcosm incubation (all soils)

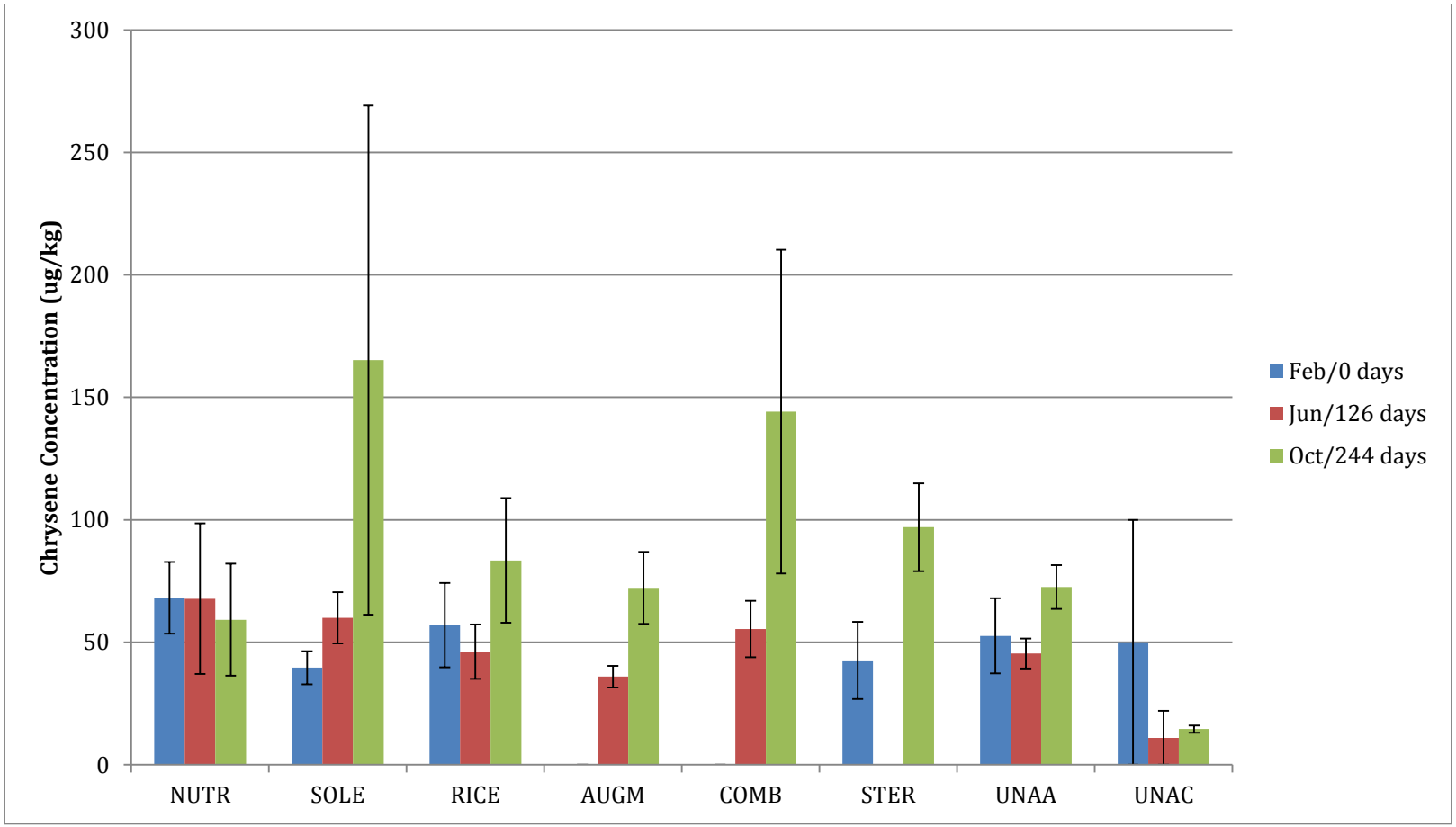


Figure 51: Chrysene concentrations during microcosm incubation (A and C)

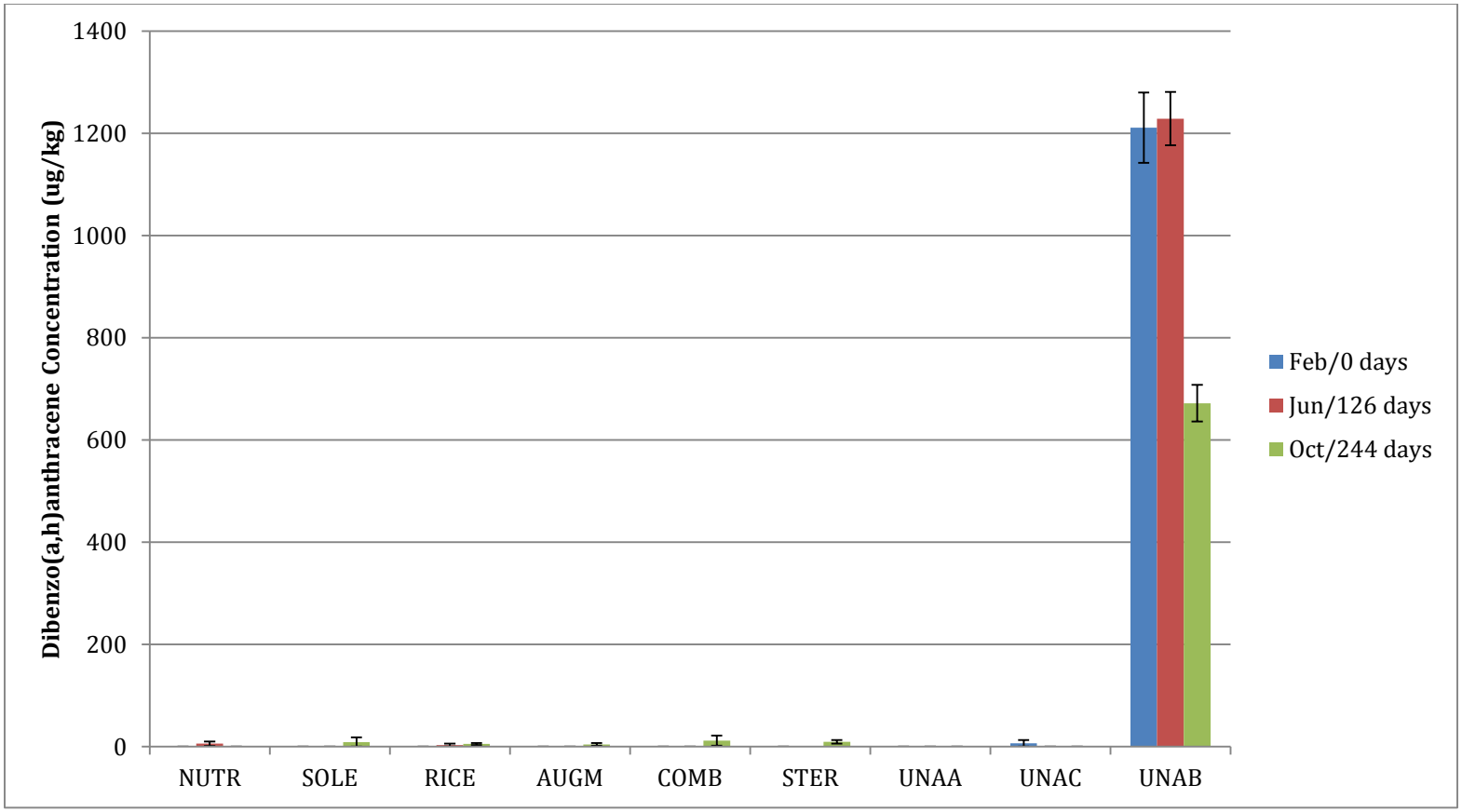


Figure 52: Dibenzo(a,h)anthracene concentrations during microcosm incubation (all soils)

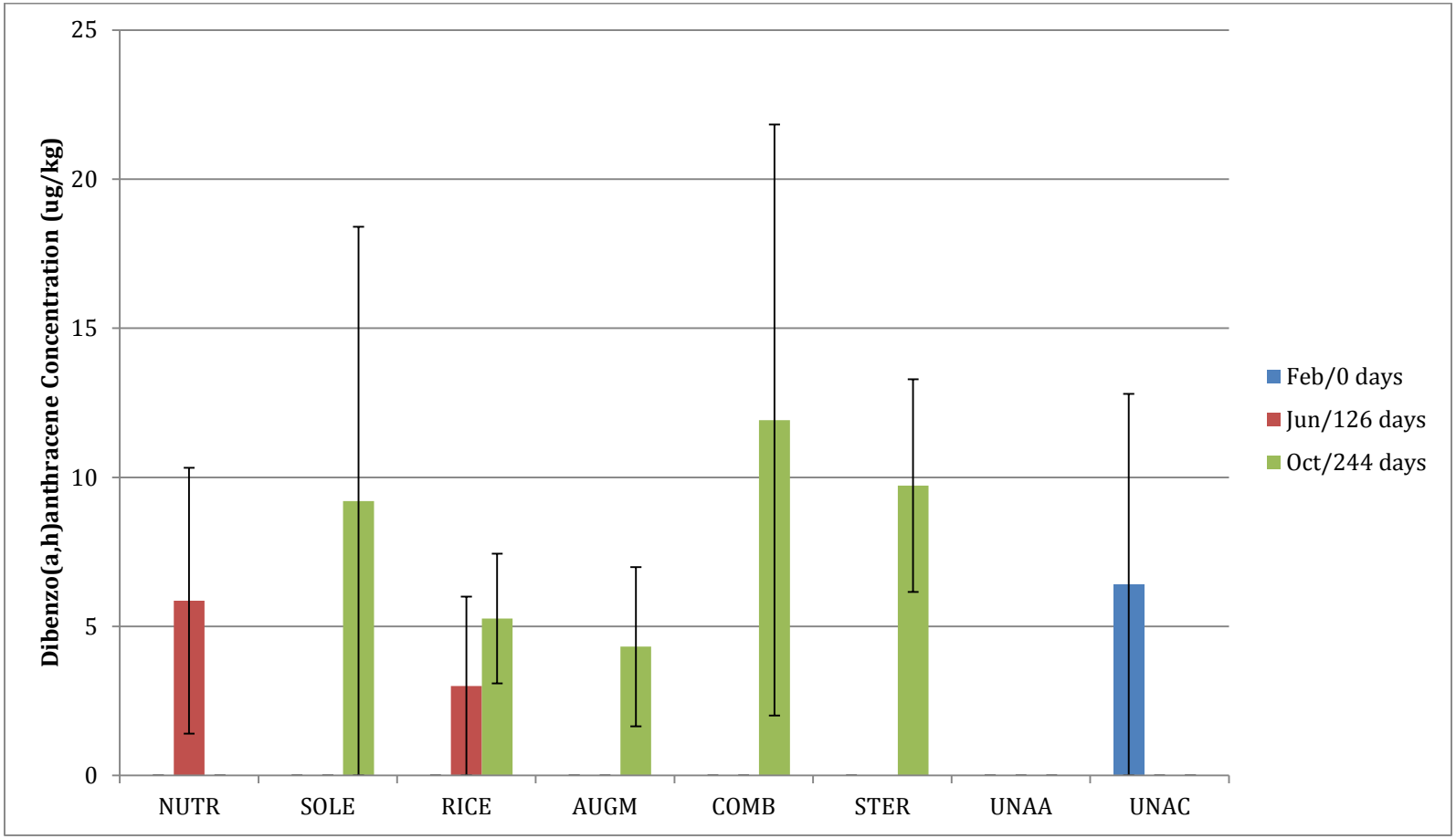


Figure 53: Dibenzo(a,h)anthracene concentrations during microcosm incubation (A and C)

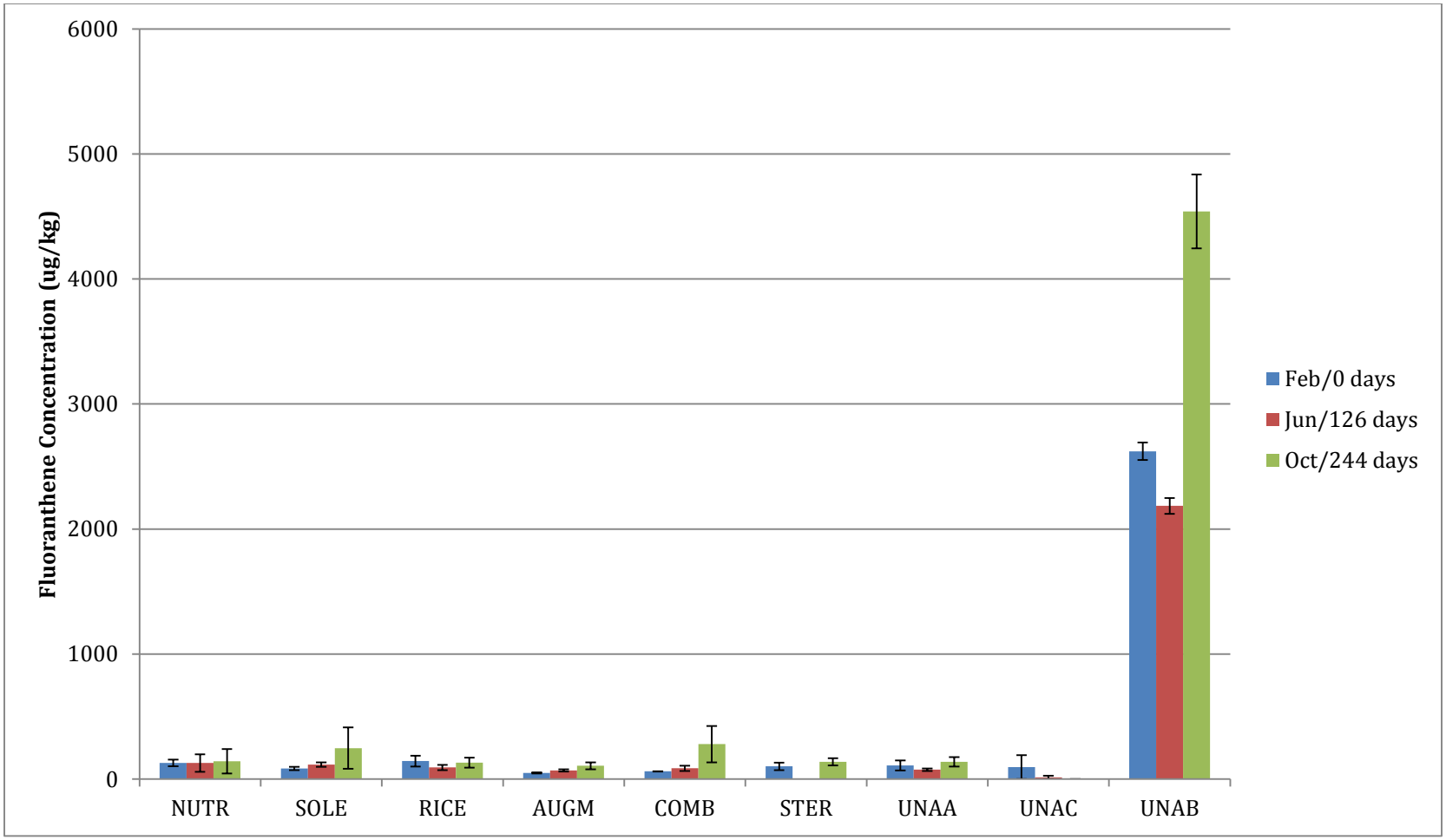


Figure 54: Fluoranthene concentrations during microcosm incubation (all soils)

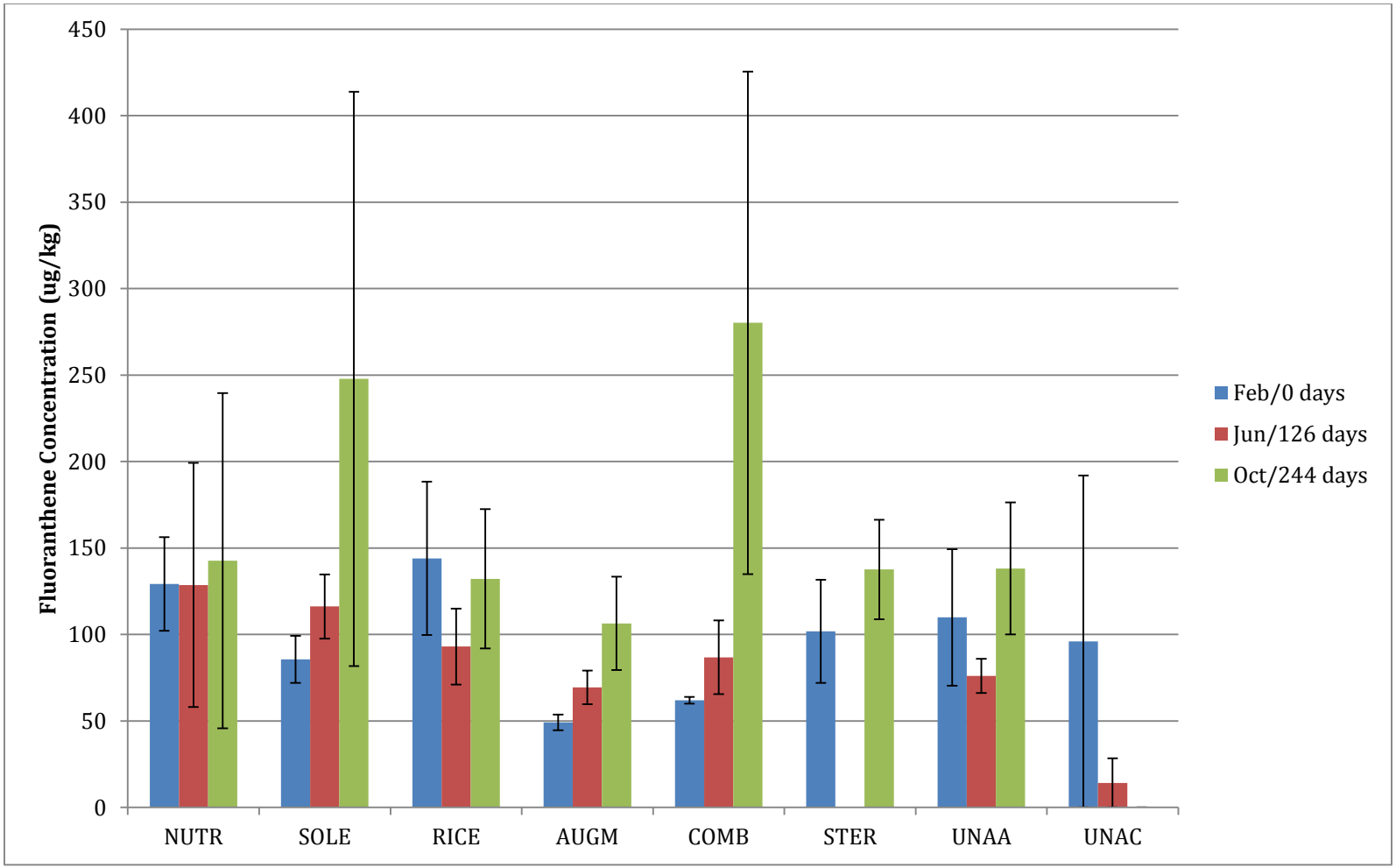


Figure 55: Flouranthene concentrations during microcosm incubation (A and C)

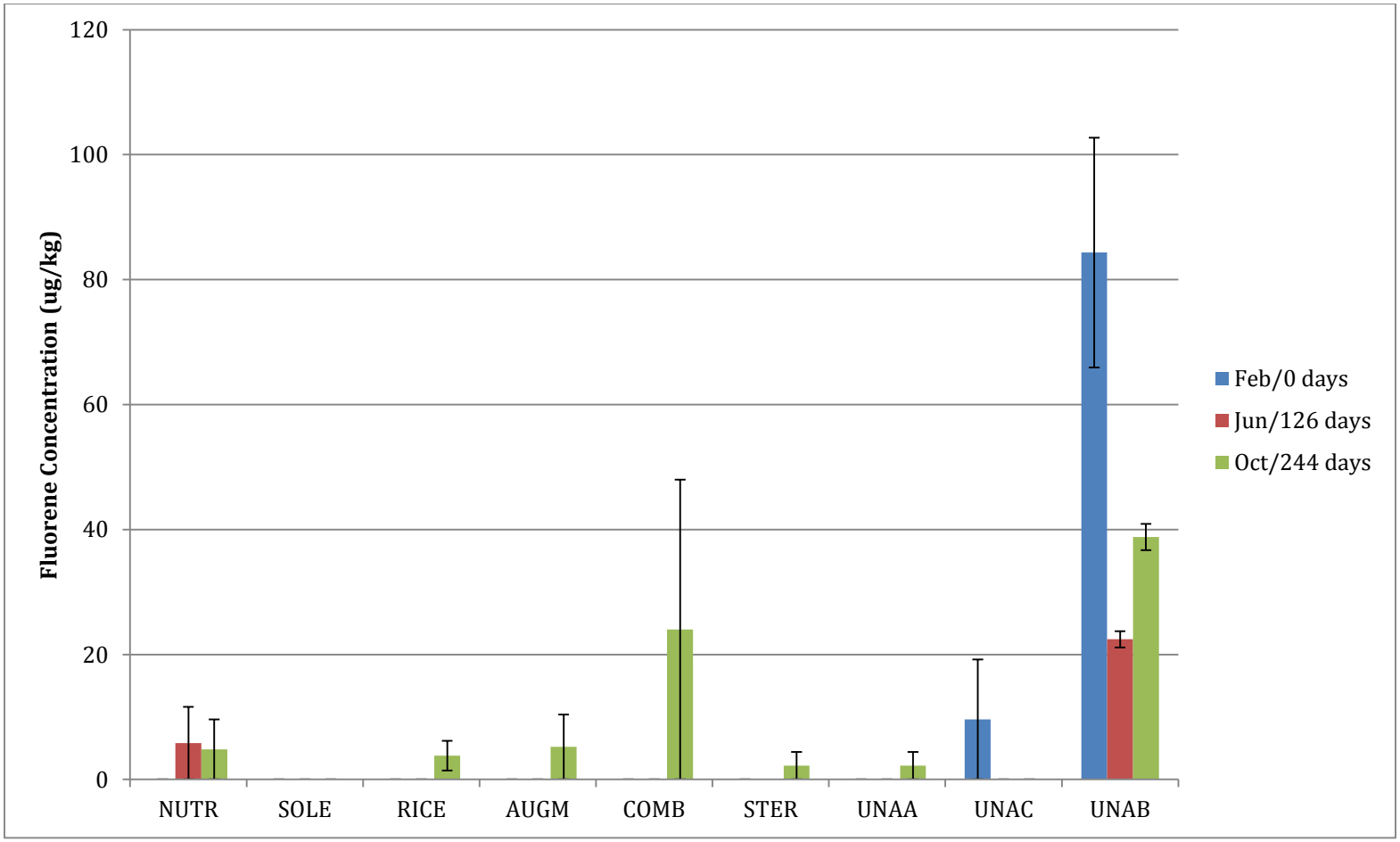


Figure 56: Fluorene concentrations during microcosm incubation (all soils)

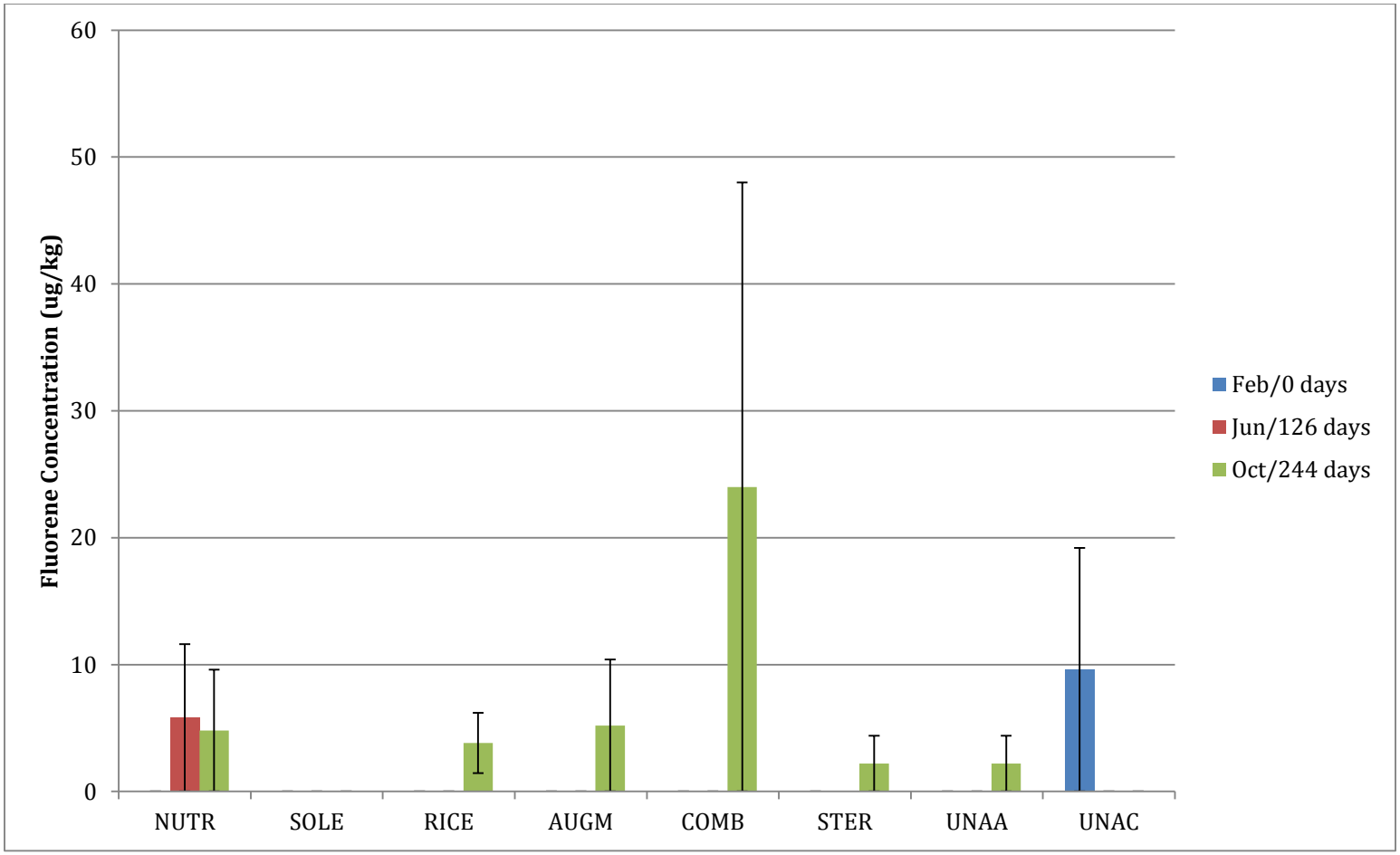


Figure 57: Fluorene concentrations during microcosm incubation (A and C)

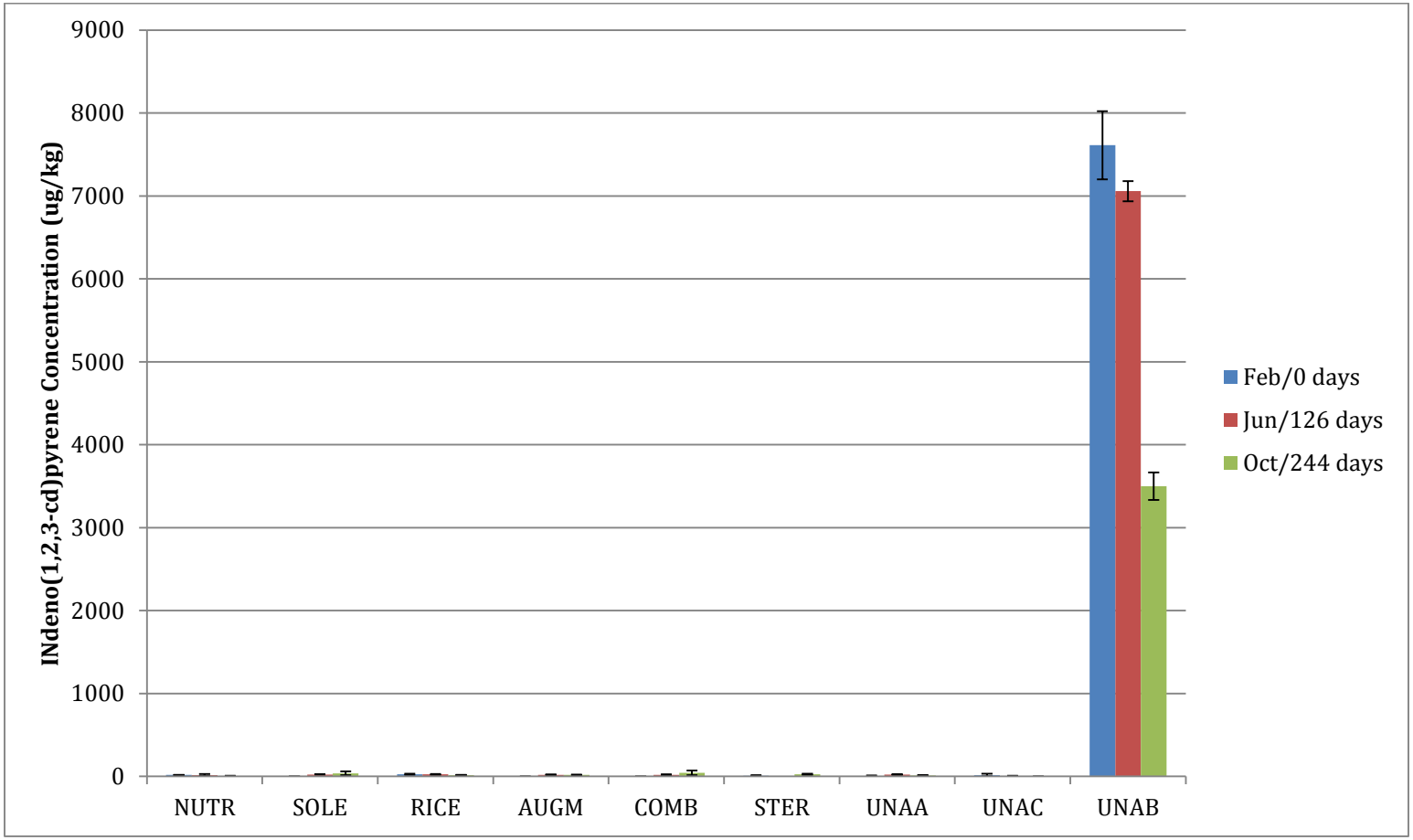


Figure 58: Indeno(1,2,3-cd)pyrene concentrations during microcosm incubation (all soils)

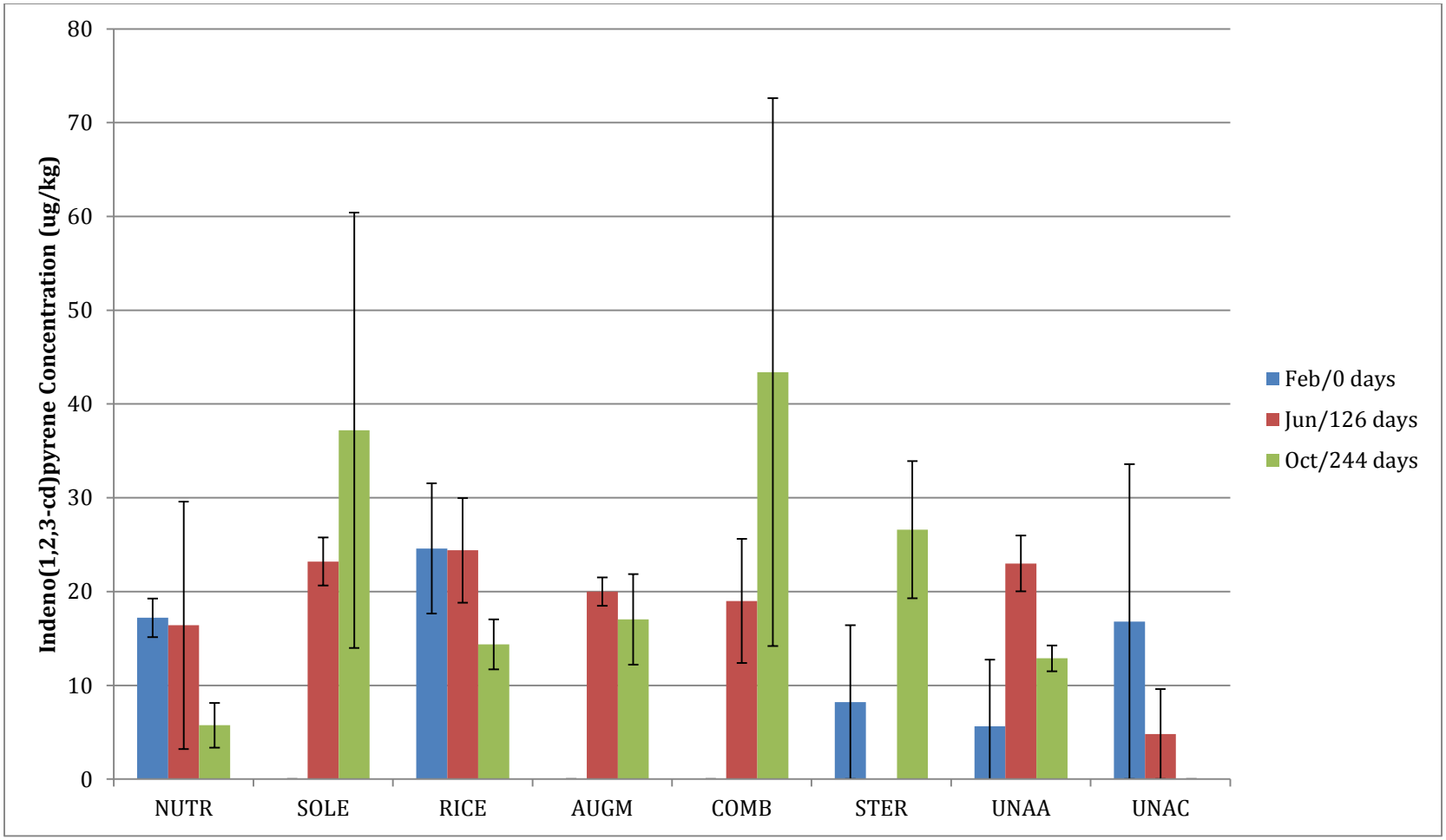


Figure 59: Indeno(1,2,3-cd)pyrene concentrations during microcosm incubation (A and C)

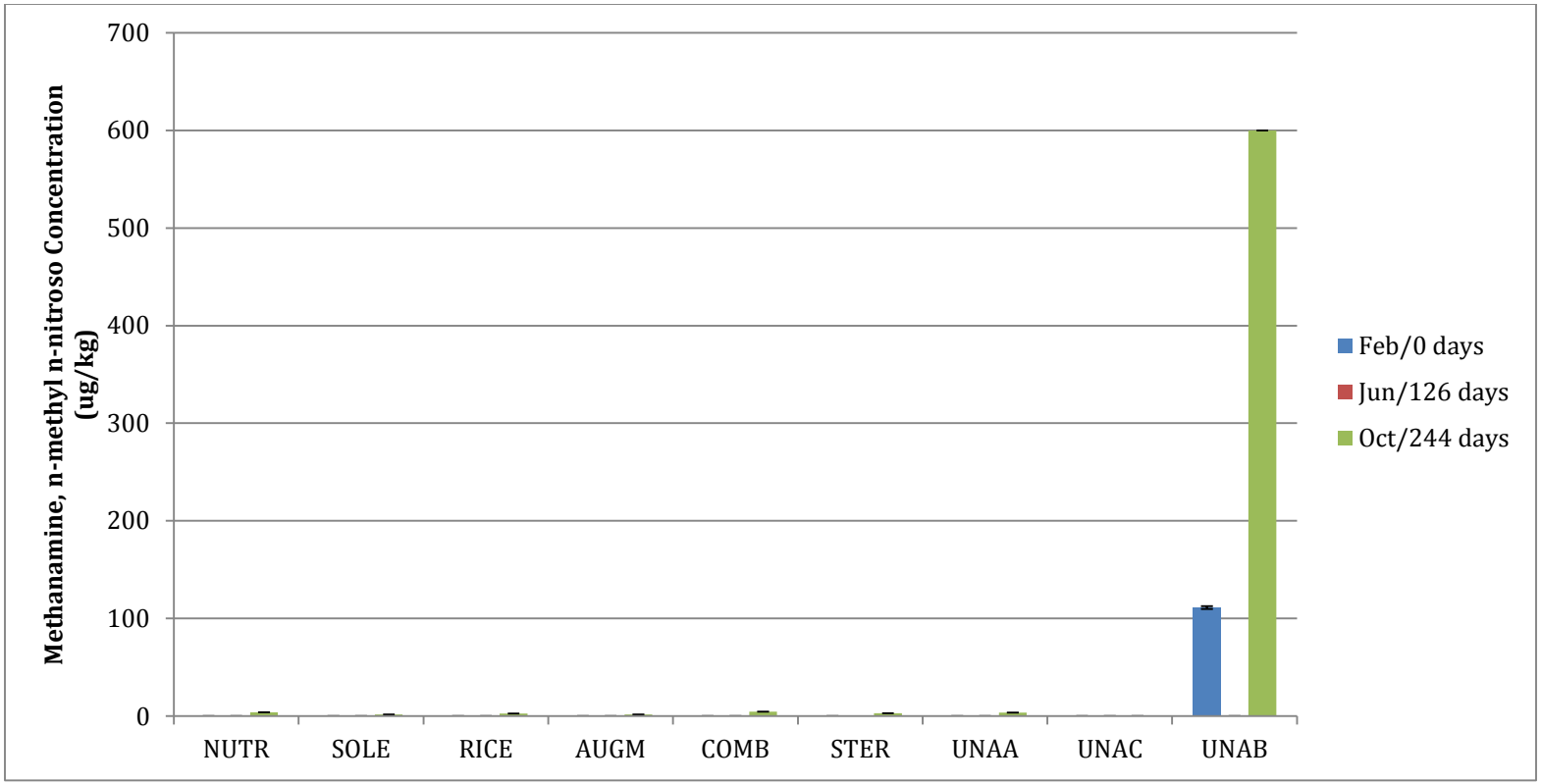


Figure 60: Methanamine, n-methyl n-nitroso concentrations during microcosm incubation

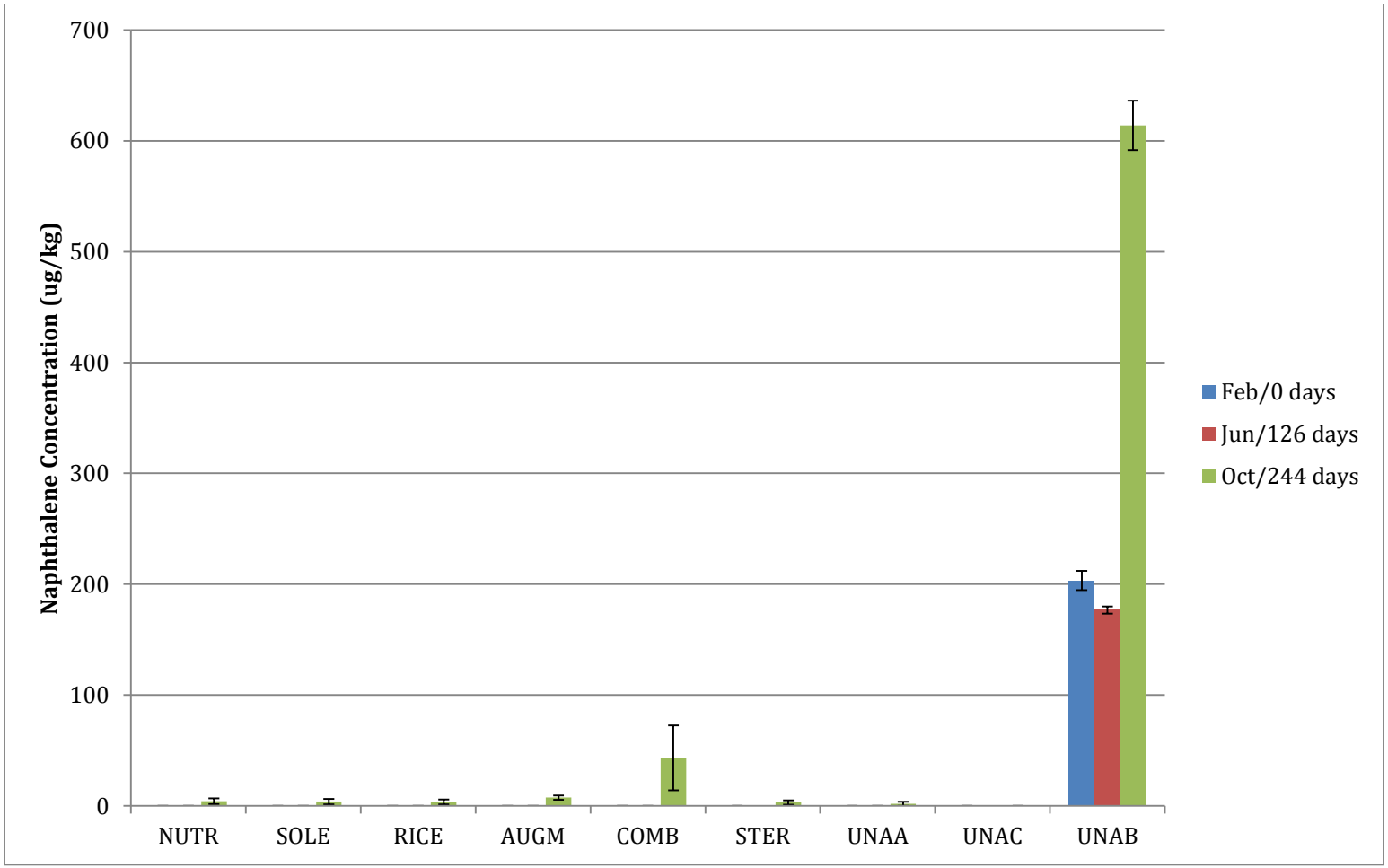


Figure 61: Naphthalene concentrations during microcosm incubation (all soils)

Appendix D: Bar Graphs of Aroclor Concentrations

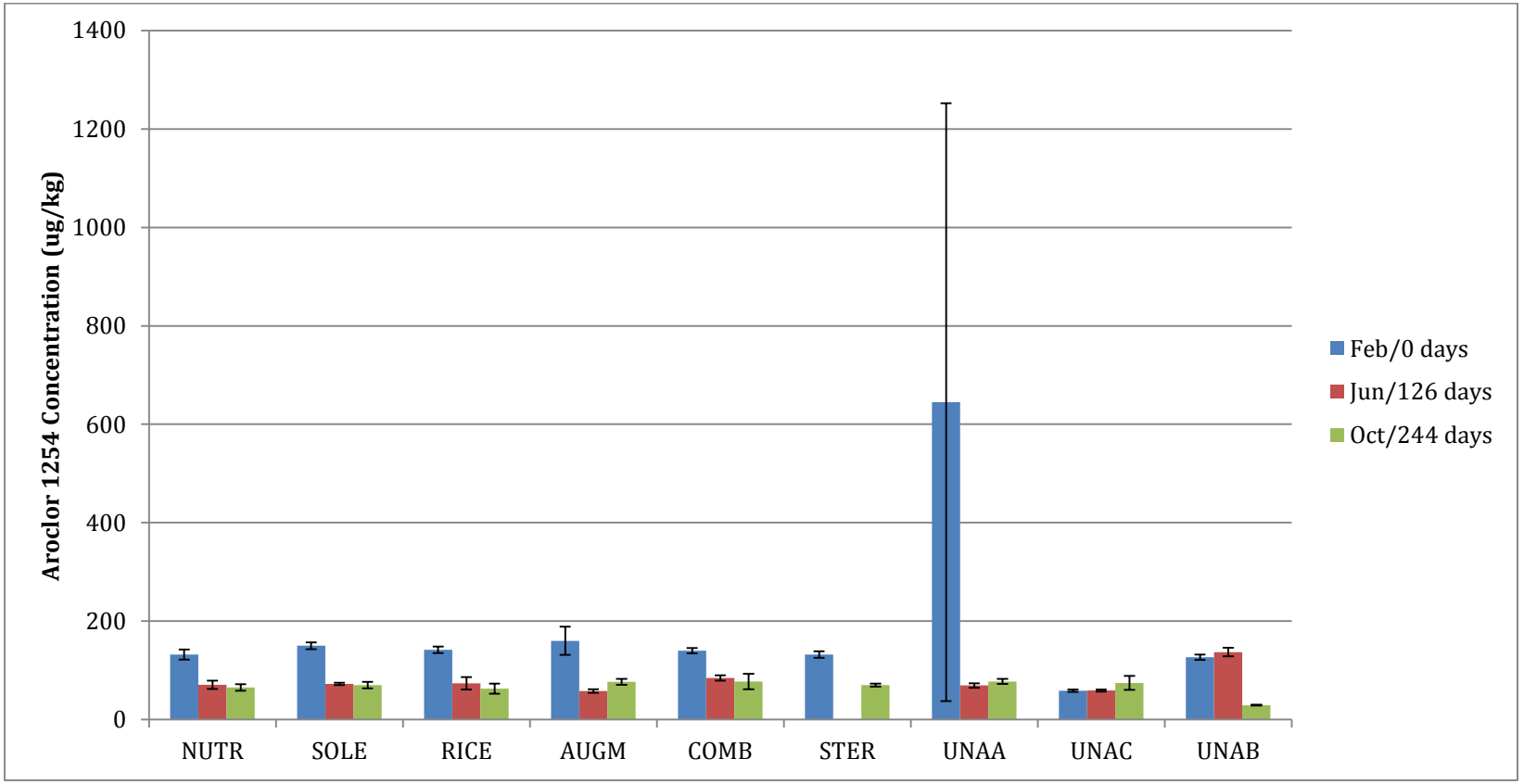


Figure 62: Aroclor 1254 concentration during microcosm incubation

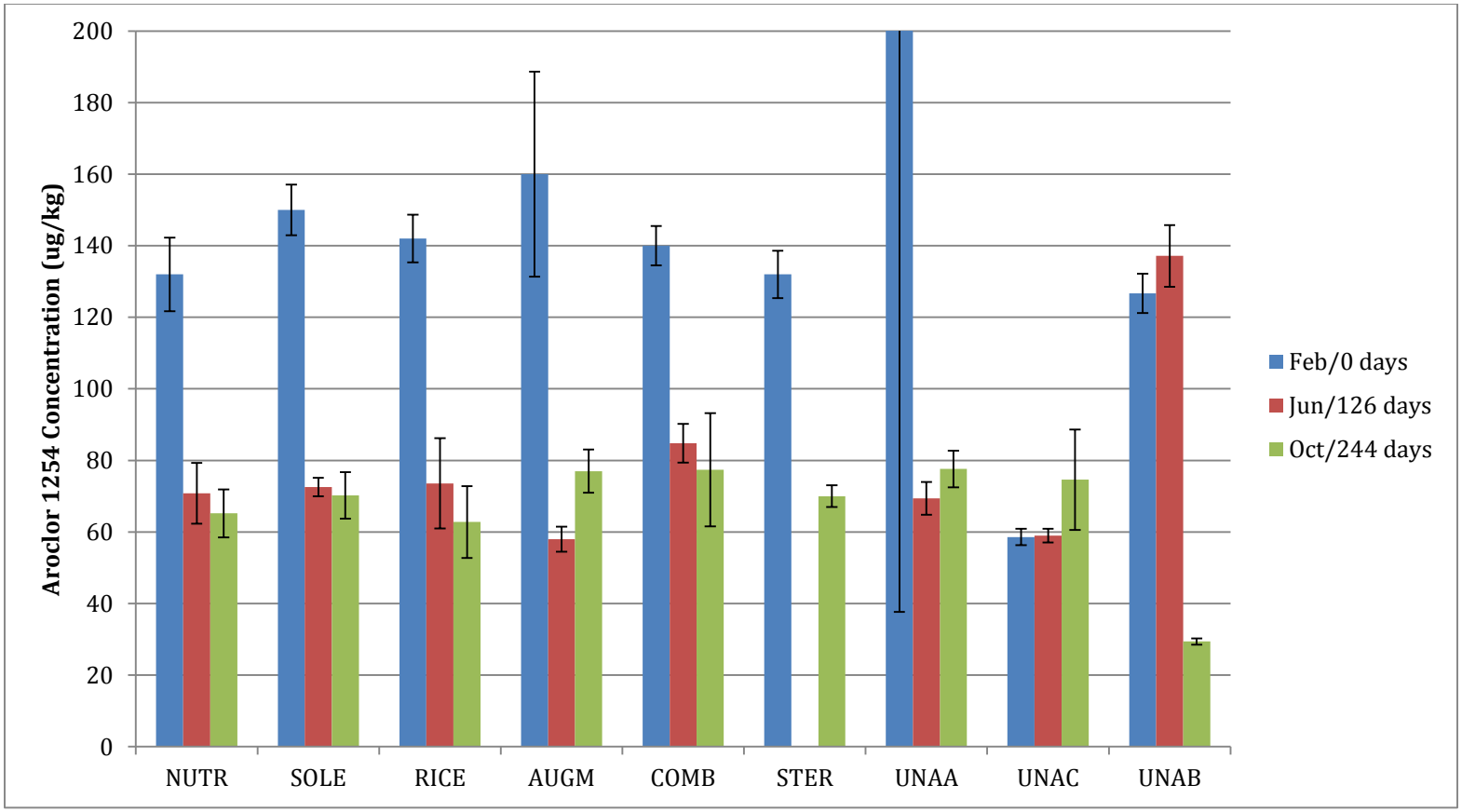


Figure 63: Truncated Aroclor 1254 concentrations during microcosm incubation

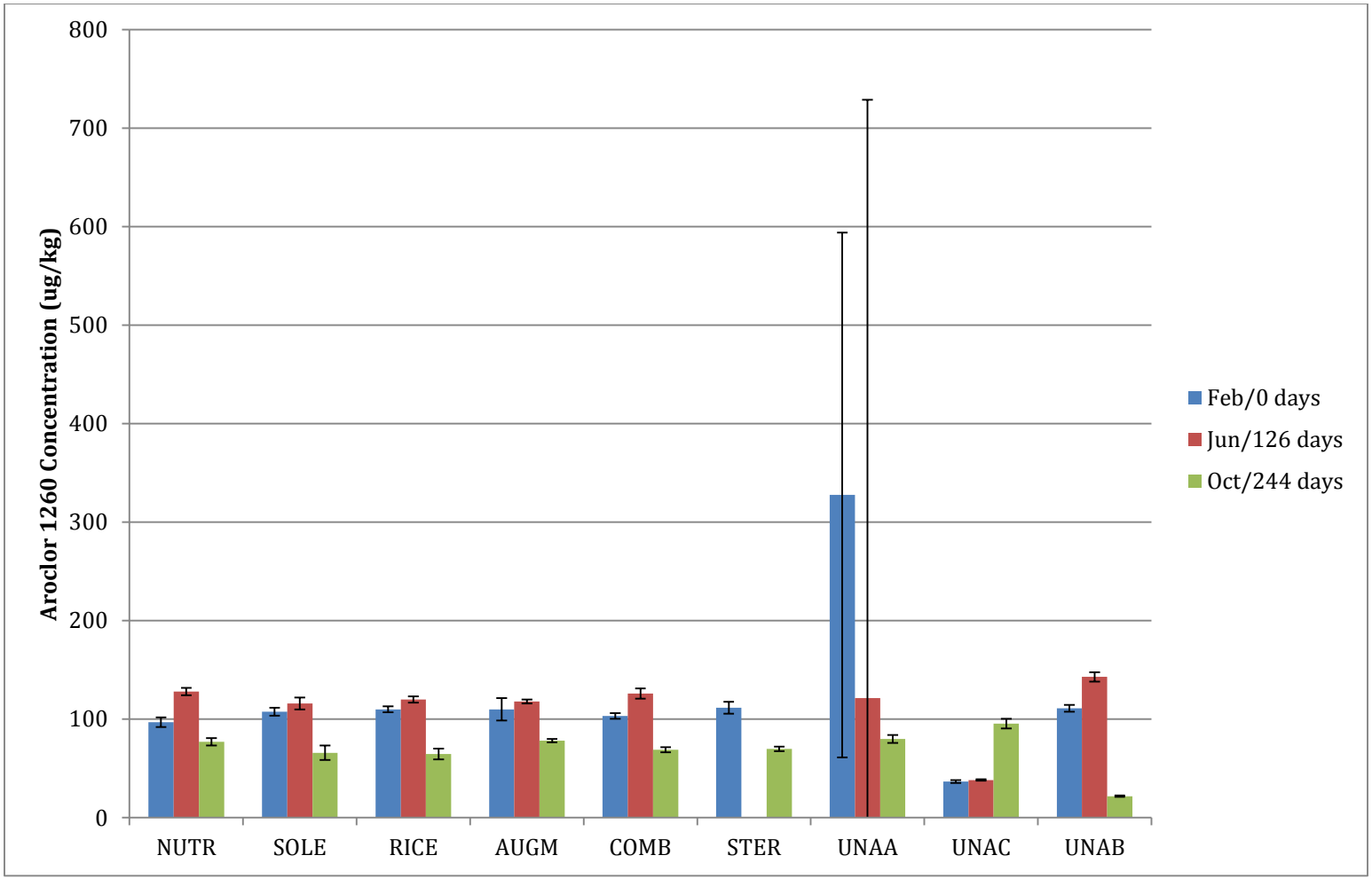


Figure 64: Aroclor 1260 concentrations during microcosm incubation

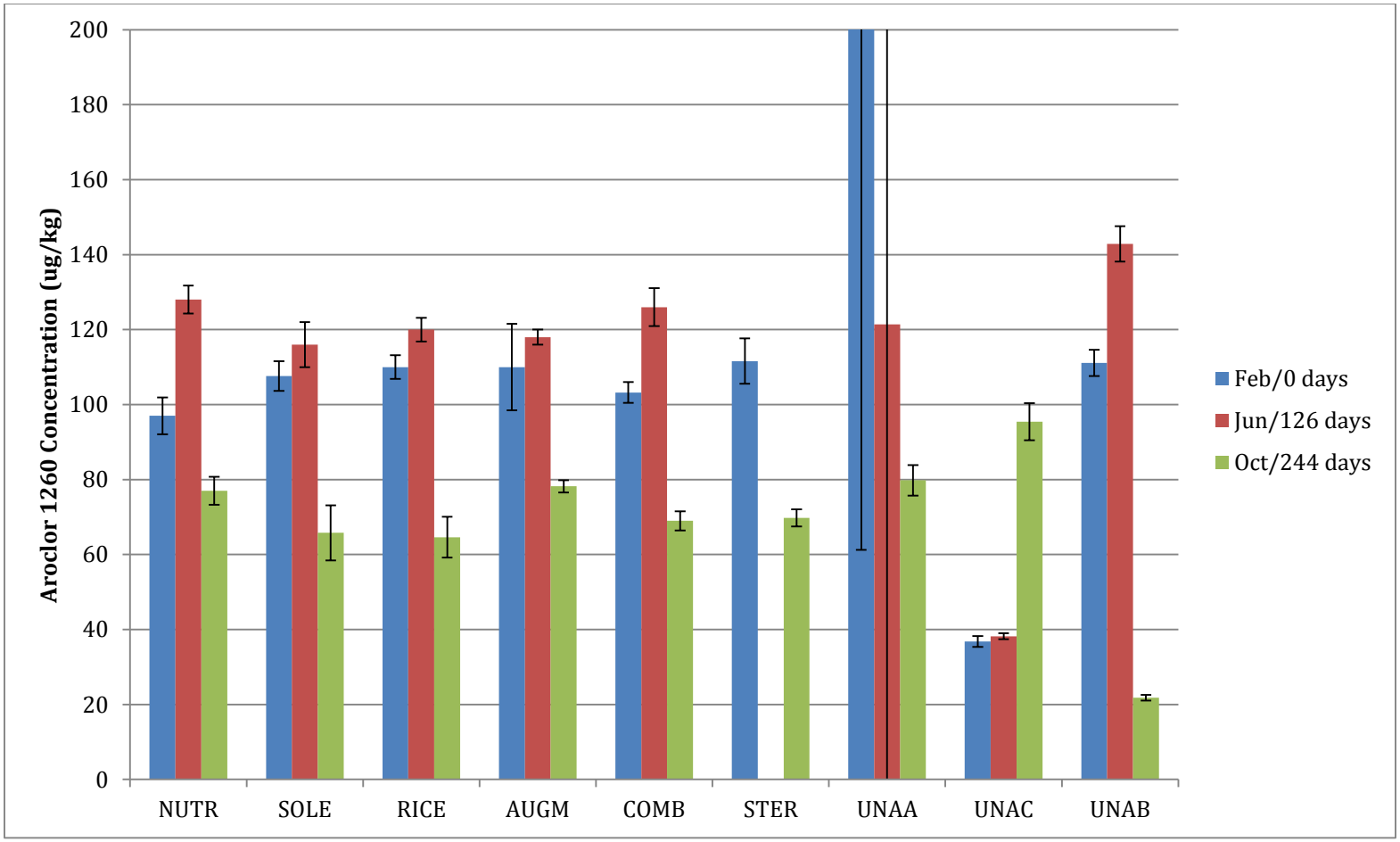


Figure 65: Truncated Aroclor 1260 concentrations during microcosm incubation

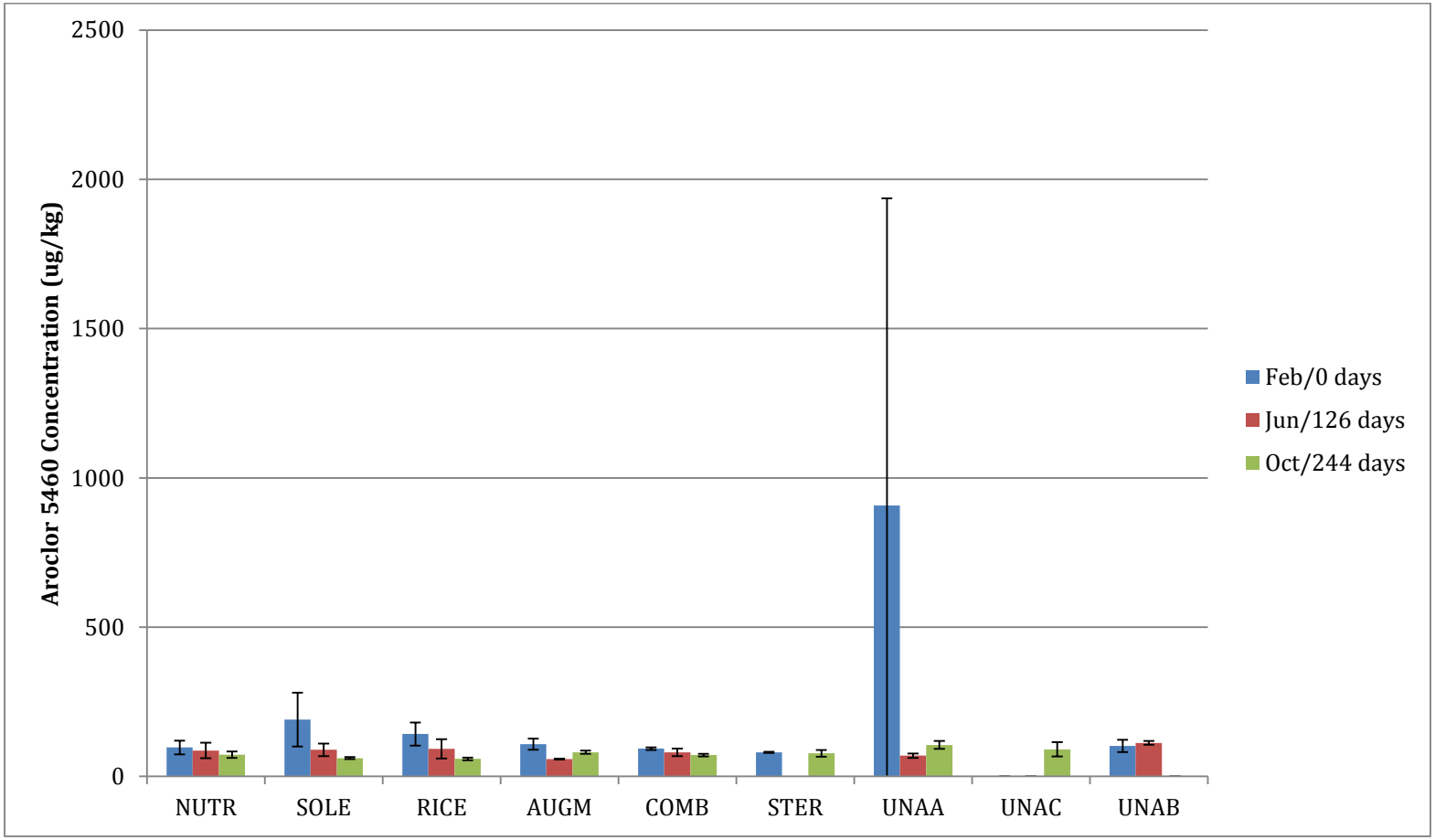


Figure 66: Aroclor 5460 concentrations during microcosm incubation

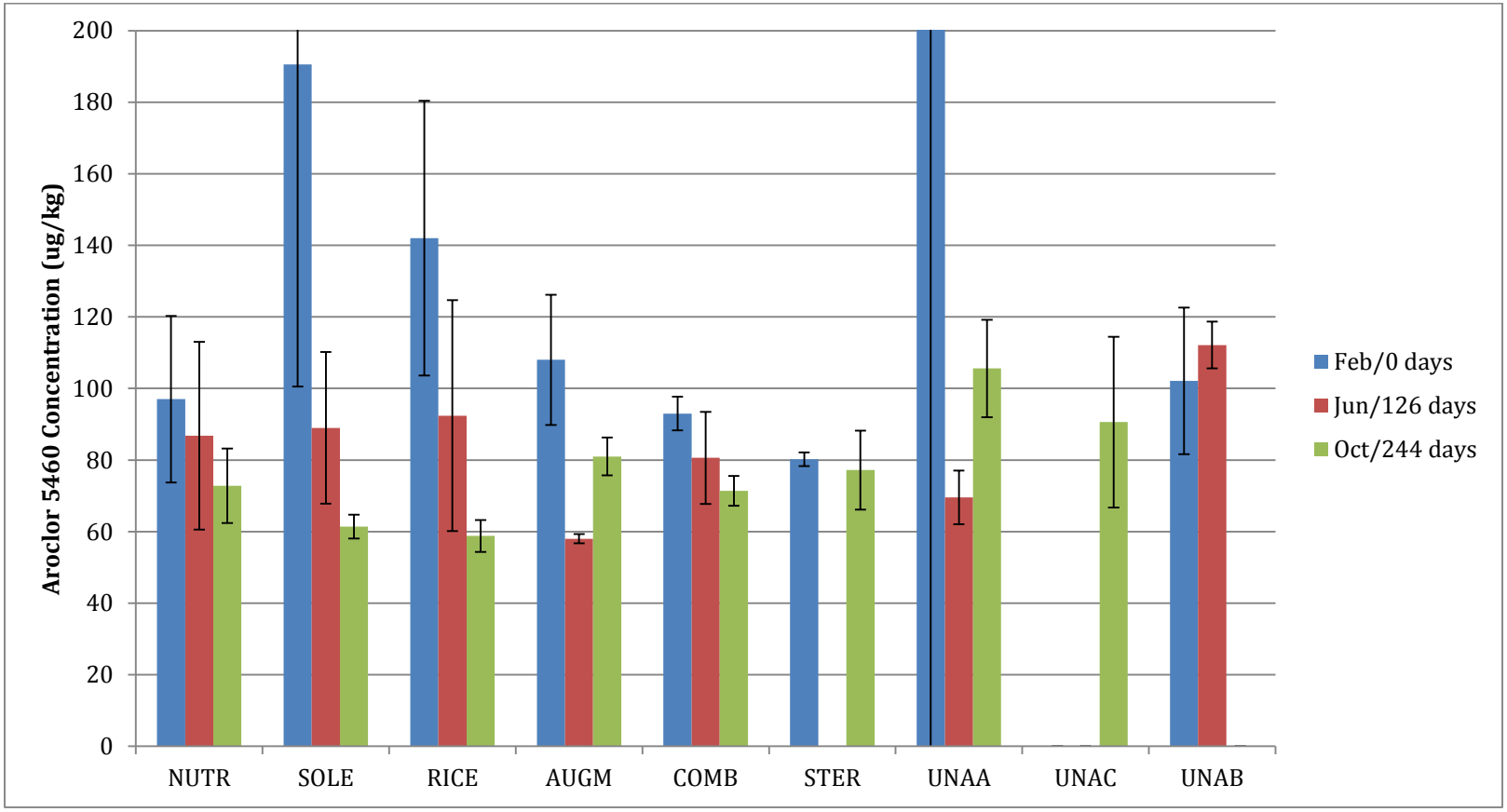


Figure 67: Truncated Aroclor 5460 concentrations during microcosm incubation

Appendix E: Microcosm Incubator Temperature Electronic Data Sheet

Sampling Date	Sampling Point	Raw Temp.	degC	degF	Temp. (degF)		
5/1/2014	1	25	x		77.0		
	2	23.6	x		74.5		
	3	24.2	x		75.6		
	4	25.5	x		77.9		
	5	22.9	x		73.2		
Statistics				***Average***	75.6	***St. Dev.***	1.9
5/6/2014	1	19.1	x		66.4		
	2	18.2	x		64.8		
	3	20.7	x		69.3		
	4	22.8	x		73.0		
	5	18.3	x		64.9		
Statistics				***Average***	67.7	***St. Dev.***	3.5
5/11/2014	1	26.8	x		80.2		
	2	27.1	x		80.8		
	3	27	x		80.6		
	4	26.9	x		80.4		
	5	27	x		80.6		
Statistics				***Average***	80.5	***St. Dev.***	0.2
5/16/2014	1	26.7	x		80.1		

	2	26.2	x		79.2		
	3	27	x		80.6		
	4	26.5	x		79.7		
	5	28	x		82.4		
Statistics				***Average***	80.4	***St. Dev.***	1.2
5/23/2014	1	27.1	x		80.8		
	2	26.8	x		80.2		
	3	26.9	x		80.4		
	4	27	x		80.6		
	5	26.6	x		79.9		
Statistics				***Average***	80.4	***St. Dev.***	0.3
5/28/2014	1	26	x		78.8		
	2	25.5	x		77.9		
	3	26.2	x		79.2		
	4	26.1	x		79.0		
	5	26.7	x		80.1		
Statistics				***Average***	79.0	***St. Dev.***	0.8
6/3/2014	1	74.2		x	74.2		
	2	73.9		x	73.9		
	3	74.5		x	74.5		
	4	73.7		x	73.7		
	5	75.1		x	75.1		
Statistics				***Average***	74.3	***St. Dev.***	0.5
6/9/2014	1	76.2		x	76.2		
	2	77.1		x	77.1		
	3	75.8		x	75.8		

	4	76.4		x	76.4		
	5	76.8		x	76.8		
Statistics				***Average***	76.5	***St. Dev.***	0.5
6/16/2014	1	77.4		x	77.4		
	2	76.6		x	76.6		
	3	77		x	77.0		
	4	76.8		x	76.8		
	5	77.4		x	77.4		
Statistics				***Average***	77.0	***St. Dev.***	0.4
6/28/2014	1	26.2	x		79.2		
	2	25.4	x		77.7		
	3	26.8	x		80.2		
	4	25.8	x		78.4		
	5	26.6	x		79.9		
Statistics				***Average***	79.1	***St. Dev.***	1.0
6/30/2014	1	25.4	x		77.7		
	2	25.6	x		78.1		
	3	25.3	x		77.5		
	4	25.6	x		78.1		
	5	25	x		77.0		
Statistics				***Average***	77.7	***St. Dev.***	0.4
7/7/2014	1	25.3	x		77.5		
	2	25.7	x		78.3		
	3	26.4	x		79.5		
	4	25.2	x		77.4		
	5	25.6	x		78.1		
Statistics				***Average***	78.2	***St. Dev.***	0.9
7/14/2014	1	24	x		75.2		

	2	24.3	x		75.7		
	3	24.3	x		75.7		
	4	24.2	x		75.6		
	5	24.6	x		76.3		
Statistics				***Average***	75.7	***St. Dev.***	0.4
7/21/2014	1	25.9	x		78.6		
	2	26.3	x		79.3		
	3	26.7	x		80.1		
	4	26.1	x		79.0		
	5	26.7	x		80.1		
Statistics				***Average***	79.4	***St. Dev.***	0.6
7/28/2014	1	26	x		78.8		
	2	26.2	x		79.2		
	3	27	x		80.6		
	4	26.7	x		80.1		
	5	25.8	x		78.4		
Statistics				***Average***	79.4	***St. Dev.***	0.9
8/4/2014	1	25.8	x		78.4		
	2	26.3	x		79.3		
	3	26.9	x		80.4		
	4	25.9	x		78.6		
	5	26.7	x		80.1		
Statistics				***Average***	79.4	***St. Dev.***	0.9
8/14/2014	1	27.7	x		81.9		
	2	30.6	x		87.1		
	3	29	x		84.2		
	4	30.8	x		87.4		
	5	29.5	x		85.1		
Statistics				***Average***	85.1	***St. Dev.***	2.3

8/26/2014	1	32.3	x		90.1		
	2	31.3	x		88.3		
	3	30.5	x		86.9		
	4	31.7	x		89.1		
	5	32.1	x		89.8		
Statistics				***Average***	88.8	***St. Dev.***	1.3
9/1/2014	1	31.8	x		89.2		
	2	31.3	x		88.3		
	3	30.2	x		86.4		
	4	30.8	x		87.4		
	5	30.6	x		87.1		
Statistics				***Average***	87.7	***St. Dev.***	1.1
9/7/2014	1	32.4	x		90.3		
	2	31.6	x		88.9		
	3	31.2	x		88.2		
	4	31.6	x		88.9		
	5	30.5	x		86.9		
Statistics				***Average***	88.6	***St. Dev.***	1.2
9/15/2014	1	30.8	x		87.4		
	2	32.3	x		90.1		
	3	31.5	x		88.7		
	4	30.6	x		87.1		
	5	31.7	x		89.1		
Statistics				***Average***	88.5	***St. Dev.***	1.2
9/22/2014	1	30.7	x		87.3		
	2	31.3	x		88.3		
	3	32	x		89.6		
	4	30.2	x		86.4		

	5	31.7	x		89.1		
Statistics				***Average***	88.1	***St. Dev.***	1.3
9/29/2014	1	31.2	x		88.2		
	2	30.4	x		86.7		
	3	30.8	x		87.4		
	4	29.2	x		84.6		
	5	31.3	x		88.3		
Statistics				***Average***	87.0	***St. Dev.***	1.5
10/6/2014	1	30.5	x		86.9		
	2	31.9	x		89.4		
	3	30.2	x		86.4		
	4	29.8	x		85.6		
	5	31.5	x		88.7		
Statistics				***Average***	87.4	***St. Dev.***	1.6
10/13/2014	1	29.9	x		85.8		
	2	31.4	x		88.5		
	3	29.7	x		85.5		
	4	30.2	x		86.4		
	5	30.8	x		87.4		
Statistics				***Average***	86.7	***St. Dev.***	1.3
10/20/2014	1	29.8	x		85.6		
	2	31.2	x		88.2		
	3	30.6	x		87.1		
	4	30.5	x		86.9		
	5	30.7	x		87.3		
Statistics				***Average***	87.0	***St. Dev.***	0.9
10/27/2014	1	31.7	x		89.1		
	2	30.3	x		86.5		

		3	30.6	x		87.1		
		4	30.5	x		86.9		
		5	30.7	x		87.3		
Statistics					***Average***	87.4	***St. Dev.***	1.0
11/3/2014		1	25.2	x		77.4		
		2	24.7	x		76.5		
		3	23.9	x		75.0		
		4	24.6	x		76.3		
		5	24.2	x		75.6		
Statistics					***Average***	76.1	***St. Dev.***	0.9

Overall Average	81.4
Overall St. Dev	5.6

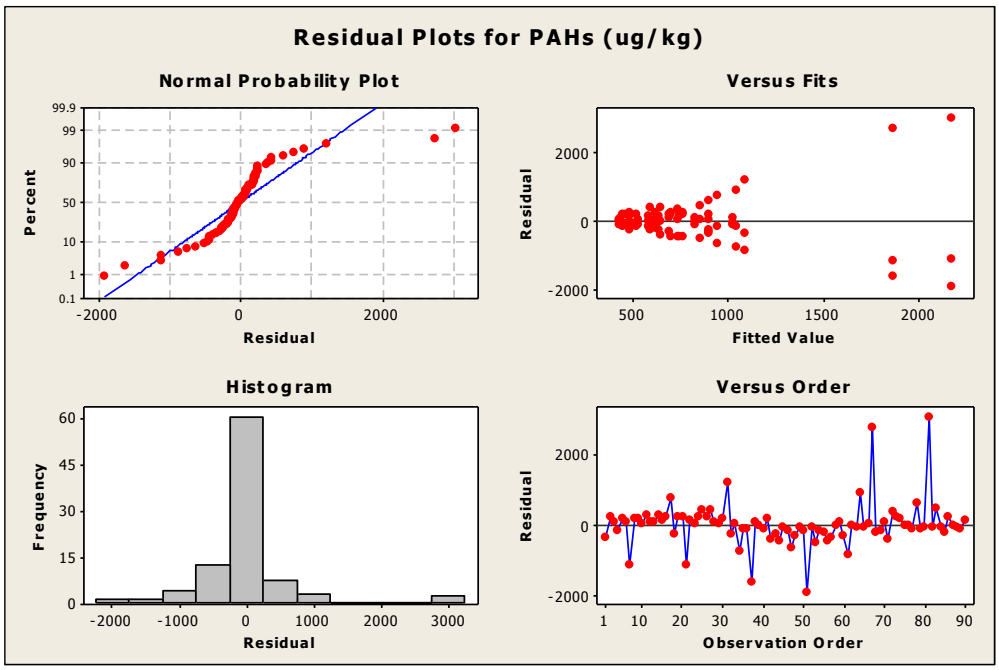
Appendix F: Statistics: Effect of Treatment on Changes in Soil A COIs

General Linear Model: PAHs (ug/kg) versus Treatment, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        6  A1, A2, A3, A4, A5, A6
Replicate(Treatment)  random      30  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30


Analysis of Variance for PAHs (ug/kg), using Adjusted SS for Tests

Source                DF    Seq SS    Adj SS  Adj MS     F      P
Treatment              5   1985332   1985332  397066  0.86  0.525
Replicate(Treatment)  24  11142335  11142335  464264  0.81  0.705
Error                 60  34215143  34215143  570252
Total                 89  47342811


S = 755.151   R-Sq = 27.73%   R-Sq(adj) = 0.00%


Unusual Observations for PAHs (ug/kg)

        PAHs
Obs   (ug/kg)       Fit  SE Fit  Residual  St Resid
 37    235.07  1860.69  435.99  -1625.62     -2.64 R
 51    262.00  2175.37  435.99  -1913.37     -3.10 R
 67   4615.00  1860.69  435.99   2754.31      4.47 R
 81   5214.11  2175.37  435.99   3038.74      4.93 R

R denotes an observation with a large standardized residual.
```

High p values. Not

Residual Plots for PAHs (ug/kg)



Fanning. Not straight probability plot. Probably need to take a log of fits to see if we can even out the variance a bit. S-shaped normal

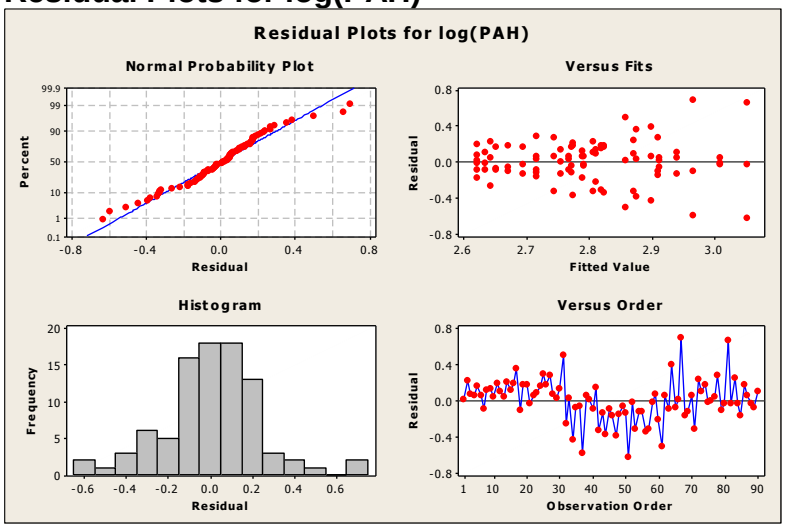
logPAHs

General Linear Model: log(PAH) versus Treatment, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        6  A1, A2, A3, A4, A5, A6
Replicate(Treatment)  random      30  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30


Analysis of Variance for log(PAH), using Adjusted SS for Tests

Source                DF   Seq SS   Adj SS   Adj MS     F      P
Treatment              5  0.22966  0.22966  0.04593  1.17  0.354
Replicate(Treatment)  24  0.94503  0.94503  0.03938  0.49  0.971
Error                 60  4.78383  4.78383  0.07973
Total                 89  5.95851


S = 0.282366   R-Sq = 19.71%   R-Sq(adj) = 0.00%


Unusual Observations for log(PAH)

Obs  log(PAH)      Fit   SE Fit  Residual  St Resid
 31   3.36135  2.85943  0.16302   0.50192      2.18 R
 37   2.37120  2.96663  0.16302  -0.59543     -2.58 R
 51   2.41830  3.05222  0.16302  -0.63392     -2.75 R
 61   2.34713  2.85943  0.16302  -0.51230     -2.22 R
 67   3.66417  2.96663  0.16302   0.69755      3.03 R
 81   3.71718  3.05222  0.16302   0.66496      2.88 R

R denotes an observation with a large standardized residual.
```

P values are huge. Not statistically significant

Residual Plots for log(PAH)



Taking logs fixes everything

Dioxins

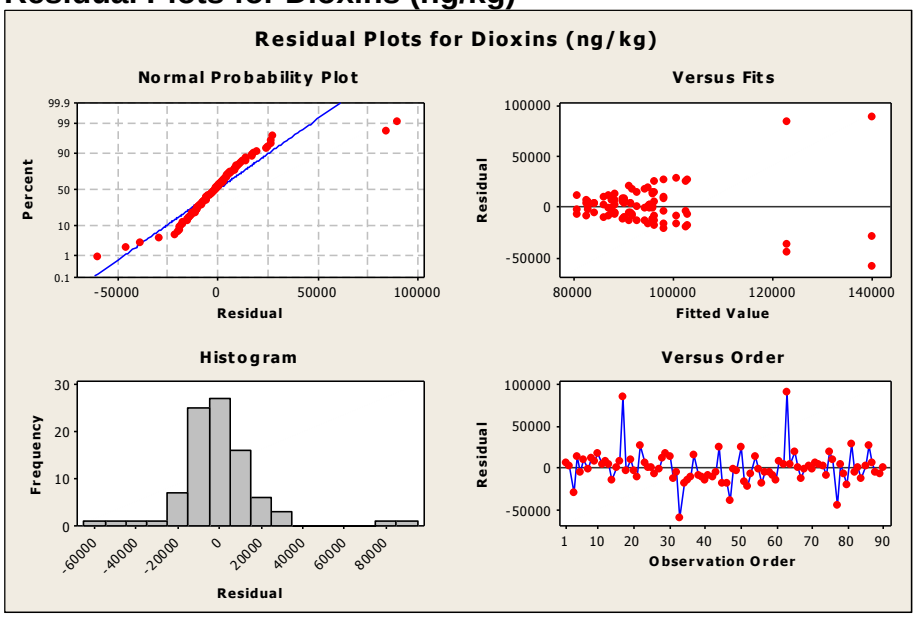
General Linear Model: Dioxins (ng/kg) versus Treatment, Replicate

```
Factor                 Type    Levels  Values
Treatment              fixed        6  A1, A2, A3, A4, A5, A6
Replicate(Treatment)   random      30  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30


Analysis of Variance for Dioxins (ng/kg), using Adjusted SS for Tests

Source                 DF       Seq SS       Adj SS     Adj MS     F      P
Treatment               5   1558214254   1558214254  311642851  0.71  0.620
Replicate(Treatment)   24  10504532277  10504532277  437688845  0.76  0.773
Error                  60  34747889888  34747889888  579131498
Total                  89  46810636419


S = 24065.2   R-Sq = 25.77%   R-Sq(adj) = 0.00%


Unusual Observations for Dioxins (ng/kg)

     Dioxins
Obs  (ng/kg)      Fit  SE Fit  Residual  St Resid
 17   206618   122788   13894     83830      4.27 R
 33    80074   140004   13894    -59930     -3.05 R
 63   229423   140004   13894     89419      4.55 R
 77    77292   122788   13894    -45496     -2.32 R

R denotes an observation with a large standardized residual.
```

P values are huge.

Not statistically

Residual Plots for Dioxins (ng/kg)



Fanning. Not straight probability plot. Probably need to

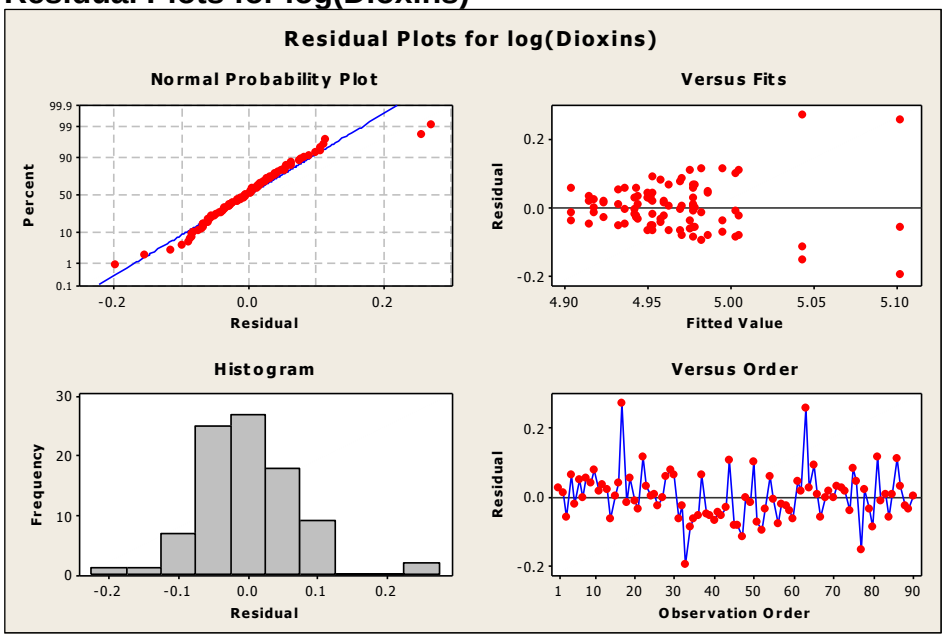
logDioxins

General Linear Model: log(Dioxins) versus Treatment, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        6  A1, A2, A3, A4, A5, A6
Replicate(Treatment)  random      30  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30


Analysis of Variance for log(Dioxins), using Adjusted SS for Tests

Source                DF    Seq SS    Adj SS    Adj MS     F      P
Treatment              5  0.017035  0.017035  0.003407  0.70  0.631
Replicate(Treatment)  24  0.117449  0.117449  0.004894  0.64  0.887
Error                 60  0.459894  0.459894  0.007665
Total                 89  0.594378


S = 0.0875494   R-Sq = 22.63%   R-Sq(adj) = 0.00%


Unusual Observations for log(Dioxins)

Obs  log(Dioxins)      Fit   SE Fit  Residual  St Resid
 17       5.31517  5.04331  0.05055   0.27186      3.80 R
 33       4.90349  5.10252  0.05055  -0.19902     -2.78 R
 63       5.36064  5.10252  0.05055   0.25812      3.61 R
 77       4.88813  5.04331  0.05055  -0.15517     -2.17 R

R denotes an observation with a large standardized residual.
```

P values are huge. Not statistically significant.

Residual Plots for log(Dioxins)



Fanning. straight probability plot. Probably need to take a square root of responses to see if we can even out the versus fits

Sqrt (Dioxins)

General Linear Model: sqrt(Dioxins) versus Treatment, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        6  A1, A2, A3, A4, A5, A6
Replicate(Treatment)  random      30  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30
```

Analysis of Variance for sqrt(Dioxins), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	5	2857	2857	571	0.70	0.629
Replicate(Treatment)	24	19594	19594	816	0.70	0.836
Error	60	70453	70453	1174		
Total	89	92903				

P values are huge. Not statistically

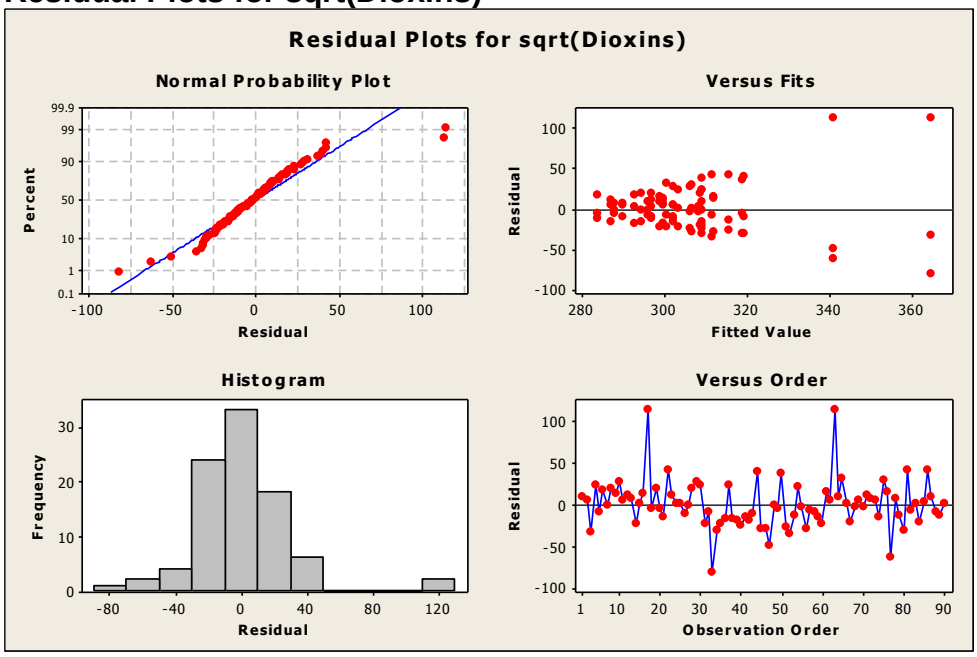
S = 34.2668 R-Sq = 24.17% R-Sq(adj) = 0.00%

Unusual Observations for sqrt(Dioxins)

Obs	sqrt(Dioxins)	Fit	SE Fit	Residual	St Resid
17	454.553	341.059	19.784	113.494	4.06 R
33	282.974	364.797	19.784	-81.823	-2.92 R

```
 63         478.981   364.797  19.784    114.184       4.08 R
 77         278.014   341.059  19.784    -63.045      -2.25 R

R denotes an observation with a large standardized residual.
```

Residual Plots for sqrt(Dioxins)



Still fanning.

Iono what the

PCBs

General Linear Model: PCBs (ug/kg) versus Treatment, Replicate

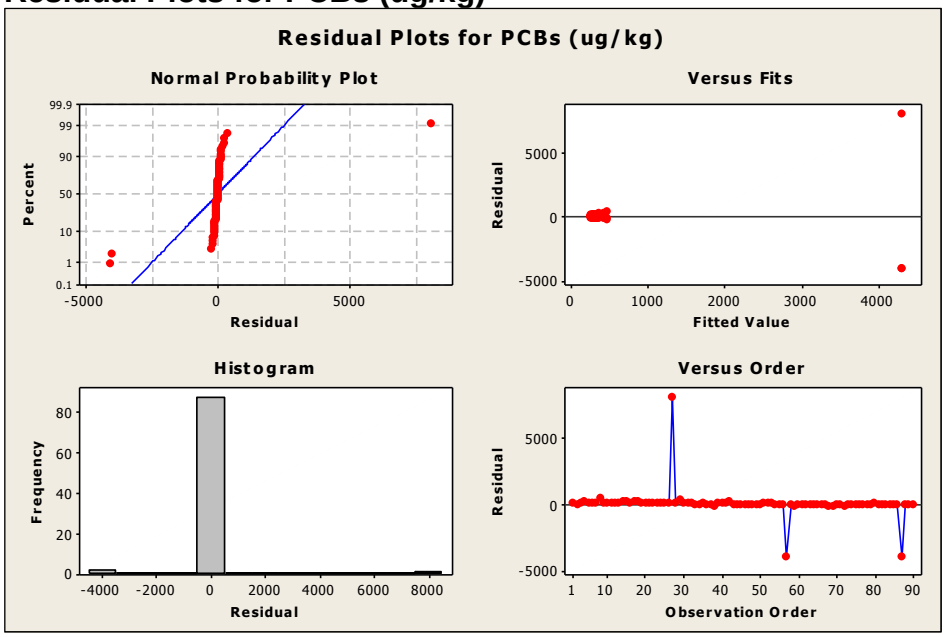
```
Factor                Type    Levels  Values
Treatment             fixed        6  A1, A2, A3, A4, A5, A6
Replicate(Treatment)  random      30  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30


Analysis of Variance for PCBs (ug/kg), using Adjusted SS for Tests

Source                DF     Seq SS    Adj SS   Adj MS     F      P
Treatment              5    8437177   8437177  1687435  1.05  0.411
Replicate(Treatment)  24   38525024  38525024  1605209  0.97  0.513
Error                 60   99050933  99050933  1650849
Total                 89  146013134

S = 1284.85   R-Sq = 32.16%   R-Sq(adj) = 0.00%

Unusual Observations for PCBs (ug/kg)
```

P values are

huge. Not

```
        PCBs
Obs   (ug/kg)      Fit   SE Fit   Residual   St Resid
 27   12400.0   4306.3    741.8     8093.7      7.72 R
 57     272.0   4306.3    741.8    -4034.3     -3.85 R
 87     247.0   4306.3    741.8    -4059.3     -3.87 R

R denotes an observation with a large standardized residual.
```

Residual Plots for PCBs (ug/kg)



… Oh no.

Log(PCBS)

General Linear Model: log(PCBs) versus Treatment, Replicate

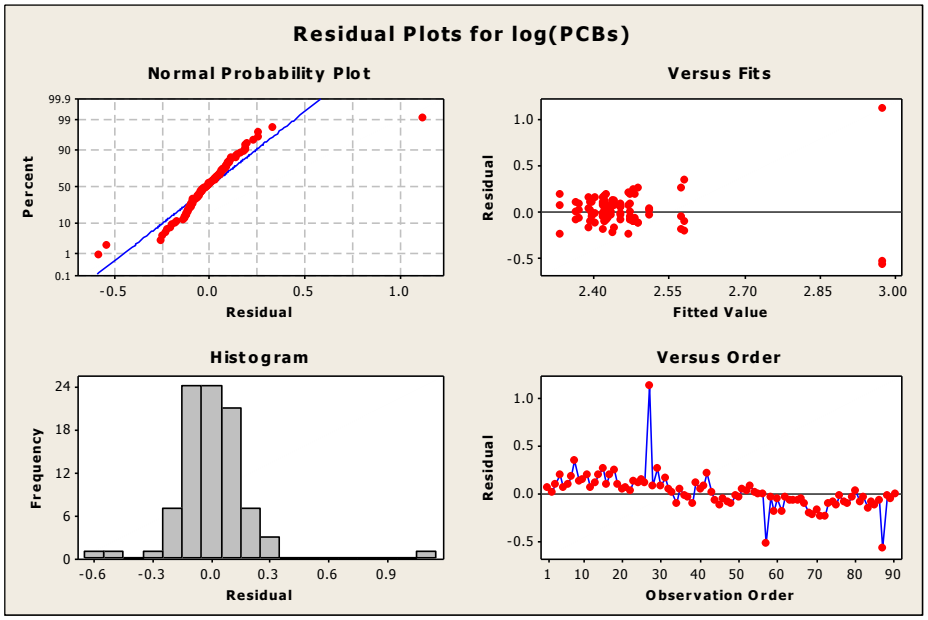
```
Factor                Type    Levels  Values
Treatment             fixed        6  A1, A2, A3, A4, A5, A6
Replicate(Treatment)  random      30  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30


Analysis of Variance for log(PCBs), using Adjusted SS for Tests

Source                DF   Seq SS   Adj SS   Adj MS     F      P
Treatment              5  0.22352  0.22352  0.04470  1.26  0.314
Replicate(Treatment)  24  0.85317  0.85317  0.03555  0.66  0.865
Error                 60  3.21068  3.21068  0.05351
Total                 89  4.28737


S = 0.231325   R-Sq = 25.11%   R-Sq(adj) = 0.00%
```

P values are huge.

Not statistically

```
Unusual Observations for log(PCBs)

Obs  log(PCBs)      Fit   SE Fit  Residual  St Resid
 27    4.09342  2.97356  0.13356   1.11986      5.93 R
 57    2.43457  2.97356  0.13356  -0.53899     -2.85 R
 87    2.39270  2.97356  0.13356  -0.58087     -3.08 R

R denotes an observation with a large standardized residual.
```

Residual Plots for log(PCBs)



Better normal prob plot. Take sqrt to see if we can even out versus fits.

Sqrt(PCBs)

General Linear Model: sqrt(PCBs) versus Treatment, Replicate

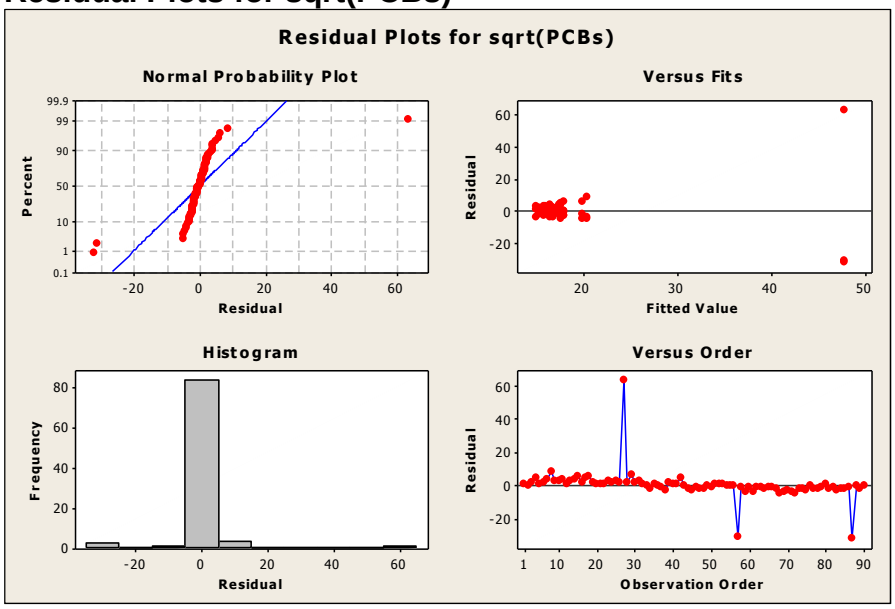
```
Factor                Type    Levels  Values
Treatment             fixed        6  A1, A2, A3, A4, A5, A6
Replicate(Treatment)  random      30  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30


Analysis of Variance for sqrt(PCBs), using Adjusted SS for Tests

Source                DF  Seq SS  Adj SS  Adj MS     F      P
Treatment              5   565.8   565.8   113.2  1.16  0.359
Replicate(Treatment)  24  2348.2  2348.2    97.8  0.89  0.615
Error                 60  6607.9  6607.9   110.1
Total                 89  9521.9

S = 10.4944   R-Sq = 30.60%   R-Sq(adj) = 0.00%
```

P values are huge.

Not statistically

```
Unusual Observations for sqrt(PCBs)

Obs  sqrt(PCBs)      Fit  SE Fit  Residual  St Resid
 27      111.355  47.855   6.059    63.501      7.41 R
 57       16.492  47.855   6.059   -31.362     -3.66 R
 87       15.716  47.855   6.059   -32.138     -3.75 R

R denotes an observation with a large standardized residual.
```

Residual Plots for sqrt(PCBs)



Square root is

. . .

Total EFH (C8-C40) (excluding A2 and A5 because no final measurement)

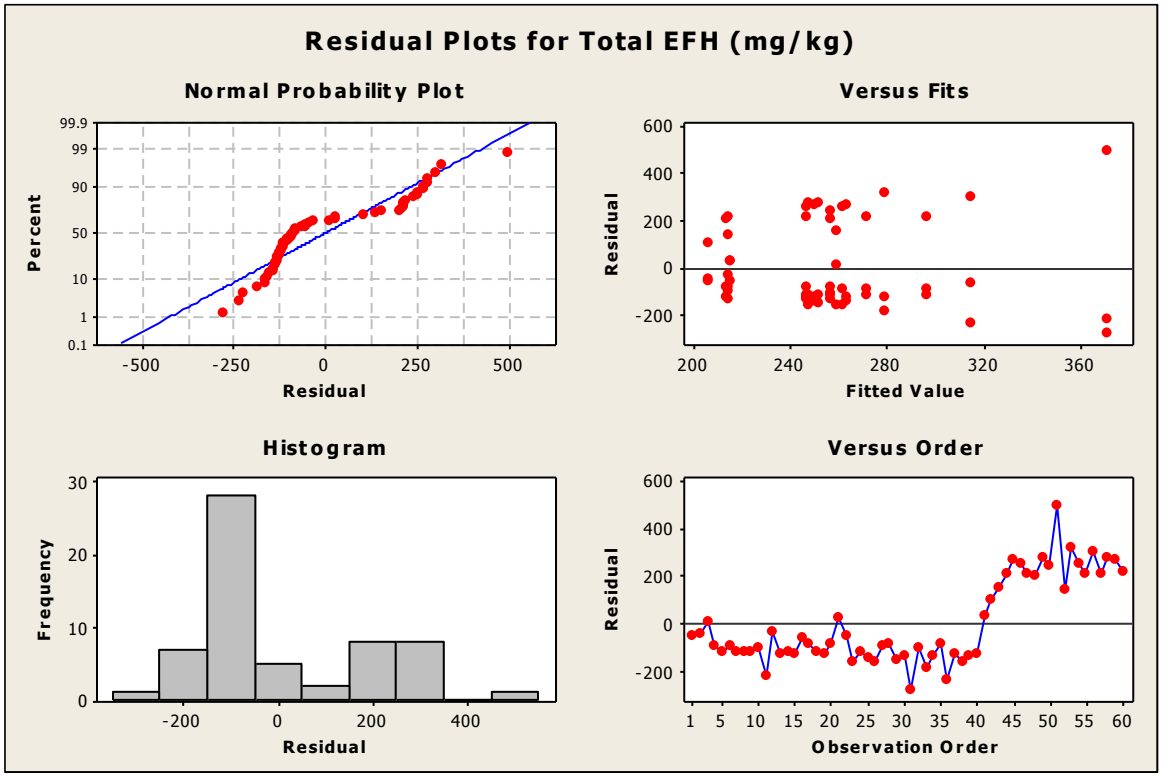
General Linear Model: Total EFH (mg/kg) versus Treatment, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        4  A1, A3, A4, A6
Replicate(Treatment)  random      20  1, 2, 3, 4, 5, 11, 12, 13, 14, 15, 16,
                                      17, 18, 19, 20, 26, 27, 28, 29, 30


Analysis of Variance for Total EFH (mg/kg), using Adjusted SS for Tests

Source                DF   Seq SS   Adj SS  Adj MS     F      P
Treatment              3     8304     8304    2768  0.56  0.649
Replicate(Treatment)  16    79049    79049    4941  0.10  1.000
Error                 40  1911167  1911167   47779
```

P values are huge. Not statistically significant

```
Total                 59  1998520

S = 218.584   R-Sq = 4.37%   R-Sq(adj) = 0.00%

Unusual Observations for Total EFH (mg/kg)

     Total EFH
Obs    (mg/kg)      Fit   SE Fit  Residual  St Resid
 51    869.000  371.333  126.200   497.667      2.79 R

R denotes an observation with a large standardized residual.
```

Residual Plots for Total EFH (mg/kg)



Log(Total EFH)

General Linear Model: log(Total EFH) versus Treatment, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        4  A1, A3, A4, A6
Replicate(Treatment)  random      20  1, 2, 3, 4, 5, 11, 12, 13, 14, 15, 16,
                                      17, 18, 19, 20, 26, 27, 28, 29, 30

Analysis of Variance for log(Total EFH), using Adjusted SS for Tests
```

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	3	0.0391	0.0391	0.0130	2.07	0.145
Replicate(Treatment)	16	0.1011	0.1011	0.0063	0.05	1.000
Error	40	4.7521	4.7521	0.1188		
Total	59	4.8923				

P values are huge. Not statistically significant.

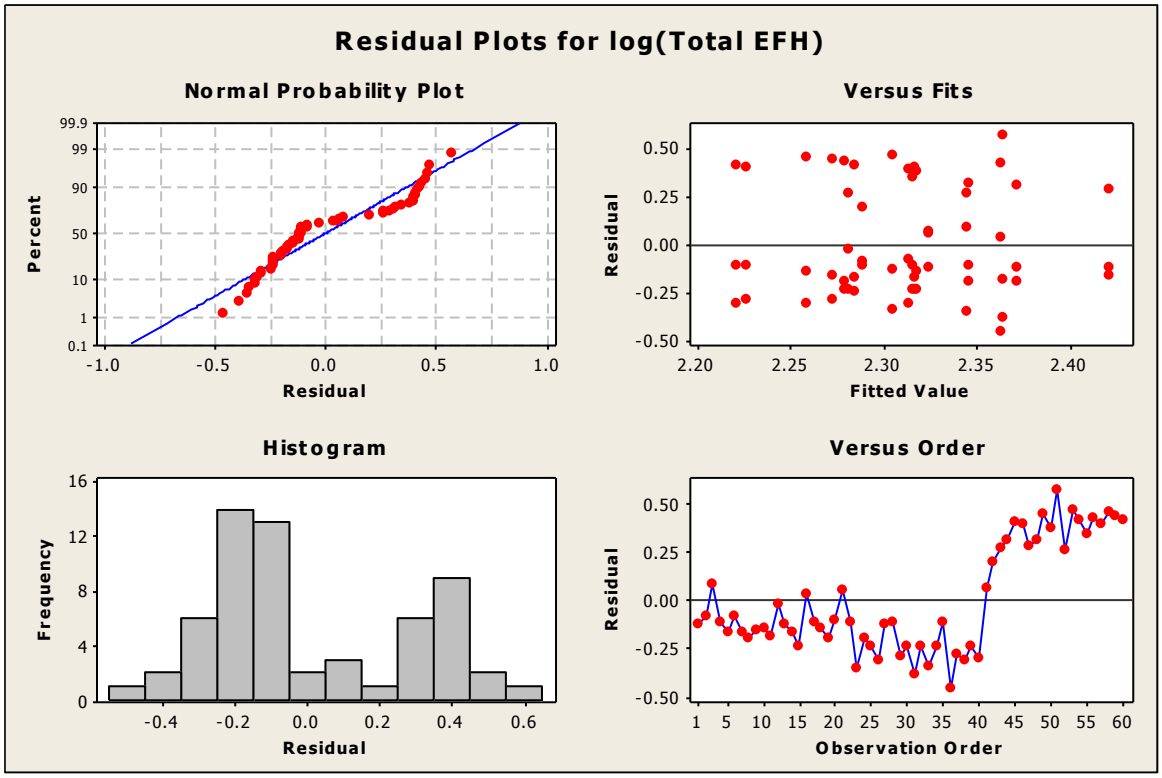
S = 0.344676 R-Sq = 2.87% R-Sq(adj) = 0.00%

Unusual Observations for log(Total EFH)

Obs	log(Total EFH)	Fit	SE Fit	Residual	St Resid
51	2.93902	2.36428	0.19900	0.57474	2.04 R

R denotes an observation with a large standardized residual.

Residual Plots for log(Total EFH)



General Linear Model: TCDD TEQ (ng/kg) versus Treatment, Replicate

Factor	Type	Levels	Values
Treatment	fixed	6	A1, A2, A3, A4, A5, A6
Replicate(Treatment)	random	30	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30

Analysis of Variance for TCDD TEQ (ng/kg), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	5	11334	11334	2267	0.99	0.446
Replicate(Treatment)	24	55121	55121	2297	0.72	0.811
Error	60	191401	191401	3190		
Total	89	257856				

P values are huge. Not statistically significant

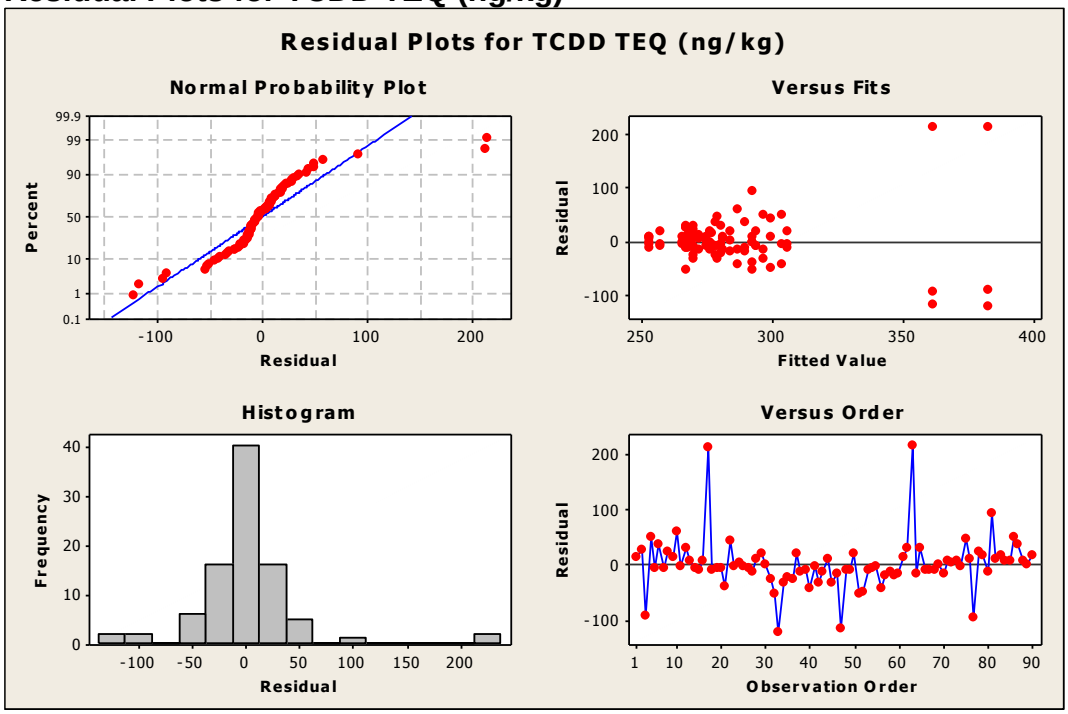
S = 56.4802 R-Sq = 25.77% R-Sq(adj) = 0.00%

Unusual Observations for TCDD TEQ (ng/kg)

Obs	TCDD TEQ (ng/kg)	Fit	SE Fit	Residual	St Resid
17	575.000	362.000	32.609	213.000	4.62 R
33	260.000	382.667	32.609	-122.667	-2.66 R
47	244.000	362.000	32.609	-118.000	-2.56 R
63	597.000	382.667	32.609	214.333	4.65 R
77	267.000	362.000	32.609	-95.000	-2.06 R
81	385.000	292.667	32.609	92.333	2.00 R

R denotes an observation with a large standardized residual.

Residual Plots for TCDD TEQ (ng/kg)



Log(TCDD TEQ)

General Linear Model: log(TCDDTEQ) versus Treatment, Replicate

Factor	Type	Levels	Values
Treatment	fixed	6	A1, A2, A3, A4, A5, A6
Replicate(Treatment)	random	30	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22,

23, 24, 25, 26, 27, 28, 29, 30

Analysis of Variance for log(TCDDTEQ), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	5	0.018170	0.018170	0.003634	1.22	0.331
Replicate(Treatment)	24	0.071661	0.071661	0.002986	0.64	0.888
Error	60	0.281277	0.281277	0.004688		
Total	89	0.371107				

P values are huge. Not statistically significant.

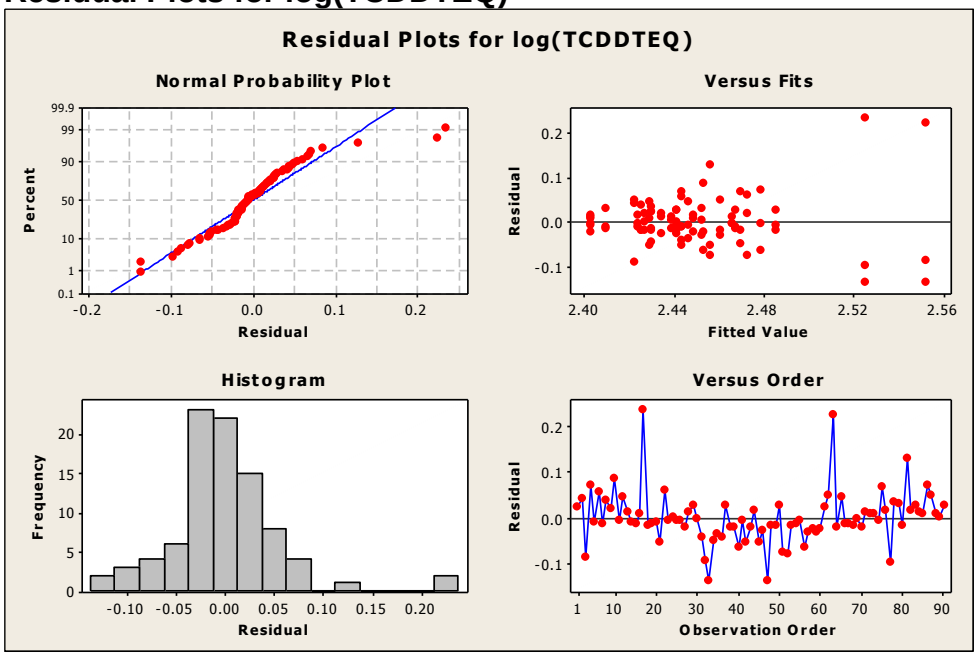
S = 0.0684686 R-Sq = 24.21% R-Sq(adj) = 0.00%

Unusual Observations for log(TCDDTEQ)

Obs	log(TCDDTEQ)	Fit	SE Fit	Residual	St Resid
17	2.75967	2.52452	0.03953	0.23514	4.21 R
33	2.41497	2.55161	0.03953	-0.13664	-2.44 R
47	2.38739	2.52452	0.03953	-0.13713	-2.45 R
63	2.77597	2.55161	0.03953	0.22436	4.01 R
81	2.58546	2.45626	0.03953	0.12920	2.31 R

R denotes an observation with a large standardized residual.

Residual Plots for log(TCDDTEQ)



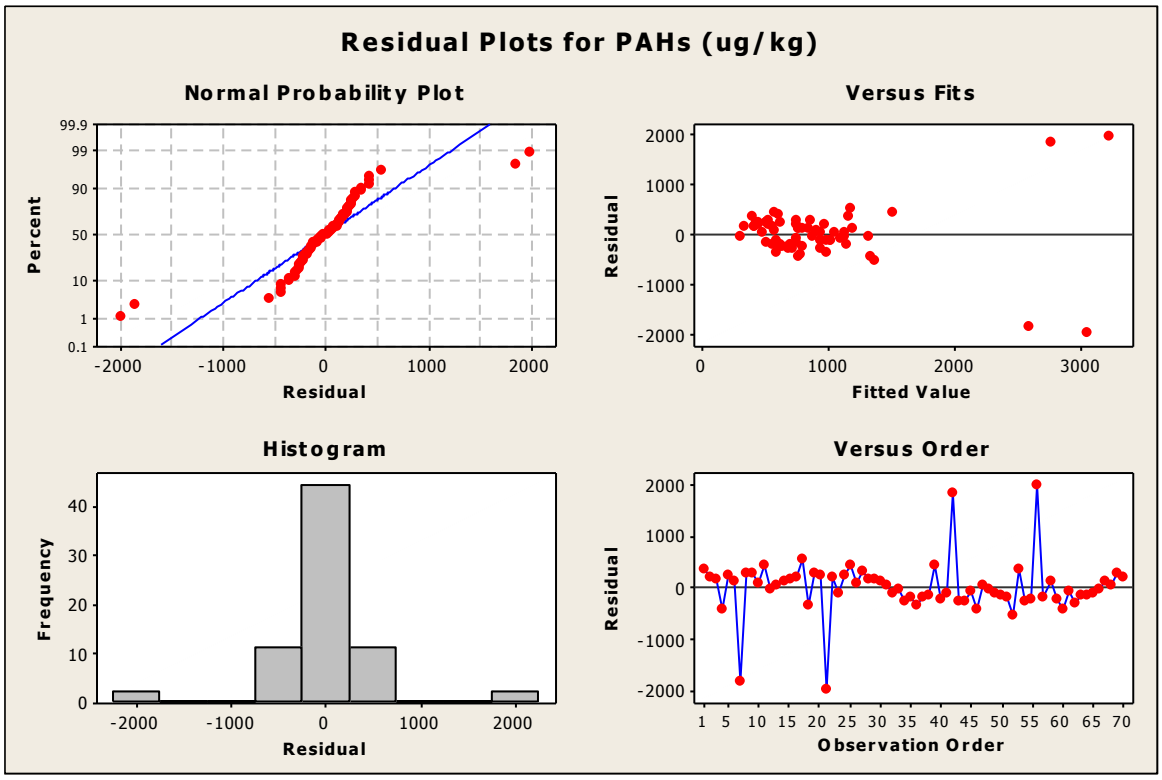
Appendix G: Statistics: Effect of Gamma Irradiation on Changes in Soil A COIs

General Linear Model: PAHs (ug/kg) versus Treatment, Time, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        7  A1, A2, A3, A4, A5, A6, A7
Time                  fixed        2  1, 3
Replicate(Treatment)  random      35  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30, 31, 32,
                                      33, 34, 35


Analysis of Variance for PAHs (ug/kg), using Adjusted SS for Tests

Source                DF    Seq SS    Adj SS  Adj MS     F      P
Treatment              6   3320638   3320638  553440  0.83  0.554
Time                   1    571110    571110  571110  1.03  0.317
Replicate(Treatment)  28  18594685  18594685  664096  1.20  0.302
Error                 34  18788465  18788465  552602
Total                 69  41274898


S = 743.372   R-Sq = 54.48%   R-Sq(adj) = 7.62%


Unusual Observations for PAHs (ug/kg)

        PAHs
Obs   (ug/kg)      Fit  SE Fit  Residual  St Resid
  7   732.00  2583.17  533.10  -1851.17     -3.57 R
 21  1050.00  3041.73  533.10  -1991.73     -3.84 R
 42  4615.00  2763.83  533.10   1851.17      3.57 R
 56  5214.11  3222.38  533.10   1991.73      3.84 R

R denotes an observation with a large standardized residual.
```

High p

Residual Plots for PAHs (ug/kg)



General Linear Model: log(PAH) versus Treatment, Time, Replicate

Factor	Type	Levels	Values
Treatment	fixed	7	A1, A2, A3, A4, A5, A6, A7
Time	fixed	2	1, 3
Replicate(Treatment)	random	35	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35

Analysis of Variance for log(PAH), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	6	0.36689	0.36689	0.06115	0.87	0.529
Time	1	0.00353	0.00353	0.00353	0.07	0.792
Replicate(Treatment)	28	1.96868	1.96868	0.07031	1.41	0.170
Error	34	1.69921	1.69921	0.04998		
Total	69	4.03831				

High p

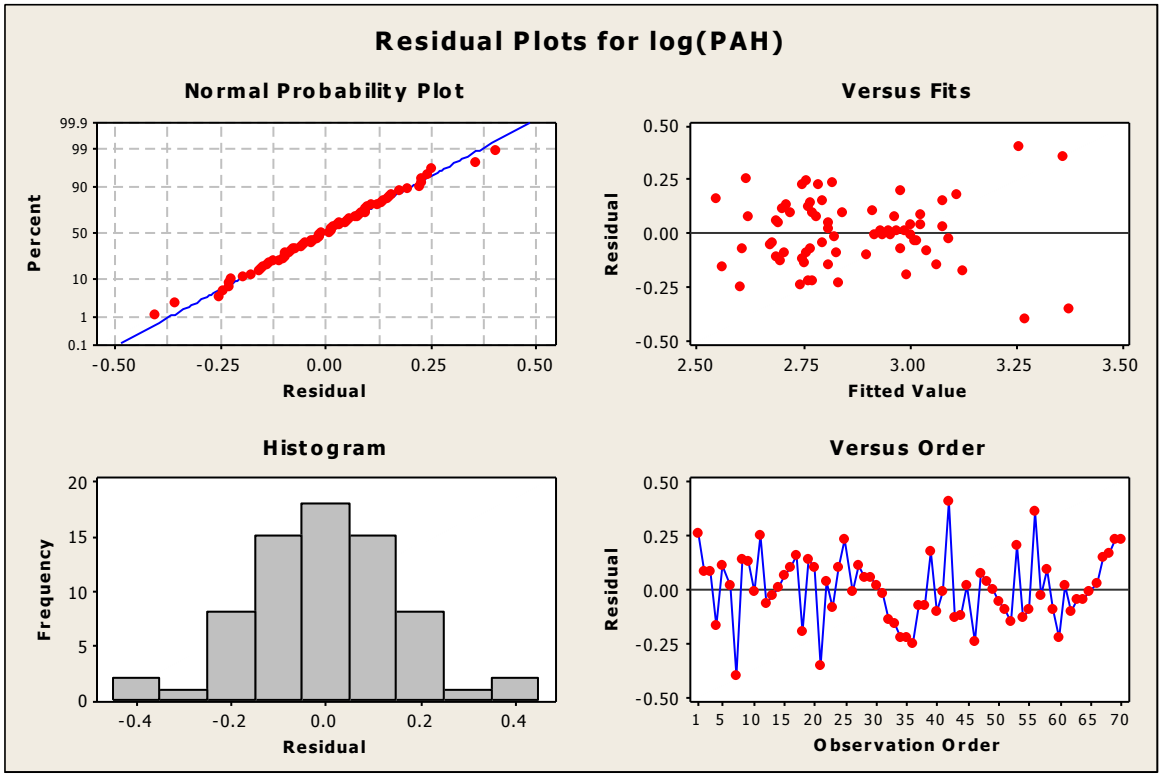
S = 0.223555 R-Sq = 57.92% R-Sq(adj) = 14.61%

Unusual Observations for log(PAH)

Obs	log(PAH)	Fit	SE Fit	Residual	St Resid
7	2.86451	3.27144	0.16032	-0.40693	-2.61 R
21	3.02119	3.37629	0.16032	-0.35510	-2.28 R
42	3.66417	3.25724	0.16032	0.40693	2.61 R
56	3.71718	3.36208	0.16032	0.35510	2.28 R

R denotes an observation with a large standardized residual.

Residual Plots for log(PAH)



General Linear Model: Dioxins (ng/kg) versus Treatment, Time, Replicate

Factor	Type	Levels	Values
Treatment	fixed	7	A1, A2, A3, A4, A5, A6, A7
Time	fixed	2	1, 3
Replicate(Treatment)	random	35	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35

Analysis of Variance for Dioxins (ng/kg), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	6	2926809955	2926809955	487801659	0.86	0.537
Time	1	25059269	25059269	25059269	0.04	0.839
Replicate(Treatment)	28	15898895857	15898895857	567817709	0.95	0.553
Error	34	20342899904	20342899904	598320585		
Total	69	39193664986				

High p

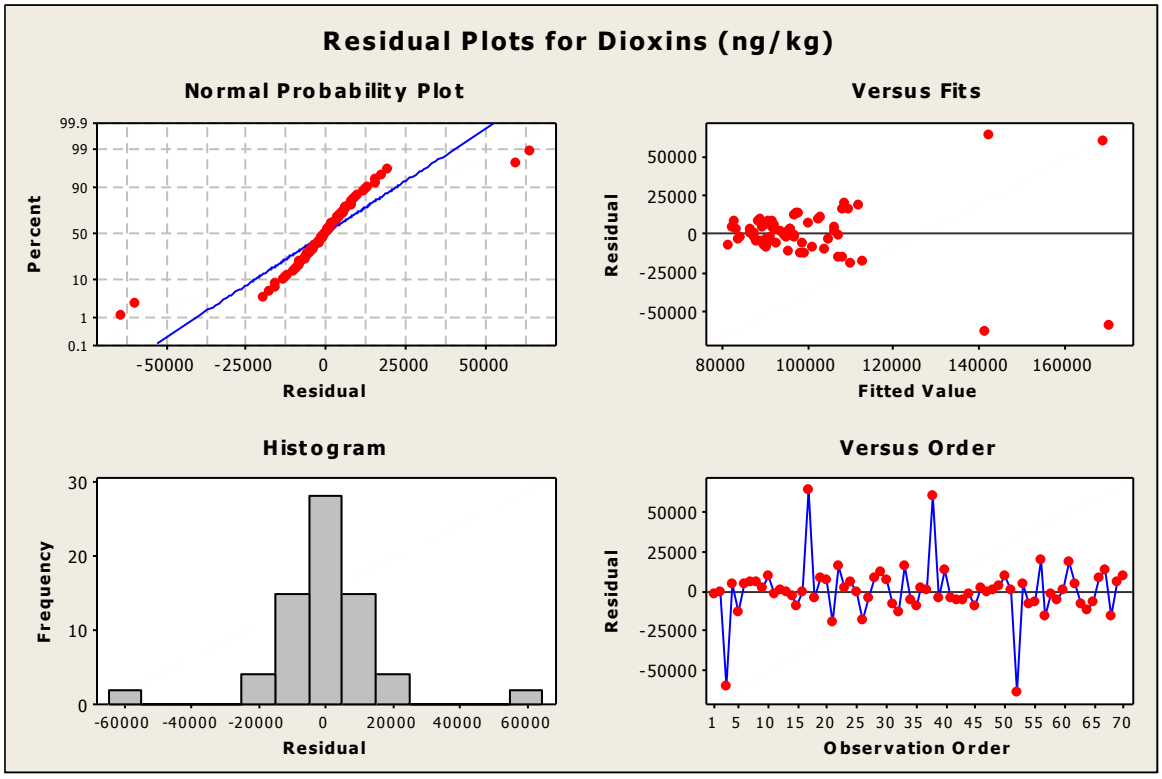
S = 24460.6 R-Sq = 48.10% R-Sq(adj) = 0.00%

Unusual Observations for Dioxins (ng/kg)

Obs	Dioxins (ng/kg)	Fit	SE Fit	Residual	St Resid	
3	110514	170567	17542	-60053	-3.52	R
17	206618	142553	17542	64065	3.76	R
38	229423	169370	17542	60053	3.52	R
52	77292	141357	17542	-64065	-3.76	R

R denotes an observation with a large standardized residual.

Residual Plots for Dioxins (ng/kg)



General Linear Model: log(Dioxins) versus Treatment, Time, Replicate

Factor	Type	Levels	Values
Treatment	fixed	7	A1, A2, A3, A4, A5, A6, A7
Time	fixed	2	1, 3
Replicate(Treatment)	random	35	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35

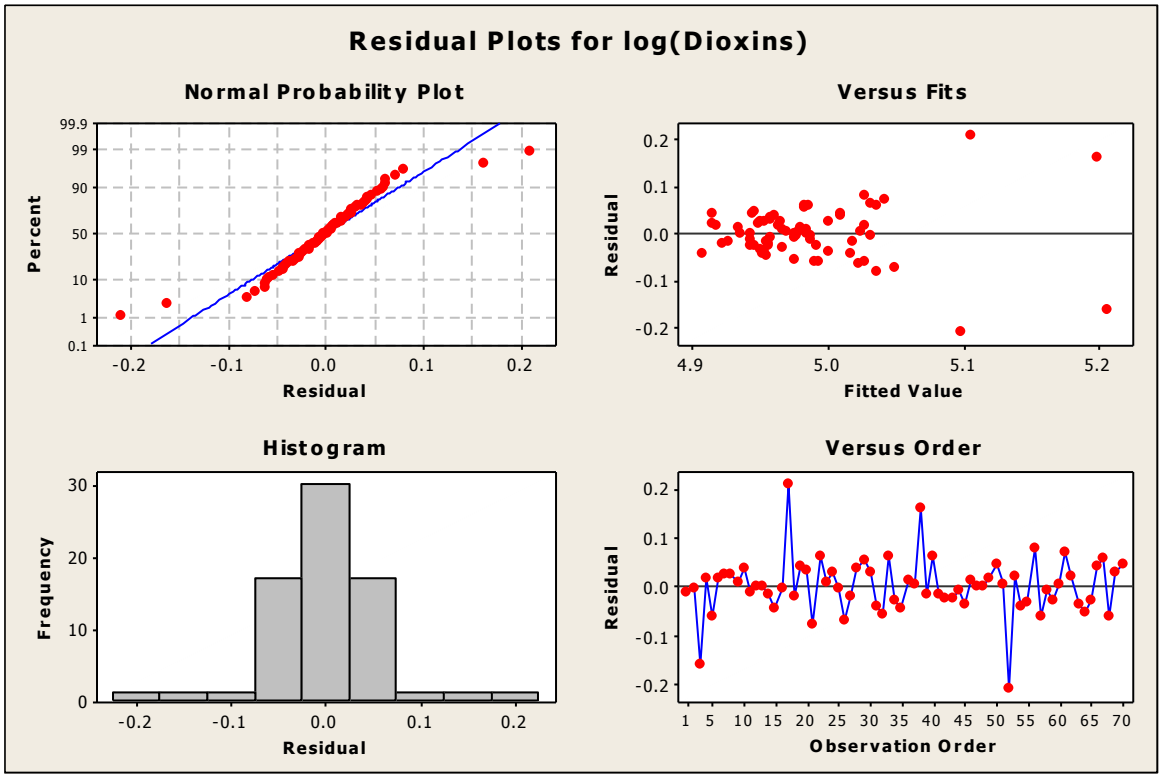
Analysis of Variance for log(Dioxins), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	6	0.034056	0.034056	0.005676	0.92	0.494

High p

```
Time                    1  0.001079  0.001079  0.001079  0.16  0.694
Replicate(Treatment)   28  0.172286  0.172286  0.006153  0.90  0.613
Error                  34  0.233299  0.233299  0.006862
Total                  69  0.440719


S = 0.0828355   R-Sq = 47.06%   R-Sq(adj) = 0.00%


Unusual Observations for log(Dioxins)

Obs  log(Dioxins)      Fit   SE Fit  Residual  St Resid
  3       5.04342  5.20595  0.05940  -0.16254     -2.82 R
 17       5.31517  5.10558  0.05940   0.20959      3.63 R
 38       5.36064  5.19810  0.05940   0.16254      2.82 R
 52       4.88813  5.09773  0.05940  -0.20959     -3.63 R

R denotes an observation with a large standardized residual.
```

Residual Plots for log(Dioxins)



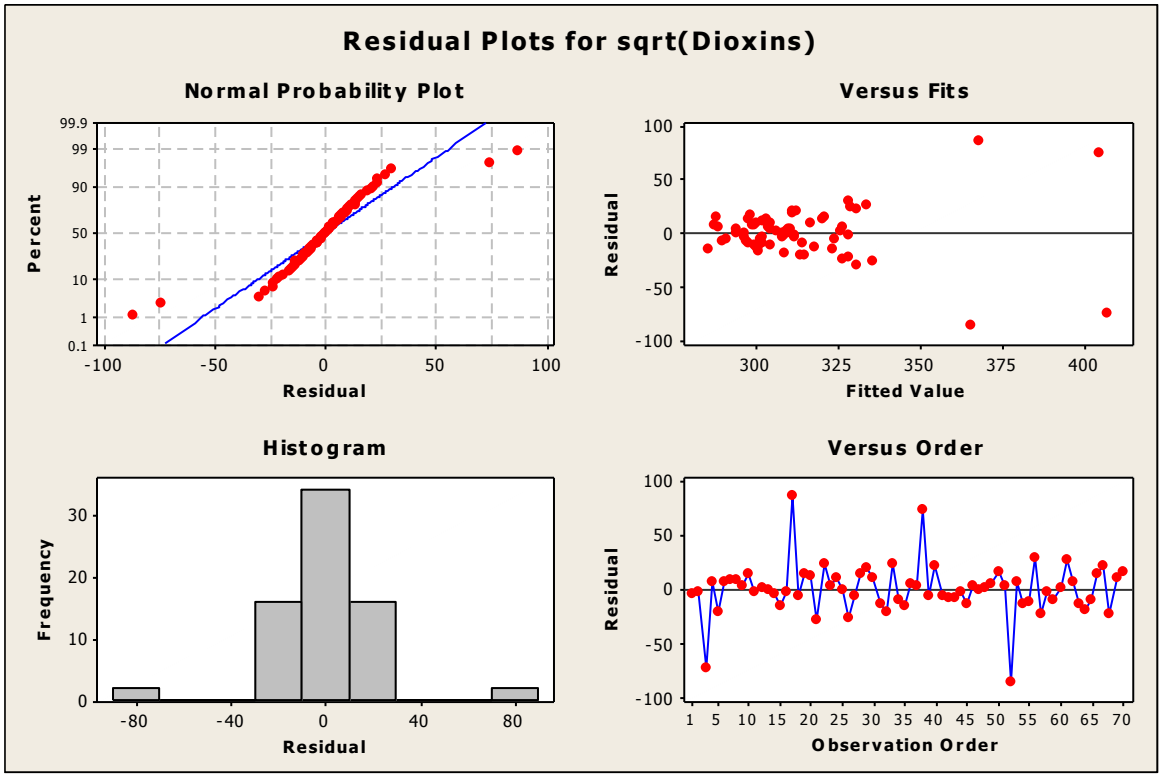
General Linear Model: sqrt(Dioxins) versus Treatment, Time, Replicate

```
Factor                 Type    Levels  Values
Treatment              fixed        7  A1, A2, A3, A4, A5, A6, A7
Time                   fixed        2  1, 3
Replicate(Treatment)   random      35  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                       13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
```

```
                                  23, 24, 25, 26, 27, 28, 29, 30, 31, 32,
                                  33, 34, 35

Analysis of Variance for sqrt(Dioxins), using Adjusted SS for Tests

Source                 DF  Seq SS  Adj SS  Adj MS     F      P
Treatment               6    5554    5554     926  0.89  0.519
Time                    1     103     103     103  0.09  0.765
Replicate(Treatment)   28   29284   29284    1046  0.92  0.581
Error                  34   38479   38479    1132
Total                  69   73419

S = 33.6412   R-Sq = 47.59%   R-Sq(adj) = 0.00%

Unusual Observations for sqrt(Dioxins)

Obs  sqrt(Dioxins)      Fit  SE Fit  Residual  St Resid
  3        332.436  406.921  24.125   -74.485     -3.18 R
 17        454.553  367.496  24.125    87.057      3.71 R
 38        478.981  404.497  24.125    74.485      3.18 R
 52        278.014  365.071  24.125   -87.057     -3.71 R

R denotes an observation with a large standardized residual.
```

High p

Residual Plots for sqrt(Dioxins)

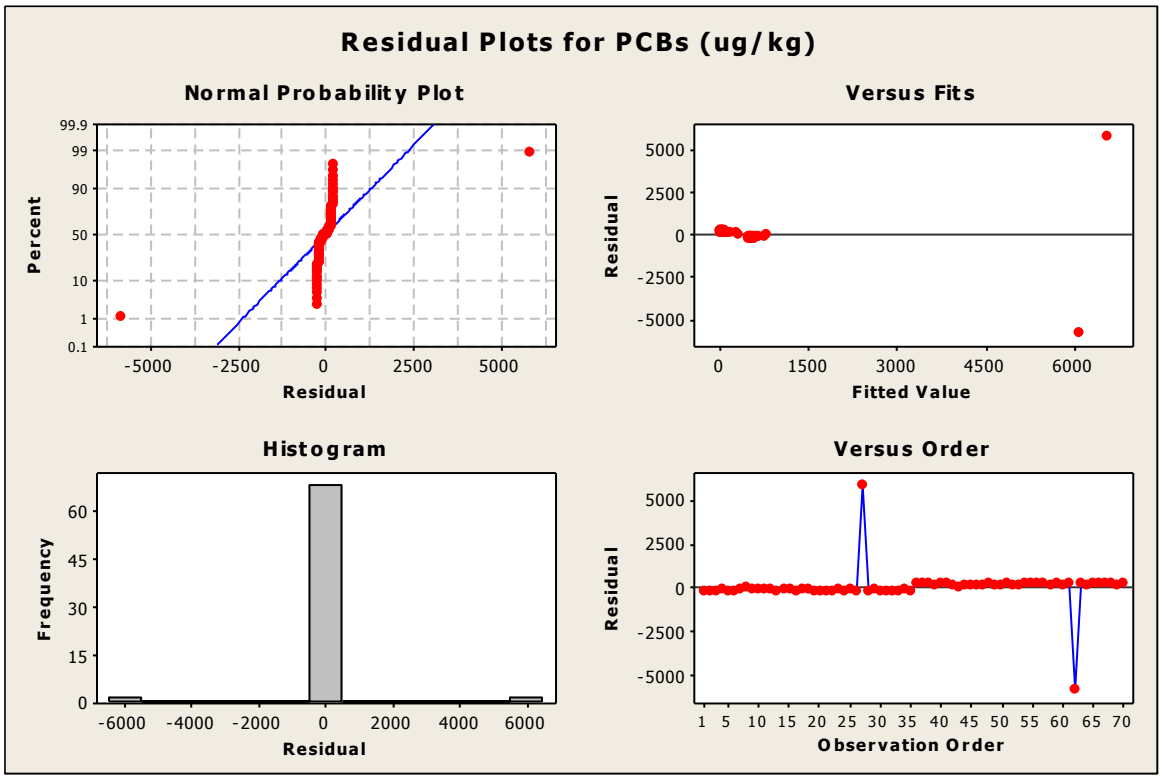


General Linear Model: PCBs (ug/kg) versus Treatment, Time, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        7  A1, A2, A3, A4, A5, A6, A7
Time                  fixed        2  1, 3
Replicate(Treatment)  random      35  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30, 31, 32,
                                      33, 34, 35


Analysis of Variance for PCBs (ug/kg), using Adjusted SS for Tests

Source                DF     Seq SS    Adj SS   Adj MS     F      P
Treatment              6   13360507  13360507  2226751  1.08  0.396
Time                   1    4329618   4329618  4329618  2.10  0.157
Replicate(Treatment)  28   57535717  57535717  2054847  1.00  0.500
Error                 34   70132475  70132475  2062720
Total                 69  145358318


S = 1436.22   R-Sq = 51.75%   R-Sq(adj) = 2.08%


Unusual Observations for PCBs (ug/kg)

        PCBs
Obs  (ug/kg)     Fit  SE Fit  Residual  St Resid
 27  12400.0  6572.2  1030.0    5827.8      5.82 R
 62    247.0  6074.8  1030.0   -5827.8     -5.82 R

R denotes an observation with a large standardized residual.
```

High p

Residual Plots for PCBs (ug/kg)

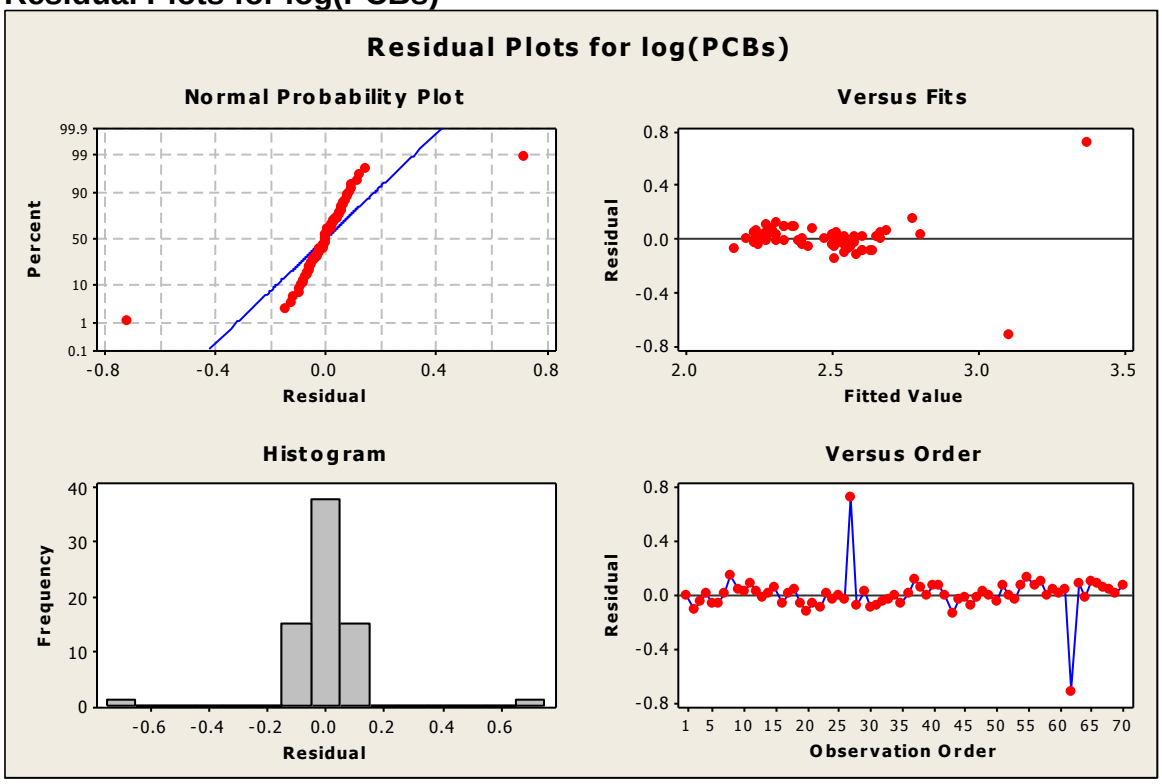


General Linear Model: log(PCBs) versus Treatment, Time, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        7  A1, A2, A3, A4, A5, A6, A7
Time                  fixed        2  1, 3
Replicate(Treatment)  random      35  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30, 31, 32,
                                      33, 34, 35


Analysis of Variance for log(PCBs), using Adjusted SS for Tests

Source                DF   Seq SS   Adj SS   Adj MS      F      P
Treatment              6  0.42909  0.42909  0.07152   1.64  0.174
Time                   1  1.25020  1.25020  1.25020  33.03  0.000
Replicate(Treatment)  28  1.22242  1.22242  0.04366   1.15  0.343
Error                 34  1.28701  1.28701  0.03785
Total                 69  4.18872


S = 0.194559   R-Sq = 69.27%   R-Sq(adj) = 37.65%


Unusual Observations for log(PCBs)

Obs  log(PCBs)      Fit   SE Fit  Residual  St Resid
 27    4.09342  3.37670  0.13953   0.71672      5.29 R
 62    2.39270  3.10942  0.13953  -0.71672     -5.29 R

R denotes an observation with a large standardized residual.
```

Significant p value for time? Run after midterm Treatment|

Residual Plots for log(PCBs)



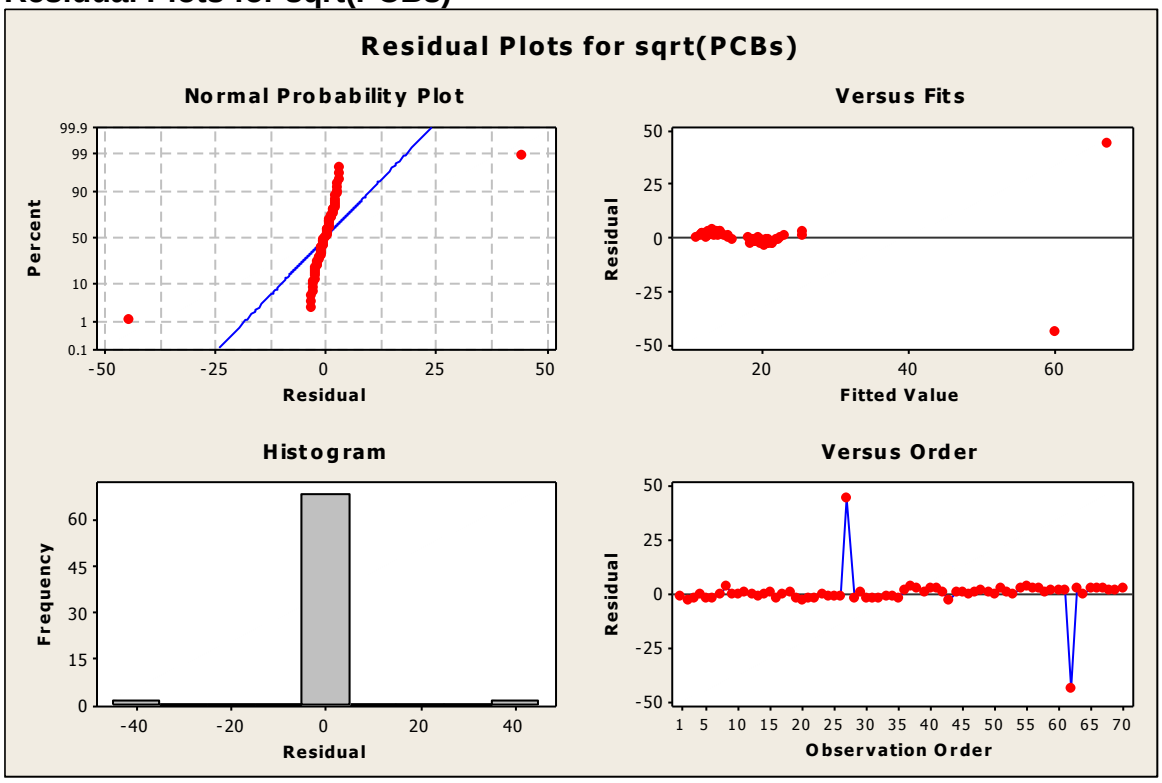
General Linear Model: sqrt(PCBs) versus Treatment, Time, Replicate

```
Factor                 Type    Levels  Values
Treatment              fixed        7  A1, A2, A3, A4, A5, A6, A7
Time                   fixed        2  1, 3
Replicate(Treatment)   random      35  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30, 31, 32,
                                      33, 34, 35


Analysis of Variance for sqrt(PCBs), using Adjusted SS for Tests

Source                 DF  Seq SS  Adj SS  Adj MS     F      P
Treatment               6   952.6   952.6   158.8  1.28  0.296
Time                    1   863.8   863.8   863.8  7.07  0.012
Replicate(Treatment)   28  3460.1  3460.1   123.6  1.01  0.483
Error                  34  4156.3  4156.3   122.2
Total                  69  9432.8


S = 11.0564   R-Sq = 55.94%   R-Sq(adj) = 10.58%


Unusual Observations for sqrt(PCBs)

Obs  sqrt(PCBs)     Fit  SE Fit  Residual  St Resid
 27     111.355  67.049   7.929    44.307      5.75 R
```

High p

```
 62       15.716   60.023    7.929    -44.307      -5.75 R

R denotes an observation with a large standardized residual.
```

Residual Plots for sqrt(PCBs)



General Linear Model: TCDD TEQ (ng/kg) versus Treatment, Time, Replicate

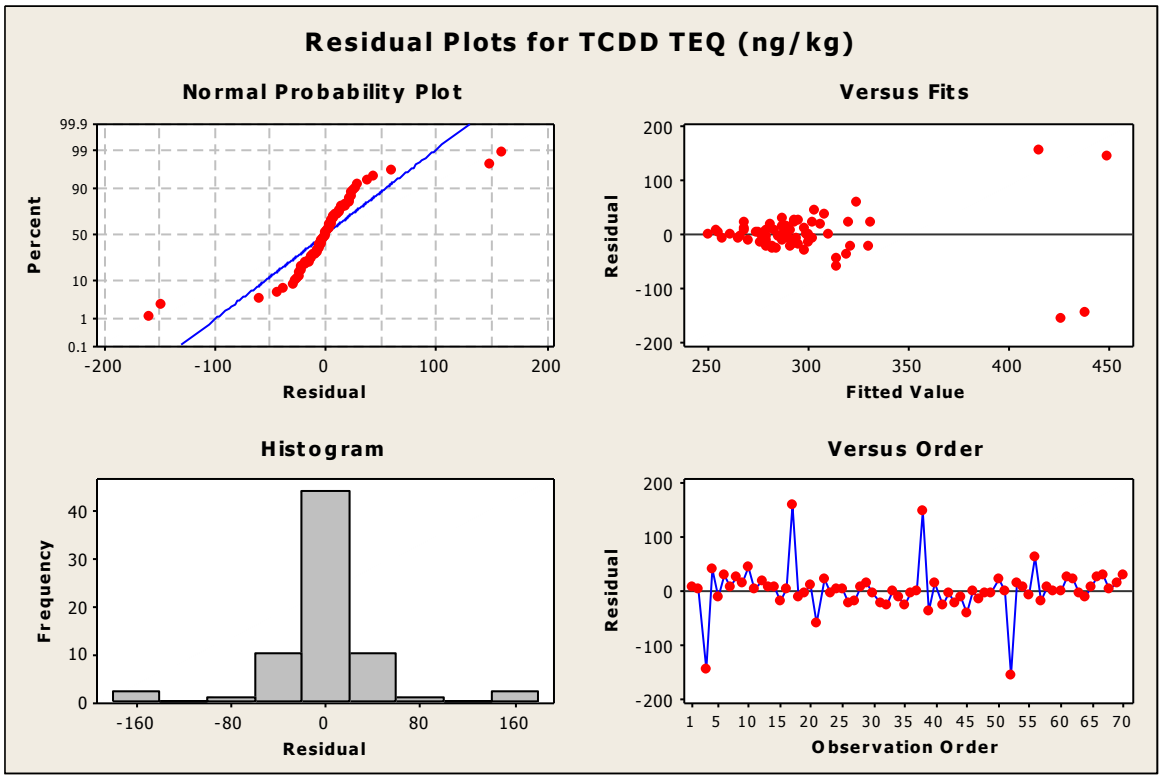
```
Factor                Type    Levels  Values
Treatment             fixed        7  A1, A2, A3, A4, A5, A6, A7
Time                  fixed        2  1, 3
Replicate(Treatment)  random      35  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20, 21, 22,
                                      23, 24, 25, 26, 27, 28, 29, 30, 31, 32,
                                      33, 34, 35


Analysis of Variance for TCDD TEQ (ng/kg), using Adjusted SS for Tests

Source                DF  Seq SS  Adj SS  Adj MS     F      P
Treatment              6   17290   17290    2882  1.00  0.443
Time                   1    2041    2041    2041  0.57  0.455
Replicate(Treatment)  28   80508   80508    2875  0.80  0.721
Error                 34  121619  121619    3577
Total                 69  221458


S = 59.8082   R-Sq = 45.08%   R-Sq(adj) = 0.00%


Unusual Observations for TCDD TEQ (ng/kg)
```

High p

Obs	TCDD TEQ (ng/kg)	Fit	SE Fit	Residual	St Resid	
3	291.000	438.600	42.891	-147.600	-3.54	R
17	575.000	415.600	42.891	159.400	3.82	R
38	597.000	449.400	42.891	147.600	3.54	R
52	267.000	426.400	42.891	-159.400	-3.82	R

R denotes an observation with a large standardized residual.

Residual Plots for TCDD TEQ (ng/kg)



General Linear Model: log(TCDDTEQ) versus Treatment, Time, Replicate

Factor	Type	Levels	Values
Treatment	fixed	7	A1, A2, A3, A4, A5, A6, A7
Time	fixed	2	1, 3
Replicate(Treatment)	random	35	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35

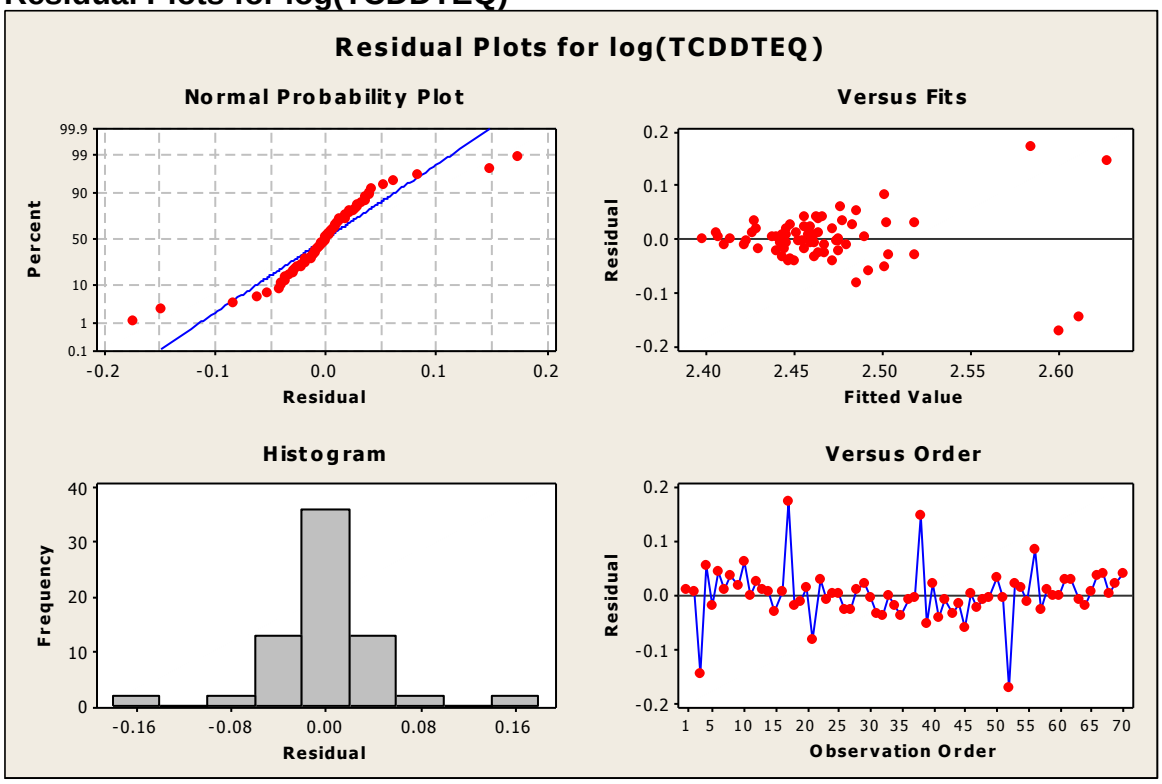
Analysis of Variance for log(TCDDTEQ), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	6	0.025881	0.025881	0.004314	1.23	0.321
Time	1	0.004291	0.004291	0.004291	0.90	0.348
Replicate(Treatment)	28	0.098145	0.098145	0.003505	0.74	0.792

High p

```
Error                 34  0.161304  0.161304  0.004744
Total                 69  0.289621


S = 0.0688784   R-Sq = 44.31%   R-Sq(adj) = 0.00%


Unusual Observations for log(TCDDTEQ)

Obs  log(TCDDTEQ)      Fit   SE Fit  Residual  St Resid
  3       2.46389  2.61210  0.04940  -0.14821     -3.09 R
 17       2.75967  2.58526  0.04940   0.17441      3.63 R
 38       2.77597  2.62776  0.04940   0.14821      3.09 R
 52       2.42651  2.60092  0.04940  -0.17441     -3.63 R

R denotes an observation with a large standardized residual.
```

Residual Plots for log(TCDDTEQ)

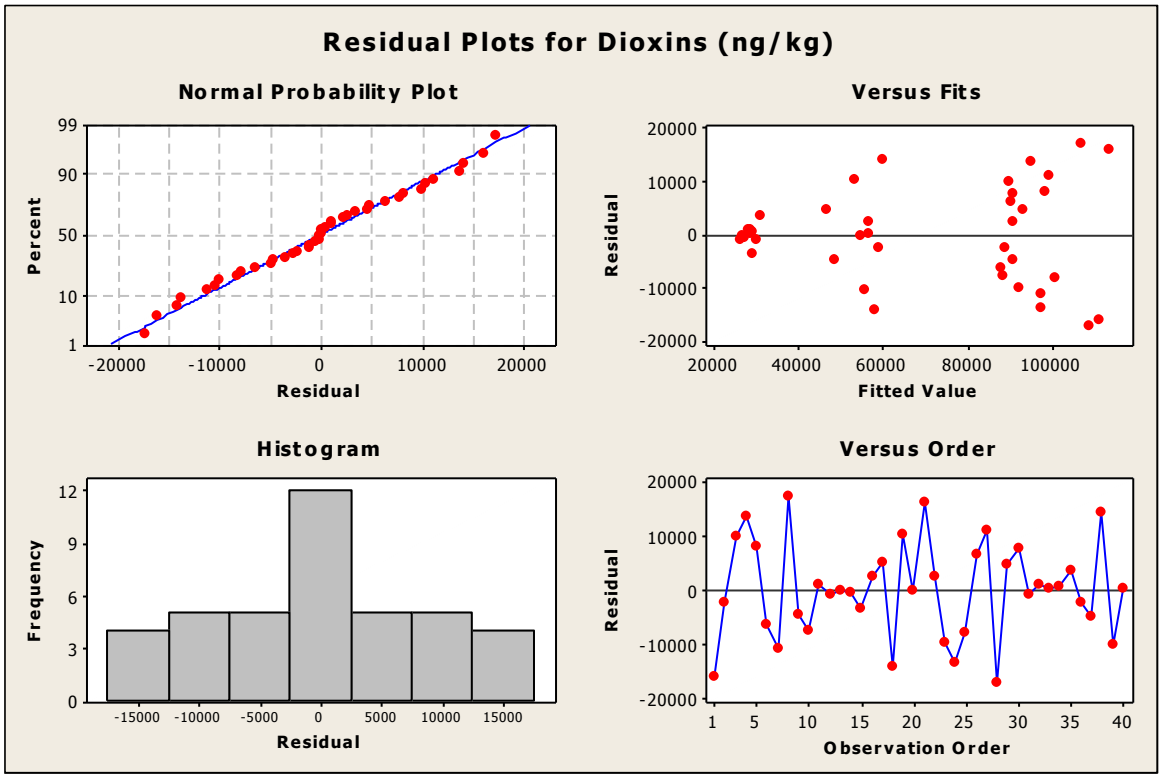


Appendix H: Statistics: Effect of Soil Type (A, B, or C) on COIs

General Linear Model: Dioxins (ng/kg) versus Treatment, Time, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        4  A6, A7, B6, C6
Time                  fixed        2  1, 3
Replicate(Treatment)  random      20  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20


Analysis of Variance for Dioxins (ng/kg), using Adjusted SS for Tests

Source                DF       Seq SS       Adj SS       Adj MS       F      P
Treatment              3  33668518629  33668518629  11222839543  136.64  0.000
Time                   1     47955466     47955466     47955466    0.30  0.591
Replicate(Treatment)  16   1314145543   1314145543     82134096    0.51  0.909
Error                 19   3043712649   3043712649    160195403
Total                 39  38074332288

S = 12656.8   R-Sq = 92.01%   R-Sq(adj) = 83.59%
```

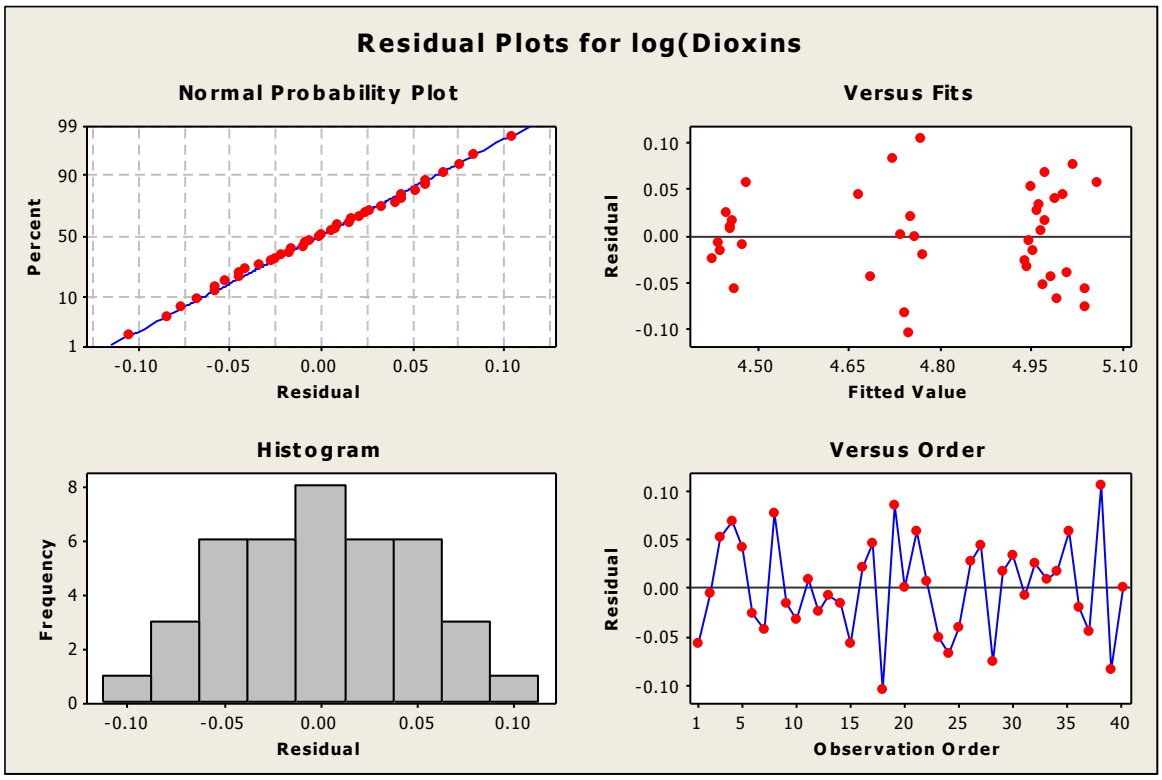
Residual Plots for Dioxins (ng/kg)



General Linear Model: log(Dioxins versus Treatment, Time, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        4  A6, A7, B6, C6
Time                  fixed        2  1, 3
Replicate(Treatment)  random      20  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20


Analysis of Variance for log(Dioxins, using Adjusted SS for Tests

Source                DF    Seq SS    Adj SS    Adj MS       F      P
Treatment              3  1.897128  1.897128  0.632376  323.29  0.000
Time                   1  0.003974  0.003974  0.003974    0.80  0.381
Replicate(Treatment)  16  0.031297  0.031297  0.001956    0.40  0.967
Error                 19  0.093964  0.093964  0.004945
Total                 39  2.026363


S = 0.0703242   R-Sq = 95.36%   R-Sq(adj) = 90.48%


Unusual Observations for log(Dioxins

Obs  log(Dioxins      Fit   SE Fit  Residual  St Resid
 18      4.64137  4.74657  0.05095  -0.10520     -2.17 R
 38      4.87171  4.76651  0.05095   0.10520      2.17 R

R denotes an observation with a large standardized residual.
```

Residual Plots for log(Dioxins

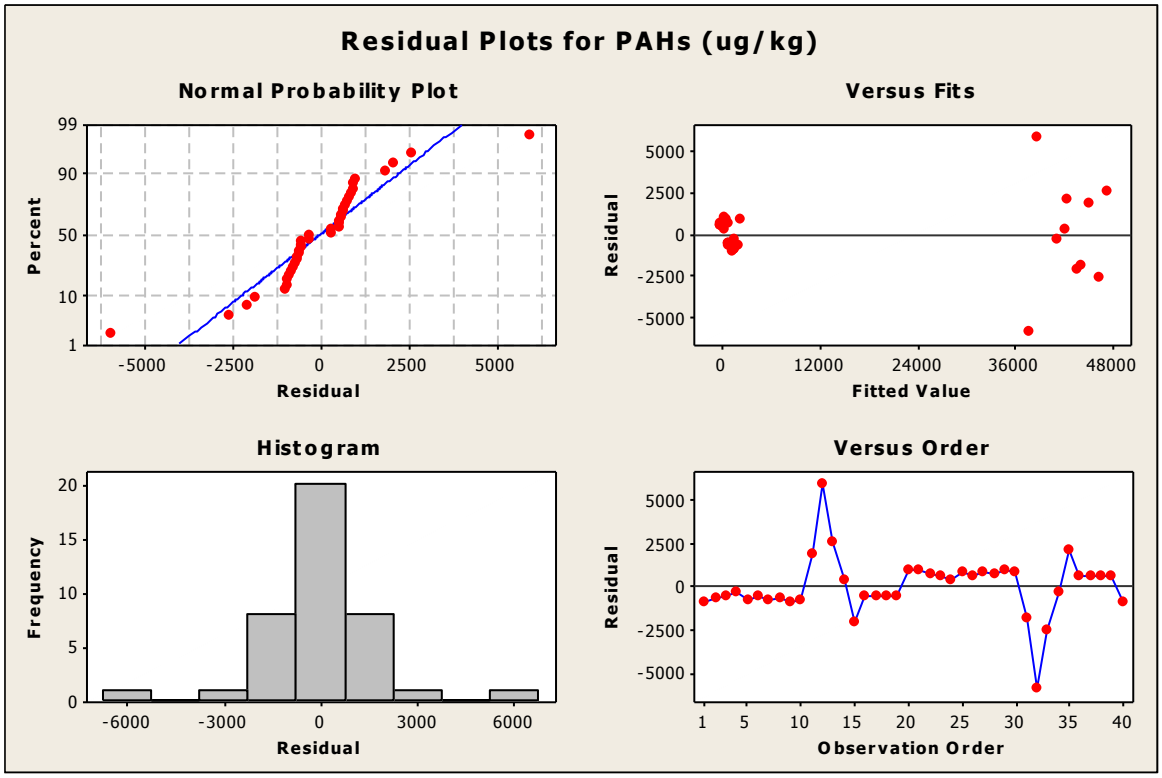


General Linear Model: PAHs (ug/kg) versus Treatment, Time, Replicate

```
Factor                 Type    Levels  Values
Treatment              fixed        4  A6, A7, B6, C6
Time                   fixed        2  1, 3
Replicate(Treatment)   random      20  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                       13, 14, 15, 16, 17, 18, 19, 20


Analysis of Variance for PAHs (ug/kg), using Adjusted SS for Tests

Source                 DF       Seq SS       Adj SS      Adj MS       F      P
Treatment               3  13429037070  13429037070  4476345690  795.99  0.000
Time                    1     12619489     12619489    12619489    2.09  0.165
Replicate(Treatment)   16     89978318     89978318     5623645    0.93  0.554
Error                  19    114930205    114930205     6048958
Total                  39  13646565082


S = 2459.46    R-Sq = 99.16%    R-Sq(adj) = 98.27%


Unusual Observations for PAHs (ug/kg)

        PAHs
```

```
Obs   (ug/kg)      Fit   SE Fit  Residual  St Resid
 12   44616.0  38696.2  1782.1    5919.8      3.49 R
 32   31653.0  37572.8  1782.1   -5919.8     -3.49 R

R denotes an observation with a large standardized residual.
```

Residual Plots for PAHs (ug/kg)

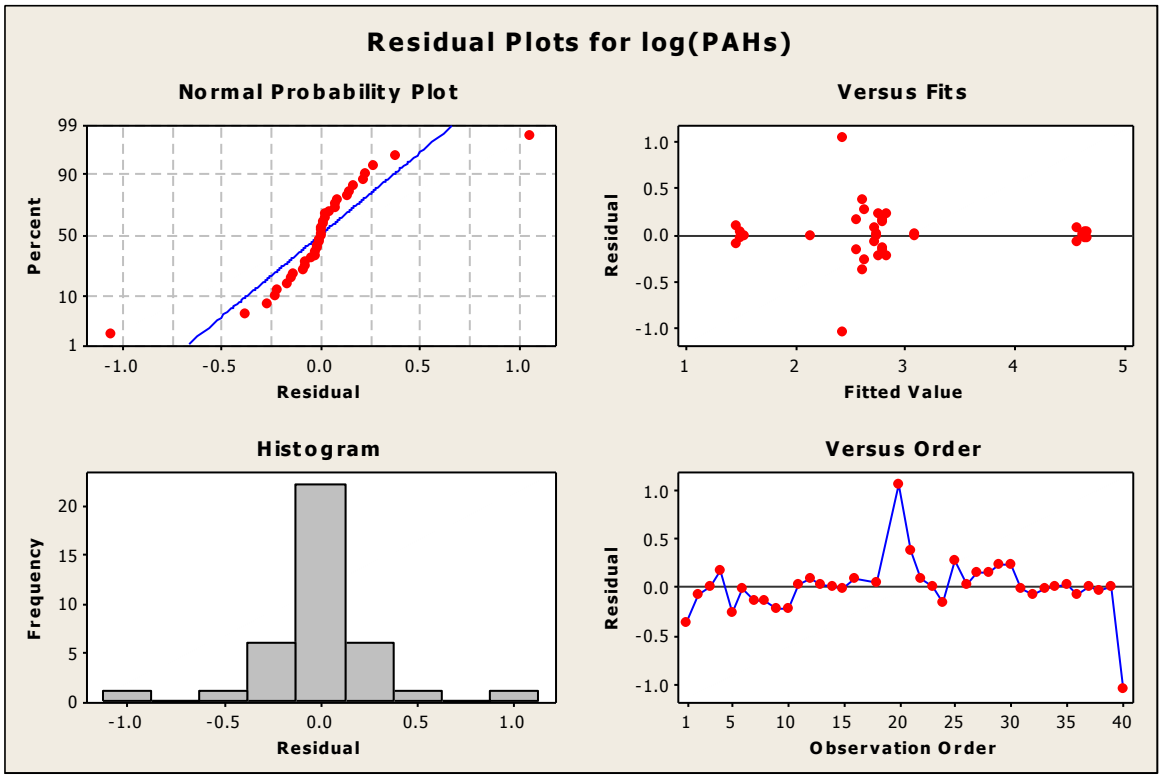


General Linear Model: log(PAHs) versus Treatment, Time, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        4  A6, A7, B6, C6
Time                  fixed        2  1, 3
Replicate(Treatment)  random      20  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20


Analysis of Variance for log(PAHs), using Adjusted SS for Tests

Source                DF   Seq SS   Adj SS   Adj MS       F      P
Treatment              3  39.0214  37.2246  12.4082  112.65  0.000 x
Time                   1   0.0001   0.0000   0.0000    0.00  0.997
Replicate(Treatment)  16   1.7303   1.7303   0.1081    0.61  0.838
Error                 17   3.0272   3.0272   0.1781
Total                 37  43.7790

x Not an exact F-test.
```

```
S = 0.421984   R-Sq = 93.09%   R-Sq(adj) = 84.95%


Unusual Observations for log(PAHs)

Obs  log(PAHs)      Fit   SE Fit  Residual  St Resid
 20    3.48572  2.43271  0.30656   1.05301      3.63 R
 37    1.53148  1.53148  0.42198   0.00000         * X
 39    2.14613  2.14613  0.42198   0.00000         * X
 40    1.38021  2.43322  0.30656  -1.05301     -3.63 R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.
```

Residual Plots for log(PAHs)



General Linear Model: PCBs (ug/kg) versus Treatment, Time, Replicate

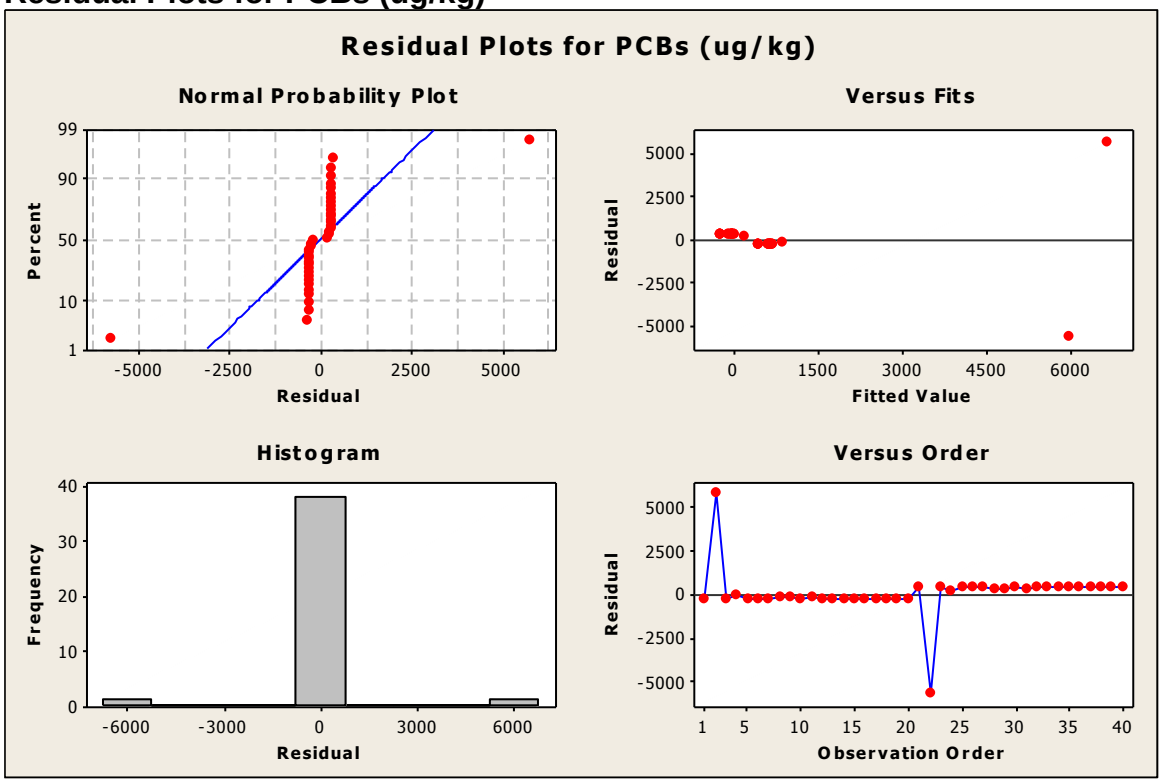
```
Factor                Type    Levels  Values
Treatment             fixed        4  A6, A7, B6, C6
Time                  fixed        2  1, 3
Replicate(Treatment)  random      20  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20


Analysis of Variance for PCBs (ug/kg), using Adjusted SS for Tests

Source                DF     Seq SS    Adj SS   Adj MS     F      P
```

```
Treatment              3   13453098  13453098  4484366  1.25  0.324
Time                   1    4790024   4790024  4790024  1.32  0.266
Replicate(Treatment)  16   57347751  57347751  3584234  0.98  0.507
Error                 19   69187555  69187555  3641450
Total                 39  144778428
```

```
S = 1908.26    R-Sq = 52.21%    R-Sq(adj) = 1.91%
```

```
Unusual Observations for PCBs (ug/kg)

        PCBs
Obs   (ug/kg)      Fit  SE Fit  Residual  St Resid
  2  12400.0   6669.6  1382.7    5730.4      4.36 R
 22    247.0   5977.5  1382.7   -5730.5     -4.36 R

R denotes an observation with a large standardized residual.
```

Residual Plots for PCBs (ug/kg)



General Linear Model: log(PCBs) versus Treatment, Time, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        4  A6, A7, B6, C6
Time                  fixed        2  1, 3
Replicate(Treatment)  random      20  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20
```

```
Analysis of Variance for log(PCBs), using Adjusted SS for Tests
```

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	3	3.66557	3.66557	1.22186	19.86	0.000
Time	1	0.65893	0.65893	0.65893	10.62	0.004
Replicate(Treatment)	16	0.98447	0.98447	0.06153	0.99	0.501
Error	19	1.17846	1.17846	0.06202		
Total	39	6.48743				

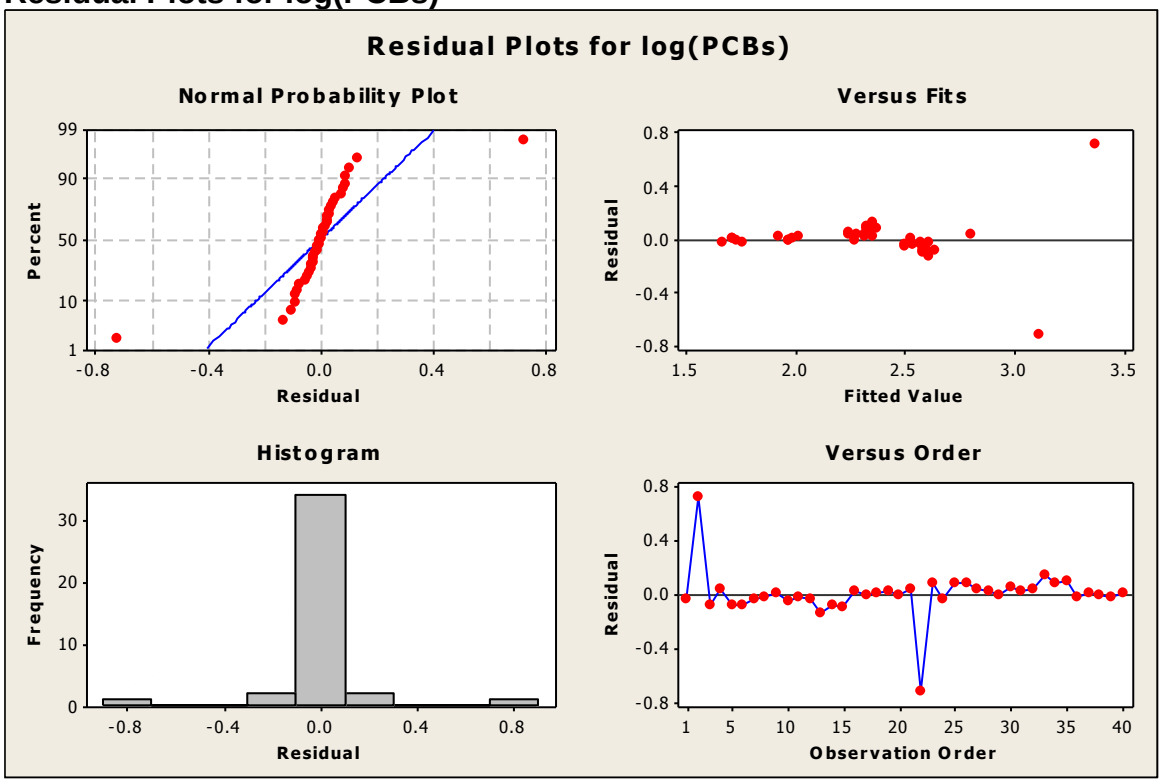
S = 0.249047 R-Sq = 81.83% R-Sq(adj) = 62.71%

Unusual Observations for log(PCBs)

Obs	log(PCBs)	Fit	SE Fit	Residual	St Resid
2	4.09342	3.37141	0.18045	0.72201	4.21 R
22	2.39270	3.11471	0.18045	-0.72201	-4.21 R

R denotes an observation with a large standardized residual.

Residual Plots for log(PCBs)



General Linear Model: TCDD TEQ (ng/kg) versus Treatment, Time, Replicate

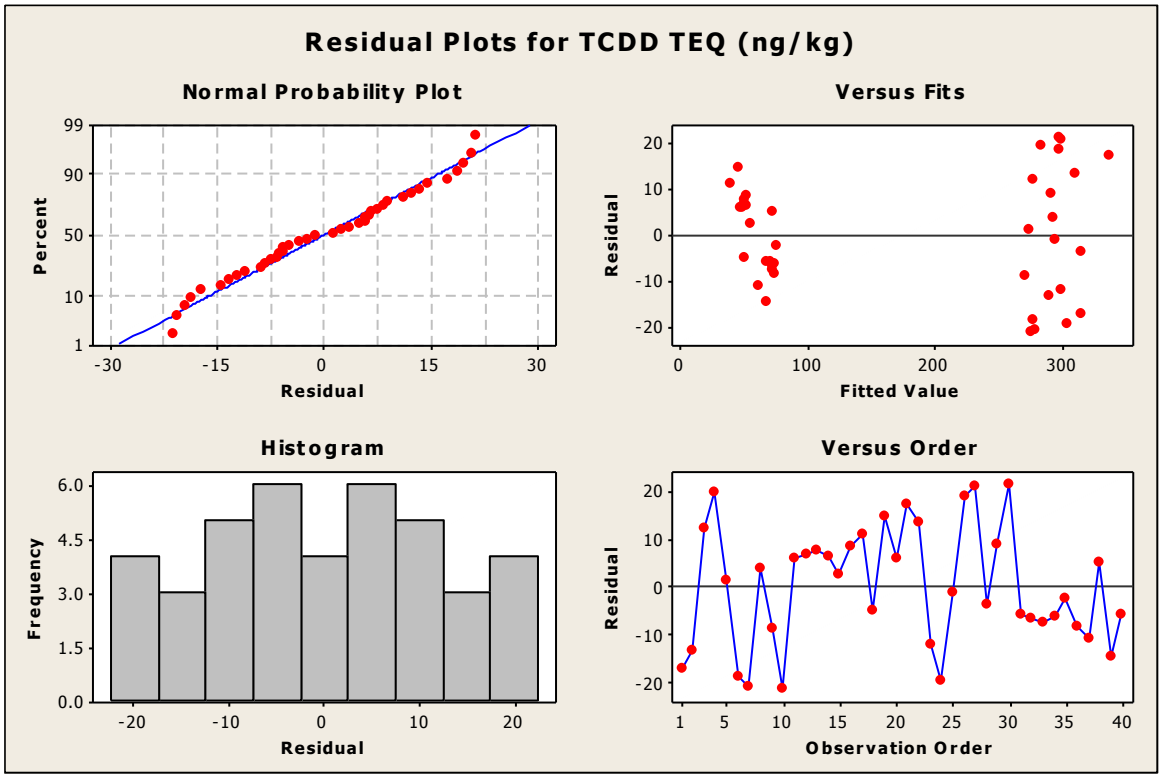
Factor	Type	Levels	Values
Treatment	fixed	4	A6, A7, B6, C6
Time	fixed	2	1, 3
Replicate(Treatment)	random	20	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

Analysis of Variance for TCDD TEQ (ng/kg), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	3	547152	547152	182384	974.09	0.000
Time	1	4537	4537	4537	14.37	0.001
Replicate(Treatment)	16	2996	2996	187	0.59	0.852
Error	19	6000	6000	316		
Total	39	560685				

S = 17.7709 R-Sq = 98.93% R-Sq(adj) = 97.80%

Residual Plots for TCDD TEQ (ng/kg)



General Linear Model: Total EFH (C8-C4 versus Treatment, Time, Replicate

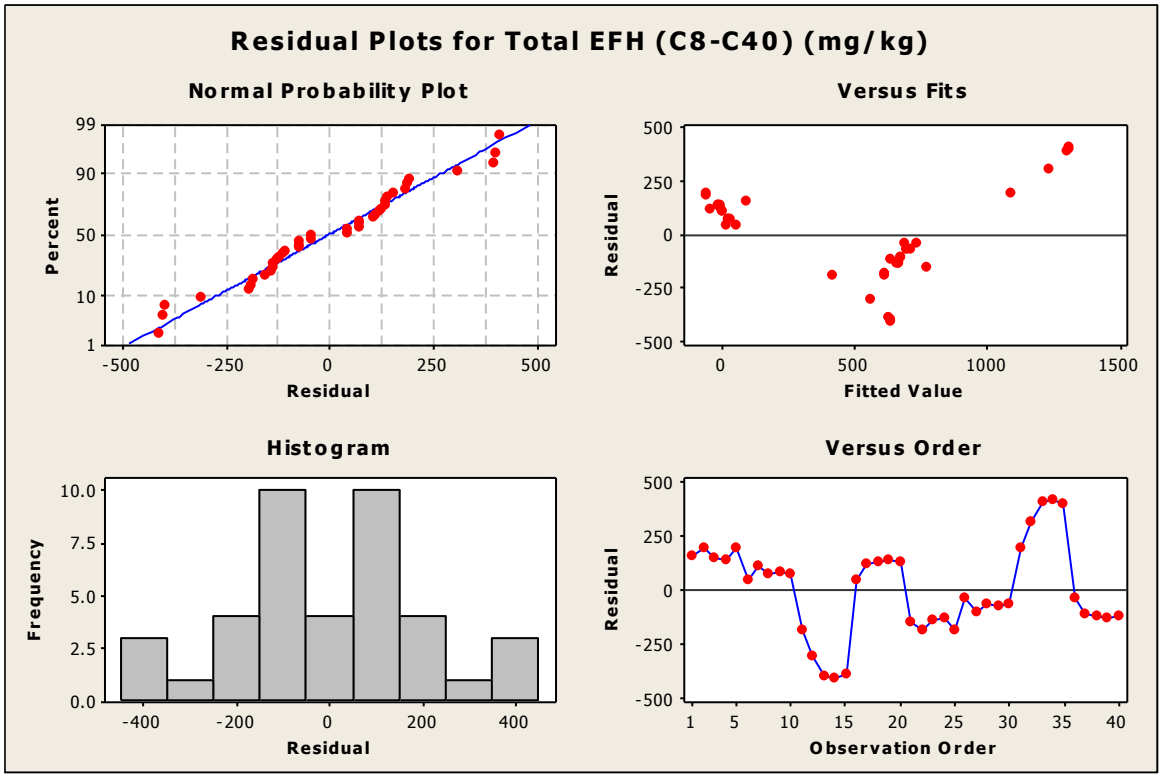
Factor	Type	Levels	Values
Treatment	fixed	4	A6, A7, B6, C6
Time	fixed	2	1, 3
Replicate(Treatment)	random	20	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

Analysis of Variance for Total EFH (C8-C40) (mg/kg), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	3	2438732	2438732	812911	118.26	0.000
Time	1	4534420	4534420	4534420	50.78	0.000

```
Replicate(Treatment)  16   109982   109982     6874    0.08  1.000
Error                 19  1696658  1696658    89298
Total                 39  8779792


S = 298.827   R-Sq = 80.68%   R-Sq(adj) = 60.33%


Unusual Observations for Total EFH (C8-C40) (mg/kg)

     Total EFH
      (C8-C40)
Obs     (mg/kg)       Fit  SE Fit  Residual  St Resid
 14      220.00    633.31  216.52   -413.31     -2.01 R
 34     1720.00   1306.69  216.52    413.31      2.01 R

R denotes an observation with a large standardized residual.
```

Residual Plots for Total EFH (C8-C40) (mg/kg)



General Linear Model: log(TotalEFH) versus Treatment, Time, Replicate

```
Factor                Type    Levels  Values
Treatment             fixed        4  A6, A7, B6, C6
Time                  fixed        2  1, 3
Replicate(Treatment)  random      20  1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,
                                      13, 14, 15, 16, 17, 18, 19, 20
```

Analysis of Variance for log(TotalEFH), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	3	1.11243	1.11243	0.37081	55.52	0.000
Time	1	5.34375	5.34375	5.34375	449.81	0.000
Replicate(Treatment)	16	0.10686	0.10686	0.00668	0.56	0.875
Error	19	0.22572	0.22572	0.01188		
Total	39	6.78876				

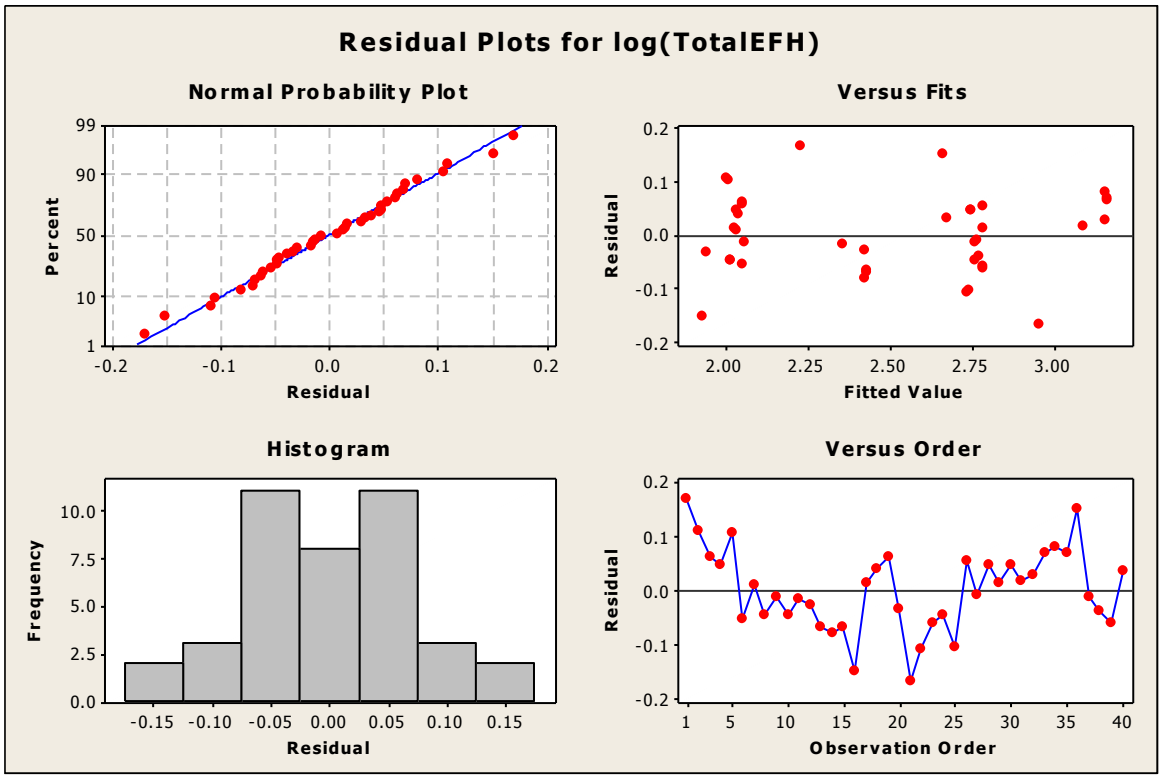
S = 0.108996 R-Sq = 96.68% R-Sq(adj) = 93.18%

Unusual Observations for log(TotalEFH)

Obs	log(TotalEFH)	Fit	SE Fit	Residual	St Resid
1	2.39794	2.22757	0.07897	0.17037	2.27 R
16	1.77815	1.93003	0.07897	-0.15188	-2.02 R
21	2.78821	2.95858	0.07897	-0.17037	-2.27 R
36	2.81291	2.66104	0.07897	0.15188	2.02 R

R denotes an observation with a large standardized residual.

Residual Plots for log(TotalEFH)



Appendix I: Microcosm Data and Graphs

Table 9: Microcosm soil pH values and statistics

Microcosm ID/Type	***Average Value***		***Standard Deviation***		***Standard Error***	
Sampling time (month/days)	Feb/0 days	Jun/126 days	Feb/0 days	Jun/126 days	Feb/0 days	Jun/126 days
A1 Nutrients	6.53	6.28	0.04	0.06	0.02	0.03
A2 Soya lecithin	5.87	6.31	0.03	0.19	0.01	0.08
A3 Rice hulls	6.60	6.24	0.07	0.17	0.03	0.08
A4 Nutrients+rice hulls+*P. chrysosporium*	6.44	6.35	0.06	0.18	0.03	0.08
A5 Nutrients+soya lecithin+rice hulls+*P. chrysosporium*	6.03	6.18	0.03	0.09	0.01	0.04
A6 Unamended site A	6.64	6.30	0.03	0.02	0.01	0.01
B6 Unamended site B	6.84	6.68	0.03	0.05	0.01	0.02
C6 Unamended site C	7.35	7.33	0.05	0.05	0.02	0.02
A7 Unamended, gamma-irradiated site A	6.676	N/A	0.038471	N/A	0.017205	N/A

Table 10: Microcosm soil TOC concentrations and statistics

Microcosm ID/Type	***Average Concentration (mg/kg)***		***Standard Deviation***		***Standard Error***	
Sampling time (month/days)	Feb/0 days	Jun/126 days	Feb/0 days	Jun/126 days	Feb/0 days	Jun/126 days
A1 nutrient	11976	7986	7266	2594	3250	1160
A2 soya lecithin	24960	12524	9630	2892	4307	1294
A3 rice hulls	36420	23820	17833	6181	7975	2764
A4 nutrients+rice hulls+P. chrysosporium	33464	19840	22393	3331	10015	1490
A5 nutrients+soya lecithin+rice hulls+P. chrysosporium	37640	23740	11336	4426	5070	1979
A6 unamended site A	11298	9268	5606	3056	2507	1367
B6 unamended site B	61060	37530	19453	28015	8700	12529
C6 unamended site C	3236	2770	1023	1231	458	551
A7 gamma-irradiated unamended site a	10830	N/A	3732	N/A	1669	N/A

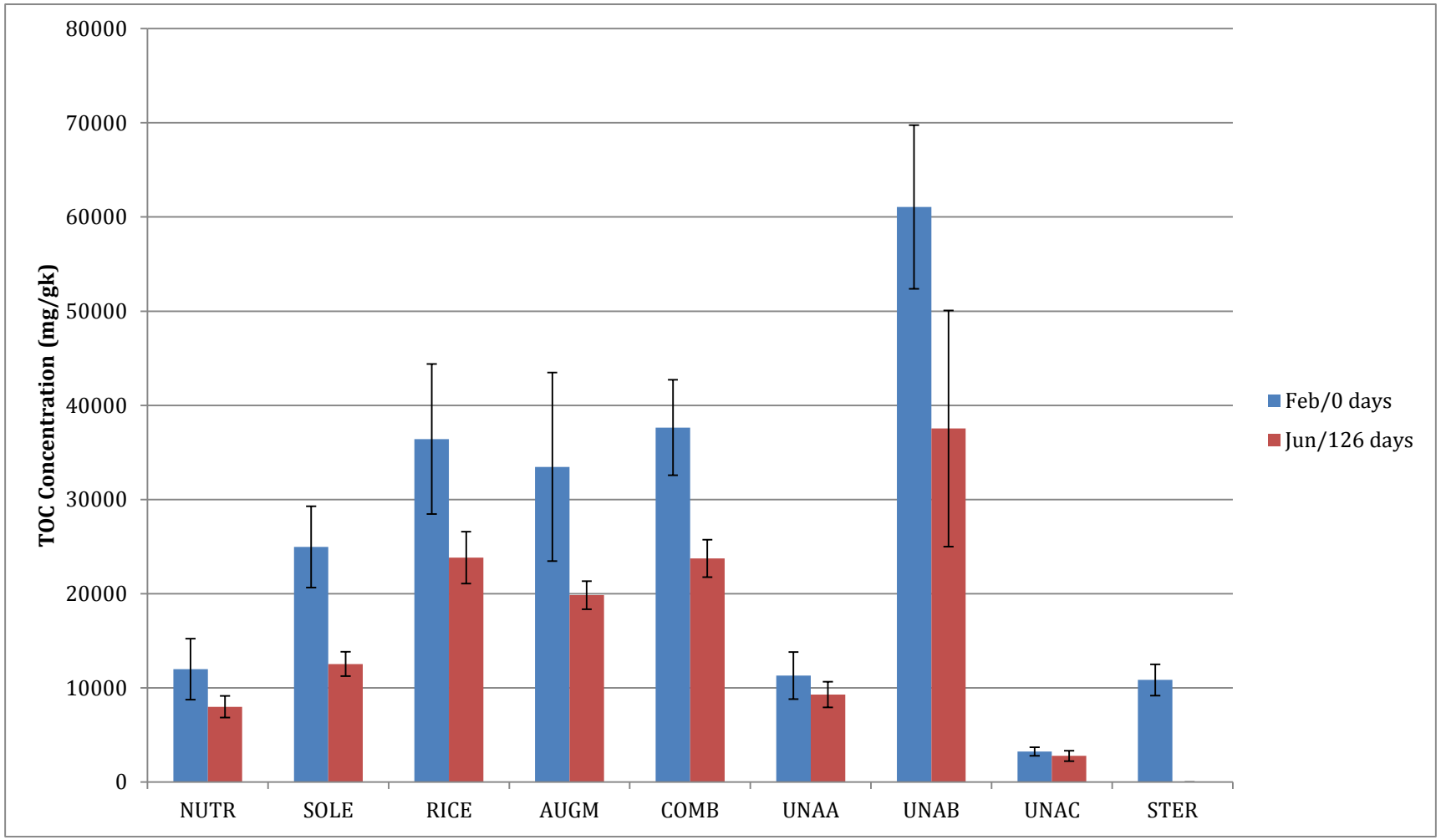


Figure 68: TOC in microcosms during incubation

Table 11: Microcosm soil Nitrate/Nitrate concentrations and statistics

Microcosm ID/Type	*Average Concentration (mg/kg)*		*Standard Deviation*		*Standard Error*	
Sampling time (month/days)	**Feb/0 days**	**Jun/126 days**	**Feb/0 days**	**Jun/126 days**	**Feb/0 days**	**Feb/0 days**
A1 nutrient	701	991	146	126	65	57
A2 soya lecithin	772	1148	104	138	47	62
A3 rice hulls	856	1066	181	657	81	294
A4 nutrients+rice hulls+P. chrysosporium	884	1103	464	149	207	66
A5 nutrients+soya lecithin+rice hulls+P. chrysosporium	996	1584	117	454	52	203
A6 unamended site A	834	1168	198	318	88	142
B6 unamended site B	1814	2178	437	229	195	103
C6 unamended site C	186	143	41	82	18	37
A7 gamma-irradiated unamended site a	679	N/A	77	N/A	34	N/A

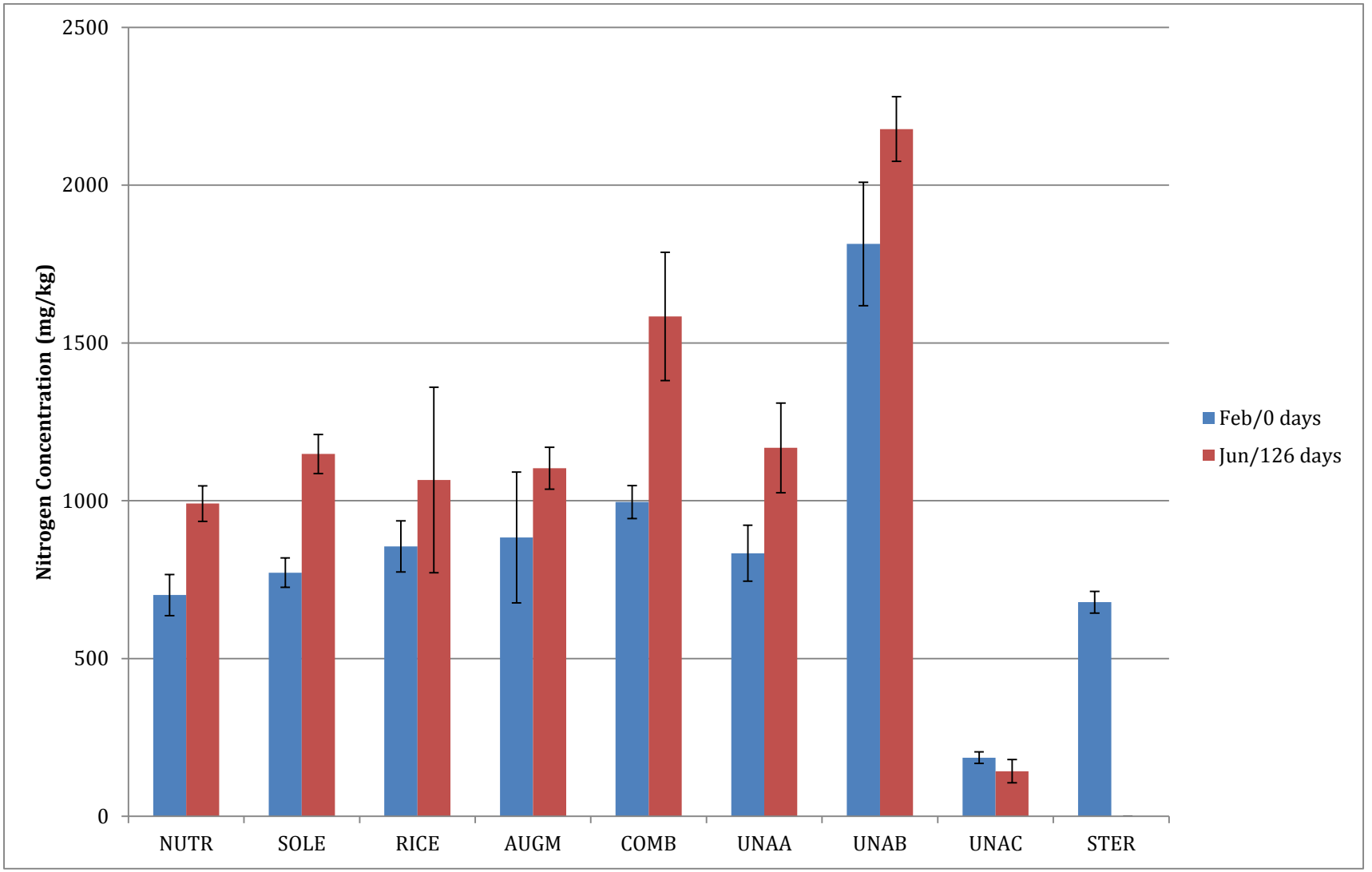


Figure 69: Nitrogen in microcosms during incubation

Table 12: Microcosm soil moisture content and statistics

Microcosm ID/Type	***Average moisture content (%)***			***Standard Deviation***			***Standard Error***		
Sampling time (month/day)	Feb/0	Jun/126	Oct/244	Feb/0	Jun/126	Oct/244	Feb/0	Jun/126	Oct/244
A1 nutrient	11.7	11.6	15.6	0.3	1.5	1.6	0.2	0.7	0.7
A2 soya lecithin	11.3	13.2	15.5	2.6	0.9	0.8	1.1	0.4	0.4
A3 rice hulls	8.9	12.4	15.4	1.0	1.2	0.5	0.4	0.5	0.2
A4 nutrients+rice hulls+P. chrysosporium	12.2	13.0	15.3	1.3	1.5	1.6	0.6	0.7	0.7
A5 nutrients+soya lecithin+rice hulls+P. chrysosporium	12.8	12.2	16.8	1.0	0.7	1.7	0.4	0.3	0.7
A6 unamended site A	11.9	11.5	14.4	0.6	0.6	0.3	0.3	0.3	0.1
B6 unamended site B	12.2	11.1	14.9	1.3	0.9	0.9	0.6	0.4	0.4
C6 unamended site C	11.6	12.2	15.5	0.4	0.9	1.8	0.2	0.4	0.8
A7 gamma-irradiated unamended site a	11.4	N/A	11.5	0.8	N/A	0.4	0.3	N/A	0.2

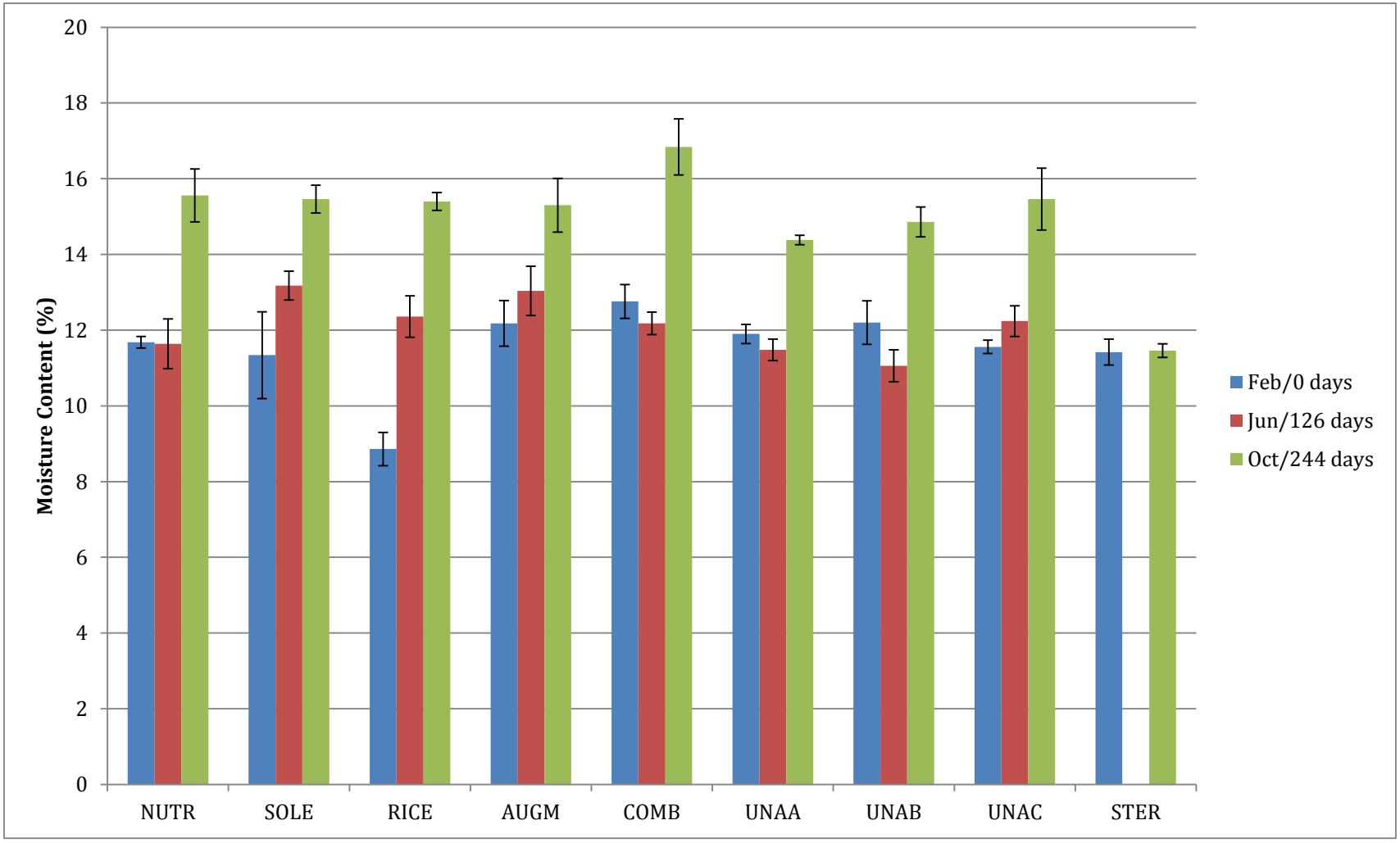


Figure 70: Microcosm moisture content during incubation

Table 13: Microcosm soil total EFH concentrations and statistics

Microcosm ID/type	*Average Concentration (mg/kg)*			*Standard Deviation*			*Standard Error*		
Sampling time (month/day)	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**
A1 nutrient	182	152	152	51	54	119	23	24	53
A2 soya lecithin	1640	172	N/A	219	54	N/A	98	24	N/A
A3 rice hulls	154	137	502	22	46	502	9	20	225
A4 nutrients+rice hulls+P. chrysosporium	146	113	556	23	27	556	10	12	249
A5 nutrients+soya lecithin+rice hulls+P. chrysosporium	1980	156	N/A	327	32	N/A	146	14	N/A
A6 unamended site A	152	89	502	55	12	79	25	5	35
B6 unamended site B	230	226	1589	12	30	188	5	14	84
C6 unamended site C	100	105	558	29	26	54	13	12	24
A7 gamma-irradiated unamended site A	101	N/A	628	9	N/A	42	4	N/A	19

Table 14: Microcosm total PAH concentrations and statistics

Microcosm ID/type	*Average Concentration (ug/kg)*			*Standard Deviation*			*Standard Error*		
Sampling time (month/day)	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**
A1 nutrient	626	727	673	228	881	714	102	394	319
A2 soya lecithin	350	538	1390	191	195	1812	85	87	810
A3 rice hulls	714	489	759	414	282	372	185	126	166
A4 nutrients+rice hulls+P. chrysosporium	214	382	710	39	113	479	15	50	214
A5 nutrients+soya lecithin+rice hulls+P. chrysosporium	87	485	1672	56	282	2014	25	126	901
A6 unamended site A	467	429	684	297	158	224	133	71	100
B6 unamended site B	45139	39238	40585	3441	1746	5198	1539	781	2325
C6 unamended site C	626	153	50	1361	211	50	609	94	23
A7 gamma-irradiated unamended site A	523	N/A	943	364	N/A	289	163	N/A	129

Table 15: Microcosm soil total PCB concentrations and statistics

Microcosm ID/type	*Average Concentration (ug/kg)*			*Standard Deviation*			*Standard Error*		
Sampling time (month/day)	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**
A1 nutrient	326.4	285.6	215	81.36523	54.6562	37.22902	36.38764	24.44299	16.64932
A2 soya lecithin	448.2	277.6	197.4	214.9353	46.59184	34.07785	96.12201	20.83651	15.24008
A3 rice hulls	394	286	186.2	98.66357	104.8308	43.47643	44.12369	46.88177	19.44325
A4 nutrients+rice hulls+P. chrysosporium	378	234	240.2	101.4569	10.41633	19.17551	45.3729	4.658326	8.575547
A5 nutrients+soya lecithin+rice hulls+P. chrysosporium	336.2	291.4	217.8	19.46022	43.51781	44.81852	8.702873	19.46176	20.04345
A6 unamended site A	2811.8	251.4	263	5362.195	17.7426	49.86482	2398.047	7.934734	22.30022
B6 unamended site B	329.2	414	260.6	37.66563	33.61547	30.66431	16.84458	15.0333	13.7135
C6 unamended site C	95.4	97.2	51.2	8.414274	5.674504	3.563706	3.762978	2.537716	1.593738
A7 gamma-irradiated unamended site A	323.8		217	27.98571		30.8788	12.51559		13.80942

Table 16: Microcosm total dioxin concentration and statistics

Microcosm ID/type	*Average Concentration (ng/kg)*			*Standard Deviation*			*Standard Error*		
Sampling time (month/day)	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**
A1 nutrient	98898	79230	126710	11141	3779	57719	4982	1690	25813
A2 soya lecithin	99547	84227	88048	6749	14579	4316	3018	6520	1930
A3 rice hulls	89064	85548	93723	6327	19916	11257	2830	8907	5034
A4 nutrients+rice hulls+P. chrysosporium	116316	90113	85415	51418	20613	85415	22995	9219	38199
A5 nutrients+soya lecithin+rice hulls+P. chrysosporium	100358	88368	97854	13966	12666	17633	6246	5665	7886
A6 unamended site A	99432	81967	96257	9032	2047	19335	4039	915	8647
B6 unamended site B	26581	26041	30452	1536	2396	2397	687	1072	1072
C6 unamended site C	54509	54526	55342	7608	6219	12275	3403	2781	5490
A7 gamma-irradiated unamended site a	91803		99035	18189		7052	8135		3154

Table 17: Microcosm soil TCDD TEQ concentrations and statistics

Microcosm ID/type	*Average Concentration (ng/kg)*			*Standard Deviation*			*Standard Error*		
Sampling time (month/day)	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**	**Feb/0 days**	**Jun/126 days**	**Oct/244 days**
A1 nutrient	297	247	247	28	20	137	13	9	61
A2 soya lecithin	303	264	264	27	27	10	12	12	4
A3 rice hulls	267	250	276	18	15	28	8	7	12
A4 nutrients+rice hulls+P. chrysosporium	332	266	282	137	34	11	61	15	5
A5 nutrients+soya lecithin+rice hulls+P. chrysosporium	286	262	314	33	19	41	15	8	18
A6 unamended site A	288.4	263.8	308.8	12.66096	4.32435	29.72709	5.662155	1.933908	13.29436
B6 unamended site B	57.22	53.92	66.98	2.277499	2.20159	4.350517	1.018528	0.984581	1.94561
C6 unamended site C	55.14	56.24	62.38	6.518666	4.646827	10.97802	2.915236	2.078124	4.909521
A7 gamma-irradiated unamended site a	266		313.8	17.50714		8.074652	7.829432		3.611094

Appendix J: Microcosm Soil Temperature Log

Table 18: Microcosm Temperature Data

Date	Number of days of incubation	Average Temp (degC)	Standard Deviation	Standard Error
5/1/2014	77	24.2	1.0	0.5
5/6/2014	82	19.8	1.9	0.9
5/11/2014	87	27.0	0.1	0.1
5/16/2014	92	26.9	0.7	0.3
5/23/2014	99	26.9	0.2	0.1
5/28/2014	104	26.1	0.4	0.2
6/3/2014	110	23.5	0.3	0.1
6/9/2014	116	24.7	0.3	0.1
6/16/2014	123	25.0	0.2	0.1
6/28/2014	135	26.2	0.6	0.3
6/30/2014	137	25.4	0.2	0.1
7/7/2014	144	25.6	0.5	0.2
7/14/2014	151	24.3	0.2	0.1
7/21/2014	158	26.3	0.4	0.2
7/28/2014	165	26.3	0.5	0.2
8/4/2014	172	26.3	0.5	0.2
8/14/2014	182	29.5	1.3	0.6
8/26/2014	194	31.6	0.7	0.3
9/1/2014	200	30.9	0.6	0.3
9/7/2014	206	31.5	0.7	0.3
9/15/2014	214	31.4	0.7	0.3
9/22/2014	221	31.2	0.7	0.3
9/29/2014	228	30.6	0.8	0.4
10/6/2014	235	30.8	0.9	0.4
10/13/2014	242	30.4	0.7	0.3

Appendix K: COI Concentrations, Standard Deviation, and Standard Error

Table 19: Individual compound concentration including standard deviation and error

Treatment		NUTR	SOLE	RICE	AUGM	COMB	STER	UNAA	UNAC	UNAB
Feb/0 days										
Chemical	Units	Mean Concentration								
1,2,3,4,6,7,8-HEPTACHLORODIBENZO-P-DIOXIN	ng/kg	10510	11740	9756	11382	10826	9078	9953	2798	2083
1,2,3,4,6,7,8-HPCDF	ng/kg	983	861	818	1249	979	815	870	176	255
1,2,3,4,7,8,9-HPCDF	ng/kg	84	76	72	88	68	69	75	10	19
1,2,3,4,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	83	83	74	92	79	75	81	5	16
1,2,3,4,7,8-HXCDF	ng/kg	25	22	22	31	24	22	24	3	10
1,2,3,6,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	478	484	429	523	441	430	444	61	80
1,2,3,6,7,8-HXCDF	ng/kg	31	25	25	55	44	24	26	3	9
1,2,3,7,8,9-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	189	190	169	205	173	169	178	14	34
1,2,3,7,8,9-HXCDF	ng/kg	7	6	6	8	2	4	3	0	3
1,2,3,7,8-PENTACHLORODIBENZOFURAN	ng/kg	8	8	8	9	7	7	8	1	3
1,2,3,7,8-PENTACHLORODIBENZO-P-DIOXIN	ng/kg	56	53	50	62	50	53	55	2	8
2,3,4,6,7,8-HXCDF	ng/kg	49	44	42	54	41	42	45	3	13
2,3,4,7,8-PECDF	ng/kg	12	10	10	13	10	10	11	1	7
2,3,7,8-TCDD	ng/kg	9	9	8	10	8	9	9	0	1
2,3,7,8-	ng/kg	3	2	2	3	2	2	2	1	4

TETRACHLORODIBENZOFURAN										
OCDD	ng/kg	84340	84080	75840	100420	85980	79280	84738	50860	22600
OCDF	ng/kg	2034	1854	1734	2112	1626	1714	1794	572	835
TCDD TEQ	ng/kg	297	303	267	332	286	266	288	55	57
1,1'-Biphenyl	UG/KG	0	0	0	0	0	0	0	0	62
1-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0	0	0	0	0
2-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0	0	0	0	138
ACENAPHTHENE	UG/KG	0	0	0	0	0	0	0	16	0
ACENAPHTHYLENE	ug/kg	0	0	8	0	0	0	0	0	151
ANTHRACENE	ug/kg	7	0	9	0	0	0	5	22	639
AZOBENZENE	UG/KG	0	0	0	0	0	0	0	0	0
BENZO(A)ANTHRACENE	ug/kg	39	21	20	0	0	19	27	38	1322
BENZO(A)PYRENE	ug/kg	38	24	48	12	0	38	37	44	4500
BENZO(B)FLUORANTHENE	ug/kg	66	55	69	35	0	67	69	54	6278
Benzo(e)pyrene	ug/kg	49	40	61	26	12	47	53	42	4356
BENZO(G,H,I)PERYLENE	ug/kg	27	18	58	34	0	38	35	20	7922
BENZO(K)FLUORANTHENE	ug/kg	16	0	7	0	0	6	0	18	1157
bis(2-Ethylhexyl)phthalate	ug/kg	0	0	0	0	0	0	0	0	0
Butylbenzylphthalate	ug/kg	0	0	0	0	0	0	0	0	0
Chrysene	ug/kg	68	40	57	0	0	43	53	50	2256
Di-n-butylphthalate	ug/kg	0	0	0	0	0	0	0	0	0
DIBENZO(A,H)ANTHRACENE	UG/KG	0	0	0	0	0	0	0	6	1211
Di-n-octylphthalate	ug/kg	0	0	0	0	0	0	0	0	0

FLUORANTHENE	ug/kg	129	86	144	49	62	102	110	96	2622
FLUORENE	UG/KG	0	0	0	0	0	0	0	10	84
INDENO(1,2,3-CD)PYRENE	ug/kg	17	0	25	0	0	8	6	17	7611
METHANAMINE, N-METHYL-N-NITROSO	UG/KG	0	0	0	0	0	0	0	0	111
NAPHTHALENE	UG/KG	0	0	0	0	0	0	0	0	203
PHENANTHRENE	ug/kg	55	47	92	16	0	61	38	100	2222
PYRENE	ug/kg	114	20	117	42	24	93	94	94	1678
Aroclor 1016	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1221	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1232	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1242	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1248	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1254	ug/kg	132	150	142	160	140	132	645	59	127
Aroclor 1260	ug/kg	97	108	110	110	103	112	328	37	111
Aroclor 1262	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1268	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5432	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5442	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5460	ug/kg	97	191	142	108	93	80	908	0	102

EFH (C12-C14)	MG/KG	0	21	0	0	1	0	1	0	1
EFH (C15-C20)	MG/KG	0	376	4	5	404	0	2	0	17
EFH (C21-C30)	mg/kg	94	1046	79	84	1414	55	79	49	133
EFH (C30-C40)	mg/kg	87	166	73	57	130	45	52	50	86
EFH (C8-C11)	MG/KG	0	14	0	0	1	0	1	0	1
Jun/126 days										
Chemical	Units	Mean Concentration								
1,2,3,4,6,7,8-HEPTACHLORODIBENZO-P-DIOXIN	ng/kg	9292	9774	9186	10120	9850	N/A	9571	2956	2171
1,2,3,4,6,7,8-HPCDF	ng/kg	781	790	789	821	850	N/A	828	167	252
1,2,3,4,7,8,9-HPCDF	ng/kg	70	70	68	71	72	N/A	72	12	19
1,2,3,4,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	72	73	69	73	70	N/A	74	5	16
1,2,3,4,7,8-HXCDF	ng/kg	21	21	21	22	23	N/A	22	2	10
1,2,3,6,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	411	427	402	406	427	N/A	432	60	82
1,2,3,6,7,8-HXCDF	ng/kg	23	23	23	23	25	N/A	25	2	8
1,2,3,7,8,9-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	169	172	158	172	167	N/A	176	13	35
1,2,3,7,8,9-HXCDF	ng/kg	5	7	3	4	4	N/A	2	0	0
1,2,3,7,8-PENTACHLORODIBENZOFURAN	ng/kg	7	7	7	7	7	N/A	7	0	3
1,2,3,7,8-PENTACHLORODIBENZO-P-DIOXIN	ng/kg	49	50	46	48	48	N/A	52	2	8
2,3,4,6,7,8-HXCDF	ng/kg	42	41	40	42	42	N/A	42	4	13

2,3,4,7,8-PECDF	ng/kg	8	10	9	9	9	N/A	9	1	7
2,3,7,8-TCDD	ng/kg	9	9	8	8	9	N/A	8	0	1
2,3,7,8-TETRACHLORODIBENZOFURAN	ng/kg	2	2	2	2	2	N/A	2	1	4
OCDD	ng/kg	66580	71080	76000	76500	74900	N/A	68871	50720	23129
OCDF	ng/kg	1688	1672	13584	1786	1864	N/A	1804	580	831
TCDD TEQ	ng/kg	247	264	534	266	262	N/A	264	56	56
1,1'-Biphenyl	UG/KG	0	0	0	0	0	N/A	0	0	48
1-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0	N/A	0	0	67
2-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0	N/A	0	0	103
ACENAPHTHENE	UG/KG	9	0	0	0	0	N/A	0	0	12
ACENAPHTHYLENE	ug/kg	0	3	0	0	0	N/A	0	0	129
ANTHRACENE	ug/kg	16	6	3	7	0	N/A	0	0	566
AZOBENZENE	UG/KG	0	0	0	0	0	N/A	0		0
BENZO(A)ANTHRACENE	ug/kg	46	27	24	8	30	N/A	23	16	1171
BENZO(A)PYRENE	ug/kg	49	29	36	26	36	N/A	33	6	3757
BENZO(B)FLUORANTHENE	ug/kg	75	59	58	45	60	N/A	58	17	5043
Benzo(e)pyrene	ug/kg	49	34	37	35	44	N/A	40	33	3514
BENZO(G,H,I)PERYLENE	ug/kg	36	29	36	33	28	N/A	35	15	7057
BENZO(K)FLUORANTHENE	ug/kg	13	13	11	5	15	N/A	10	3	1060
bis(2-Ethylhexyl)phthalate	ug/kg	0	0	0	0	0	N/A	0	0	0
Butylbenzylphthalate	ug/kg	0	0	0	0	0	N/A	0	0	0
Chrysene	ug/kg	68	60	46	36	55	N/A	45	11	1814
Di-n-butylphthalate	ug/kg	0	0	0	0	0	N/A	0	0	0

DIBENZO(A,H)ANTHRACENE	UG/KG	6	0	3	0	0	N/A	0	0	1229
Di-n-octylphthalate	ug/kg	0	0	0	0	0	N/A	0	0	0
FLUORANTHENE	ug/kg	129	116	93	69	87	N/A	76	14	2186
FLUORENE	UG/KG	6	0	0	0	0	N/A	0	0	22
INDENO(1,2,3-CD)PYRENE	ug/kg	16	23	24	20	19	N/A	23	5	7057
METHANAMINE, N-METHYL-N-NITROSO	UG/KG	0	0	0	0	0	N/A	0	0	0
NAPHTHALENE	UG/KG	0	0	0	0	0	N/A	0		177
PHENANTHRENE	ug/kg	91	55	38	38	39	N/A	31	7	1900
PYRENE	ug/kg	117	100	79	62	73	N/A	68	11	1414
Aroclor 1016	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1221	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1232	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1242	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1248	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1254	ug/kg	71	73	74	58	85	N/A	69	59	137
Aroclor 1260	ug/kg	128	116	120	118	126	N/A	121	38	143
Aroclor 1262	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1268	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 5432	UG/KG	0	0	0	0	0	N/A	0	0	0

Aroclor 5442	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 5460	ug/kg	87	89	92	58	81	N/A	70	0	112
EFH (C12-C14)	MG/KG	0	0	0	0	0	N/A	0	0	1
EFH (C15-C20)	MG/KG	0	5	2	1	7	N/A	0	0	21
EFH (C21-C30)	mg/kg	40	55	67	58	71	N/A	49	46	137
EFH (C30-C40)	mg/kg	109	109	68	54	78	N/A	42	59	73
EFH (C8-C11)	MG/KG	0	0	0	0	0	N/A	0	0	0
Oct/244 days										
Chemical	Unit of Measure	Mean Concentration								
1,2,3,4,6,7,8-HEPTACHLORODIBENZO-P-DIOXIN	ng/kg	13110	9340	10086	10182	12070	11180	11160	3288	2388
1,2,3,4,6,7,8-HPCDF	ng/kg	1269	852	879	878	864	926	893	163	268
1,2,3,4,7,8,9-HPCDF	ng/kg	100	73	73	77	79	83	81	11	20
1,2,3,4,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	90	77	75	81	83	95	90	6	18
1,2,3,4,7,8-HXCDF	ng/kg	28	22	24	23	23	25	81	2	12
1,2,3,6,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	593	446	461	459	499	489	490	70	90
1,2,3,6,7,8-HXCDF	ng/kg	31	24	26	25	26	27	27	2	9
1,2,3,7,8,9-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	214	181	178	182	197	209	197	15	38
1,2,3,7,8,9-HXCDF	ng/kg	6	0	0		0	0	0	2	0

1,2,3,7,8-PENTACHLORODIBENZOFURAN	ng/kg	10	8	9	8	7	8	7	1	4
1,2,3,7,8-PENTACHLORODIBENZO-P-DIOXIN	ng/kg	59	51	51	53	57	62	60	2	9
2,3,4,6,7,8-HXCDF	ng/kg	57	44	45	46	47	51	50	3	16
2,3,4,7,8-PECDF	ng/kg	12	9	10	10	10	11	11	1	8
2,3,7,8-TCDD	ng/kg	10	10	9	10	11	11	10	0	1
2,3,7,8-TETRACHLORODIBENZOFURAN	ng/kg	3	3	3	3	3	3	3	1	4
OCDD	ng/kg	108200	75060	79860	71480	82020	83840	81260	51200	26680
OCDF	ng/kg	2918	1848	1936	1898	1860	2016	1894	575	887
TCDD TEQ	ng/kg	469	269	276	282	314	314	309	62	67
1,1'-Biphenyl	UG/KG	0	0	0	0	0	0	0	0	0
1-METHYLNAPHTHALENE	UG/KG	4	2	3	2	5	3	4	0	600
2-METHYLNAPHTHALENE	UG/KG	9	10	8	9	9	9	10	0	782
ACENAPHTHENE	UG/KG	5	0	5	7	34	3	2	0	24
ACENAPHTHYLENE	ug/kg	3	1	7	0	7	2	2	0	148
ANTHRACENE	ug/kg	9	16	11	12	48	13	9	0	846
AZOBENZENE	UG/KG	0	0	0	0	0	0	0	0	0
BENZO(A)ANTHRACENE	ug/kg	21	126	38	42	96	54	29	3	1780
BENZO(A)PYRENE	ug/kg	19	87	34	40	82	49	27	0	3620
BENZO(B)FLUORANTHENE	ug/kg	47	142	66	70	127	86	58	6	5380
Benzo(e)pyrene	ug/kg	10	56	32	24	56	36	16	0	3320
BENZO(G,H,I)PERYLENE	ug/kg	12	42	19	20	51	33	17	6	2640
BENZO(K)FLUORANTHENE	ug/kg	21	57	25	28	58	32	24	0	1900

bis(2-Ethylhexyl)phthalate	ug/kg	92	79	73	51	137	56	75	20	430
Butylbenzylphthalate	ug/kg	0	0	15	0	0	15	0	0	0
Chrysene	ug/kg	59	165	83	72	144	97	73	15	2780
Di-n-butylphthalate	ug/kg	18	34	0	30	0	0	0	0	0
DIBENZO(A,H)ANTHRACENE	UG/KG	0	9	5	4	12	10	0	0	672
Di-n-octylphthalate	ug/kg	0	0	0	0	0	0	0	0	270
FLUORANTHENE	ug/kg	143	248	132	106	280	138	138	0	4540
FLUORENE	UG/KG	5	0	4	5	24	2	2	0	39
INDENO(1,2,3-CD)PYRENE	ug/kg	6	37	14	17	43	27	13	0	3500
METHANAMINE, N-METHYL-N-NITROSO	UG/KG	0	0	0	0	0	0	0	0	0
NAPHTHALENE	UG/KG	4	4	4	7	43	3	2	0	614
PHENANTHRENE	ug/kg	86	1848	75	73	229	77	74	0	4600
PYRENE	ug/kg	100	216	104	89	222	103	102	0	2100
Aroclor 1016	UG/KG	0	0	0	4	0	0	0	0	0
Aroclor 1221	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1232	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1242	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1248	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1254	ug/kg	65	70	63	77	77	70	78	75	29
Aroclor 1260	ug/kg	77	66	65	78	69	70	80	95	22
Aroclor 1262	UG/KG	0	0	0	0	0	0	0	0	0

Aroclor 1268	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5432	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5442	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5460	ug/kg	73	61	59	81	71	77	106	91	0
EFH (C12-C14)	MG/KG	0		0	0		0	0	0	0
EFH (C15-C20)	MG/KG	3		10	19		28	0	0	140
EFH (C21-C30)	mg/kg	108		132	164		174	128	144	560
EFH (C30-C40)	mg/kg	284		360	372		420	372	414	888
EFH (C8-C11)	MG/KG	0		0	0		0	0	0	0
Feb/0 days										
Chemical	Unit of Measure	Standard Deviation								
1,2,3,4,6,7,8-HEPTACHLORODIBENZO-P-DIOXIN	ng/kg	1377	1422	1509	5018	2227	818	797	312	73
1,2,3,4,6,7,8-HPCDF	ng/kg	189	65	37	589	376	18	47	36	13
1,2,3,4,7,8,9-HPCDF	ng/kg	14	5	5	36	5	2	5	1	1
1,2,3,4,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	6	10	4	35	9	3	7	1	0
1,2,3,4,7,8-HXCDF	ng/kg	3	2	2	12	6	1	2	0	0
1,2,3,6,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	54	52	19	219	56	15	27	6	3

1,2,3,6,7,8-HXCDF	ng/kg	8	3	2	50	40	1	3	2	1
1,2,3,7,8,9-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	12	24	7	83	20	2	13	2	1
1,2,3,7,8,9-HXCDF	ng/kg	1	1	1	3	3	3	3	1	2
1,2,3,7,8-PENTACHLORODIBENZOFURAN	ng/kg	1	0	1	4	2	1	1	0	0
1,2,3,7,8-PENTACHLORODIBENZO-P-DIOXIN	ng/kg	2	2	2	26	5	2	4	0	0
2,3,4,6,7,8-HXCDF	ng/kg	6	3	2	21	2	1	4	0	0
2,3,4,7,8-PECDF	ng/kg	0	1	0	5	1	1	1	0	0
2,3,7,8-TCDD	ng/kg	0	0	1	5	1	0	0	0	0
2,3,7,8-TETRACHLORODIBENZOFURAN	ng/kg	0	0	0	1	0	0	0	0	0
OCDD	ng/kg	9825	5465	5226	44883	11854	17348	6611	7244	1384
OCDF	ng/kg	428	104	119	838	133	24	92	56	53
TCDD TEQ	ng/kg	28	27	18	137	33	18	13	2	7
1,1'-Biphenyl	UG/KG	0	0	0	0	0	0	0	0	4
1-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0	0	0	0	0
2-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0	0	0	0	22
ACENAPHTHENE	UG/KG	0	0	0	0	0	0	0	36	0
ACENAPHTHYLENE	ug/kg	0	0	18	0	0	0	0	0	9
ANTHRACENE	ug/kg	10	0	13	0	0	0	14	49	48
AZOBENZENE	UG/KG	0	0	0	0	0	0	0	0	0
BENZO(A)ANTHRACENE	ug/kg	12	28	19	0	0	29	25	85	120
BENZO(A)PYRENE	ug/kg	11	24	19	17	0	29	27	98	255

BENZO(B)FLUORANTHENE	ug/kg	22	22	21	4	0	31	27	121	507
Benzo(e)pyrene	ug/kg	10	12	35	15	28	14	17	57	251
BENZO(G,H,I)PERYLENE	ug/kg	4	17	31	4	0	10	17	44	1190
BENZO(K)FLUORANTHENE	ug/kg	5	0	10	0	0	13	0	39	138
bis(2-Ethylhexyl)phthalate	ug/kg	0	0	0	0	0	0	0	0	0
Butylbenzylphthalate	ug/kg	0	0	0	0	0	0	0	0	0
Chrysene	ug/kg	33	15	38	0	0	35	34	112	321
Di-n-butylphthalate	ug/kg	0	0	0	0	0	0	0	0	0
DIBENZO(A,H)ANTHRACENE	ug/kg	0	0	0	0	0	0	0	14	154
Di-n-octylphthalate	ug/kg	0	0	0	0	0	0	0	0	0
FLUORANTHENE	ug/kg	60	30	99	10	4	67	88	215	156
FLUORENE	ug/kg	0	0	0	0	0	0	0	21	41
INDENO(1,2,3-CD)PYRENE	ug/kg	5	0	16	0	0	18	16	38	918
METHANAMINE, N-METHYL-N-NITROSO	ug/kg	0	0	0	0	0	0	0	0	3
NAPHTHALENE	ug/kg	0	0	0	0	0	0	0	0	19
PHENANTHRENE	ug/kg	34	23	106	22	0	61	62	224	199
PYRENE	ug/kg	55	44	60	8	33	66	73	210	97
Aroclor 1016	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1221	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1232	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1242	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1248	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1254	ug/kg	23	16	15	64	12	15	1358	5	12

Aroclor 1260	ug/kg	11	9	7	26	6	14	596	3	8
Aroclor 1262	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1268	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5432	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5442	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5460	ug/kg	52	201	86	41	11	4	2300	0	46
EFH (C12-C14)	MG/KG	0	5	0	0	2	0	2	0	2
EFH (C15-C20)	MG/KG	0	53	0	1	71	0	4	0	2
EFH (C21-C30)	mg/kg	43	140	5	16	252	6	22	16	15
EFH (C30-C40)	mg/kg	11	5	20	11	16	7	20	14	10
EFH (C8-C11)	MG/KG	0	3	0	0	2	0	2	0	2
Jun/126 days										
Chemical	Unit of Measure	Standard Deviation								
1,2,3,4,6,7,8-HEPTACHLORODIBENZO-P-DIOXIN	ng/kg	436	1516	373	2046	783	N/A	344	237	262
1,2,3,4,6,7,8-HPCDF	ng/kg	30	46	20	66	91	N/A	34	12	18
1,2,3,4,7,8,9-HPCDF	ng/kg	3	4	2	8	9	N/A	4	2	1
1,2,3,4,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	5	6	4	7	9	N/A	3	0	1

1,2,3,4,7,8-HXCDF	ng/kg	1	3	1	1	2	N/A	1	0	1
1,2,3,6,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	11	19	18	31	37	N/A	10	2	4
1,2,3,6,7,8-HXCDF	ng/kg	1	3	2	1	4	N/A	2	0	1
1,2,3,7,8,9-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	6	15	7	15	14	N/A	5	1	2
1,2,3,7,8,9-HXCDF	ng/kg	3	1	4	4	4	N/A	3	0	1
1,2,3,7,8-PENTACHLORODIBENZOFURAN	ng/kg	1	1	1	1	1	N/A	1	0	1
1,2,3,7,8-PENTACHLORODIBENZO-P-DIOXIN	ng/kg	3	1	4	2	3	N/A	3	0	4
2,3,4,6,7,8-HXCDF	ng/kg	1	2	2	2	4	N/A	2	0	1
2,3,4,7,8-PECDF	ng/kg	2	1	1	1	1	N/A	1	0	1
2,3,7,8-TCDD	ng/kg	2	2	1	0	1	N/A	1	0	0
2,3,7,8-TETRACHLORODIBENZOFURAN	ng/kg	0	0	0	0	1	N/A	0	0	0
OCDD	ng/kg	3454	13006	21351	18368	12520	N/A	1632	6003	2859
OCDF	ng/kg	40	50	26618	149	203	N/A	132	34	64
TCDD TEQ	ng/kg	20	27	635	34	19	N/A	5	5	5
1,1'-Biphenyl	UG/KG	0	0	0	0	0	N/A	0	0	4
1-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0	N/A	0	0	5
2-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0	N/A	0	0	8
ACENAPHTHENE	UG/KG	21	0	0	0	0	N/A	0	0	6
ACENAPHTHYLENE	ug/kg	0	7	0	0	0	N/A	0	0	11
ANTHRACENE	ug/kg	31	9	7	10	0	N/A	0	0	48
AZOBENZENE	UG/KG	0	0	0	0	0	N/A	0	0	0

BENZO(A)ANTHRACENE	ug/kg	64	25	27	11	29	N/A	15	12	111
BENZO(A)PYRENE	ug/kg	56	10	24	8	23	N/A	13	14	270
BENZO(B)FLUORANTHENE	ug/kg	70	22	29	7	40	N/A	16	22	486
Benzo(e)pyrene	ug/kg	30	7	17	7	19	N/A	11	16	248
BENZO(G,H,I)PERYLENE	ug/kg	29	5	16	4	11	N/A	9	10	577
BENZO(K)FLUORANTHENE	ug/kg	23	8	12	7	18	N/A	10	6	92
bis(2-Ethylhexyl)phthalate	ug/kg	0	0	0	0	0	N/A	0	0	0
Butylbenzylphthalate	ug/kg	0	0	0	0	0	N/A	0	0	0
Chrysene	ug/kg	69	23	25	10	26	N/A	16	25	135
Di-n-butylphthalate	ug/kg	0	0	0	0	0	N/A	0	0	0
DIBENZO(A,H)ANTHRACENE	ug/kg	10	0	7	0	0	N/A	0	0	138
Di-n-octylphthalate	ug/kg	0	0	0	0	0	N/A	0	0	0
FLUORANTHENE	ug/kg	158	42	49	22	48	N/A	26	32	168
FLUORENE	UG/KG	13	0	0	0	0	N/A	0	0	3
INDENO(1,2,3-CD)PYRENE	ug/kg	29	6	12	3	15	N/A	8	11	326
METHANAMINE, N-METHYL-N-NITROSO	UG/KG	0	0	0	0	0	N/A	0	0	0
NAPHTHALENE	UG/KG	0	0	0	0	0	N/A	0		6
PHENANTHRENE	ug/kg	139	20	19	23	25	N/A	9	15	153
PYRENE	ug/kg	142	34	45	20	39	N/A	23	25	135
Aroclor 1016	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1221	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1232	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1242	UG/KG	0	0	0	0	0	N/A	0	0	0

Aroclor 1248	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1254	ug/kg	19	6	28	8	12	N/A	12	4	23
Aroclor 1260	ug/kg	8	13	7	4	11	N/A	7	2	13
Aroclor 1262	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 1268	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 5432	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 5442	UG/KG	0	0	0	0	0	N/A	0	0	0
Aroclor 5460	ug/kg	59	47	72	3	29	N/A	20	0	17
EFH (C12-C14)	MG/KG	0	0	0	0	0	N/A	0	0	2
EFH (C15-C20)	MG/KG	0	7	3	1	4	N/A	0	0	2
EFH (C21-C30)	mg/kg	12	10	22	14	7	N/A	5	10	14
EFH (C30-C40)	mg/kg	42	38	21	12	25	N/A	8	18	15
EFH (C8-C11)	MG/KG	0	0	0	0	0	N/A	0	0	1
Oct/244 days										
Chemical	Unit of Measure	Standard Deviation								
1,2,3,4,6,7,8-HEPTACHLORODIBENZO-P-DIOXIN	ng/kg	6077	758	1718	665	2901	554	1078	569	229
1,2,3,4,6,7,8-HPCDF	ng/kg	827	22	113	78	19	29	48	27	15

1,2,3,4,7,8,9-HPCDF	ng/kg	54	1	8	4	2	4	4	1	1
1,2,3,4,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	22	1	6	3	2	2	8	1	1
1,2,3,4,7,8-HXCDF	ng/kg	11	1	3	2	1	2	4	0	3
1,2,3,6,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	257	23	51	24	59	10	38	9	5
1,2,3,6,7,8-HXCDF	ng/kg	12	1	2	1	1	1	1	0	1
1,2,3,7,8,9-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	54	4	13	5	19	4	12	2	2
1,2,3,7,8,9-HXCDF	ng/kg	5	0	0	0	0	0	0	2	0
1,2,3,7,8-PENTACHLORODIBENZOFURAN	ng/kg	3	1	1	1	1	1	1	0	1
1,2,3,7,8-PENTACHLORODIBENZO-P-DIOXIN	ng/kg	11	1	3	2	2	1	6	0	1
2,3,4,6,7,8-HXCDF	ng/kg	27	2	4	3	0	2	3	0	1
2,3,4,7,8-PECDF	ng/kg	5	2	2	0	0	1	1	0	2
2,3,7,8-TCDD	ng/kg	2	1	1	1	1	1	2	0	0
2,3,7,8-TETRACHLORODIBENZOFURAN	ng/kg	1	0	0	0	0	0	1	0	0
OCDD		48267	4678	9008	13162	14696	6723	18256	11601	2100
OCDF	ng/kg	2154	66	338	240	64	105	73	97	65
TCDD TEQ	ng/kg	270	10	28	11	41	8	30	11	4
1,1'-Biphenyl	UG/KG	0	0	0	0	0	0	0	0	0
1-METHYLNAPHTHALENE	UG/KG	8	4	6	4	10	4	5	0	60
2-METHYLNAPHTHALENE	UG/KG	9	3	9	5	10	1	6	0	77
ACENAPHTHENE	UG/KG	11	0	7	15	76	8	5	0	3
ACENAPHTHYLENE	ug/kg	8	2	7	0	3	3	5	0	16

ANTHRACENE	ug/kg	11	18	9	9	85	10	4	0	88
AZOBENZENE	UG/KG	0	0	0	0	0	0	0	0	0
BENZO(A)ANTHRACENE	ug/kg	13	209	24	27	148	34	11	8	259
BENZO(A)PYRENE	ug/kg	7	131	19	25	128	30	9	0	614
BENZO(B)FLUORANTHENE	ug/kg	29	195	34	34	154	40	12	5	858
Benzo(e)pyrene	ug/kg	21	83	33	34	74	38	22	0	432
BENZO(G,H,I)PERYLENE	ug/kg	3	50	7	10	67	18	3	6	288
BENZO(K)FLUORANTHENE	ug/kg	16	81	13	15	75	16	6	0	255
bis(2-Ethylhexyl)phthalate	ug/kg	87	48	42	47	261	53	44	45	207
Butylbenzylphthalate	ug/kg	0	0	34	0	0	33	0	0	0
Chrysene	ug/kg	51	232	57	33	148	40	20	3	460
Di-n-butylphthalate	ug/kg	41	76	0	67	0	0	0	0	0
DIBENZO(A,H)ANTHRACENE	ug/kg	0	21	5	6	22	8	0	0	81
Di-n-octylphthalate	ug/kg	0	0	0	0	0	0	0	0	48
FLUORANTHENE	ug/kg	217	371	90	60	325	64	85	0	662
FLUORENE	ug/kg	11	0	5	12	54	5	5	0	5
INDENO(1,2,3-CD)PYRENE	ug/kg	5	52	6	11	65	16	3	0	367
METHANAMINE, N-METHYL-N-NITROSO	UG/KG	0	0	0	0	0	0	0	0	0
NAPHTHALENE	UG/KG	6	5	5	4	65	4	4	0	50
PHENANTHRENE	ug/kg	142	66	71	68	359	40	53	0	534
PYRENE	ug/kg	145	339	72	55	273	45	59	0	255
Aroclor 1016	UG/KG	0	0	0	9	0	0	0	0	0
Aroclor 1221	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1232	UG/	0	0	0	0	0	0	0	0	0

	KG									
Aroclor 1242	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1248	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1254	ug/kg	15	15	22	13	35	7	11	31	2
Aroclor 1260	ug/kg	8	16	12	4	6	5	9	11	2
Aroclor 1262	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1268	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5432	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5442	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5460	ug/kg	23	7	10	12	9	25	30	53	0
EFH (C12-C14)	MG/KG	0		0	0		0	0	0	0
EFH (C15-C20)	MG/KG	6		10	29		4	0	0	22
EFH (C21-C30)	mg/kg	28		8	54		11	22	15	60
EFH (C30-C40)	mg/kg	89		16	139		34	58	40	108
EFH (C8-C11)	MG/KG	0		0	0		0	0	0	0
Feb/0 days										
Chemical	Unit of Measure	Standard Error of the Mean								
1,2,3,4,6,7,8-	ng/kg	616	636	675	2244	996	366	356	140	32

HEPTACHLORODIBENZO-P-DIOXIN										
1,2,3,4,6,7,8-HPCDF	ng/kg	85	29	17	263	168	8	21	16	6
1,2,3,4,7,8,9-HPCDF	ng/kg	6	2	2	16	2	1	2	0	0
1,2,3,4,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	3	5	2	16	4	1	3	0	0
1,2,3,4,7,8-HXCDF	ng/kg	1	1	1	5	3	0	1	0	0
1,2,3,6,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	24	23	9	98	25	7	12	3	1
1,2,3,6,7,8-HXCDF	ng/kg	3	1	1	22	18	1	1	1	1
1,2,3,7,8,9-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	5	11	3	37	9	1	6	1	0
1,2,3,7,8,9-HXCDF	ng/kg	0	0	0	1	1	1	1	0	1
1,2,3,7,8-PENTACHLORODIBENZOFURAN	ng/kg	0	0	1	2	1	0	0	0	0
1,2,3,7,8-PENTACHLORODIBENZO-P-DIOXIN	ng/kg	1	1	1	11	2	1	2	0	0
2,3,4,6,7,8-HXCDF	ng/kg	3	1	1	9	1	0	2	0	0
2,3,4,7,8-PECDF	ng/kg	0	0	0	2	0	0	1	0	0
2,3,7,8-TCDD	ng/kg	0	0	0	2	0	0	0	0	0
2,3,7,8-TETRACHLORODIBENZOFURAN	ng/kg	0	0	0	1	0	0	0	0	0
OCDD		4394	2444	2337	20072	5301	7758	2956	3240	619
OCDF	ng/kg	191	46	53	375	59	11	41	25	24
TCDD TEQ	ng/kg	13	12	8	61	15	8	6	3	1
1,1'-Biphenyl	UG/KG	0	0	0	0	0	0	0	0	2
1-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0	0	0	0	0
2-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0	0	0	0	10

ACENAPHTHENE	UG/KG	0	0	0	0	0	0	0	16	0
ACENAPHTHYLENE	ug/kg	0	0	8	0	0	0	0	0	4
ANTHRACENE	ug/kg	4	0	6	0	0	0	6	22	21
AZOBENZENE	UG/KG	0	0	0	0	0	0	0	0	0
BENZO(A)ANTHRACENE	ug/kg	5	13	9	0	0	13	11	38	54
BENZO(A)PYRENE	ug/kg	5	11	8	7	0	13	12	44	114
BENZO(B)FLUORANTHENE	ug/kg	10	10	9	2	0	14	12	54	227
Benzo(e)pyrene	ug/kg	4	5	16	7	12	6	8	26	112
BENZO(G,H,I)PERYLENE	ug/kg	2	8	14	2	0	5	8	20	532
BENZO(K)FLUORANTHENE	ug/kg	2	0	4	0	0	6	0	18	62
bis(2-Ethylhexyl)phthalate	ug/kg	0	0	0	0	0	0	0	0	0
Butylbenzylphthalate	ug/kg	0	0	0	0	0	0	0	0	0
Chrysene	ug/kg	15	7	17	0	0	16	15	50	143
Di-n-butylphthalate	ug/kg	0	0	0	0	0	0	0	0	0
DIBENZO(A,H)ANTHRACENE	ug/kg	0	0	0	0	0	0	0	6	69
Di-n-octylphthalate	ug/kg	0	0	0	0	0	0	0	0	0
FLUORANTHENE	ug/kg	27	14	44	5	2	30	39	96	70
FLUORENE	ug/kg	0	0	0	0	0	0	0	10	18
INDENO(1,2,3-CD)PYRENE	ug/kg	2	0	7	0	0	8	7	17	411
METHANAMINE, N-METHYL-N-NITROSO	UG/KG	0	0	0	0	0	0	0	0	1
NAPHTHALENE	UG/KG	0	0	0	0	0	0	0	0	9
PHENANTHRENE	ug/kg	15	10	47	10	0	27	28	100	89
PYRENE	ug/kg	24	20	27	3	15	29	33	94	43
Aroclor 1016	UG/KG	0	0	0	0	0	0	0	0	0

Aroclor 1221	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1232	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1242	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1248	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1254	ug/kg	10	7	7	29	5	7	607	2	5
Aroclor 1260	ug/kg	5	4	3	12	3	6	266	1	3
Aroclor 1262	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1268	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5432	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5442	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5460	ug/kg	23	90	38	18	5	2	1029	0	21
EFH (C12-C14)	MG/KG	0	2	0	0	1	0	1	0	1
EFH (C15-C20)	MG/KG	0	24	0	1	32	0	2	0	1
EFH (C21-C30)	mg/kg	19	63	2	7	113	3	10	7	7
EFH (C30-C40)	mg/kg	5	2	9	5	7	3	9	6	5
EFH (C8-C11)	MG/KG	0	1	0	0	1	0	1	0	1
Jun/126 days										
Chemical	Unit of	Standard Error								

	Measure	of the Mean								
1,2,3,4,6,7,8-HEPTACHLORODIBENZO-P-DIOXIN	ng/kg	195	678	167	915	350		130	106	99
1,2,3,4,6,7,8-HPCDF	ng/kg	14	21	9	29	41		13	5	7
1,2,3,4,7,8,9-HPCDF	ng/kg	1	2	1	4	4		1	1	0
1,2,3,4,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	2	3	2	3	4		1	0	0
1,2,3,4,7,8-HXCDF	ng/kg	1	1	1	0	1		0	0	0
1,2,3,6,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	5	9	8	14	17		4	1	1
1,2,3,6,7,8-HXCDF	ng/kg	0	1	1	0	2		1	0	0
1,2,3,7,8,9-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	2	7	3	7	6		2	0	1
1,2,3,7,8,9-HXCDF	ng/kg	1	1	2	2	2		1	0	0
1,2,3,7,8-PENTACHLORODIBENZOFURAN	ng/kg	0	0	0	0	0		0	0	0
1,2,3,7,8-PENTACHLORODIBENZO-P-DIOXIN	ng/kg	1	1	2	1	1		1	0	1
2,3,4,6,7,8-HXCDF	ng/kg	0	1	1	1	2		1	0	0
2,3,4,7,8-PECDF	ng/kg	1	1	0	0	0		1	0	0
2,3,7,8-TCDD	ng/kg	1	1	0	0	1		0	0	0
2,3,7,8-TETRACHLORODIBENZOFURAN	ng/kg	0	0	0	0	1		0	0	0
OCDD	ng/kg	1545	5817	9548	8214	5599		617	2685	1081
OCDF	ng/kg	18	22	11904	67	91		50	15	24
TCDD TEQ	ng/kg	9	12	284	15	8		2	2	2
1,1'-Biphenyl	UG/KG	0	0	0	0	0		0	0	1

1-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0		0	0	2
2-METHYLNAPHTHALENE	UG/KG	0	0	0	0	0		0	0	3
ACENAPHTHENE	UG/KG	9	0	0	0	0		0	0	2
ACENAPHTHYLENE	ug/kg	0	3	0	0	0		0	0	4
ANTHRACENE	ug/kg	14	4	3	5	0		0	0	18
AZOBENZENE	UG/KG	0	0	0	0	0		0	0	0
BENZO(A)ANTHRACENE	ug/kg	29	11	12	5	13		5	5	42
BENZO(A)PYRENE	ug/kg	25	4	11	3	10		5	6	102
BENZO(B)FLUORANTHENE	ug/kg	31	10	13	3	18		6	10	184
Benzo(e)pyrene	ug/kg	13	3	8	3	8		4	7	94
BENZO(G,H,I)PERYLENE	ug/kg	13	2	7	2	5		4	5	218
BENZO(K)FLUORANTHENE	ug/kg	10	4	5	3	8		4	3	35
bis(2-Ethylhexyl)phthalate	ug/kg	0	0	0	0	0		0	0	0
Butylbenzylphthalate	ug/kg	0	0	0	0	0		0	0	0
Chrysene	ug/kg	31	11	11	4	12		6	11	51
Di-n-butylphthalate	ug/kg	0	0	0	0	0		0	0	0
DIBENZO(A,H)ANTHRACENE	ug/kg	4	0	3	0	0		0	0	52
Di-n-octylphthalate	ug/kg	0	0	0	0	0		0	0	0
FLUORANTHENE	ug/kg	71	19	22	10	21		10	14	63
FLUORENE	ug/kg	6	0	0	0	0		0	0	1
INDENO(1,2,3-CD)PYRENE	ug/kg	13	3	6	2	7		3	5	123
METHANAMINE, N-METHYL-N-NITROSO	UG/KG	0	0	0	0	0		0	0	0
NAPHTHALENE	UG/KG	0	0	0	0	0		0		3

PHENANTHRENE	ug/kg	62	9	9	10	11		3	7	58
PYRENE	ug/kg	64	15	20	9	17		9	11	51
Aroclor 1016	UG/KG	0	0	0	0	0		0	0	0
Aroclor 1221	UG/KG	0	0	0	0	0		0	0	0
Aroclor 1232	UG/KG	0	0	0	0	0		0	0	0
Aroclor 1242	UG/KG	0	0	0	0	0		0	0	0
Aroclor 1248	UG/KG	0	0	0	0	0		0	0	0
Aroclor 1254	ug/kg	8	3	13	4	5		5	2	9
Aroclor 1260	ug/kg	4	6	3	2	5		607	1	5
Aroclor 1262	UG/KG	0	0	0	0	0		0	0	0
Aroclor 1268	UG/KG	0	0	0	0	0		0	0	0
Aroclor 5432	UG/KG	0	0	0	0	0		0	0	0
Aroclor 5442	UG/KG	0	0	0	0	0		0	0	0
Aroclor 5460	ug/kg	26	21	32	1	13		7	0	7
EFH (C12-C14)	MG/KG	0	0	0	0	0		0	0	1
EFH (C15-C20)	MG/KG	0	3	1	1	2		0	0	1
EFH (C21-C30)	mg/kg	5	4	10	6	3		2	4	5
EFH (C30-C40)	mg/kg	19	17	9	6	11		3	8	6
EFH (C8-C11)	MG/	0	0	0	0	0		0	0	0

	KG									
Oct/244 days										
Chemical	Unit of Measure	Standard Error of the Mean								
1,2,3,4,6,7,8-HEPTACHLORODIBENZO-P-DIOXIN	ng/kg	2718	339	768	297	1297	248	482	255	103
1,2,3,4,6,7,8-HPCDF	ng/kg	370	10	51	35	8	13	22	12	7
1,2,3,4,7,8,9-HPCDF	ng/kg	24	1	3	2	1	2	2	1	0
1,2,3,4,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	10	1	3	2	1	1	3	0	0
1,2,3,4,7,8-HXCDF	ng/kg	5	0	1	1	0	1	2	1	1
1,2,3,6,7,8-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	115	10	23	11	26	5	17	4	2
1,2,3,6,7,8-HXCDF	ng/kg	5	0	1	1	1	0	0	0	0
1,2,3,7,8,9-HEXACHLORODIBENZO-P-DIOXIN	ng/kg	24	2	6	2	8	2	6	1	1
1,2,3,7,8,9-HXCDF	ng/kg	2	0	0	0	0	0	0	1	0
1,2,3,7,8-PENTACHLORODIBENZOFURAN	ng/kg	1	0	0	1	0	0	0	0	0
1,2,3,7,8-PENTACHLORODIBENZO-P-DIOXIN	ng/kg	5	1	1	1	1	1	3	0	0
2,3,4,6,7,8-HXCDF	ng/kg	12	1	2	1	0	1	2	0	0
2,3,4,7,8-PECDF	ng/kg	2	1	1	0	0	0	0	0	1
2,3,7,8-TCDD	ng/kg	1	0	0	1	0	0	1	0	0
2,3,7,8-TETRACHLORODIBENZOFURAN	ng/kg	0	0	0	0	0	0	0	0	0
OCDD	ng/kg	21586	2092	4029	5886	6572	3006	8164	5188	939

OCDF	ng/kg	963	30	151	107	29	47	33	43	29
TCDD TEQ	ng/kg	121	4	12	5	18	4	13	5	2
1,1'-Biphenyl	UG/KG	0	0	0	0	0	0	0	0	0
1-METHYLNAPHTHALENE	UG/KG	4	2	3	2	5	2	2	0	27
2-METHYLNAPHTHALENE	UG/KG	4	1	4	2	4	1	3	0	35
ACENAPHTHENE	UG/KG	5	0	3	7	34	3	2	0	1
ACENAPHTHYLENE	ug/kg	3	1	3	0	1	2	2	0	7
ANTHRACENE	ug/kg	5	8	4	4	38	4	2	0	40
AZOBENZENE	UG/KG	0	0	0	0	0	0	0	0	0
BENZO(A)ANTHRACENE	ug/kg	6	94	11	12	66	15	5	3	116
BENZO(A)PYRENE	ug/kg	3	58	8	11	57	13	4	0	275
BENZO(B)FLUORANTHENE	ug/kg	13	87	15	15	69	18	5	2	384
Benzo(e)pyrene	ug/kg	10	37	15	15	33	17	10	0	193
BENZO(G,H,I)PERYLENE	ug/kg	1	22	3	5	30	8	1	3	129
BENZO(K)FLUORANTHENE	ug/kg	7	36	6	7	33	7	3	0	114
bis(2-Ethylhexyl)phthalate	ug/kg	39	22	19	21	117	24	20	20	93
Butylbenzylphthalate	ug/kg	0	0	15	0	0	15	0	0	0
Chrysene	ug/kg	23	104	25	15	66	18	9	1	206
Di-n-butylphthalate	ug/kg	18	34	0	30	0	0	0	0	0
DIBENZO(A,H)ANTHRACENE	ug/kg	0	9	2	3	10	4	0	0	36
Di-n-octylphthalate	ug/kg	0	0	0	0	0	0	0	0	22
FLUORANTHENE	ug/kg	97	166	40	27	145	29	38	0	296
FLUORENE	ug/kg	5	0	2	5	24	2	2	0	2
INDENO(1,2,3-CD)PYRENE	ug/kg	2	23	3	5	29	7	1	0	164

METHANAMINE, N-METHYL-N-NITROSO	UG/KG	0	0	0	0	0	0	0	0	0
NAPHTHALENE	UG/KG	3	2	2	2	29	2	2	0	22
PHENANTHRENE	ug/kg	64	30	32	30	161	18	24	0	239
PYRENE	ug/kg	65	152	32	24	122	20	26	0	114
Aroclor 1016	UG/KG	0	0	0	4	0	0	0	0	0
Aroclor 1221	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1232	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1242	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1248	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1254	ug/kg	7	7	10	6	16	3	5	14	1
Aroclor 1260	ug/kg	4	7	5	2	3	2	4	5	1
Aroclor 1262	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 1268	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5432	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5442	UG/KG	0	0	0	0	0	0	0	0	0
Aroclor 5460	ug/kg	10	3	4	5	4	11	14	24	0
EFH (C12-C14)	MG/KG	0	N/A	0	0	N/A	0	0	0	0
EFH (C15-C20)	MG/KG	3	N/A	4	13	N/A	2	0	0	10
EFH (C21-C30)	mg/k	12	N/A	4	24	N/A	5	10	7	27

	g									
EFH (C30-C40)	mg/kg	40	N/A	7	62	N/A	15	26	18	48
EFH (C8-C11)	MG/KG	0	N/A	0	0	N/A	0	0	0	0

Table 20: Total EFH concentration in microcosms during incubation

	Time	NUTR	SOLE	RICE	AUGM	COMB	UNAA	UNAB	UNAC	STER
Average (mg/kg)	Feb/0 days	182	1640	154	146	1980	152	230	100	101
	Jun/126 days	152	172	137	113	156	89	226	105	N/A
	Oct/244 days	152	N/A	502	556	N/A	502	1589	558	628
Standard Deviation (mg/kg)	Feb/0 days	51	219	21	23	327	55	12	29	9
	Jun/126 days	54	54	46	27	32	12	30	26	N/A
	Oct/244 days	119	N/A	502	556	N/A	79	188	54	42
Standard Error (mg/kg)	Feb/0 days	23	98	9	10	146	25	5	13	4
	Jun/126 days	24	24	20	12	14	5	14	12	N/A
	Oct/244 days	53	N/A	225	248	N/A	35	84	24	19

Table 21: Total PAH concentration in microcosms during incubation

	Time	NUTR	SOLE	RICE	AUGM	COMB	UNAA	UNAB	UNAC	STER
Average (µg/kg)	Feb/0 days	626	350	714	214	87	467	45139	626	523
	Jun/126 days	727	538	489	382	485	429	39238	153	N/A
	Oct/244 days	673	1390	759	710	1672	684	40585	50	943
Standard Deviation (µg/kg)	Feb/0 days	228	191	414	34	56	297	3441	1361	364
	Jun/126 days	882	195	282	113	282	158	1746	211	N/A
	Oct/244 days	714	1812	372	479	2014	224	5198	50	289
Standard Error (µg/kg)	Feb/0 days	102	85	185	15	25	133	1539	609	163
	Jun/126 days	394	87	126	50	126	71	781	94	N/A
	Oct/244 days	319	810	166	214	901	100	2325	23	129

Table 22: Aroclor 1260, 5460, and 1254 concentrations in microcosms during incubation

AROCLOR 1260		NUTR	SOLE	RICE	AUGM	COMB	UNAA	UNAB	UNAC	STER
	Feb/0 days	97	108	110	110	103	328	111	37	112
	Jun/126 days	128	116	120	118	126	121	143	38	N/A
Average (µg/kg)	Oct/244 days	77	66	65	78	69	80	22	95	70
	Feb/0 days	11	9	7	26	6	596	8	3	14
	Jun/126 days	8	13	7	4	11	7	13	2	N/A
Standard Deviation (µg/kg)	Oct/244 days	8	16	12	4	6	9	2	11	5
	Feb/0 days	5	4	3	12	3	266	3	1	6
	Jun/126 days	4	6	3	2	5	607	5	1	N/A
Standard Error (µg/kg)	Oct/244 days	4	7	5	2	3	4	1	5	2
AROCLOR 5460		NUTR	SOLE	RICE	AUGM	COMB	UNAA	UNAB	UNAC	STER
	Feb/0 days	97	191	142	108	93	908	102	0	80
	Jun/126 days	87	89	92	58	81	70	112	0	N/A
Average (µg/kg)	Oct/244 days	73	61	59	81	71	106	0	91	77
	Feb/0 days	52	201	86	41	11	2300	46	0	4
	Jun/126 days	59	47	72	3	29	20	17	0	
Standard Deviation (µg/kg)	Oct/244 days	23	7	10	12	9	30	0	53	25
	Feb/0 days	23	90	38	18	5	1029	21	0	2
	Jun/126 days	26	21	32	1	13	7	7	0	
Standard Error (µg/kg)	Oct/244 days	10	3	4	5	4	14	0	24	11

AROCLOR 1254		NUTR	SOLE	RICE	AUGM	COMB	UNAA	UNAB	UNAC	STER
Average (µg/kg)	Feb/0 days	132	150	142	160	140	645	127	59	132
	Jun/126 days	71	73	74	58	85	69	137	59	
	Oct/244 days	65	70	63	77	77	78	29	75	70
Standard Deviation (µg/kg)	Feb/0 days	23	16	15	64	12	1358	12	5	15
	Jun/126 days	19	6	28	8	12	12	23	4	
	Oct/244 days	15	15	22	13	35	11	2	31	7
Standard Error (µg/kg)	Feb/0 days	10	7	7	29	5	607	5	2	7
	Jun/126 days	8	3	13	4	5	5	9	2	
	Oct/244 days	7	7	10	6	16	5	1	14	3

Table 23: Total dioxin concentration in microcosms during incubation

	Time	NUTR	SOLE	RICE	AUGM	COMB	UNAA	UNAB	UNAC	STER
Average (ng/kg)	Feb/0 days	98898	99547	89064	116316	100358	99432	26581	54509	91803
	Jun/126 days	79230	84227	85548	90113	88368	81967	26041	54526	N/A
	Oct/244 days	126710	88048	93723	85415	97854	96257	30452	55342	99035
Standard Deviation (ng/kg)	Feb/0 days	11141	6749	6327	51418	13966	9032	1536	7608	18189
	Jun/126 days	3779	14579	19916	20613	12666	2047	2396	6219	N/A
	Oct/244 days	57719	4316	11257	85415	17633	19335	2397	12275	7052
Standard Error (ng/kg)	Feb/0 days	4982	3018	2830	22995	6246	4039	687	3403	8135
	Jun/126 days	1690	6520	8907	9219	5665	915	1072	2781	N/A
	Oct/244 days	25813	1930	5034	38199	7886	8647	1072	5490	3154

Table 24: TCDD TEQ in microcosms during incubation

	Time	NUTR	SOLE	RICE	AUGM	COMB	UNAA	UNAB	UNAC	STER
Average (ng/kg)	Feb/0 days	297	303	267	332	286	288	57	55	266
	Jun/126 days	247	264	250	266	262	264	54	56	N/A
	Oct/244 days	247	264	276	282	314	309	67	62	314
Standard Deviation (ng/kg)	Feb/0 days	28	27	18	137	33	13	2	7	18
	Jun/126 days	20	27	15	34	19	4	2	5	N/A
	Oct/244 days	137	10	28	11	41	30	4	11	8
Standard Error (ng/kg)	Feb/0 days	13	12	8	61	15	6	1	3	8
	Jun/126 days	9	12	7	15	8	2	1	2	N/A
	Oct/244 days	61	4	12	5	18	13	2	5	4

Appendix L: Raw Soil Gas Data

Depth (ft-bgs)	CO2 (%)	CO2 Average (%)	CO2 St Dev (%)	O2 (%)	O2 Average (%)	O2 St Dev (%)	Date Collected
5	0.8	1.761363636	2.446375193	20	18.27727273	3.505534736	Jun-14
5	0.8			18.8			Jun-14
5	0.7			20.3			Jun-14
5	0.9			20			Jun-14
5	1.7			19			Jun-14
5	1.6			19.5			Jun-14
5	11.8			5.6			Jun-14
5	4			16.8			Jun-14
5	0			20.3			Jun-14
5	0			20.1			Jun-14
5	0.1			19.9			Jun-14
5.5	3.4			17.4			Jun-14
5.5	1			19.8			Jun-14
5.5	1			19.8			Jun-14
5.5	2.4			18.8			Jun-14
5.5	0.7			19.6			Jun-14
5.5	0.4			19.8			Jun-14
5.5	0.4			19			Jun-14
5.5	3.1			17.1			Jun-14
5.5	10.3			2.1			Jun-14
5.5	2.7			16.9			Jun-14
5.5	0.4			19.7			Jun-14
5.5	0.1			18.1			Jun-14
5.5	1			20			Jun-14

5.5	1			19.9			Jun-14
5.5	0.8			20.2			Jun-14
5.5	0.3			20.5			Jun-14
5.5	1.5			19.2			Jun-14
5.5	2.4			18.6			Jun-14
5.5	0			19.2			Jun-14
5.5	2.4			18.4			Jun-14
5.5	0.5			19.8			Jun-14
5.5	3.9			16.4			Jun-14
5.5	0.1			20.1			Jun-14
5.5	2			18.6			Jun-14
5.5	4.6			14.2			Jun-14
5.5	0.2			19.9			Jun-14
5.5	0.3			20			Jun-14
5.5	0.2			19.5			Jun-14
5.5	0			20.1			Jun-14
5.5	1.4			18.2			Jun-14
5.5	0.7			19			Jun-14
5.6	0.7			19.2			Jun-14
5.75	5.2			14.8			Jun-14
6	0.9	1.986666667	1.524966822	20	16.91333333	5.014958576	Jun-14
6	0.9			19.8			Jun-14
6	0.9			19.8			Jun-14
6	0.6			19.6			Jun-14
6	2.4			15			Jun-14
6	1.5			19.5			Jun-14
6	2.2			18.1			Jun-14
6	4.5			13.3			Jun-14
6.5	0			17.8			Jun-14

6.5	1			20.1			Jun-14
6.5	1.9			0.3			Jun-14
6.5	5			16.2			Jun-14
6.5	3.9			17			Jun-14
6.5	0.9			19.2			Jun-14
6.5	3.2			18			Jun-14
7	1.5	2.14	1.360042016	18.8	17.43333333	3.894990678	Jun-14
7	3.2			17.6			Jun-14
7	1			19.8			Jun-14
7	0.5			19.4			Jun-14
7.5	4			16.8			Jun-14
7.5	3.4			17.8			Jun-14
7.5	0.8			19.4			Jun-14
7.5	2.1			4.1			Jun-14
7.5	3.2			17.1			Jun-14
7.5	3			18.5			Jun-14
7.5	1.2			19.6			Jun-14
7.5	1.2			19.2			Jun-14
7.5	0			20.1			Jun-14
7.5	2.6			17.5			Jun-14
7.5	4.4			15.8			Jun-14
8	0.6	1.533333333	1.41509717	19.8	18.43333333	1.188486432	Jun-14
8	1.4			18.2			Jun-14
8	2			18.5			Jun-14
8.5	2			17.4			Jun-14
8.5	0.4			19.8			Jun-14
8.5	0			18.6			Jun-14
8.5	0.1			19.7			Jun-14
8.5	3.5			16.5			Jun-14

8.9	3.8			17.4			Jun-14
9	5.8	2.875	2.526361019	12.7	17.225	3.348009359	Jun-14
9	1.6			19.5			Jun-14
9.5	0.1			20			Jun-14
9.5	4			16.7			Jun-14
10	1.3	3.007692308	3.202983385	19.1	15.5	6.232976817	Jun-14
10	0.1			18.5			Jun-14
10.5	4.6			15.9			Jun-14
10.5	7.9			0			Jun-14
10.5	8.3			6.7			Jun-14
10.5	1.2			19.3			Jun-14
10.5	2.8			18.3			Jun-14
10.5	0			18.5			Jun-14
10.5	1.8			18.6			Jun-14
10.5	8.1			9			Jun-14
10.5	0.1			19.7			Jun-14
10.5	0			19.9			Jun-14
10.6	2.9			18			Jun-14
11	1.4	2.45	1.711306936	18.7	17.5125	1.589642817	Jun-14
11	4.5			15.8			Jun-14
11	0			20.2			Jun-14
11.08	0.8			19			Jun-14
11.5	4.9			16.4			Jun-14
11.5	2.9			16.1			Jun-14
11.5	2.9			16.8			Jun-14
11.5	2.2			17.1			Jun-14
12	5.2	3.24	2.154762168	15	13.88	8.053384382	Jun-14
12	4			0			Jun-14
12.5	2			18.8			Jun-14

12.5	0.1			20.1			Jun-14
12.5	4.9			15.5			Jun-14
13	0	1.22	1.62080227	20	18.44	1.494322589	Jun-14
13.3	1.5			18.3			Jun-14
13.5	0.7			19.6			Jun-14
13.5	3.9			16.2			Jun-14
13.5	0			18.1			Jun-14
14.5	1			15.9			Jun-14
15.5	5.9	4.014285714	4.490519113	14.4	14.48571429	6.862562343	Jun-14
15.5	12.7			0			Jun-14
15.5	1.2			19.4			Jun-14
15.5	0			16.8			Jun-14
15.5	5.1			13.3			Jun-14
15.5	0			20.4			Jun-14
15.6	3.2			17.1			Jun-14
16	1.6			19			Jun-14
17.5	0			20			Jun-14
18.5	3.2	2.4	1.13137085	16.5	16.55	0.070710678	Jun-14
18.5	1.6			16.6			Jun-14
19	4.6			16.2			Jun-14
20.5	6.1	6.3	3.772929896	14.1	10.12	7.748354664	Jun-14
20.5	9.9			0			Jun-14
20.5	0			20.6			Jun-14
20.5	7.9			9.1			Jun-14
20.5	7.6			6.8			Jun-14
25.5	0.6			19.4			Jun-14
25.5	7.7			6.8			Jun-14
30.5	7.7			0			Jun-14
40.5	1.4			0			Jun-14

Appendix M: Kinetics Estimations Using Microcosm Data

Notes: Kinetics calculations were only performed for average concentrations that showed a reduction in COI concentrations over the duration of the microcosm study. Standard error was not considered for these calculations. To review calculations, see Excel file 'graphs for thesis and kinetics_MB_19Dec2014.xlsx'.

Table 25: EFH kinetics estimate

EFH	UNAA	AUGM	RICE	NUTR
Feb/0 days	152	146	154	182
Jun/126 days	89.4	113.4	137.2	151.6
First-Order Reaction Constant (1/d)	4.2E-03	2.0E-03	9.2E-04	1.5E-03
Time to reach LUT (First-Order), days	7.8E+02	1.6E+03	3.6E+03	2.4E+03
Time to reach LUT (First-Order), years	**2.1**	**4.4**	**9.9**	**6.5**
Zero-Order Reaction Constant (ppm/d)	5.0E-01	2.6E-01	1.3E-01	2.4E-01
Time to reach LUT (Zero-Order), days	2.9E+02	5.4E+02	1.1E+03	7.3E+02
Time to reach LUT (Zero-Order), years	**0.8**	**1.5**	**3.0**	**2.0**

Table 26: PAHs kinetics estimate

PAHs	Benzo(a)pyrene in UNAB
Feb/0 days	4.5E+03
Oct/244 days	3.6E+03
First-Order Reaction Constant (1/d)	8.9E-04
Time to reach LUT (First-Order), days	7.8E+03
Time to reach LUT (First-Order), years	**21.2**
Zero-Order Reaction Constant (ppb/d)	7.0E+00
Time to reach LUT (Zero-Order), days	6.4E+02
Time to reach LUT (Zero-Order), years	**1.8**

Note: LUT value is BaP TEQ; performed kinetic analysis on Benzo(a)pyrene in Soil B (PUBS 1044)

Table 27: PCBs kinetics estimate

PCBs	NUTR	SOLE	RICE	AUGM	COMB	UNAA	UNAB	UNAC	STER
Feb/0 days	326.4	448.2	394	378	336.2	2811.8	329.2	95.4	323.8
Oct/244 days	215	197.4	186.2	240.2	217.8	263	260.6	51.2	217
First-Order Reaction Constant (1/d)	1.7E-03	3.4E-03	3.1E-03	1.9E-03	1.8E-03	9.7E-03	9.6E-04	2.6E-03	1.6E-03
Time to reach LUT (First-Order), days	1.1E+03	6.3E+02	6.5E+02	1.1E+03	1.0E+03	4.1E+02	1.9E+03	2.3E+02	1.1E+03
Time to reach LUT (First-Order), years	**2.9**	**1.7**	**1.8**	**2.9**	**2.8**	**1.1**	**5.2**	**0.6**	**3.0**
Zero-Order Reaction Constant (ppb/d)	4.6E-01	1.0E+00	8.5E-01	5.6E-01	4.9E-01	1.0E+01	2.8E-01	1.8E-01	4.4E-01
Time to reach LUT (Zero-Order), days	6.0E+02	3.8E+02	4.0E+02	5.7E+02	5.8E+02	2.6E+02	9.8E+02	2.3E+02	6.2E+02
Time to reach LUT (Zero-Order), years	**1.6**	**1.1**	**1.1**	**1.6**	**1.6**	**0.7**	**2.7**	**0.6**	**1.7**

Table 28: Dioxins kinetics estimate

TCDD TEQ	SOLE	AUGM	NUTR
Feb/0 days	303.4	332.2	297.2
Oct/244 days	263.8	282	247.4
First-Order Reaction Constant (1/d)	5.7E-04	6.7E-04	7.5E-04
Time to reach LUT (First-Order), days	1.0E+04	8.8E+03	7.7E+03
Time to reach LUT (First-Order), years	**27.8**	**24.1**	**21.1**
Zero-Order Reaction Constant (ppt/d)	1.6E-01	2.1E-01	2.0E-01
Time to reach LUT (Zero-Order), days	1.9E+03	1.6E+03	1.5E+03
Time to reach LUT (Zero-Order), years	**5.1**	**4.4**	**4.0**