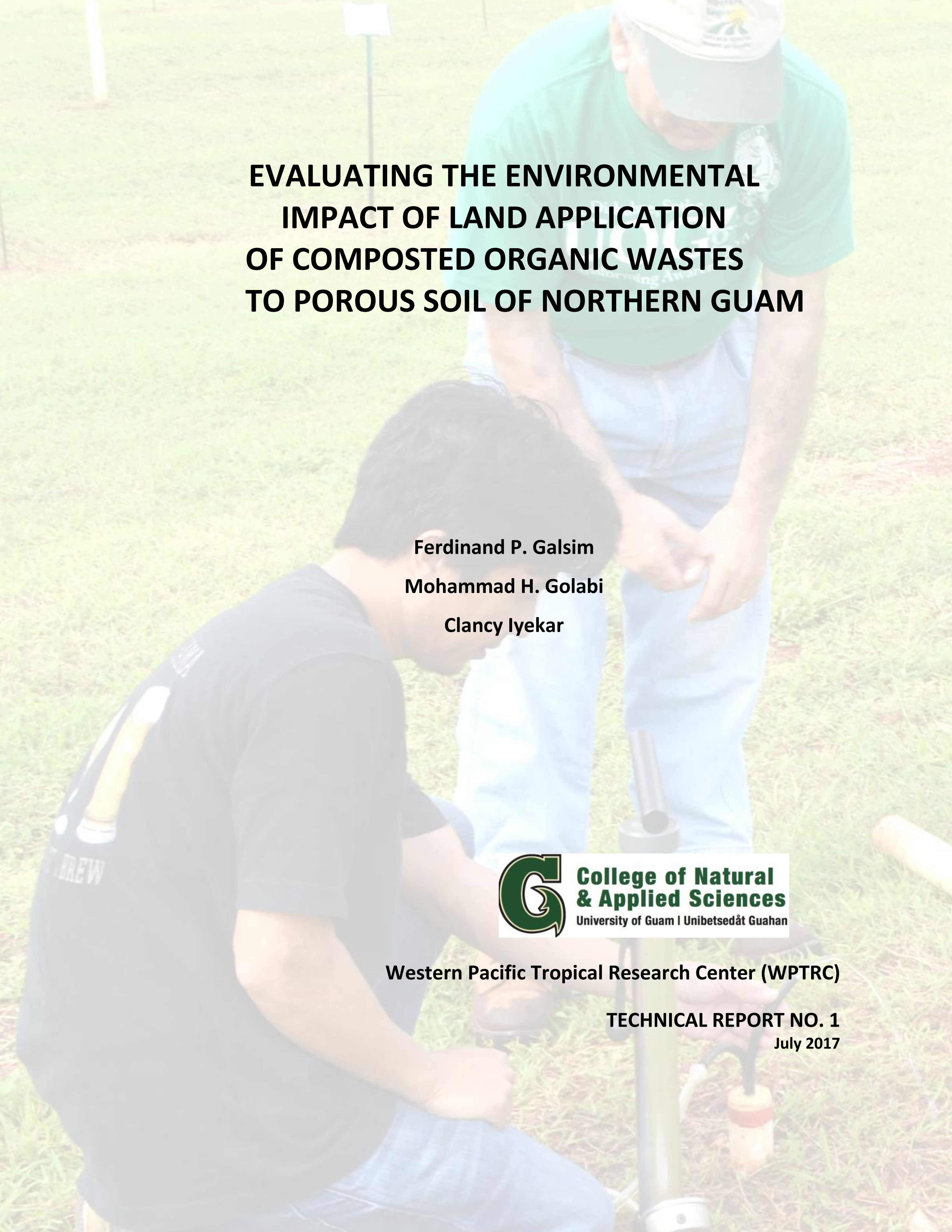

EVALUATING THE ENVIRONMENTAL IMPACT OF LAND APPLICATION OF COMPOSTED ORGANIC WASTES TO POROUS SOIL OF NORTHERN GUAM

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Western Pacific Tropical Research Center (WPTRC)

TECHNICAL REPORT NO. 1
July 2017

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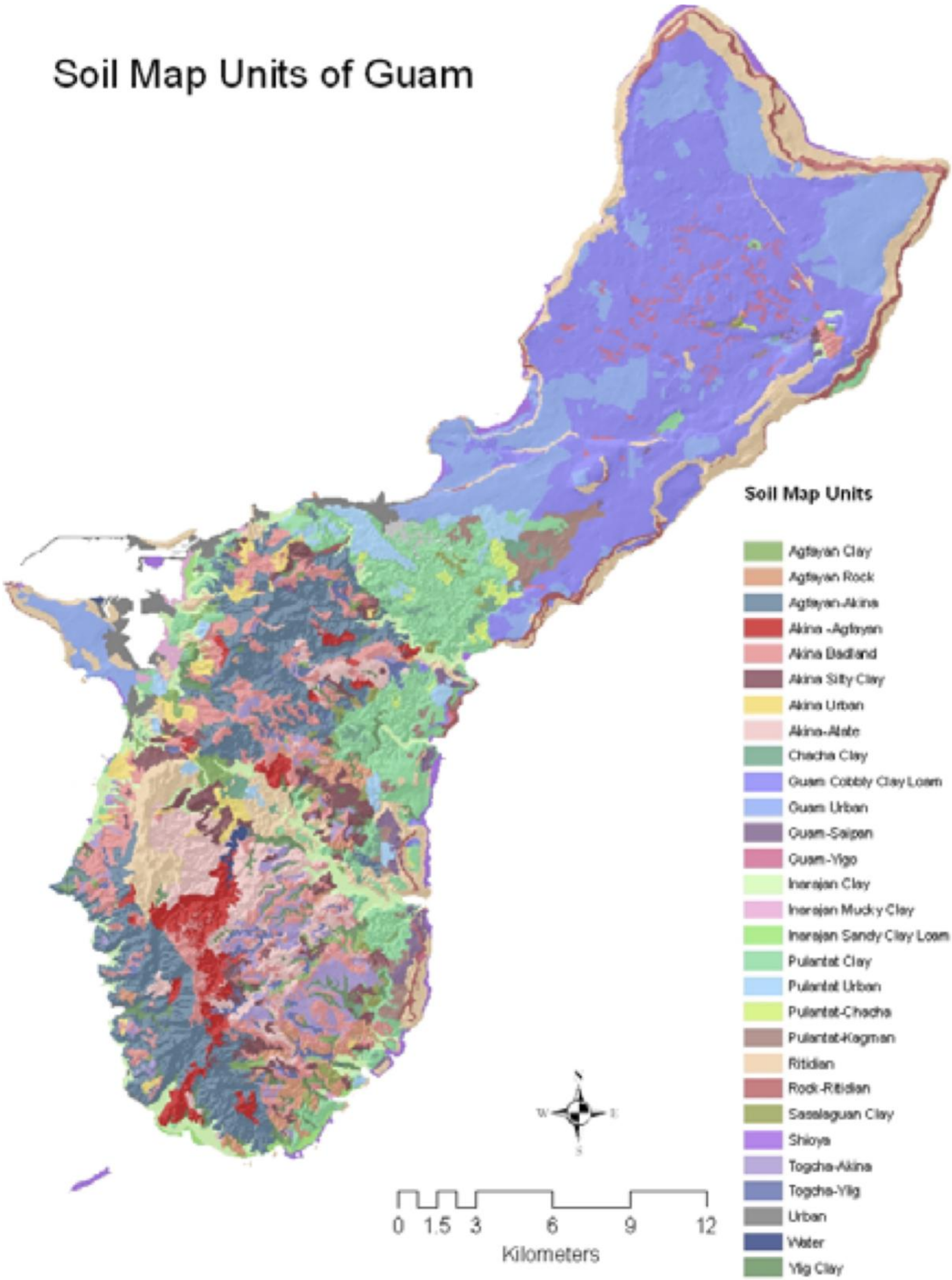
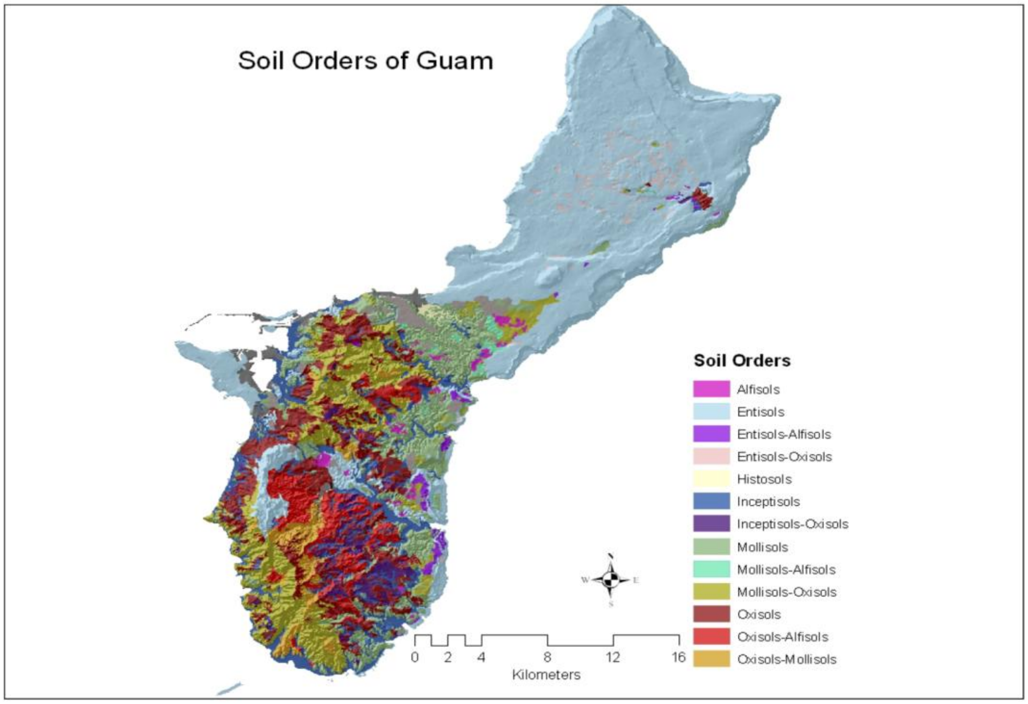


Map: courtesy Jonathan Deenik & NRCS



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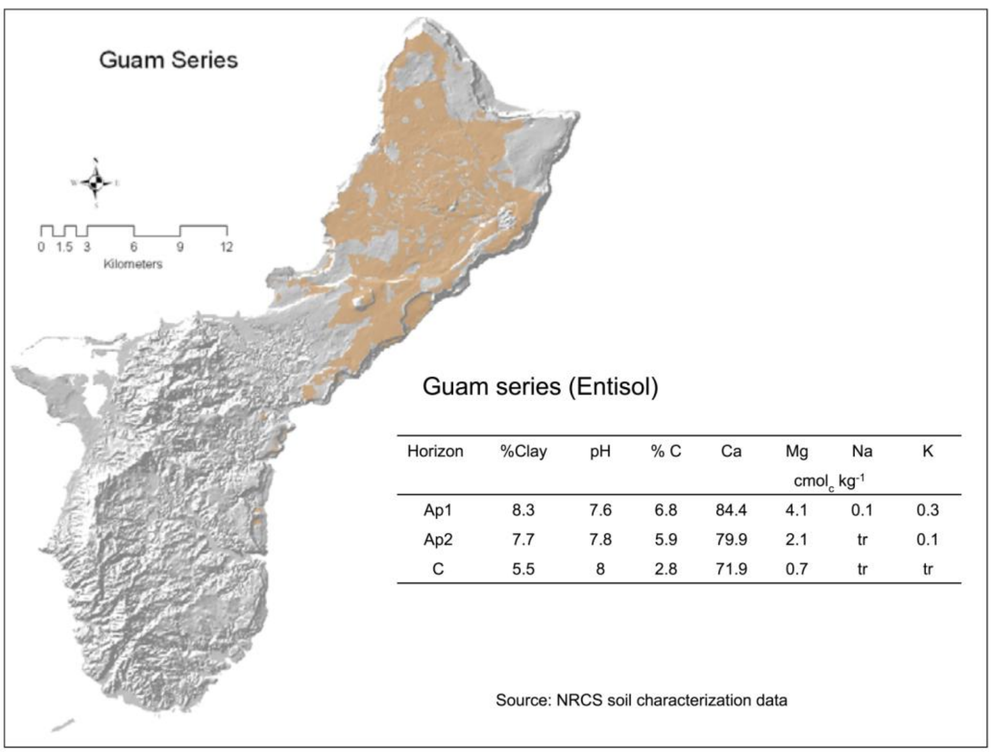

Horizon	%Clay	pH	% C	Ca	Mg	Na	K
					cmol$_c$ kg^{-1}		
Ap1	8.3	7.6	6.8	84.4	4.1	0.1	0.3
Ap2	7.7	7.8	5.9	79.9	2.1	tr	0.1
C	5.5	8	2.8	71.9	0.7	tr	tr

Map: courtesy Jonathan Deenik & NRC

ACKNOWLEDGEMENTS

We would like to express our special thanks to our field technicians Edwin Paulino, Ray Gumataotao, and Karl “Von” Nelson. We are also indebted to Dr. Gary Denton and Dr. Timothy Righetti who provided valuable inputs and analyses to this report. Many thanks to Sheeka Tareyama who initiated the plot layout and developed protocol for data collection. Also, to Sydonia Manibusan who helped with field works and sampling. We are thankful to Anderson Air Force Base for woodchip materials for our composting part of the project. Also we would like to extend our gratitude to Dr. Mari Marutani for composting materials and the help from her employees during the corn harvesting.

TABLE OF CONTENTS

LIST OF FIGURES

Page

Page

LIST OF TABLES

Page

LIST OF APPENDICES

ABSTRACT

Monitoring and protecting our natural resources is vital for the quality of life and the integrity of the ecosystem. The majority of the farmlands in Guam are infertile and not ideal for farming. At the same time, Guam relies on 80 % of its drinking water source from the underground aquifer in northern Guam. This research evaluated the application of both composted organic waste and commercial fertilizer for crop production in northern Guam for possible leaching of excess plant nutrients below the root zone. Nutrients such as nitrate and phosphate were collected below the root zone using subsurface lysimeters to monitor subsurface soil pore waters and chemical movement. Data collected were evaluated for the amount of subsurface leachate of excess chemicals.

INTRODUCTION

Among the major concerns regarding the agricultural activities on Guam and other tropical islands of the Pacific is the low organic matter content of soils especially the calcareous soil of northern Guam (Golabi, 2004). The application and continued additions of organic matter create a soft, tillable soil, important for plant growth while adding nutrients, storing nitrogen, creating stronger aggregate that will enhance soil stability therefore reducing water erosion (Environmental Encyclopedia, 2011). On the other hand, the increasing use of inorganic fertilizers and the disposal of wastes in animal farms are just some of the major contributors to the elevated nitrate levels in groundwater supplies over the last 20 years (WHO, 2016). However, because of the delayed response of groundwater to changes in soil, the long-term environmental impact of excess nitrate, phosphate and other agricultural chemicals to ground water remained unknown.

Overlying the northern half of Guam is a highly porous limestone plateau developed from ancient coral reefs. The natural aquifer that has developed in this geological feature satisfies the drinking water needs of approximately 80 % of island residents (~180,000 people plus 1 million visitors/year). Since the freshwater-lens are found in limestone, the main source of freshwater are from the high-permeable limestone rocks of northern Guam and the water table is just a few feet above sea level at almost zero slope (Gingerech, 2003).

Resource managers and water regulators continually test and monitor major contaminants in the Guam's groundwater system (Table 1), but the population density in northern Guam and the rapid recharge rates to the underlying aquifer may increase the risk of major contaminants (Denton, 2010). Any future increase in crop production and animal farming may also affect the levels of contaminants in the groundwater system.

Table 1: Reported Nitrate-N by Guam Waterworks Authority (GWA) with Maximum Contaminant Level (MCL) allowed at 10 ppm.

YEAR	Groundwater RANGE	UGUM RIVER RANGE	FENA LAKE RANGE
2015	0.9 - 4.8	<0.2	0.23 - 2.7
2014	.08 – 4.8	<0.2	0.23 - 2.7
2013	<0.2 - 5.0	<0.2	0.23 - 2.1
2012	0.8 - 5.0	nd	0.34 - 3.5
2011	0.2 - 4.7	nd	0.3 - 2.1

2010	nd - 4.6	nd	0.04 - 2.21
2009	nd - 4.8	nd	0.08 - 2.20

Notes: MCL = Maximum Contaminant Level, or the highest level of a contaminant allowed in drinking water and is the legally enforceable standard. Phosphate (PO_4^{-3}) falls under secondary drinking water standard (nuisance chemical) and is not enforceable by EPA (Secondary Drinking Water Standards, 2017) and was not added.

Little information exists on the environmental impact of using composted organic wastes above the aquifer in northern Guam. Guam's fresh water is obtained from wells that tap the upper part of groundwater lens in the aquifer, which is composed mainly of limestone (Gingerich, 2003). The study of land application of composted organic waste reported here was not only for soil quality evaluation but also as an environmental quality assessment in northern Guam.

Golabi et al. (2007) conducted an experiment using composted organic matter in southern Guam that resulted in higher yield than inorganic fertilizer. Although the southern Guam soil was Akina series (Very fine, kaolinitic, isohypothermic Oxic Haplustalf) formed in residuum derived from the volcanic deposit (USDA-SCS, 1988), the significant improvement in bulk density, soil organic matter content, and nutrient distribution in the soil were attributed to compost application on the study plots (Golabi et al., 2007). The chemical and physical properties of the soil plots studied improved following the addition of compost, due to the increased in the organic matter content. The goal of this study was to evaluate the:

1. Environmental impact to groundwater system following the land application of compost.

OBJECTIVES

The purpose of this experiment discussed herein were to:

1. Quantify the concentration of released chemicals (N, P) using suction cup lysimeters at two different depths and under different treatments:
    a. Commercial fertilizer (inorganic)
        1. 2 feet deep
        2. 4 feet deep
    b. Composted waste (organic)
        1. 2 feet deep
        2. 4 feet deep

2. Determine the transport of these major nutrients in the environment. Four different application rates from composted organic waste and equivalent rates of commercial fertilizer are measured.
    a. 0 tons per acre (control)
    b. 30 tons per acre
    c. 60 tons per acre
    d. 90 tons per acre

In the study reported here, the focus was primarily on a time-series analysis of aqueous samples to determine the concentration and the fate of major nutrients (N, P). The analyses of soil water at different depth below the root zones may reveal the potential vertical migration of contaminants through the underlying soil profiles into the groundwater resources.

This experiment investigated the environmental impacts of composted organic wastes and inorganic fertilizers applied in experimental plots using corn as an indicated crop on the porous soil of northern Guam. Sub-surface suction cup lysimeters predict the amount of actual solute transported within the soil matrix. The aqueous solutions in the lysimeters were tested for concentrations of nitrates as well as phosphates chemicals in different depths. Two lysimeters were installed at two different depths per plot at 61 and 122 cm below the soil surface. All treatments were replicated 4 times totaling 28 plots.

Guam farmers may use this scientific based research result to make informed decision for improving soil quality to enhance crop quality and yield, while preserving the quality of water resources. Likewise, water resource managers and regulatory agencies can use the result of this study to help in making any environmental decisions specifically in regards to Guam’s underground water supply, as well as any future economic development and expansion of farmlands on Guam.

MATERIALS AND METHODS

The experimental work described herein focused on 3 aspects of study.

a. Determination of nutrient (N) and Phosphate (P) concentration below root zone.
b. Soil pore-water (leachate) vertical migration based upon the analyzing of leachate from composted organic waste and inorganic fertilizer treatment.

Sample Collection

Soil Pore Waters: Preparations and analyses of the soil pore-waters (leachate), soil and compost samples determination were conducted in the soil-testing laboratory of College of Natural and Applied Sciences' (CNAS) at the University of Guam. Soil pore waters were collected from the 28 study plots from 3 cropping seasons between 2013 and 2016. Each study plot contained 2 ceramic suction cups, vacuum lysimeters (pore size: 1.3 µm) for subsurface flow monitoring buried to depths of 0.61m (2 ft.), and 1.22m (4ft.) (Figure 1). Negative pressure of 30 - 50 centibars, are ideal for most irrigated soils studies. After sampling, the leachate samples (Figure 2) were stored in 50 mL capped containers, placed in cooled icebox and transported to soil lab for further analysis. Leachate sampling was conducted once a week throughout the growing season (a day prior to fertilizer and compost applications and 5 weeks after harvest).

Figure 1: Preparation & Setup of subsurface Lysimeters

Sample Analysis

Nutrient determinations (NO_x-N and reactive-P) were made using QuickChem 8500, flow injection analyzer (lachat Instruments) (Figure 3). Nutrient analyses were performed within 24-h of sample collection, otherwise stored in a freezer until ready for testing.


Figure 2: Sampling of soil pore-water & Storing in 50 mL cups

Figure 3: Flow Injection Analyzer (FIA)(QuickChem 8500 Series 2 model) for nitrate (NO_3^-) and phosphate (PO_4^{3-}) analyses

Soil Analysis

Soil and compost samples were analyzed using the carbon and nitrogen instrument (FlashEA 1112 series by Thermo Electronic Corporation) shown in figure 4. Data obtained include percentage of the carbon and nitrogen of the soils from the study plots as well as the carbon and nitrogen ratio of the compost applied to the study plots.

Figure 4: Nitrogen and carbon analyzer (FlashEA 1112 Series) that was used for soil and compost analyses

Soil samples from study plots and compost samples from compost windrow were air-dried and sieved through a 2.00 mm mesh screen. The samples were then milled using a coffee grinder and sieved again with a 0.023 mm mesh screen to prepare for carbon and nitrogen analysis using FlashEA 1112 series.

Soil pH Analysis

A soil pH is the measure of acidity and alkalinity and is important in many chemical processes such as plant nutrient availability and overal soil health. Because of the calcareous soil of northern Guam and the effects of crop residues to the soil's chemical property, pH testing was performed for overall soil quality determination (Butterly et al., 2012, Golabi et al., 2004).

The soil pH was analyzed using an Oakton glass eletrode pH meter and was calibrated before testing of samples. Generally, a 1:1 of soil to water ratio is performed but was adjusted to 1:2 due to the texture of the soil and the compost (Sparks, 1996).

Soil Organic Matter (SOM) Analysis

Walkley-Black Method (Sparks et al., 1996) was used to test for soil organic matter (SOM) in the soil study plots as well as the composted organic wastes windrow that was applied to the study plots. Soil organic matter can increase soil water-holding capacity, lower bulk density, and act as a reservoir for plant nutrients which an indicator for crop yield and soil water leaching.

Corn Crop

The corn seeds purchased from University of Hawaii that were used from 2012 and 2014 were hybrid sweet # 8 while hybrid supersweet #10 was used in 2015 and 2016 (Figure 5). Two corn plants were planted for each drip line emitter.

Figure 5: Sweet Corn Plants Nearing Harvest Stage

Experimental Site

The composting production facilities as well as the experimental plots were located at the University of Guam Experiment Station in the village of Yigo of Northern Guam.

Guam has a mean annual rainfall of approximately 2540 mm with a distinct dry season from January to June during which rainfall averages approximately 800 mm (Lander, 1994). Mean annual temperature is 26^0 C, and the monthly temperature range varies approximately $\pm 2^0$C from the mean (Karolle, 1991).

The soil underlying the study site is the ‘Guam soil series’ (clayey, gibbsitic, nonacid, isohypothermic lithic Ustorthents) formed in sediment over porous coralline limestone (Young, 1988). The bedrock underneath these soils is very porous therefore surface water can easily percolate into the groundwater aquifer, which supplies 80 % of the island’s water supply (WERI, 2017).

<u>Field Experimental Design (Layout)</u>

The 28 study plots are 7.01 m x 6.09 m (23 x 20 ft.) shown in Figure 7 were established for different compost application rates as well as equivalent rates of nitrogen by using synthetic fertilizers for comparison. The indicated study plots (Figure 3) assigned were constant throughout for the 3 planting seasons. The application rates were setup as 3 treatment levels with 4 replications for each treatment plot, and randomized complete block design was used for statistical analyses. The composted organic wastes applied to study plots were processed in the University of Guam (UOG) station in Yigo. The compost mainly consisted of restaurant food and paper wastes, woodchips from Anderson Air Force base, and hog and chicken manures from local poultry and hog farms.

There were 8 water drip lines per study plot (Figure 7) that were set up approximately 91 cm (3 ft.) apart. The water timers were set to turn on the water twice a day for 2 hours. As the corn ears neared the maturity stage, irrigation water was reduced to twice a day for 1 hr. Adjustments were also made during lengthy rains, storms, and dry or wet seasons to control erosion and guard against overwatering.

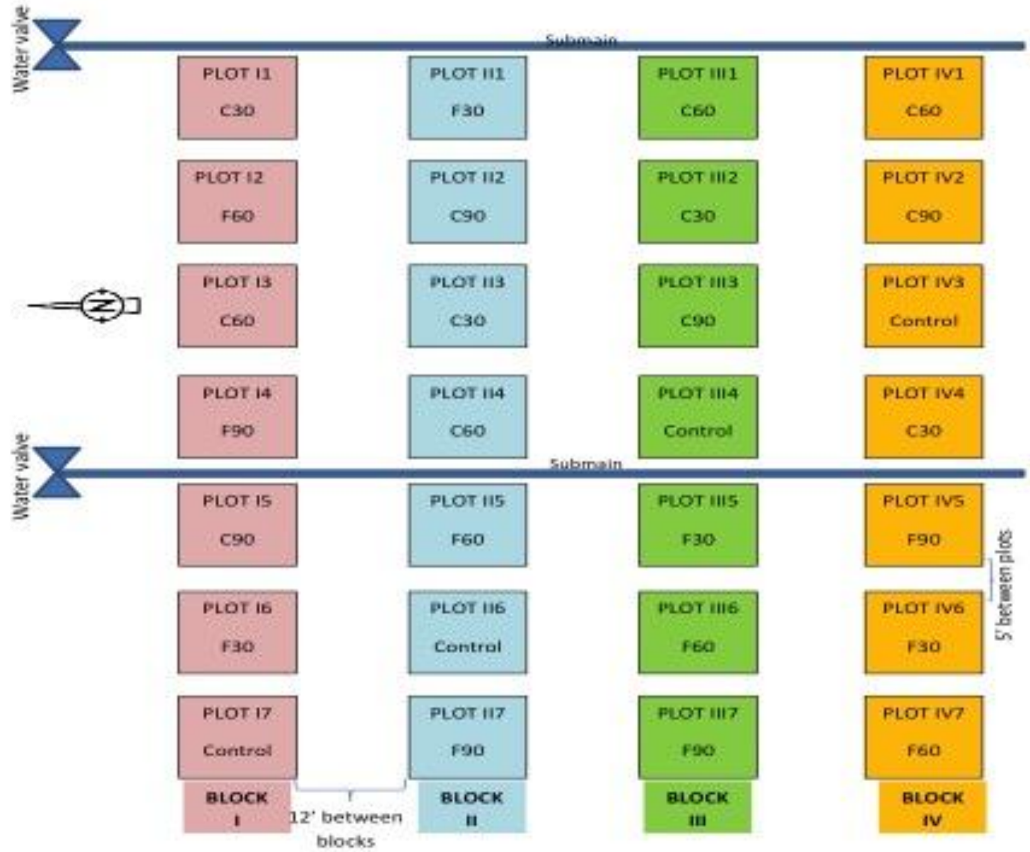

Figure 6: Study Plot Design (4 replications)(Illustration by Sheeka Tareyama)

Notes: C30 = 30 tons per acre of composted organic wastes
F30 = 30 tons per acre of inorganic fertilizer
Control = 0 tons per acre

Figure 7: Drip lines (8) with 20 drip emitters per row at 30.5 cm intervals (1 ft.)

Field Background

Before the application of compost and commercial fertilizer, the soil plots were sampled and analyzed to determine soil background characteristics including: pH, soil organic matter (SOM), bulk density, electrical conductivity, and percentage of carbon and nitrogen content. Background soil pore water was also collected from lysimeters on January 9th and 21st, 2012.

The Soil:

Soil is a dynamic and possibly the most diverse ecosystem on earth. Living organisms in the soil such as bacteria, fungi, earthworms, etc., constitute an important component of the soil. These biological activities are the key ecosystem processes important in the cycling of essential elements for plants such as nitrogen, phosphorus, and potassium (Fitter et al, 2005). Soil is capable of recycling organic materials into water and CO_2 and has the capacity to degrade synthetic compounds foreign to the soil by microbial decomposition and chemical reactions.

Another major factor is the soil's capability to store and transmit water by controlling water availability to plants and possibly reducing environmental pollutants to surface and groundwater (Fitter et al, 2005). However, modern farming has changed the soil's dynamics due to excessive tillage and chemical applications. Innovation in plant nutrients such as the use of synthetic fertilizer, pesticides, improvement in irrigation, and advancement in farming machinery significantly increased crop production, but may have decreased soil resiliency.

As we become more dependent on using synthetic fertilizer to increase crop production, the negative impact of synthetic fertilizer to the environment can lead to the decline of other ecosystems such as arable land and forestry (Mhango and Dick, 2011).

Soil organic matter (SOM), also known as humus, is a well-decomposed and stable part of organic matter in mineral soils (SSSA, 2008). Soil organic matter serves as a reservoir of nutrients for crops, improves soil aggregation, increases nutrient exchange, retains moisture, reduces compaction and surface crusting, and increases water infiltration rate (USDA, 2017).

Soil is essential for life. First, it stores and serves as water filter and medium for plant growth and physical support. Second, it provides habitat for many organisms contributing to biodiversity. Third, it can also filter solid waste in the environment. Finally, Lastly, it is an agroecosystem, which provide food, feed, fiber, and fuel (SSSA, 2002). Any disturbance to one of the key functions can change the soil's dynamic. The use of composted organic waste may help these preserve the soil functions as well as protecting living organisms involve in the soil life cycle.

When chemicals found in synthetic fertilizers such as nitrate and phosphates are over-applied, excess nutrients can easily leach into the groundwater or carried by surface runoffs into surface water body such as rivers, lakes and, ocean. There were many research works reporting that composted organic wastes minimize the level of nitrogen leaching because of its higher organic content increasing the abiotic sorption. Levanon, et al. (1993), has reported that the higher organic matter content in soils enhanced abiotic sorption as well as biotic degradation processes of synthetic chemicals, resulting in lower leaching of these chemicals.

Application of Compost and Inorganic Fertilizer

Compost (Figure) was applied to study plots with corresponding 30, 60, and 90 tons per acre. The content of nitrogen (%) in the compost corresponds to the equivalent rates of synthetic fertilizer triple 16 (N, P, K) which was applied in two half applications. The compost (Figure 9) was applied 1 week before planting while the inorganic fertilizer was applied 2 weeks after planting. First half application of commercial fertilizer (16-16-16) was applied to corresponding plots two weeks after planting at the following rates (Table 2).

Table 2: Compost and Fertilizer Application Rates Per Plot

Rate (t/ac)	Fertilizer (kg)/plot	Compost (kg)/plot
30	6.35	287.40
60	12.70	574.80
90	19.30	862.19

Note: (t/ac is tons per acre which is mass of compost equivalent to N from fertilizer (triple 16)

Composting:
The idea of organic wastes having agronomic values as a "resource recovery" management strategy sounds appealing and, in fact, has been shown to be of great benefit to soil quality and crop productivity in the island of Guam (Golabi et. al., 2003). As reported by Jackson, et al. (2003), application of compost had beneficial impacts of increasing soil microbial biomass, increasing total soil carbon and nitrogen, reducing soil bulk density, and decreasing the potential for groundwater pollution that would otherwise result from nitrate leaching below the root zone upon the application of commercial fertilizers.

Figure 8: Matured stage of a compost (windrow) after 3 months

Figure 9. Application of composted organic waste on study plots

Table 3: Plot numbers based on application rates and number of replications

Treatment #	Application Rates (tons/acre on dry basis)	Replications	Number of Plots	Grand Total of Plots #s
Treat. # 1 (control)	0	4	4	4
Treat. # 2 (compost)	30, 60, 90	4	12	12
Treat. # 3 (commercial fertilizer)	With equivalent nitrogen content to: 30, 60, 90 of compost	4	12	12
Total treatments				28

Composts were applied based on N rates (Table 3) only during 2014 and 2016 planting season while inorganic fertilizers where applied during 2014, 2015, and 2016 seasons. Composts were applied to the study compost plots 3 days before planting of corn seeds and fertilizers were applied 2 weeks after planting.

RESULTS

Carbon to Nitrogen Ratio

Table 4: 2014 Compost Carbon to Nitrogen Ratio (C:N) Results

2014 Compost C:N Result			
Site of sample taken in Windrow (compost)	**% N**	**% C**	**% C:N**
North	0.73	16.36	22.41
Northwest	0.72	16.17	22.46
Northeast	0.66	16.18	24.52
	Avg. C:N →		**23:1**

Table 5: 2016 Compost Carbon to Nitrogen Ratio Results

2016 Compost C:N Result			
Site of sample taken in Windrow (compost)	**% N**	**% C**	**% C:N**
North	0.37	8.51	22.92
Northwest	0.31	6.82	21.68
Northeast	0.22	10.65	48.25
	Avg. C:N →	**31:1**	

The composted organic wastes windrow that was applied to the study plots was tested for the percentage of N, C, and carbon to nitrogen ratio content. In 2014, the compost windrow had an ideal C:N of 23:1 (Table 4) for better soil fertility. However, in 2016, the C:N ratio of the compost was very high at 31:1 (Table 5), which affected the crop yield in the 30 and 60 tons per acre application rates.

Soil pH

Table 6: pH Levels of Soil Study Plots

	Date of Sampling →	8/14/2013	2/10/2014	6/13/2014	2/2/2015
Plots	Treatments				
I-1	C30	7.05	7.01	7.27	6.77
I-2	F60	6.83	6.87	7.01	6.88
I-3	C60	6.89	6.72	7.00	6.83
I-4	F90	6.90	6.93	6.89	6.81
I-5	C90	6.89	6.63	7.24	6.76
I-6	F30	6.92	6.88	7.06	6.85
I-7	Control	6.98	6.87	6.99	6.99
II-1	F30	7.06	7.05	7.20	6.83
II-2	C90	6.82	6.83	7.03	6.80
II-3	C30	6.88	6.81	7.02	6.98
II-4	C60	6.96	6.75	7.03	6.92
II-5	F60	7.02	6.93	7.08	6.99
II-6	Control	6.93	6.90	6.98	6.98
II-7	F90	6.99	6.93	7.06	6.93
III-1	C60	7.15	7.10	7.03	6.98
III-2	C30	6.94	6.92	6.97	6.87
III-3	C90	6.89	6.82	7.10	6.74
III-4	Control	6.99	6.96	7.02	6.94
III-5	F30	7.00	6.91	7.11	6.93
III-6	F60	7.01	6.90	7.09	6.88
III-7	F90	6.99	6.83	7.10	6.87
IV-1	C60	6.88	6.76	7.38	Missing
IV-2	C90	6.96	6.75	7.19	Missing

IV-3	Control	6.95	6.92	6.99	7.02
IV-4	C30	7.02	6.95	7.00	6.90
IV-5	F90	7.17	7.01	7.06	7.01
IV-6	F30	7.20	7.01	7.05	7.00
IV-7	F60	7.26	7.11	7.09	7.17

The soil with pH above 7 can be characterized being as calcareous (Motavalli, Marler, 1998). Most of the soil plots in this study had pH levels of 7 or above due to the presence of calcium carbonate ($CaCO_3$) in the soil. Because the optimum pH range for planting sweet corn is 5.5 to 7.5 (Motavalli, Marler, 1998), it was not necessary make any adjustments in the soil pH levels.

Nitrate Lysimeter Data Analysis

2014 Data (Dry Season**)**

During the first year of sampling (dry season), the nitrate leaching was slightly higher from the inorganic fertilizer (F30) than composted organic plots (C30) at 30 tons per acre equivalent N application in 2 ft. (Figure 10). Control was high at the first week of planting and gradually declined. However, at 4 ft. depth (figure 11) the nitrate leaching from all treatments were all equal.

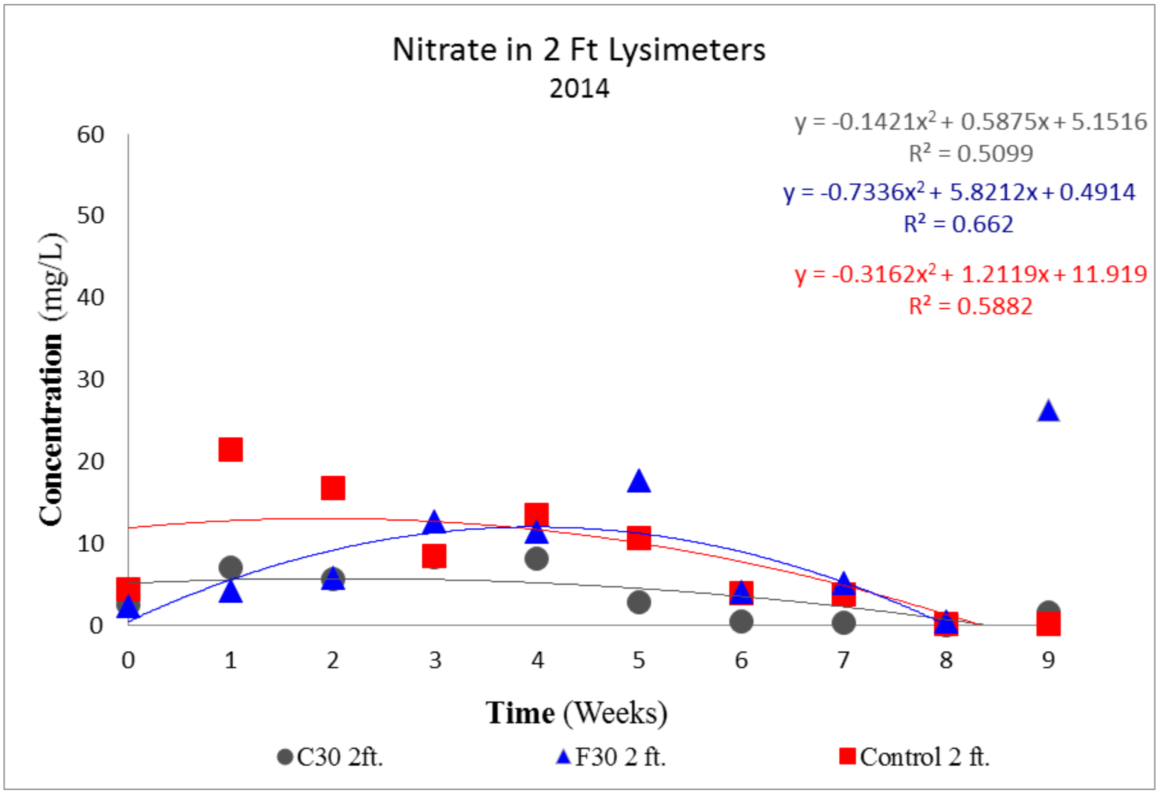

Figure 10: 2014 - Dry Season - Based on 30 tons per acre of equivalent N application (weekly samples from 2 Ft. lysimeter)

Notes: C30 = 30 t/acre of compost equivalent N

F30 = 30 t/acre of equivalent N inorganic fertilizer

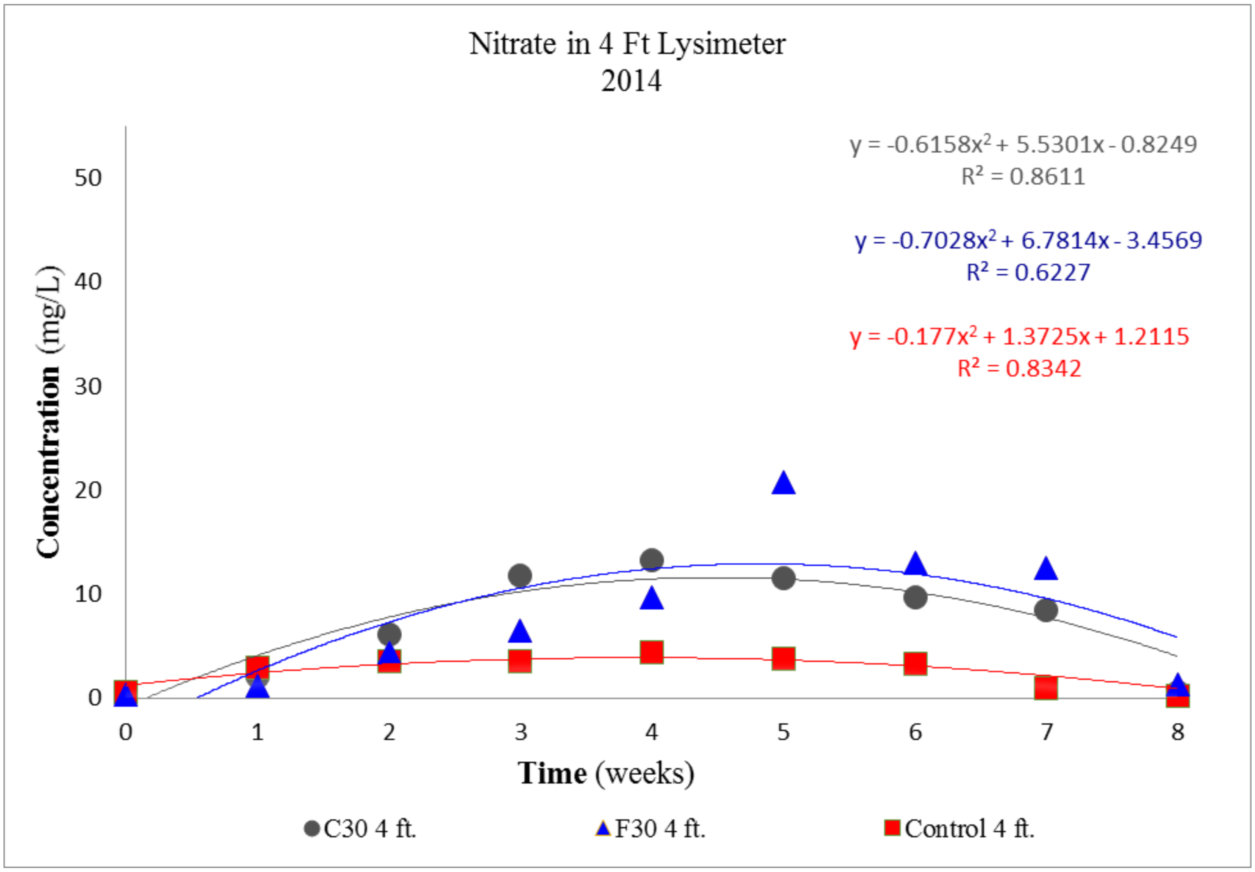

Figure 11: 2014 – dry season - Based on 30 tons per acre of N application (weekly samples from 4 Ft)

Notes: C30 = 30 t/acre of compost equivalent N

F30 = 30 t/acre of equivalent N inorganic fertilizer

For the 60 tons per acre application (dry season), there was high leaching of nitrate from the inorganic fertilizer plots at 2 ft. (Figure 12). The rate of leaching was also elevated and declined significantly. At the 4 ft. (Figure 13), there inorganic fertilizer was slightly elevated and peaked at ~25 mg/L of nitrate concentration after the second half application of inorganic fertilizer on week 5.

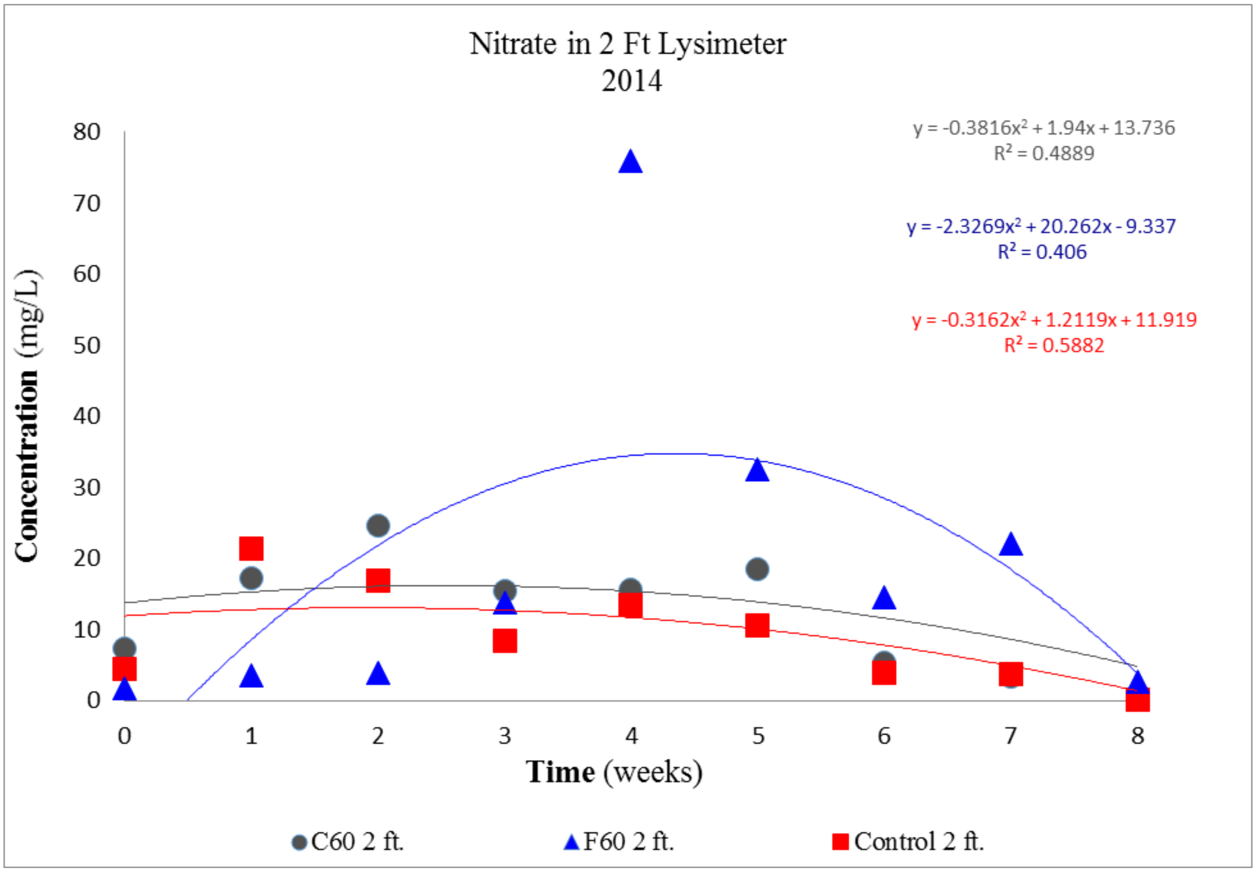

Figure 12: 2014 – dry season - Based on 60 tons per acre of compost equivalent N application (weekly samples from 2 ft.)
Notes: C60 = 60 t/acre of compost equivalent N
F60 = 60 t/acre of equivalent N inorganic fertilizer

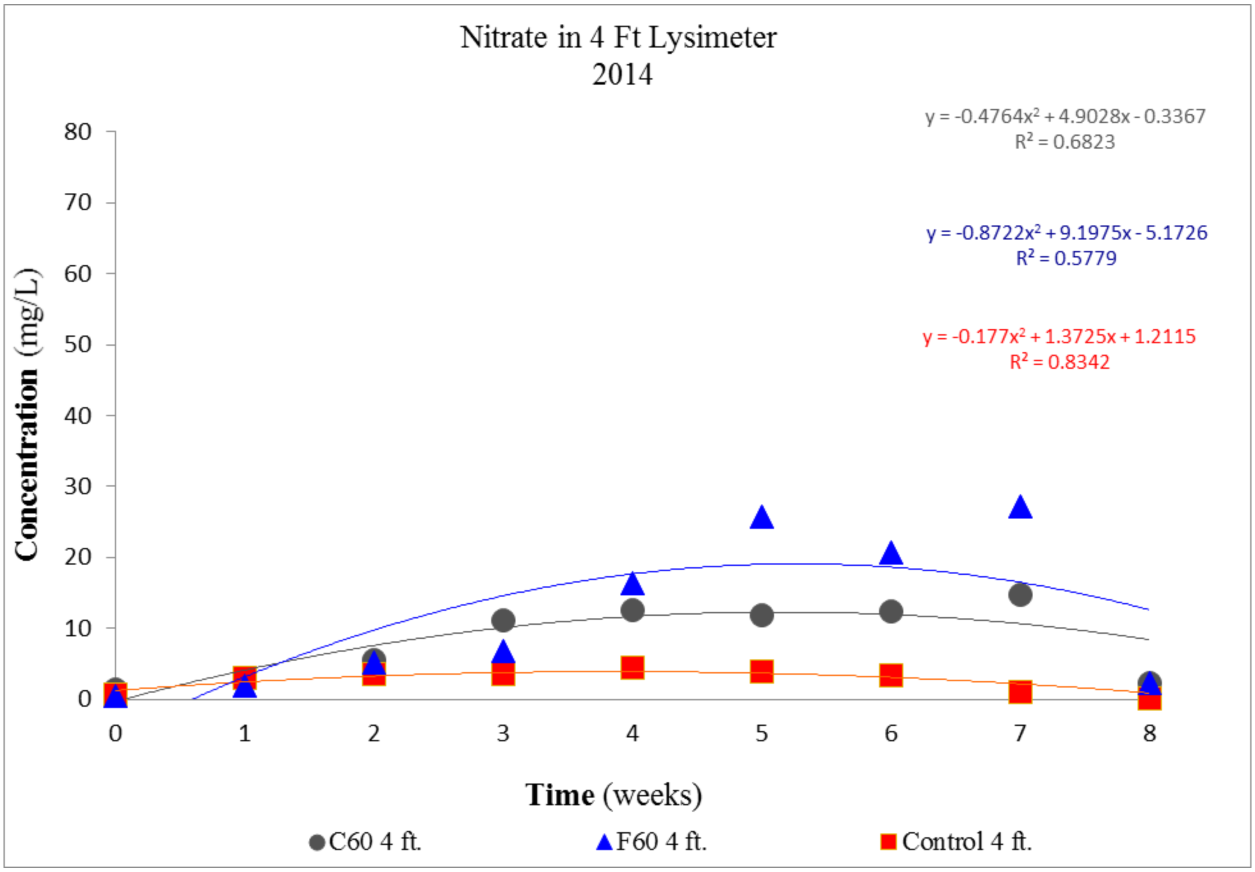

Figure 13: 2014 – dry Season - Based on 60 tons per acre of compost equivalent N application (weekly samples from 4 ft.)
Notes: C60 = 60 t/acre of compost equivalent N
F60 = 60 t/acre of equivalent N inorganic fertilizer

The high application of compost and inorganic fertilizer at 90 tons per acre equivalent N caused significant leaching in the 4 ft. depths. After the second application of inorganic fertilizer (Figure 15, week 9) nitrate leaching reached beyond 35 mg/L in the 4 ft. depths). However, the composted organic waste plots at 4 ft. were still increasing and reached slightly above 10 mg/L of nitrate leachate. This trend shows that compost applied plots continued to release nitrate in the soil in low amount.

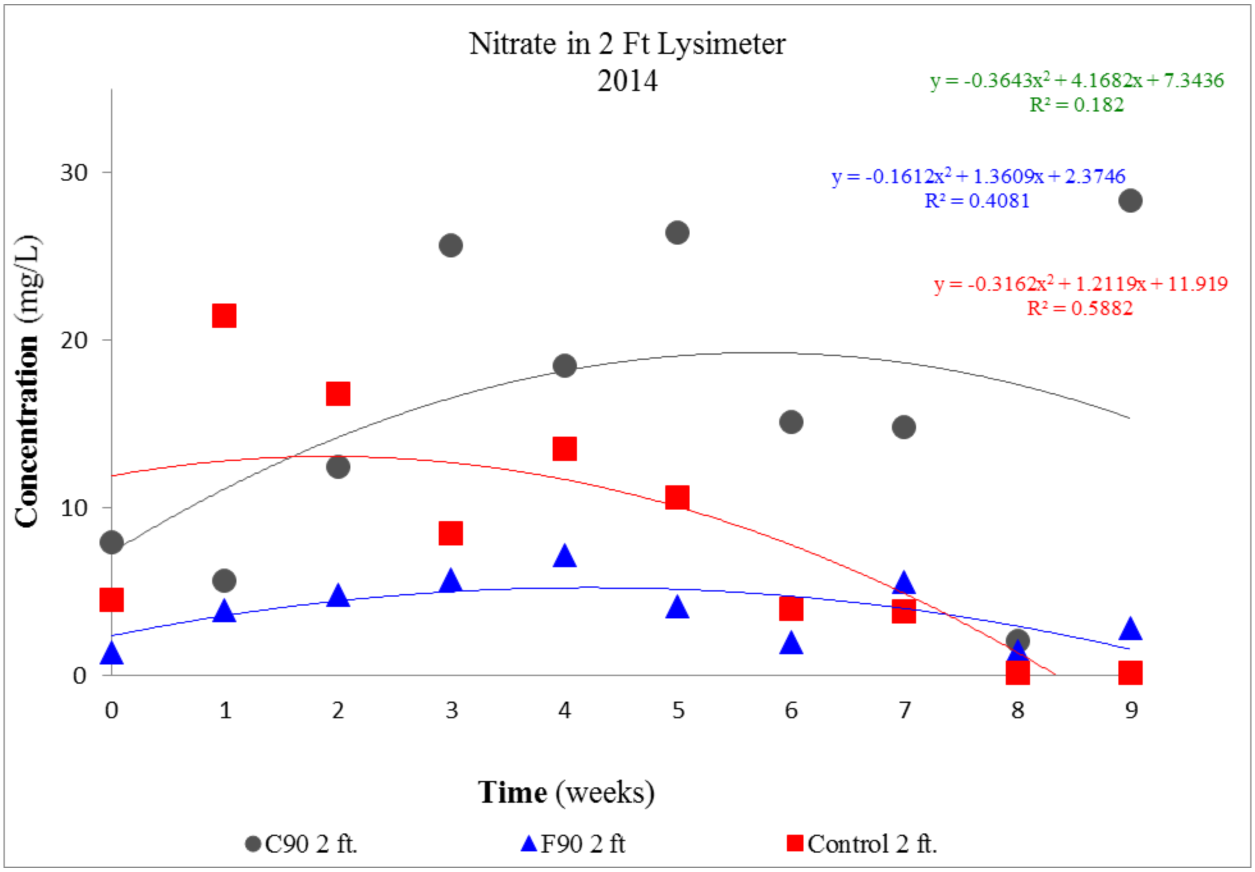

Figure 14: 2014 – dry season - Based on 90 tons per acre of compost equivalent N application (weekly samples from 2 ft.)

Notes: C90 = 90 t/acre of compost equivalent N

F90 = 90 t/acre of equivalent N inorganic fertilizer

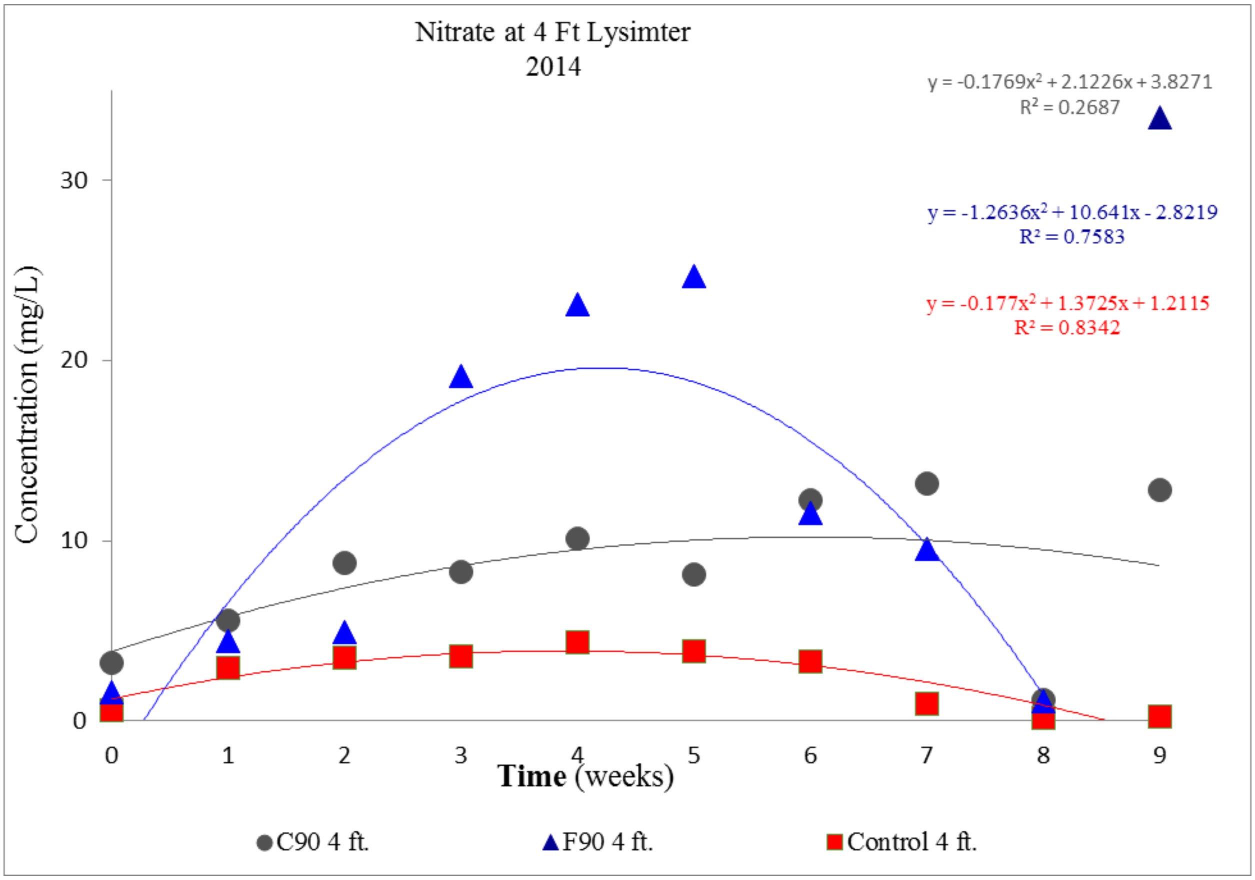

Figure 15: 2015 – dry season based on 90 tons per acre of compost equivalent N application (weekly samples from 4 ft.)

Notes: C90 = 90 t/acre of compost equivalent N

F90 = 90 t/acre of equivalent N inorganic fertilizer

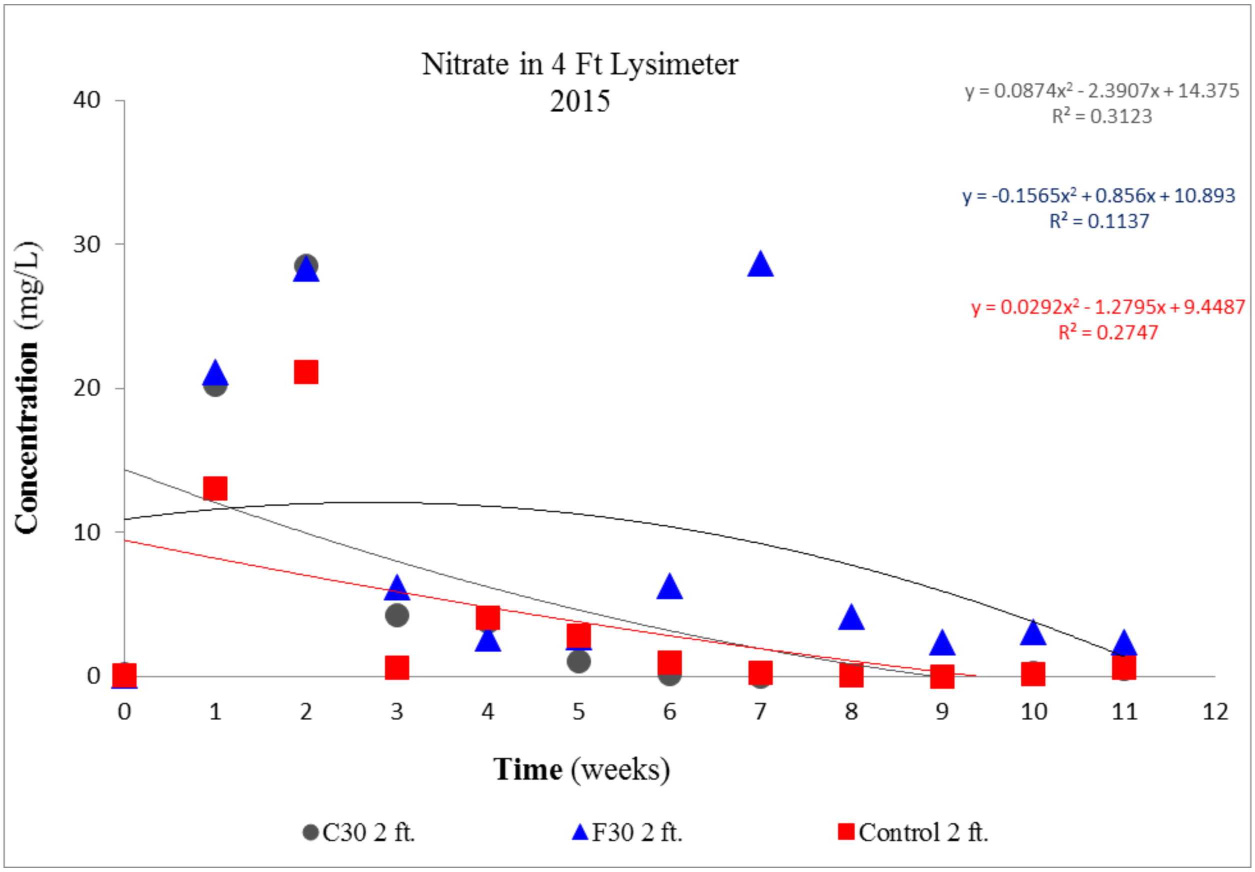

Figure 16: 2015 – dry season based on 30 tons per acre inorganic fertilizer equivalent N. No composted organic wastes were applied on (C30) study plots (weekly samples from 2 ft.)

Notes: C30 = 30 t/acre of compost equivalent N

F30 = 30 t/acre of equivalent N inorganic fertilizer

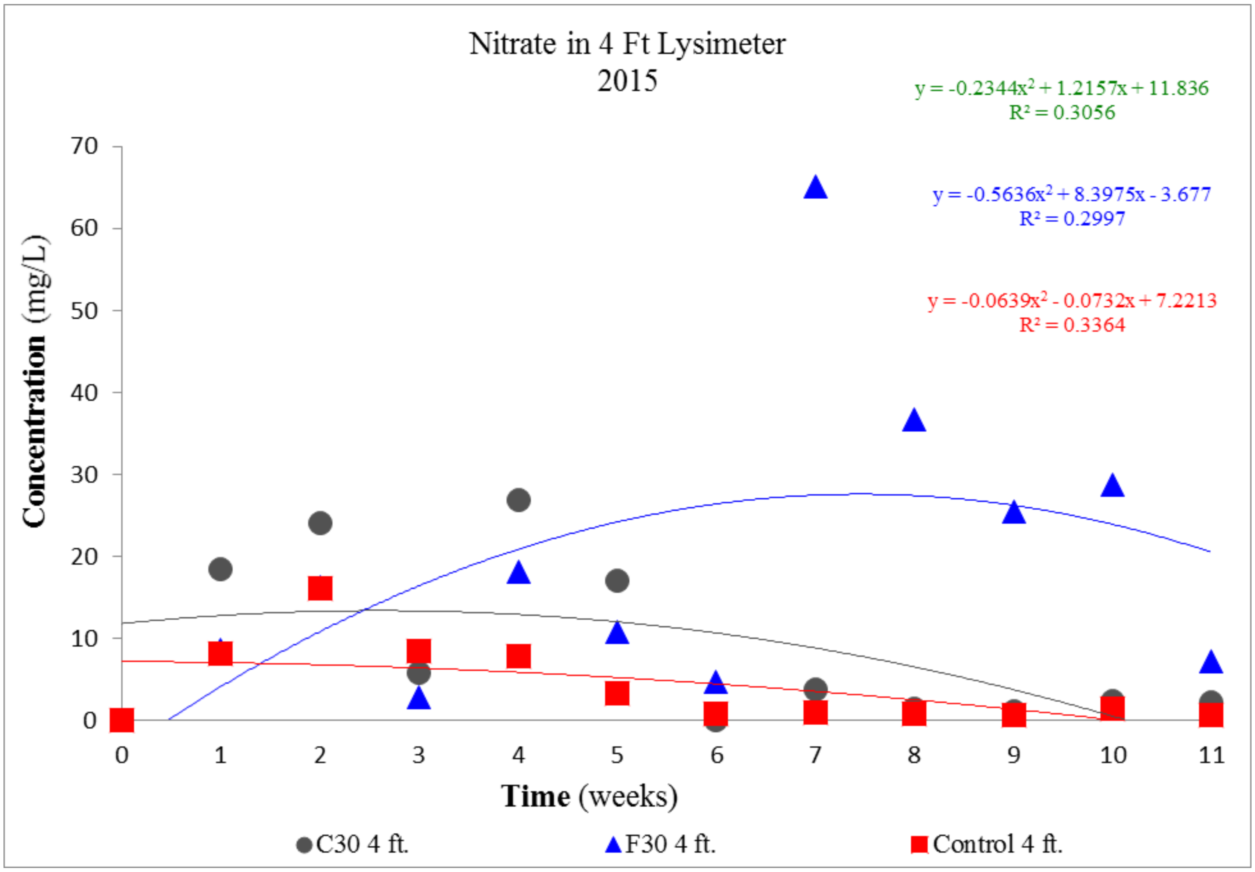

Figure 17: 2015 – dry season based on 30 tons per acre inorganic fertilizer (F30) equivalent N. No composted organic wastes were applied on (C30) study plots (weekly samples from 4 ft.)

Notes: C30 = 30 t/acre of compost equivalent N

F30 = 30 t/acre of equivalent N inorganic fertilizer

Since compost was not reapplied in 2015 (dry season) (Figure 17-18), there were low levels of nitrate leaching at the beginning of the planting season. Nitrate leaching was very high (above 40 mg/L) and followed the same pattern after the second application of inorganic fertilizer.

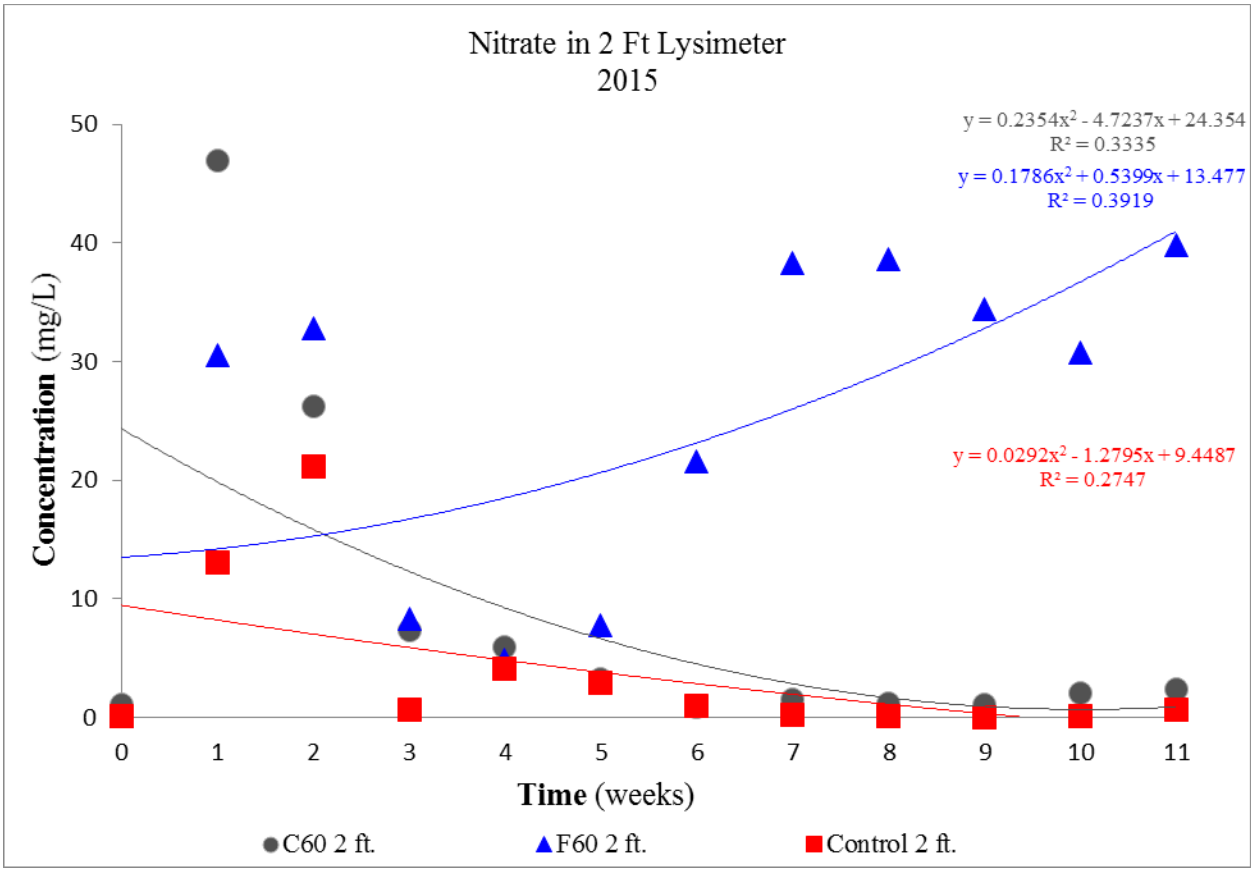

Figure 18: 2015 – Dry season based on 60 tons per acre inorganic fertilizer (F60) equivalent N. No composted organic wastes were applied on (C60) study plots (weekly samples from 2 ft. lysimeters)

Notes: C60 = 60 t/acre of compost equivalent N

F60 = 60 t/acre of N inorganic fertilizer

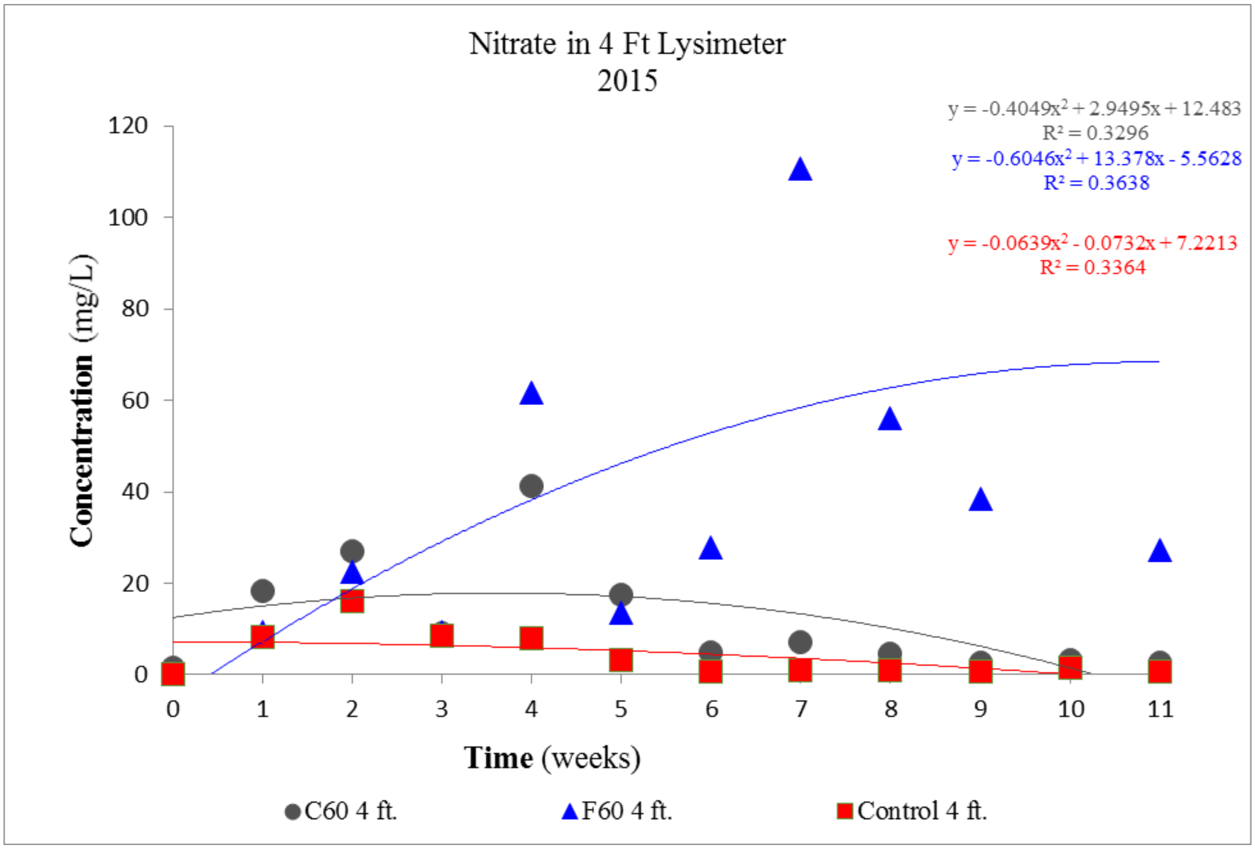

Figure 19: 2015 – Dry season based on 60 tons per acre of inorganic fertilizer (F60) equivalent N. No composts were applied on (C60) study plots study plots (weekly samples from 4 ft. lysimeters)

Notes: C60 = 60 t/acre of compost equivalent N

F60 = 60 t/acre of N inorganic fertilizer

There was high nitrate leaching at the 2 ft. (C90) composted organic plots at the beginning of the planting season. The possibility of high rainfall could have elevated the levels of nitrate leaching but could not be confirmed due to the lack of rain gauge. At 4 ft. (Figure 19), the nitrate leaching was very high (over 100 mg/L).

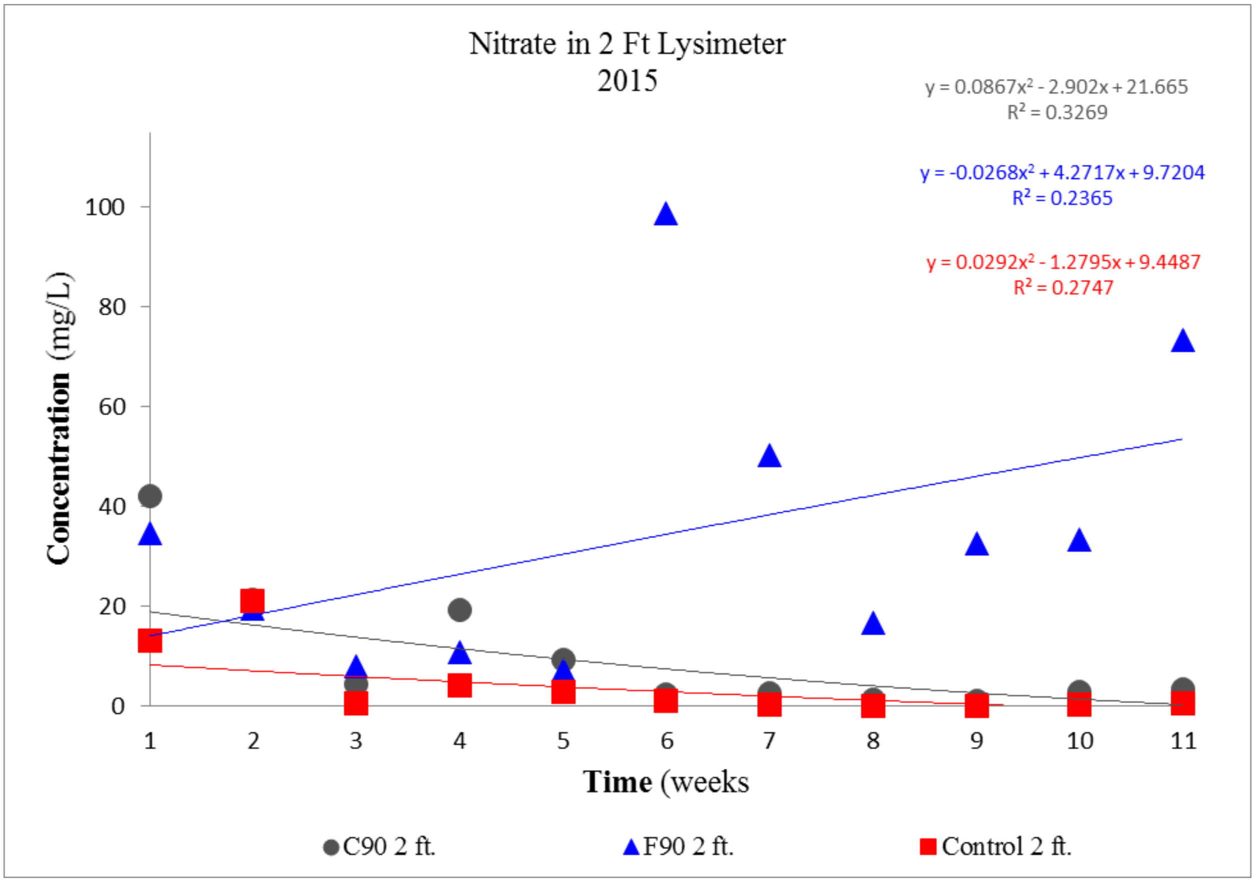

Figure 20: 2015 – Dry season based on 90 tons per acre of inorganic fertilizer equivalent N. No composted organic wastes were applied on (C90) study plots (weekly samples from 2 ft. lysimeters)

Notes: C90 = 90 t/acre of compost equivalent N

F90 = 90 t/acre of N inorganic fertilizer

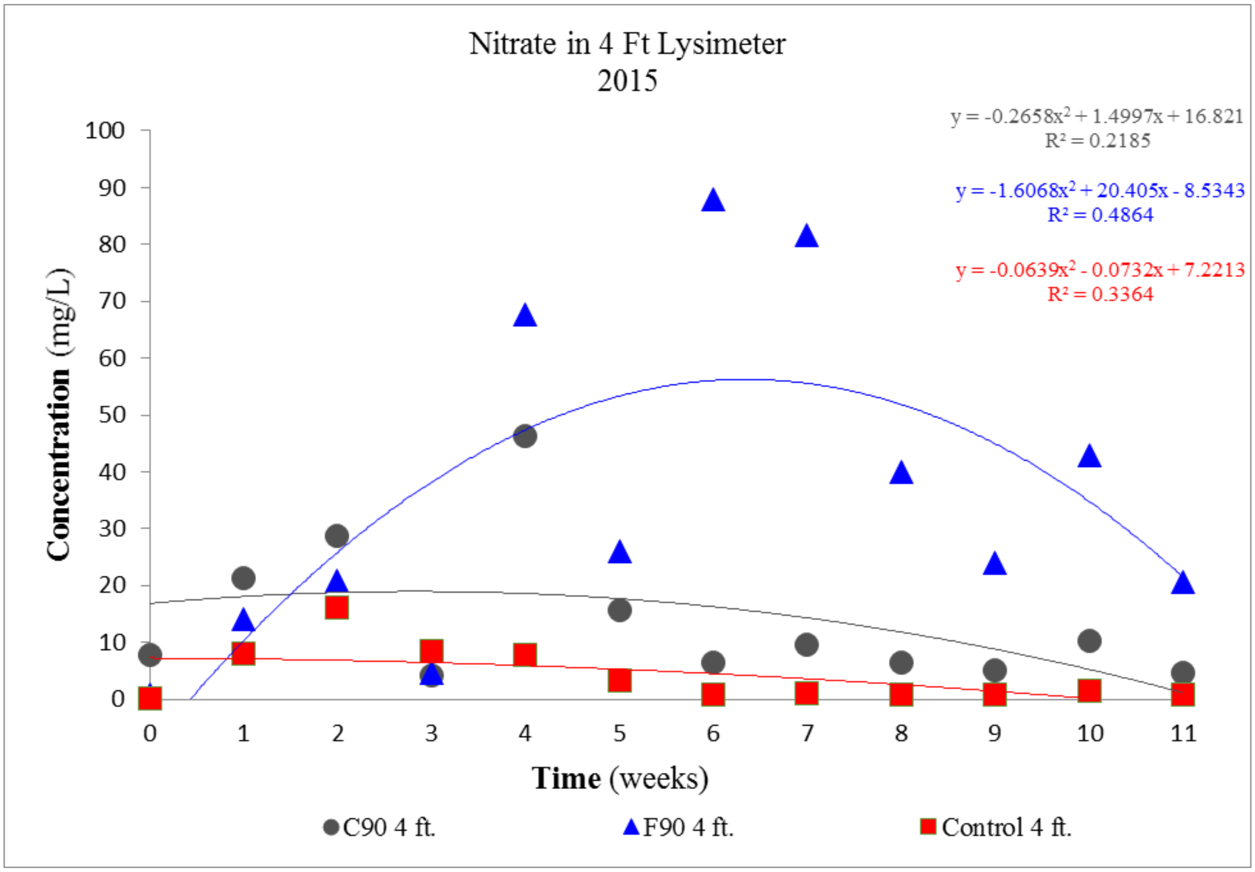

Figure 21: 2015 – Dry season based on 90 tons per acre of inorganic fertilizer equivalent N. No composted organic wastes were applied on (C90) study plots (weekly samples from 4 ft. lysimeters)

Notes: C90 = 90 t/acre of compost equivalent N

F90 = 90 t/acre of equivalent N inorganic fertilizer

At 90 tons per acre application (Figure 20, 21), followed the same pattern as the 60 tons per acre inorganic fertilizer application (figure 18, 19). At the 4 ft. depths (Figure 21), the parabola shaped trend indicated rapid leaching of nitrate of the fertilizer-applied plots.

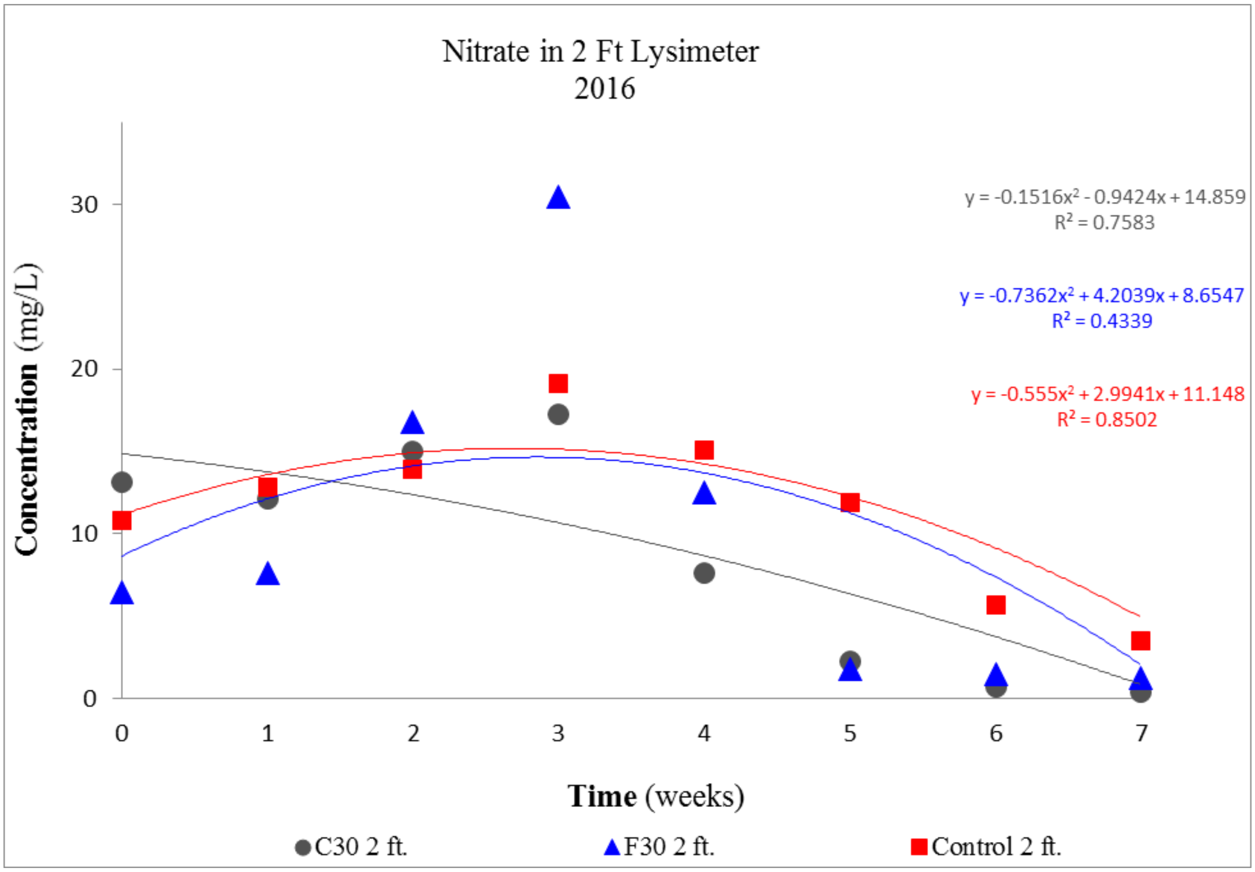

Figure 22: 2016 – Rainy season based on 30 tons per acre of compost equivalent N on study plots (weekly samples from 2 ft. lysimeters)

Notes: C30 = 30 t/acre of compost equivalent N

F30 = 30 t/acre of N inorganic fertilizer

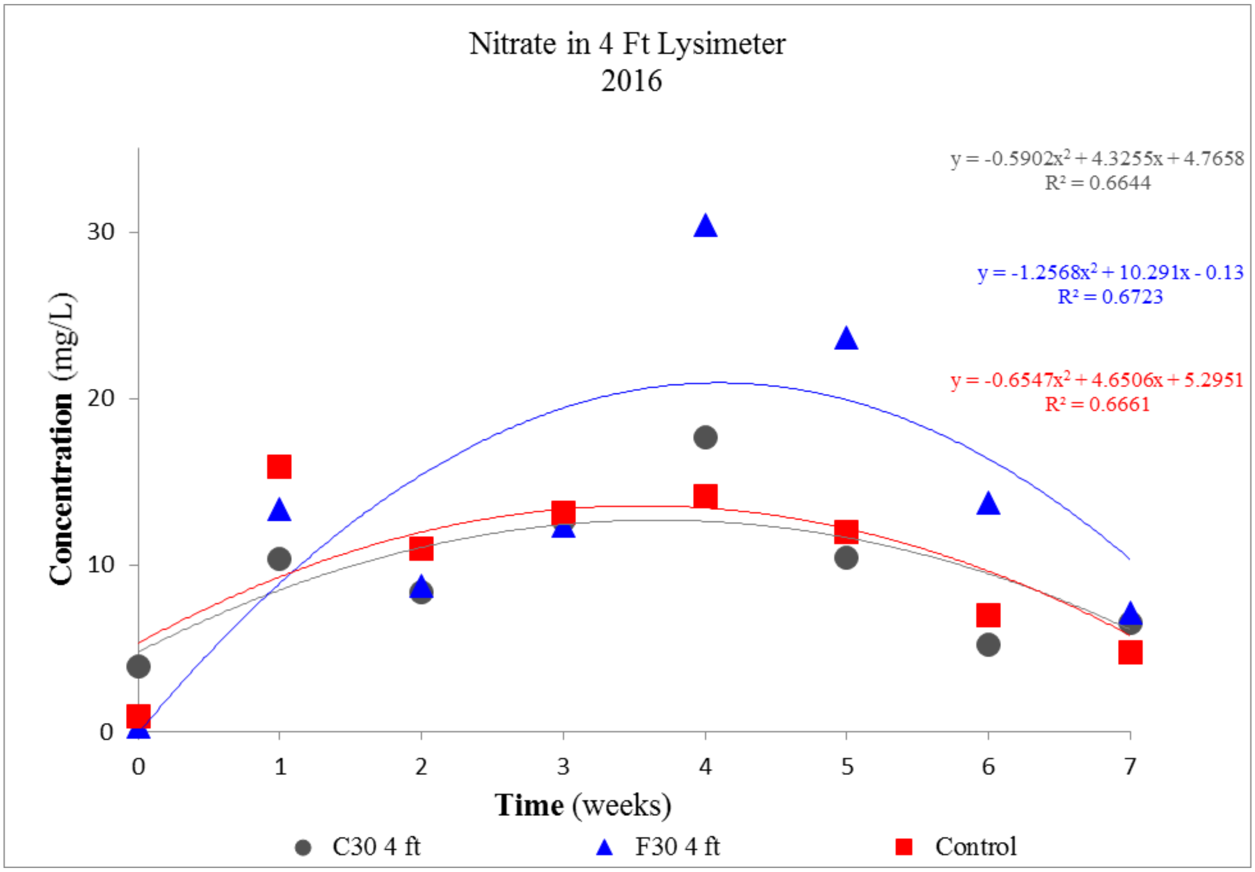

Figure 23: 2016 – Rainy season based on 30 tons per acre equivalent N application on study plots (weekly samples from 4 ft. lysimeters)
Notes: C30 = 30 t/acre of compost equivalent N
F30 = 30 t/acre of equivalent N inorganic fertilizer

During the third crop year (rainy season), nitrate leaching was rapid at 2 ft. (30 mg/L after 2 weeks of fertilizer application) (Figure 22). The nitrate leaching was also elevated at 4 ft. depth (Figure 23).

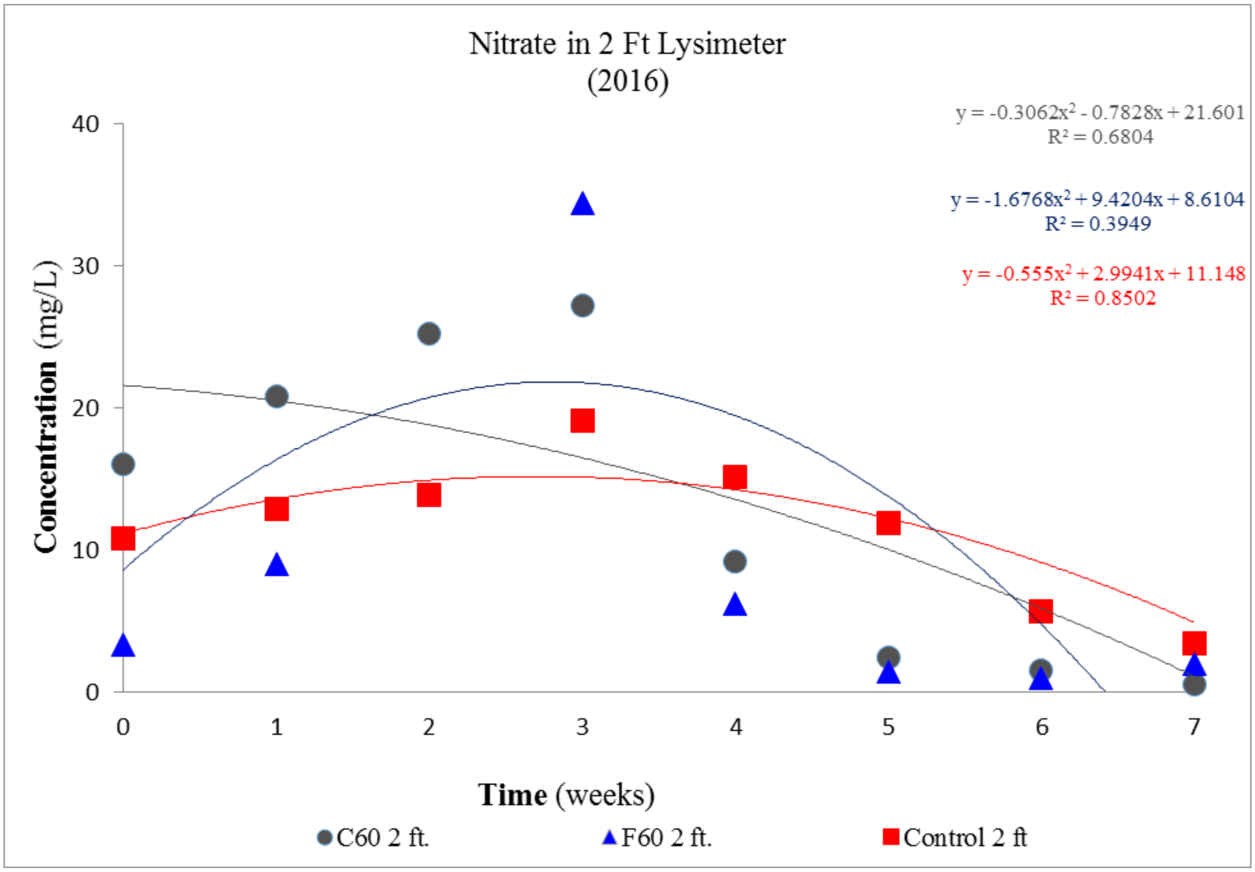

Figure 24: 2016 – Rainy season based on 60 tons per acre of equivalent N application on study plots (weekly samples from 2 ft. lysimeters)

Notes: C60 = 60 t/acre of compost equivalent N

F60 = 60 t/acre of equivalent N inorganic fertilizer

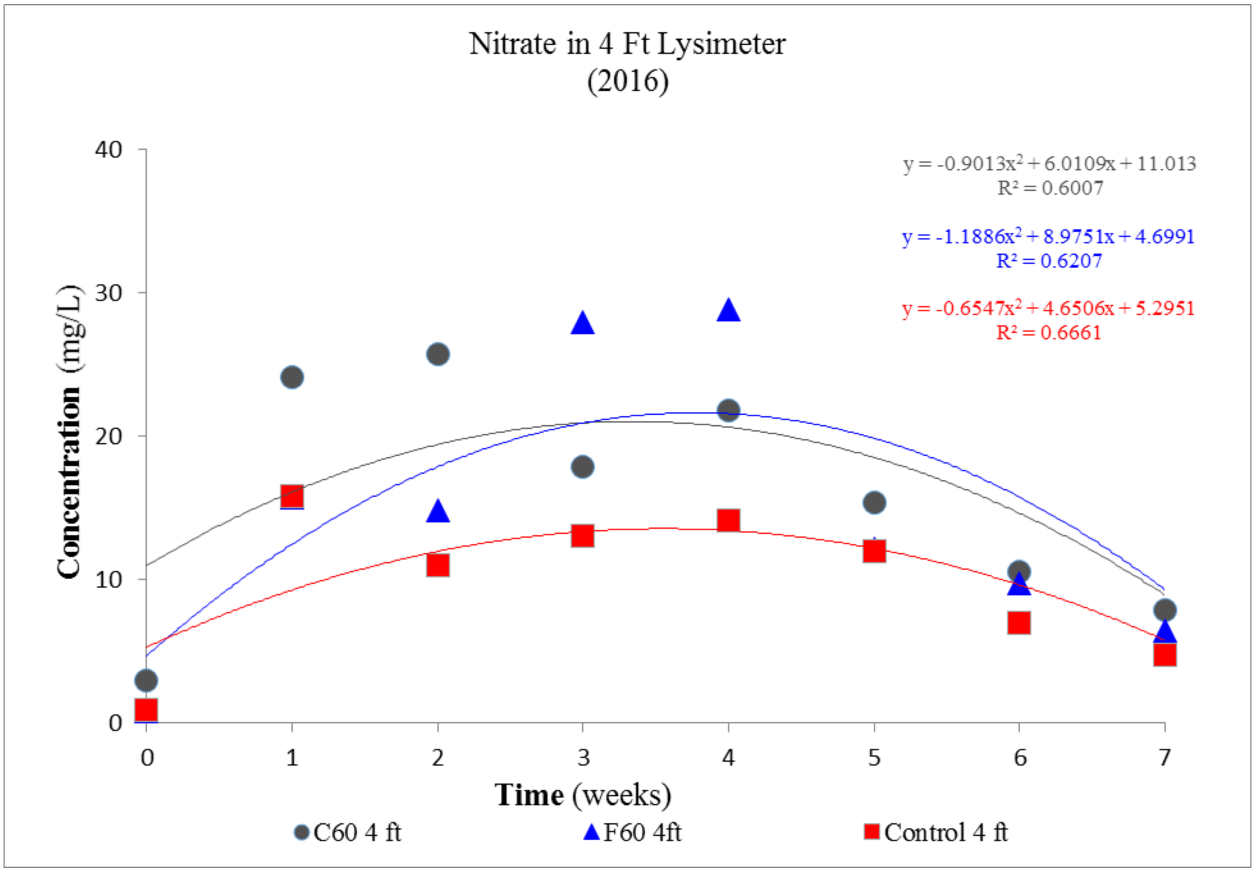

Figure 25: 2016 – Rainy season based on 60 tons per acre of equivalent N application on study plots (weekly samples from 4 ft. lysimeters)
Notes: C60 = 60 t/acre of compost equivalent N
F60 = 60 t/acre of equivalent N inorganic fertilizer

At 60 tons per acre application (Figure 24, 25), all treatments indicate equal levels of nitrate leaching. Control plots also shows elevated leaching of nitrate possibly due to surface runoffs caused by the high rainfall.

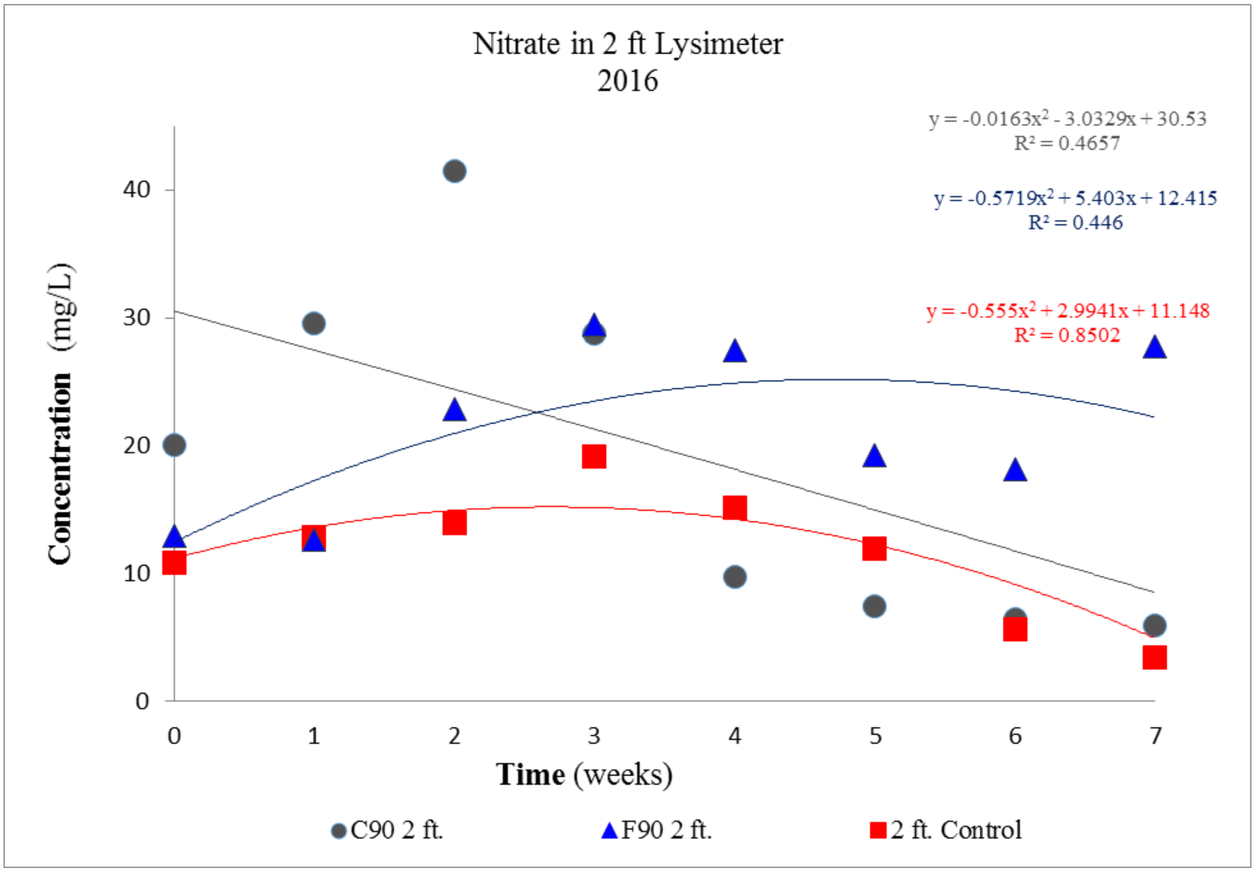

Figure 26: 2016 – Rainy season based on 90 tons per acre of equivalent N application on study plots (weekly samples from 2 ft. lysimeters)

Notes: C90 = 90 t/acre of compost equivalent N

F90 = 90 t/acre of equivalent N inorganic fertilizer

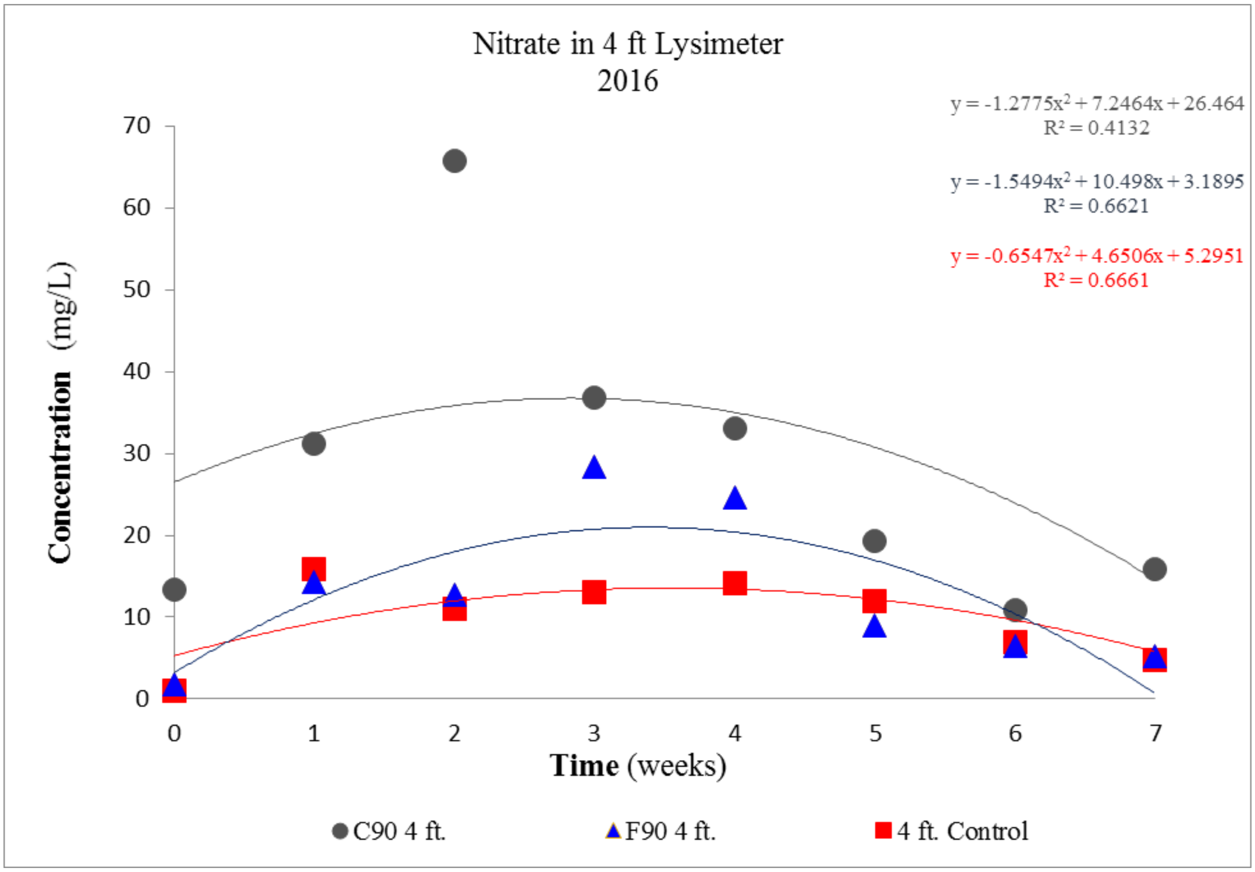

Figure 27: 2016 – rainy season based on 90 tons per acre of equivalent N application on study plots (weekly samples from 4 ft. lysimeters)
Notes: C90 = 90 t/acre of compost equivalent N
F90 = 90 t/acre of equivalent N inorganic fertilizer

At 90 tons per acre of compost and inorganic fertilizer applications (Figure 26 & 27), both treatments have the same levels of leaching in the 2 ft. zones. However, at 4 ft. depths, the composted study plots seem to indicate higher nitrate leaching than the inorganic fertilizer. Due to heavy rains brought by the rainy season, it is possible that the inorganic fertilizer was either percolated rapid in the soil profile or washed away and was not detected by the lysimeters.

Soil Organic Matter (SOM)

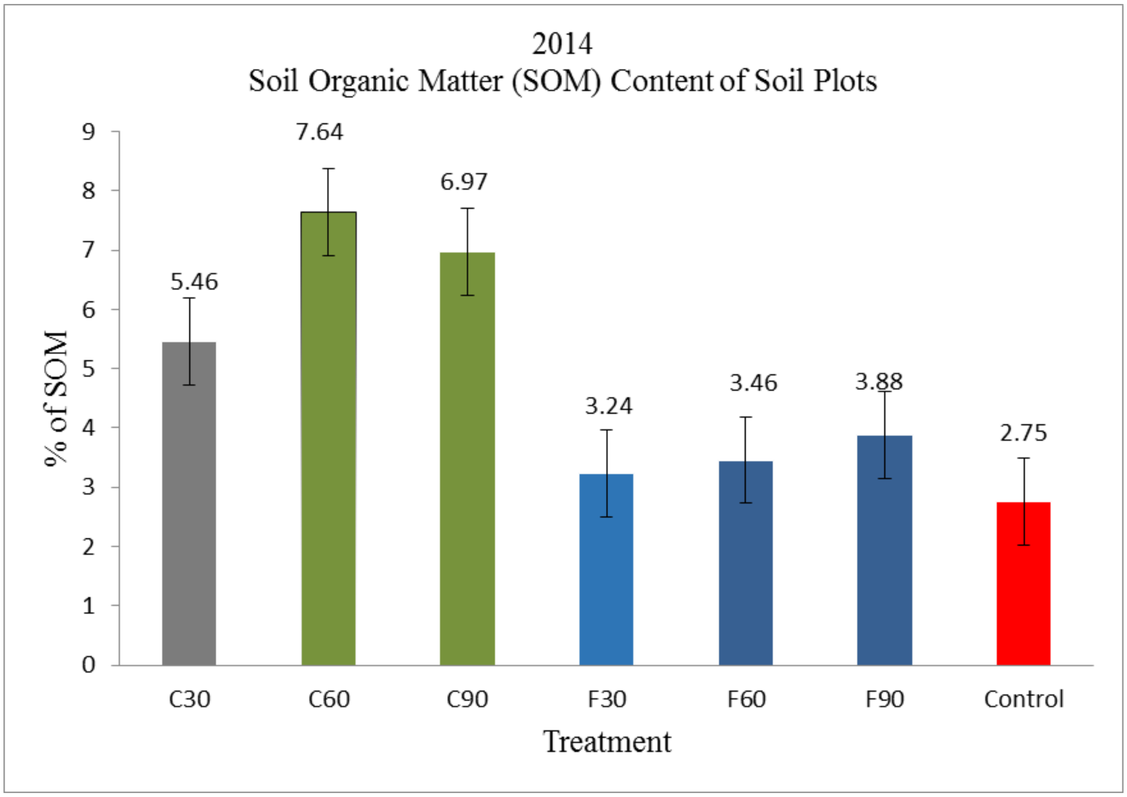

Figure 28: 2014 Soil organic matter (SOM) content (%) based on all treatments

Based on the 2014 of collected SOM (Figure 28) sampled from all study plots, compost applied study plots were significantly higher soil organic matter content than inorganic fertilizer applied plts and control plots. Both C60 and C90 (compost plots) were significantly higher (SOM) than 30 tons per acre (C30) plots.

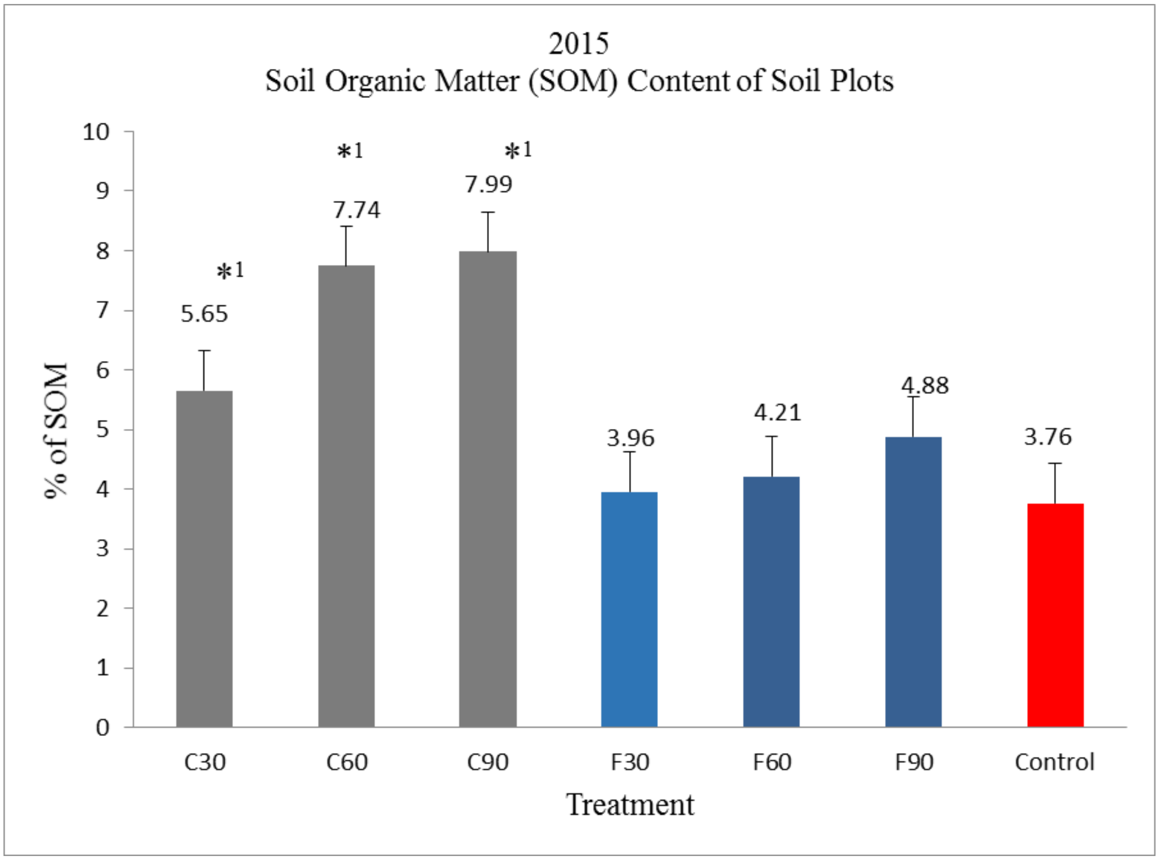

Figure 29: 2015 Soil organic matter (SOM) content (%) based on all treatment rates
Notes: *[1] = compost was not applied

In 2015, compost was not applied on all compost plots (C30, C60, C90) but inorganic fertilizers were applied on all fertilizer plots (F30, F60, F90). All compost study plots had higher SOM than fertilizer and control plots (Figure 29). The SOM content of compost plots remained the same in 2015 despite the non-application of composts.

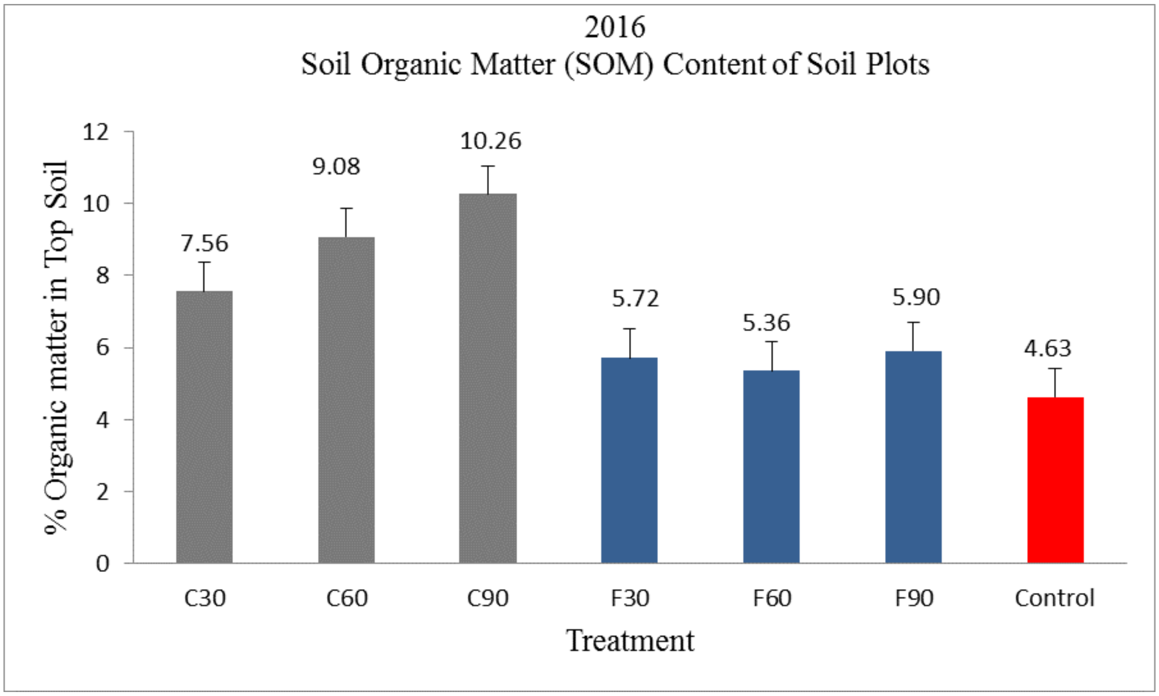

Figure 30: 2016 Soil organic matter (SOM) content (%) based on all treatments

In 2016 (rainy season), compost was re-applied again to all compost plots (C30, C60, C90) with the same rate as in 2014. SOM content (Figure 30) in the compost study plots increased due compost reapplication. Despite the high rainful and high carbon to nitrogen ratio (C:N) of 30:1 that was obtained from the compost, the SOM increased.

Bulk Density

The critical value of bulk density for restricting root growth varies with soil type (Hunt and Gilkes, 1992) but in general, bulk densities greater than 1.6 g/cm^3 tend to restrict root growth (McKenzie et al., 2004). In this study, the soil plots were tilled prior to compost and fertilizer application. Also, majority of the soil plots had high amount of sodium carbonate rocks, which increased the bulk density of the samples. However, inorganic fertilizer and control study plots showed higher bulk density (BD) had a mean of 1.36 g/cm^3 while composted organic plots mean was 1.16 g/cm^3. This showed that composted organic waste applied as soil amendment improved the soil physical property due to the increased of soil organic matter. It also showed that control soil plots and fertilizer soil plots bulk density were not significant based on the error bars.

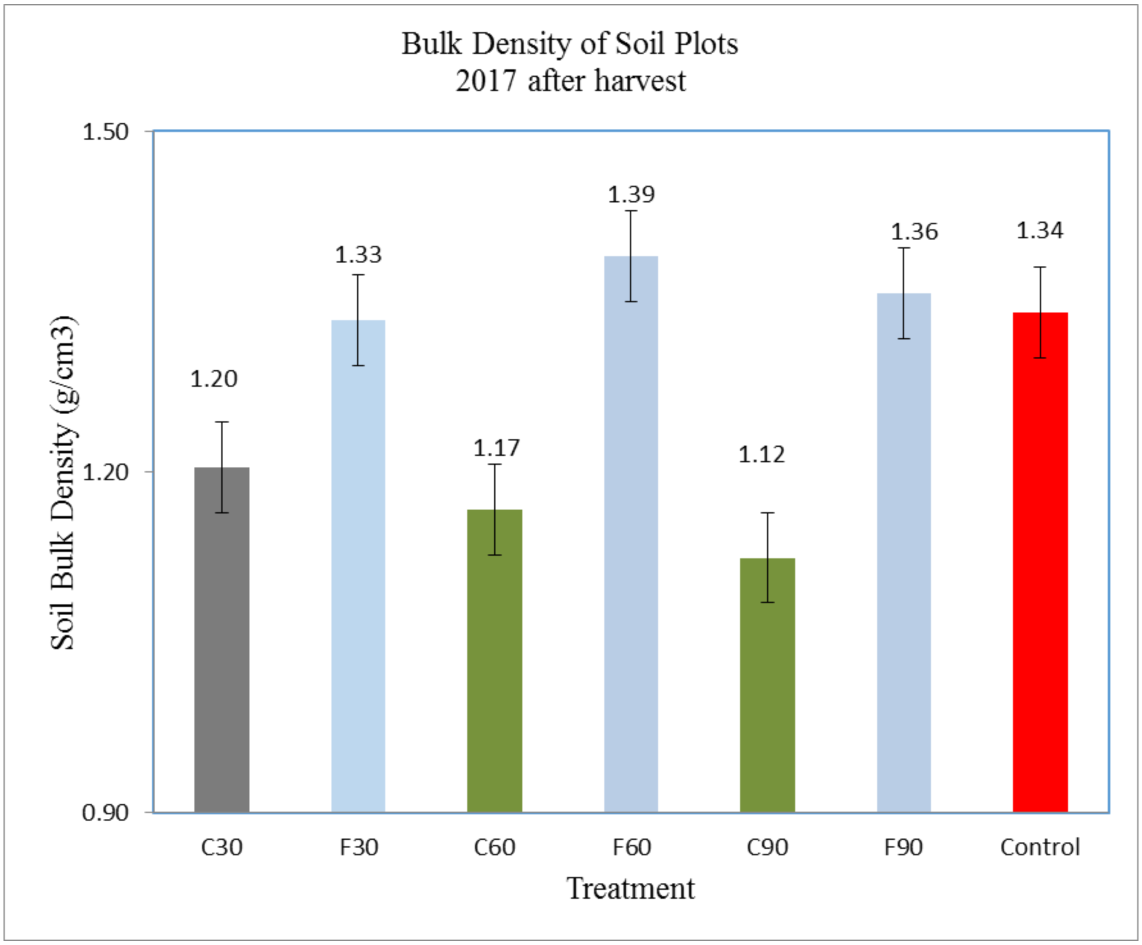

Figure 31: Bulk density of soil plots after harvest
Note: Top soil sampled only, approximately 2.5 cm deep

Nitrogen and Carbon Percentage

Table 7: Total Nitrogen Content of the Soil Plots Under Study

Level	Total Nitrogen (%)
Very low	< 0.1
Low	0.1 - 0.2
Medium	0.2 - 0.5
High	0.5 - 1.0
Very high	> 1

Total nitrogen (%) in the composted organic plots were higher than inorganic fertilizer plots (Table 8) during the first year (2014 - dry season), second year (2015 - dry season) (Table 9), and the third year (rainy season). Compost plots were in the range of medium to high nitrogen percentage while inorganic fertilizer plots were in the low to medium. Despite the non application of compost during the second year, the nitrogen percentage in the soil was still high.

Table 8: Total nitrogen and carbon and carbon to nitrogen ratio in the soil plots 2014 (dry season)

Yigo Soil Plots	2014					
	Pre-plant (8/1/2013)			After Harvest (2/10/2014)		
Treatment	% N	% C	C:N	% N	% C	C:N
C30	0.26	6.60	26:1	0.34	9.48	28:1
F30	0.26	10.18	39:1	0.26	10.51	41:1
C60	0.44	11.59	26:1	0.51	11.46	23:1
F60	0.23	10.16	45:1	0.27	13.17	49:1
C90	0.33	8.02	25:1	0.33	6.66	20:1
F90	0.28	11.46	42:1	0.29	12.14	42:1
CONTROL	0.21	8.56	42:1	0.20	8.18	40:1

Table 9: Total nitrogen and carbon and carbon to nitrogen ratio in the soil plots (2015 - dry season)

Yigo Soil Plots	2015 (no compost applied)					
	Pre-plant (6/13/2014			After Harvest (2/2/2015)		
Treatment	% N	% C	C:N	% N	% C	C:N
C30	0.38	8.70	23:1	0.39	8.97	23:1
F30	0.25	10.18	41:1	0.30	11.00	37:1
C60	0.51	11.91	23:1	0.48	12.89	27:1
F60	0.28	10.01	36:1	0.31	11.74	38:1
C90	0.50	11.50	23:1	0.45	11.26	25:1
F90	0.29	11.31	40:1	0.33	12.15	37:1
CONTROL	0.24	8.76	37:1	0.23	9.62	42:1

Table 10: Total nitrogen and carbon and carbon to nitrogen ratio in the soil plots (third year – rainy season)

Yigo Soil Plots	2016					
	Pre-plant (9/9/2016)			After Harvest (12/21/2016)		
Treatment	% N	% C	C:N	% N	% C	C:N
C30	0.44	9.21	21:1	0.40	9.85	24:1
F30	0.38	11.40	30:1	0.30	10.88	36:1
C60	0.53	11.77	22:1	0.47	12.50	27:1
F60	0.39	12.10	31:1	0.28	11.49	42:1
C90	0.53	10.72	20:1	0.50	12.62	25:1
F90	0.40	12.07	30:1	0.29	11.82	41:1
CONTROL	0.33	9.58	29:1	0.25	9.33	37:1

Carbon to Nitrogen Ratio

Carbon to nitrogen ratio (C:N) is the ratio of carbon to nitrogen in a substance. For examples, a C:N of 5:1 means there are 5 units carbon for each unit of nitrogen. The carbon to nitrogen ratio in the soil less than 24:1 can lead to nitrogen surplus while anything greater than 24:1 can lead to nitrogen deficiency. The composted plots were in ideal range of less than 24:1 while most of the inorganic fertilizer plots are beyond 30:1 carbon to nitrogen ratio.

Phosphorus

Another major essential nutrient needed by plants and also found in fertilizers is Phosphorus. Phosphorus (P) is needed for plant's growth and maturity and plays a key role in photosynthesis (Conley et al., 2009). Although phosphorus is not considered toxic to humans, high concentration in fresh water can lead to rapid growth of algae. This leads to decreased in water visibility and reduced oxygen in the water that is detrimental to the fish population. Surface runoffs containing excess phosphorus can also reach beach areas increasing algae in the water; this can affect tourism, a major contributor to Guam's economy.

Phosphorus (P) used in agriculture is in a form of phosphate. Most phosphatic fertilizers are made of highly pure monocalcium or dicalcium orthophosphate, $Ca(H_2PO_4)2$ and $CaHPO_4$ (Van Wazer, 2014). Although phosphorus is essential for plant growth, in some agriculture the availability of phosphorus is often limited (Richardson, et al., 2011). The availability of P to plants for uptake and use is reduced in alkaline and calcareous soil such as in northern Guam due to the presence of calcium phosphate minerals**.**

The application of organically complexed P from humic substances such as compost can enhance P nutrition and result in higher yield (Hopkins, Ellsworth, 2005). As an alternative, slow release and cation complexed fertilizer P may also increase crop yield. The phosphate captured from the lysimeters in this study is mostly undetectable and rarely reached 1.5 ppm. The analysis and impact of Phosphate was not reported since the emphasis was on nitrogen.

Electrical Conductivity

Electrical conductivity (EC_a) is a measurement of soil salinity, which is often associated with irrigated farmlands, or shallow water tables in arid-zone regions (Corwin, Lesch , 2005). Although plants absorb nutrients in the form of soluble salts, excessive salinity can affect plant growth (Shrivastava, Kumar, 2015). Since the northern Guam soil is highly porous and regularly receives high amount of rain, any increase in salinity can be attributed to excess application of composted organic wastes.

Though composted organic wastes can improve soil fertility, there are concerns of the salt contents in the soil. Research indicates that composts that have high salt content without leaching may affect plant growth rate (Reddy, *et al*., 2012). However, in this study, the effects of composted organic wastes in the soil salinity were minimal (table 12). Soil plots were tested again after harvest (Table 13) for soil salinity and the composted organic study plots resulted in lower electrical conductivity thus water suitability became excellent based on the standard (EC) Range (Table 11).

Table 11: Electrical Conductivity (EC) Range as Related to Water Suitability

Class of Water	Specific Conductance dS/m
Excellent	<0.25
Good	0.25 to 0.75
Permissible	0.76 to 2.00
Doubtful	2.01 to 3.00 (may contain salt)
Unsuitable for irrigation	> 3.00 (contains salts)

Table 12: 2016 (Rainy Season) Electrical Conductivity (EC) Test of Study Plots Before Planting

Treatment	Avg. dS/m	^{o}C	Class of Water
C30	0.26	22.2	Good
F60	0.24	22.2	Excellent
C60	0.26	22.2	Good
F90	0.24	22.2	Excellent
C90	0.27	22.1	Good
F30	0.22	22.1	Excellent
Control	0.20	22.2	Excellent

Table 13: 2016 (Rainy Season) Electrical Conductivity (EC) Test of Study Plots After Harvest

Treatment	Avg. dS/m	Class of water
C30	0.20	Excellent
F30	0.16	Excellent
C60	0.20	Excellent
F60	0.16	Excellent
C90	0.21	Excellent
F90	0.17	Excellent
Control	0.14	Excellent

DISCUSSION

Organic Matter

Compost application on study plots maintained higher soil organic matter (SOM) even when compost was not reapplied in 2015 (dry season). This showed that organic matter from compost has carryover effects of nutrients. By increasing organic matter, soil in northern Guam may increase soil water and nutrient holding capacity (cation exchange capacity), which can also reduce the unnecessary leaching of nutrient (N, P) chemicals in the underground water supply. Soils that were low in organic matter however experienced low crop yield.

Soil organic matter contributes for improved soil structure for better root penetration and proliferation. The lack of soil organic matter leads to increase in soil bulk density therefore affecting plant growth and development.

Nitrate Leaching

The application of composted organic waste in the porous soil of northern Guam not only increased soil fertility but also has lower leaching of nutrients such as nitrate. Inorganic fertilizer on the other hand percolated nitrate rapidly beyond 30.5 cm. especially during the rainy season.

CONCLUSION AND RECOMMENDATION

Increasing organic matter in the soil using composted organic wastes may be beneficial to farmlands located above groundwater system. Since the application of soil organic matter can slow down leaching by retaining the nutrient in the water that would otherwise drain down beyond the root zone allowing sufficient residence time within the root zone for plant uptake of available nutrients (Golabi et al., 2007). The poorly structured soils on Guam and other tropical islands in the western Pacific may benefit with the land application of composted organic wastes to increasing crop production and improving soil quality while preserving environmental quality of the groundwater system (Golabi et al., 2004).

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APPENDIX I

Physical And Chemical Data

Organic Matter (SOM) Content of Soil Study Plots

Treatment	2013	2014	2016
C30	5.11	5.54	6.68
F30	4.06	3.92	5.66
C60	7.99	8.28	8.63
F60	4.51	3.79	5.61
C90	6.58	10.05	8.02
F90	4.51	4.46	5.56
Control	3.14	3.54	4.52

Bulk Density Of Soil Study Plots

Treatment	D_b avg.
C30	1.20
F30	1.33
C60	1.17
F60	1.39
C90	1.12
F90	1.36
Control	1.34

2016 Soil Salinity Test

Plots	Treatments	µS/cm	dS/m	°C
I-1	C30	274	0.27	21.9
I-2	F60	276	0.28	21.9
I-3	C60	243	0.24	21.9
I-4	F90	260	0.26	21.8
I-5	C90	282	0.28	21.7
I-6	F30	224	0.22	21.7
I-7	Control	213	0.21	21.8
II-1	F30	211	0.21	22
II-2	C90	270	0.27	22
II-3	C30	285	0.29	22
II-4	C60	273	0.27	21.8
II-5	F60	232	0.23	22.2
II-6	Control	208	0.21	22.2
II-7	F90	244	0.24	22.1
III-1	C60	233	0.23	22.4
III-2	C30	258	0.26	22.3
III-3	C90	253	0.25	22.3
III-4	Control	187.6	0.19	22.2
III-5	F30	200	0.20	22.2
III-6	F60	231	0.23	22.1
III-7	F90	235	0.24	22.2
IV-1	C60	293	0.29	22.5
IV-2	C90	262	0.26	22.5
IV-3	Control	171.8	0.17	22.5
IV-4	C30	206	0.21	22.4
IV-5	F90	209	0.21	22.5
IV-6	F30	231	0.23	22.4
IV-7	F60	207	0.21	22.4

Soil Carbon and Nitrogen Content

Sampled on 12/21/16

Plot	Date Tested	% N	% C	Treatment
I-1	02/07/2017	0.45	8.50	C30
I-2	02/07/2017	0.37	6.81	F60
I-3	02/07/2017	0.48	13.44	C60
I-4	02/07/2017	0.28	10.93	F90
I-5	02/07/2017	0.49	13.99	C90
I-6	02/07/2017	0.26	10.63	F30
I-7	02/07/2017	0.24	10.82	CONTROL
II-1	02/07/2017	0.35	6.37	F30
II-2	02/07/2017	0.54	12.38	C90
II-3	02/07/2017	0.40	11.37	C30
II-4	02/07/2017	0.45	13.65	C60
II-5	02/07/2017	0.23	12.04	F60
II-6	02/07/2017	0.27	10.67	CONTROL
II-7	02/07/2017	0.28	10.18	F90
III-1	02/07/2017	0.42	11.44	C60
III-2	02/07/2017	0.41	9.67	C30
III-3	02/07/2017	0.47	12.12	C90
III-4	02/07/2017	0.28	11.50	CONTROL
III-5	02/07/2017	0.24	13.21	F30
III-6	02/07/2017	0.29	12.95	F60
III-7	02/07/2017	0.30	13.37	F90
IV-1	02/07/2017	0.54	11.47	C60
IV-2	02/07/2017	0.51	11.99	C90
IV-3	02/07/2017	0.23	4.32	CONTROL
IV-4	02/07/2017	0.36	9.86	C30
IV-5	02/07/2017	0.31	12.80	F90
IV-6	02/07/2017	0.37	13.33	F30
IV-7	02/07/2017	0.22	14.14	F60

APPENDIX II

NITRATE DATA FROM LYSIMETERS

2014 Nitrate Data (April to July 2014)

Time (Weeks) →		0	1	2	3	4	5	6	7	8	9
Treatment	Depth	4/7/2014	4/14/14	4/21/14	5/7/2014	5/12/2014	5/19/2014	5/27/2014	6/3/2014	6/10/14	7/16/2014
C30	2	2.59	7.15	5.75	8.32	8.22	2.82	0.54	0.41	0.073	1.57
C30	4	0.60	2.06	6.07	11.78	13.31	11.50	9.63	8.51	0.523	1.12
F60	4	0.47	1.93	5.10	6.86	16.41	25.67	20.66	27.27	2.277	62.26
F60	2	1.82	3.52	3.93	13.77	75.87	32.60	14.47	22.14	2.575	100.15
C60	2	7.36	17.33	24.59	15.37	15.59	18.50	5.38	3.33	0.943	7.51
C60	4	1.39	2.40	5.56	11.13	12.55	11.80	12.29	14.66	2.291	7.39
F90	4	1.59	4.39	4.90	19.16	23.14	24.65	11.52	9.51	1.055	33.47
F90	2	1.40	3.90	4.83	5.74	7.23	4.10	1.97	5.57	1.436	2.87
C90	2	7.99	5.65	12.43	25.69	18.53	26.47	15.15	14.84	2.045	28.39
C90	4	3.23	5.53	8.77	8.25	10.10	8.15	12.24	13.16	1.127	12.83
F30	4	0.38	1.20	4.33	6.42	9.69	20.71	13.07	12.48	1.366	60.35
F30	2	2.37	4.25	5.90	12.73	11.50	17.70	4.05	5.27	0.576	26.38
CONTROL	4	0.57	2.91	3.54	3.55	4.37	3.83	3.30	0.96	0.155	0.26
CONTROL	2	4.51	3.13	4.06	8.48	9.27	10.64	4.00	3.82	0.196	0.14

2015 Nitrate Data

Time (weeks) →		0	1	2	3	4	5	6
Treatment	Depth (ft.)	10/30/14	12/29/14	1/8/2015	1/14/2015	1/23/2015	1/30/15	2/6/15
C30	2	0.13	20.28	28.50	4.20	3.82	1.04	0.15
C30	4	0.09	18.43	24.15	5.86	26.92	17.14	0.04
F60	4	0.15	9.28	22.47	9.27	61.63	13.47	27.96
F60	2	0.05	30.58	32.75	8.25	4.87	7.78	21.63
C60	2	1.04	46.90	26.22	7.29	5.88	3.23	0.79
C60	4	1.52	18.28	26.93	9.07	41.26	17.37	4.78
F90	4	0.71	14.16	20.85	4.66	67.73	25.95	87.99
F90	2	0.25	34.55	19.47	7.86	10.78	7.25	98.81
C90	2	2.62	42.08	21.31	4.23	19.28	9.33	2.16
C90	4	7.75	21.33	28.70	4.27	46.21	15.69	6.46
F30	4	0.05	8.61	16.33	2.89	18.15	10.86	4.71
F30	2	0.08	21.15	28.33	6.18	2.62	2.72	6.31
CONTROL	4	0.08	8.12	16.16	8.44	7.89	3.27	0.81
CONTROL	2	0.07	13.03	13.70	0.62	4.05	2.86	0.98

Continued From Page F

Time (weeks) →		7	8	9	10	11
Treatment	Depth	2/13/15	2/20/15	2/27/15	3/13/15	3/17/15
C30	2	0.02	0.05	0.02	0.27	0.48
C30	4	3.80	1.42	1.13	2.39	2.31
F60	4	110.65	56.22	38.56	133.26	27.38
F60	2	38.30	38.59	34.37	30.77	39.80
C60	2	1.48	1.19	1.07	2.08	2.41
C60	4	7.24	4.72	2.63	3.19	2.63
F90	4	81.68	40.00	24.00	42.92	20.64
F90	2	50.37	16.53	32.56	33.27	73.30
C90	2	2.60	1.35	1.07	2.90	3.41
C90	4	9.55	6.35	5.00	10.36	4.66
F30	4	65.06	36.79	25.49	28.84	7.18
F30	2	28.66	4.14	2.35	3.09	2.39
CONTROL	4	0.98	0.84	0.74	1.42	0.75
CONTROL	2	0.24	0.05	0.00	0.14	0.60

2016 Nitrate Data

Time (Weeks (0-8)

Treatment	Depth	0	1	2	3	4	5	6	7	8
C30	2	13.15	12.09	14.98	17.23	7.62	2.28	0.68	0.39	0.48
C30	4	3.90	10.39	8.35	12.69	17.70	10.44	5.22	6.56	2.95
F30	4	0.28	13.38	8.72	12.37	30.43	23.70	13.76	7.12	3.18
F30	2	6.42	7.65	16.78	30.45	12.49	1.81	1.44	1.24	0.77
C60	2	16.03	20.80	25.21	27.21	9.22	2.48	1.52	0.51	0.79
C60	4	2.96	24.12	25.78	17.84	21.78	15.40	10.53	7.83	5.42
F60	4	0.85	15.76	14.87	27.93	28.88	12.16	9.71	6.40	6.37
F60	2	3.29	9.02	40.55	34.40	6.21	1.40	1.00	2.02	20.00
C90	2	20.00	29.51	41.49	28.73	9.72	7.40	6.37	5.89	13.16
C90	4	13.41	31.23	65.74	36.88	33.08	19.27	10.80	15.79	12.26
F90	4	1.75	14.30	12.72	28.38	24.60	9.01	6.54	5.24	35.73
F90	2	12.95	12.66	22.88	29.50	27.49	19.27	18.10	27.70	70.17
CONTROL	4	0.94	15.87	11.01	13.10	14.16	11.94	7.01	4.733	2.774
CONTROL	2	10.78	12.86	13.93	19.13	15.11	11.93	5.66	3.457	2.073