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COLLEGE OF AGRICULTURAL SCIENCES

A STUDY OF CONSTRUCTED SOIL-MEMBRANE DIFFUSIVITY PROBES FOR THE DETERMINATION OF GASEOUS DIFFUSIVITY COEFFICIENTS AT VARYING SOIL VOLUMETRIC WATER CONTENTS

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ABSTRACT

The goal of this project was to evaluate the use of soil-membrane diffusivity probes (based on the work of Risk et al, 2008) in the determination of the gaseous diffusivity coefficient for carbon dioxide in soil of varying volumetric water contents. The earth's soils represent the largest non-anthropogenic source of greenhouse gas emissions (US EPA, 2013); and it is therefore vital to understand both the biological and physical processes by which greenhouse gases escape the soil profile and enter the earth's atmosphere because of the effect of greenhouse gases on the earth's terrestrial and aquatic ecosystems (IPCC, 2014). Soil respiration occurs due to plant and microbial activity within the soil, but gas diffusion is also a physically-based process relating to soil porosity, water content, tortuosity, and other factors (Luo & Zhou, 2006). In this study, a probe was tested in laboratory conditions using a LiCor 6200 (LiCor Biosciences, Lincoln, Nebraska) and soil of varying simulated volumetric water contents. The method of analysis tested in this paper was found to be a novel way to measure gaseous diffusivity of soil in-situ, with minimal soil disturbance and less estimation than previous methods. The use of soil-membrane diffusivity probes warrants further in-field testing and could prove to be valuable tool for soil research in the future.

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Chapter 1

Introduction

The earth's soils are the largest non-anthropogenic source of greenhouse gases emitted to the atmosphere (US EPA, 2013) – especially carbon dioxide, which is the most prevalent greenhouse gas after water vapor (US EPA, 2013). When CO_2 and other greenhouse gases enter the atmosphere they act as a reflective layer, capturing solar heat between said layer and the earth's surface and constantly reradiating it back to the land (US EPA, 2014). This raises the surface temperature of the earth over time, contributing to global warming and in turn altering terrestrial and aquatic ecosystems (IPCC, 2014). In order to predict and mitigate the effects of changing greenhouse gas concentrations it is important to understand the pathways that these gases take to enter the atmosphere. Due to its prevalence, focusing studies on carbon dioxide would help to understand the larger climate change issue. Of all of the earth's sources of carbon dioxide – both anthropogenic and natural – the pool of CO_2 in the soils and their entry to the atmosphere are arguably the most poorly understood (Rumpel et al, 2010).

The goal of this research was to gain a better understanding of the movement of carbon dioxide through soil by evaluating the use of soil-membrane probes for gas diffusivity analysis. The accuracy, precision, and ease of use of the constructed probes were assessed for various depths, topographic locations, and soil moisture content. To evaluate this I constructed multiple soil-membrane diffusivity probes based on the design of Risk, et al (2008) with modifications. Most of these probes were installed at the Shale Hills Critical Zone Observatory in Rothrock

State Forest for later study, but testing for this project occurred in the laboratory using one probe and Hagerstown soil at varying moisture contents.

Review of Soil-Gas Diffusion

Carbon dioxide is produced in the soil mainly from two major sources: plant respiration and microbial activity (Luo & Zhou, 2006). In the photosynthetic process, plants take up carbon dioxide to use for carbon compounds to create structures within themselves. Plants are also able to break down and release these carbon compounds to the environment, and when they release them through the roots this contributes to the pool of soil carbon dioxide (Luo & Zhou, 2006). Microbes in the soil produce carbon dioxide in a process called respiration. When these heterotrophic organisms consume the aforementioned carbon compounds created by plants, they release some of the by-products in the form of carbon dioxide (Luo & Zhou, 2006). The production of carbon dioxide in the soil is a biological process; however, the actual release of the gas from the soil profile is mostly a physically-based process (Luo & Zhou, 2006).

As soil depth increases, the concentration of carbon dioxide present in the profile becomes larger (Lundegårdh, 1927). Particles escape from these depths through pores present in the soil and are driven to the atmosphere mainly by a diffusive gradient, a process termed diffusion (Luo & Zhou, 2006). However, diffusion is governed by multiple variables. Soil moisture content, tortuosity, temperature, organic matter content, and texture are all things that can affect carbon dioxide emissions from the soil profile (Davidson et al, 2006; Jassal et al, 2005). As such it is difficult for one to directly and accurately measure a soil's potential for gaseous diffusion through the soil profile.

Currently there are two prominent methods used to measure the gaseous diffusivity of a soil. The first is to physically remove the soil from a site and transport it back to a laboratory setting to conduct diffusivity testing on the sample (Klute, 1986). Unless extreme care is taken this can disturb properties of the soil such as bulk density, porosity, and moisture; thus affecting the accuracy of diffusivity measurements (Klute, 1986). The second way to measure gaseous diffusivity in a soil sample is to estimate using a mathematical model that takes parameters such as depth, porosity, and moisture into account (Moldrup et al, 2004; Ungureanu et al, 2010). While more precise, this method still cannot take minute variations in soil parameters into account because it is not a direct measurement of the soil (Moldrup et al, 2004).

Studies evaluating in-situ methods of measuring soil gaseous diffusivity are scarce, but there are some. Schwen (2011) studied a method in which a chamber was placed over a large volume of soil in the field, and diffusion of gas into the headspace was calculated using a gas analyzer. Shcherbak (2013) measured diffusivity in the field by injecting a series of inert tracer gases and following them through the soil profile. Von Fischer, et al (2009) measured methanotroph activity in upland soils through a combination of both of these methods, using tracer gases and transportable surface chambers to measure soil diffusivity and in turn calculate activity. While these methods warrant further study, I believe that a more efficient and easier-to-use method is available.

Description of Study

The method for measuring soil diffusivity tested in this study is the soil-membrane diffusivity probe, based off of the work of Risk, et al (2008). The soil-membrane diffusivity probe is a small transportable instrument that is able to be inserted into the soil profile at depth. It can then be attached to a LiCor (LiCor Biosciences, Lincoln, Nebraska) gas analyzer to measure the concentration of carbon dioxide that passes across the probe's membrane. Using this information and information about the surface area of the membrane and volume of the probe, the soil's diffusivity coefficient can be calculated using Fick's Law of diffusion.

The benefits of a probe such as this are numerous. It would allow one to measure the diffusivity of a soil in-situ, rather than transporting a sample of the soil in question back to a laboratory setting. It also allows one to take multiple measurements of the same soil in different areas; or to take measurements at varying temperatures, moistures, depths, and topographic locations easily. Additionally this method inherently takes minute differences among samples into account, as opposed to a mathematical estimation of diffusivity which cannot. The ease of this method presents an opportunity for better understanding the earth's soils as a source of greenhouse gases and will allow for a more complete picture of the diffusion process.

Chapter 2

Materials & Methods

Probe Design & Construction

Probe design was based on Risk, et al 2008 with minor modifications. The body of the probe was constructed using 15.24 cm lengths of PVC pipe with a 2.54 cm outer diameter. Using a drill press, five holes with a 1.27 cm outer diameter were drilled onto each opposing side of the length of pipe (Figure 1). Pipe inserts were laser cut from a 0.635 cm-thick acrylic sheet (Figure 1).

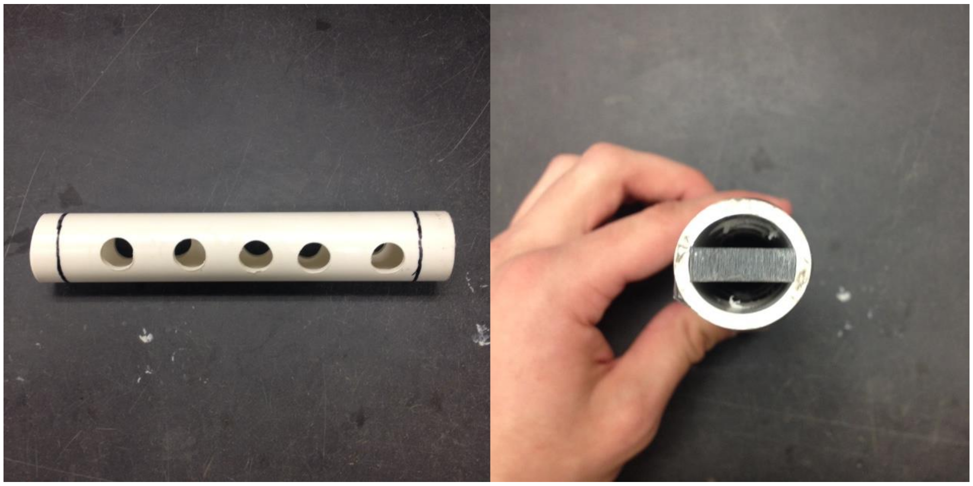

Figure 1. Plastic body of soil-membrane probe and acrylic sheet insert.

After the inserts were cut, they were inserted into the length of the pipe in order to partition each set of drilled holes from each other. Before insertion, sides of the insert were covered with weather-proof epoxy in order to bind the insert to the walls of the pipe and seal the corridor. The flat end of the insert was flush with one end of the pipe, with the curved end of the insert sticking out to be bound to pipe caps.

The membrane for the diffusivity probes was made from Tyvek® spun bonded polyolefin sheet, a protective material created and manufactured by DuPont (DuPont, Wilmington, Delaware). Membrane was cut so as to cover the entire body of the probe (including holes) and was sealed using super glue. I took care to seal around holes drilled into the probe body. In order to protect the probe membrane from the elements, stainless steel wire mesh was used to cover the membrane for the entire body of the probe. Edges of the stainless steel were covered with weather-proof tape so that sharp edges would not puncture the membrane. The wire mesh was secured using PEX cinch clamps.

For each probe, one PVC pipe cap was tapped and fitted with two brass barbed fittings. The fittings were 0.635 cm in outer diameter with a 0.3175 cm diameter barb. Two fittings were tapped into the cap, making sure to install them so that each one would be aligned with one of the separated corridors of the probe. The fitted cap was then secured to the end of the probe with the curved part of the insert sticking out. The two were bonded using weather-proof epoxy brushed onto the curved end of the insert and the inside of the cap. I took care not to cover the holes of the fittings with epoxy. The other end of the probe (the end with the flat side of the insert) was also capped and secured with epoxy. Finally, 0.3175 cm outer diameter plastic tubing was cut into appropriate lengths and secured to the barbed fittings. Tubing ends are sealed with Luer lock valves. The final probe construction is shown in Figure 2.

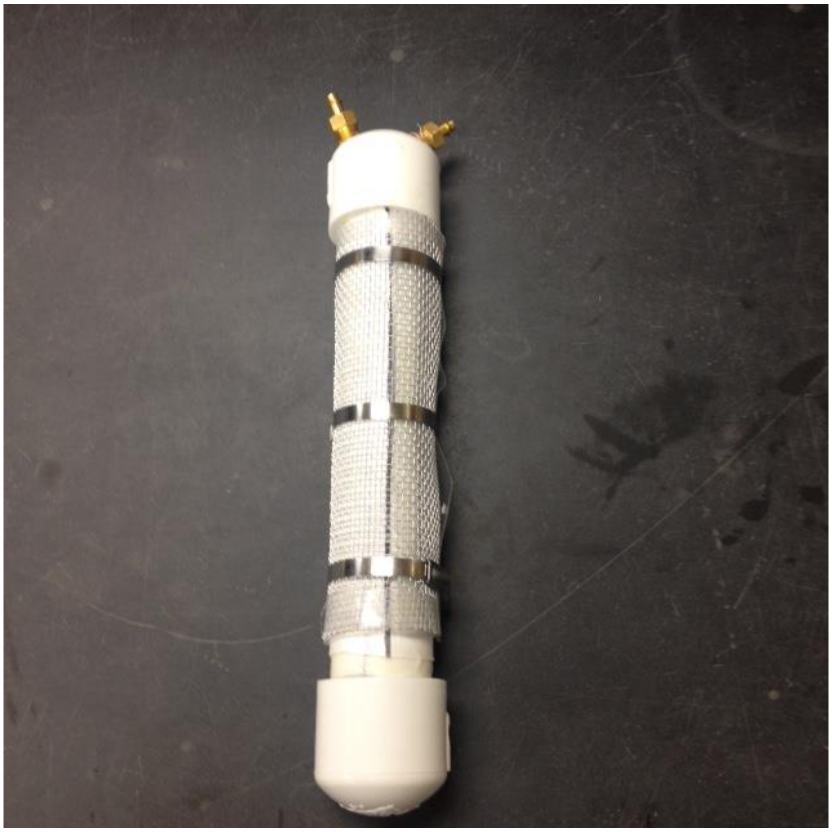

Figure 2. Final construction of the soil-membrane diffusivity probe.

CO_2 Concentration & Flux Data

Laboratory experimentation was done to test the constructed probes' accuracy and precision. For this testing I used 15067.41 cm3 of Hagerstown soil from Centre County, Pennsylvania. I placed the soil into a large bucket and buried a test probe similarly to probes that were deployed in the field with its head 10 cm deep. The probe was then connected to a LiCor 6200 gas analyzer (LiCor Biosciences, Lincoln, Nebraska). The layout of the LiCor 6200 is shown in Figure 3, and the laboratory experimental setup is shown in Figure 3. Five different volumetric water contents were tested with the probe by saturating soil and subsequent measurement using a HydroSense II Moisture Probe from Campbell Scientific (Campbell

Scientific, Logan, Utah). Volumetric water contents were as follows: 3.5%, 7.8%, 20.5%, 31.3%, and 39.6%.

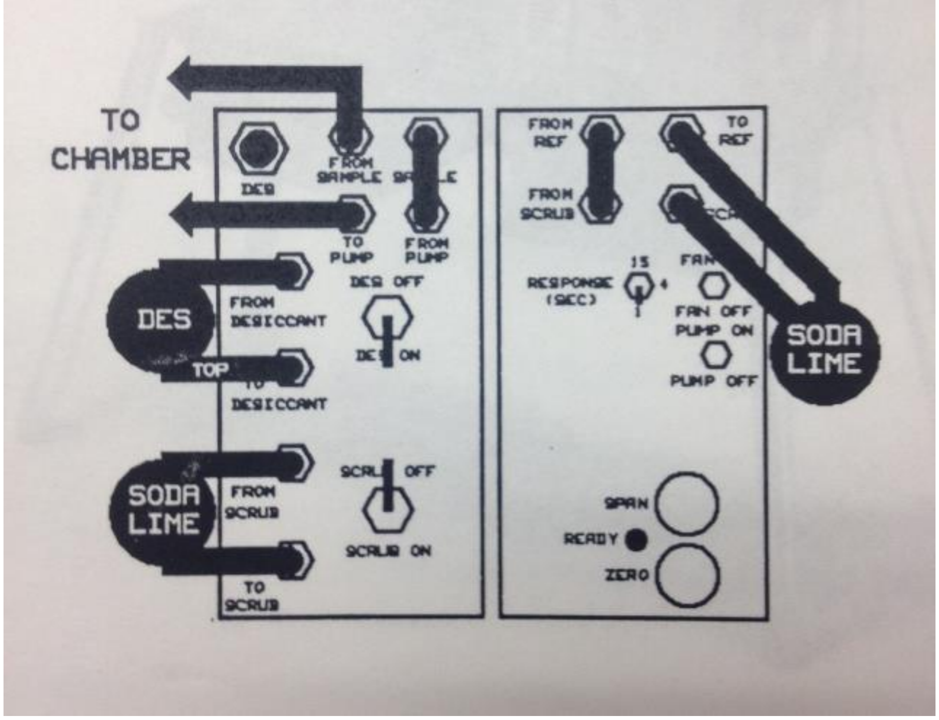

Figure 3. Layout of the LiCor 6200 (LiCor Biosciences, 1990).

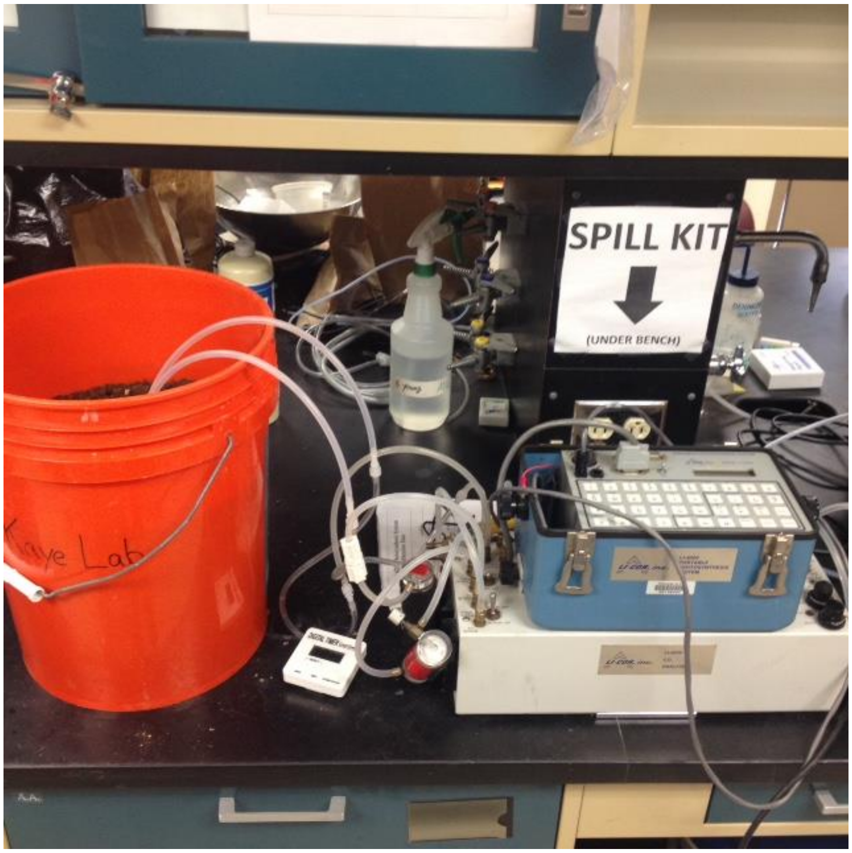

Figure 4. Final laboratory experimental set up for soil carbon dioxide monitoring.

Measurement sequences began with a control run. For this replicate soil air was pumped through a desiccant but not a carbon dioxide scrubber, in order to give a baseline reading of carbon dioxide in the soil. Soil CO_2 concentrations were measured for 2.5 minutes with a data point taken every 5 seconds. The maximum ambient soil concentration of carbon dioxide was recorded at the end of the control replicate. For each replicate after this, air was pumped through the LiCor and scrubbed through a desiccant and soda lime column for thirty seconds, then concentrations were measured for the same 2.5 minutes every 5 seconds as soil carbon dioxide built back up within the probe. Ten replicates using this method were done for each level of soil volumetric water content.

Diffusivity Calculation

Diffusivity data calculations were made using Fick's Law, which states that the flux of a gas is equal to the product of the diffusion coefficient of that gas and the molar density gradient of that gas (Tyrrell, 1964). This is given by the following formula:

$$F = D_s \frac{dC_{mol}}{dx}$$

F is the flux (mol $m^{-2}s^{-1}$) of the gas across a membrane over a single time step, D_s is the diffusion coefficient (m^2s^{-1}), dC_{mol} is the change in the molar density (mol m^{-3}) of the gas over a single time step, and dx (m) is the horizontal distance across the diffusive membrane. Flux was calculated by dividing the change in moles of CO_2 by the total surface area of diffusive membrane multiplied by one time step (5 seconds). C_{mol} was calculated by determining the change in concentration of CO_2 over a single time step.

From these data, Ds was determined by graphing dC_{mol}/dx versus F and fitting a linear trend line to the data. The slope of this trend line is equal to the diffusivity coefficient, D_s.

Chapter 3

Data & Results

Table 1. Diffusivity coefficients (D_s, m^2/s) at varying soil volumetric water contents (%).

VWC	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*Avg.*
3.5	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06
7.8	3.00E-06	3.00E-06	3.00E-06	4.00E-06	4.00E-06	3.00E-06	4.00E-06	4.00E-06	3.00E-06	3.00E-06	3.40E-06
20.5	3.00E-06	3.00E-06	3.00E-06	4.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.10E-06
31.3	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06
39.6	6.00E-07	8.00E-07	7.00E-07	6.00E-07	7.00E-07	7.00E-07	7.00E-07	7.00E-07	7.00E-07	7.00E-07	6.90E-07

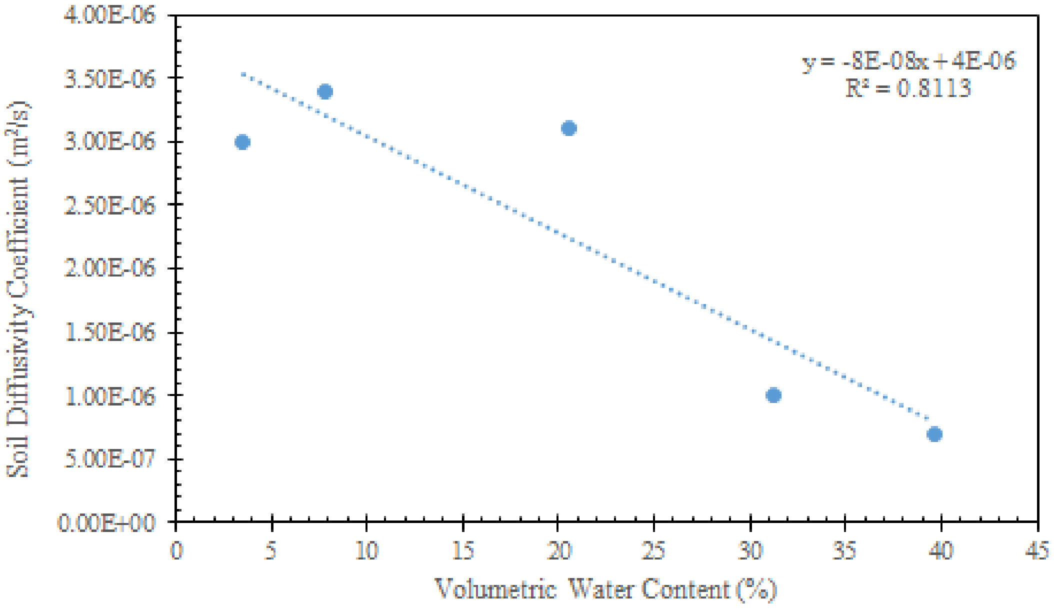

Figure 5. Fitted linear curve of soil volumetric water content versus soil diffusivity coefficients.

Table 1 shows soil diffusivity coefficients at five varying soil volumetric water contents over ten replicates. The arithmetic mean of these coefficients at each moisture content is calculated in the last column. These coefficients were calculated using the methods described in detail in the “Diffusivity Calculation” section of this report. Figure 5 displays a scatter plot of soil volumetric water content versus soil diffusivity coefficient data. I fit a linear curve to these data in order to more clearly see the relationship between these parameters and any trends in the collected data.

Chapter 4

Discussion

CO_2 Concentration and Soil Diffusivity Data

Graphs of the build-up of carbon dioxide within the soil probe over time for each level of soil moisture (averaged across ten replicates) can be seen in Appendix A. As expected, carbon dioxide within the probe built up quickly after the line was scrubbed, and then eventually slowed and leveled off when carbon dioxide concentrations reached a maximum within the probe. This maximum concentration often occurred between 1500 and 1600 parts per million. While the maximum concentration of carbon dioxide that built up within the probe did not vary much with varying levels of soil volumetric water content, the calculated gaseous diffusivity coefficients varied greatly across soil moisture levels.

The coefficient of diffusion in soils is dependent on the porosity of the soil. Specifically if a soil has a higher porosity, the coefficient of diffusion will be higher (Penman, 1940). Therefore if a soil has a higher volumetric water content and thus more water filling its pore space, it is expected that the coefficient of diffusion in the soil will be lower because it will be harder for gas to escape. My individual data points for soil diffusivity did not match this trend. This may have been due to similarities in the initial levels of volumetric water contents that were tested. For example, 3.5% to 7.8% is only a 4.3% change in moisture content. However, once a linear trend line was fit to a scatter plot of volumetric water content versus diffusivity coefficient (Figure 5), the trend line followed the expected inverse relationship between soil moisture content and the gaseous coefficient of diffusion within the soil. Estimated diffusivity data used to construct this curve can be found in Appendix B.

Probe Advantages and Disadvantages

The aforementioned calibration curve in Figure 5 allows one to estimate the gaseous diffusivity coefficient of one type of soil at one depth but over a variety of volumetric water contents. The volumetric water content of a soil can easily be measured either in-situ using a probe device or in the lab using simple procedures. Thus the soil-membrane diffusivity probe makes the in-situ measurement of soil-gas diffusivities much easier and has multiple benefits compared to other methods.

The installation of the probes is easy and requires minimal disturbance of the surrounding soil. It also allows for study of nearly any type of soil at the desired depth of the scientist. Once a probe is installed, it can remain in the field permanently and be sampled at convenience in order to gather data across large spatial and temporal ranges. This method of study does not require removal of soil to take to a lab setting for analysis. Unlike equations that estimate the diffusivity of a soil based on a specific parameter, this method can take topographic location, depth, soil type, soil temperature, soil porosity, and surrounding vegetation effects into account inherently based on its design.

Disadvantages of the soil-membrane method of in-situ diffusivity measurement arise mainly with maintenance of the probes. Probes are cheap and not difficult to construct, but great care must be taken to ensure that that every part is sealed properly and that the parts will be able to stand up to the elements when installed in the field. Once buried, probes cannot be repaired unless they are dug back up again, thus causing a large disturbance in the surrounding soil. This becomes especially problematic when using the probes in soils with much higher moisture contents, as water could potentially leak into the probe and cause inaccuracies in the measurement. This is something to consider for future studies.

Expansion of Study and Sources of Error

As stated in the introduction of this paper, a majority of the probes that I constructed were installed at the Shale Hills Critical Zone Observatory (Figure 6).

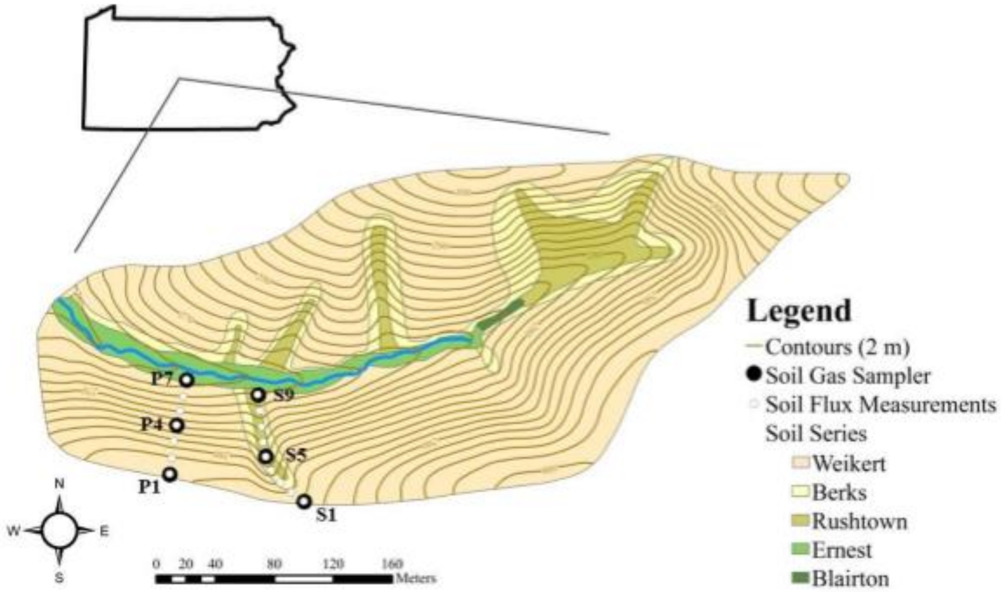

Figure 6. Topographic map of the Shale Hills Critical Zone Observatory, located in Rothrock State Forest in Stone Valley, Pennsylvania (Hasenmueller et al, 2014).

In the future an interesting course of study would be to sample these probes across a range of depths, topographic locations, and seasonal conditions. These probes were co-located with soil-gas concentration probes used in Hasenmueller, 2014; locations of which are also shown in Figure 6. This would make it easy to validate the accuracy and precision of the membrane probes by comparing CO_2 concentrations sampled from the established gas concentration probes to concentration data gathered from the adjacent soil-membrane probes at similar depths.

Sources of error in this study again lie mainly in the construction of the membrane probes. Collected data was fairly consistent, but because all of the probes were constructed by hand it is possible that the line is not completely sealed or that the probes over time will structurally break down. This would cause a fairly large loss of accuracy in measurements. It is also vital to accuracy of measurement to make sure that all instruments are properly calibrated before procedures begin

Chapter 5

Conclusion

The goal of this research was to gain a better understanding of the movement of carbon dioxide through soil by evaluating the use of soil-membrane probes for gas diffusivity analysis. The accuracy, precision, and ease of use of the constructed probes were assessed for various depths, topographic locations, and soil moisture content. To evaluate this I constructed multiple soil-membrane diffusivity probes based on the design of Risk, et al (2008) with modifications. One probe was tested in a laboratory setting using a LiCor 6200 (LiCor Biosciences, Lincoln, Nebraska) and Hagerstown soil at various soil volumetric water contents. Carbon dioxide concentration data was collected and then diffusivity coefficients of the soil were calculated using Fick's Law of Diffusion. Results indicate that the diffusivity of the soil went down with increasing moisture content. The soil-membrane diffusivity probe presents an easy, efficient, and cost-effective alternative to other labor intensive and less accurate methods of measuring gaseous diffusivity in-situ in soil. In the future, further study of the probes in the field would allow investigation into the probes' accuracy and precision at varying spatial and temporal conditions.

Appendix A

Soil Carbon Dioxide Concentration Data

Table 2. Soil CO2 Concentrations at VWC = 3.5%.

time (seconds)	***[CO_2] (ppm)***
5	39.6
10	348.6
15	553.4
20	728.0
25	877.3
30	997.5
35	1100.5
40	1183.0
45	1255.0
50	1313.2
55	1362.6
60	1402.8
65	1437.8
70	1466.5
75	1490.3
80	1507.8
85	1520.0
90	1529.1
95	1535.1
100	1539.6
105	1542.9
110	1544.0
115	1544.4
120	1544.4
125	1544.4
130	1544.4
135	1544.5
140	1544.4
145	1544.5
150	1544.6
155	1544.5
160	1544.7

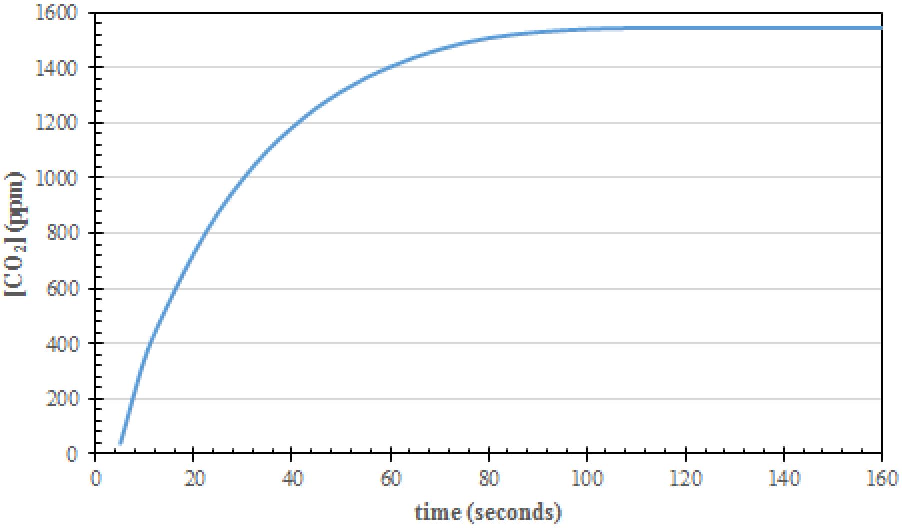

Figure 7. Soil CO_2 concentrations at VWC = 3.5%.

Table 3. Soil CO_2 Concentrations at VWC = 7.8%.

time (seconds)	*$[CO_2]$ (ppm)*
5	49.3
10	397.1
15	610.7
20	803.8
25	956.4
30	1078.5
35	1175.6
40	1257.2
45	1319.1
50	1371.2
55	1411.1
60	1445.0
65	1470.8
70	1492.7
75	1509.4
80	1523.1
85	1531.1
90	1536.1
95	1537.8
100	1538.9
105	1539.4
110	1539.5
115	1539.7
120	1539.8
125	1539.8
130	1539.8
135	1539.8
140	1539.9
145	1539.8
150	1540.0
155	1540.0
160	1540.0

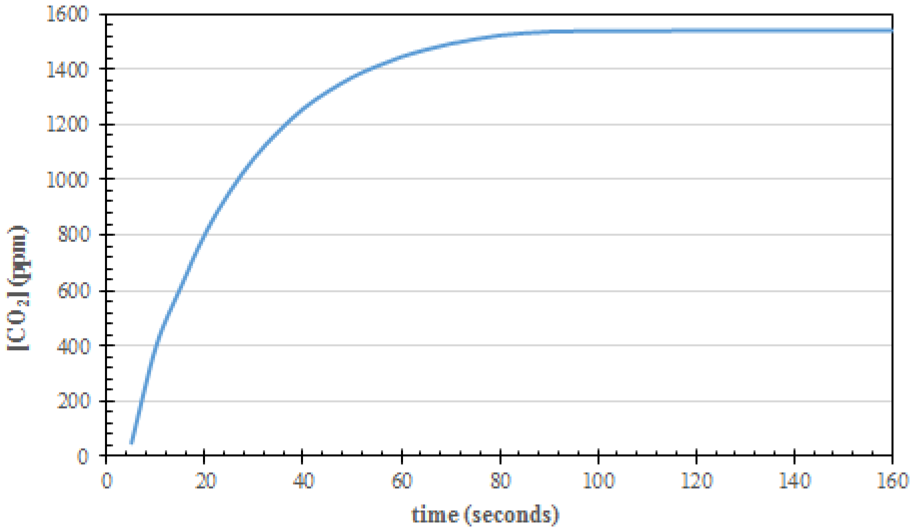

Figure 8. Soil CO_2 concentrations at VWC = 7.8%.

Table 4. Soil CO_2 Concentrations at VWC = 20.5%.

time (seconds)	*$[CO_2]$ (ppm)*
5	60.2
10	455.8
15	682.1
20	877.2
25	1071.1
30	1153.3
35	1206.3
40	1356.7
45	1395.3
50	1447.2
55	1486.5
60	1511.8
65	1529.4
70	1537.3
75	1536.3
80	1539.4
85	1539.6
90	1533.7
95	1539.7
100	1539.7
105	1539.7
110	1539.8
115	1539.8
120	1539.9
125	1539.9
130	1539.9
135	1539.9
140	1539.9
145	1540.0
150	1540.0
155	1540.0
160	1540.0

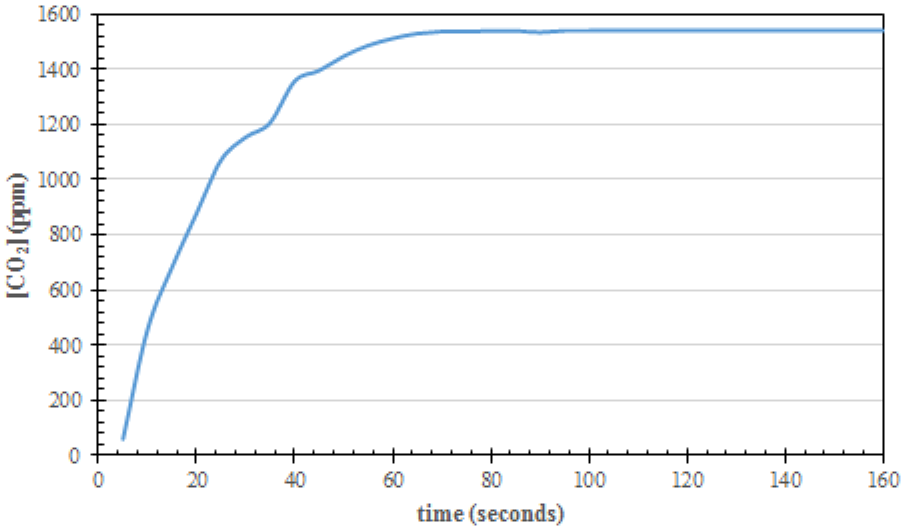

Figure 9. Soil CO_2 concentrations at VWC = 20.5%.

Table 5. Soil CO_2 Concentration at VWC = 31.3%.

time* *(seconds)	***[CO_2]* *(ppm)***
5	44.0
10	386.6
15	615.4
20	793.0
25	947.1
30	1058.7
35	1155.8
40	1227.2
45	1286.8
50	1333.2
55	1373.4
60	1399.4
65	1421.3
70	1439.9
75	1454.3
80	1466.1
85	1474.1
90	1480.8
95	1485.6
100	1489.7
105	1492.8
110	1495.3
115	1497.3
120	1498.7
125	1499.8
130	1500.5
135	1501.4
140	1501.6
145	1502.0
150	1502.0
155	1502.2
160	1502.3

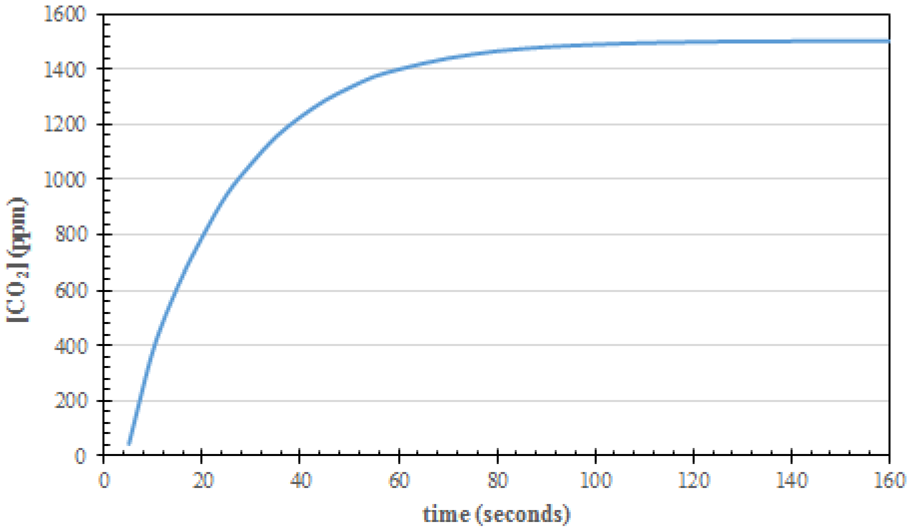

Figure 10. Soil CO_2 Concentrations at VWC = 31.3%.

Table 6. Soil CO_2 Concentrations at VWC = 39.6%.

time (seconds)	*[CO_2] (ppm)*
5	46.9
10	437.0
15	624.7
20	828.7
25	980.6
30	1094.7
35	1196.5
40	1270.5
45	1329.8
50	1407.3
55	1444.3
60	1447.6
65	1469.2
70	1485.1
75	1497.8
80	1503.7
85	1507.6
90	1513.2
95	1515.2
100	1519.1
105	1511.9
110	1513.5
115	1512.9
120	1507.1
125	1522.1
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145	1522.8
150	1522.7
155	1509.5
160	1522.7

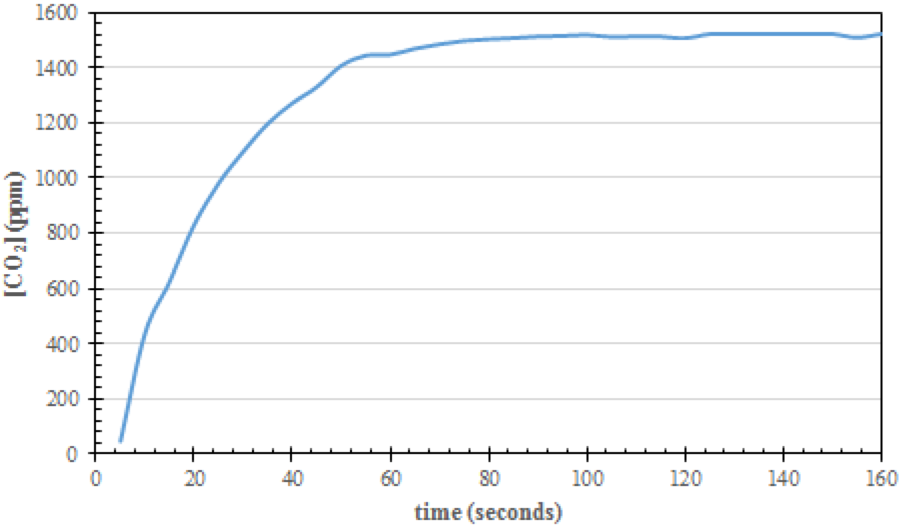

Figure 11. Soil CO_2 Concentrations at VWC = 39.6%.

Appendix B

Data Used in Calculation of Soil Gaseous Diffusion Coefficient

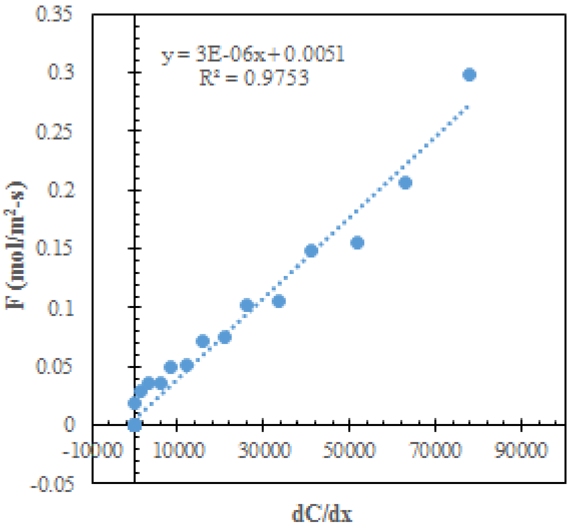

Figure 12. Soil CO_2 flux versus concentration gradient; VWC = 3.5%, replicate 1.

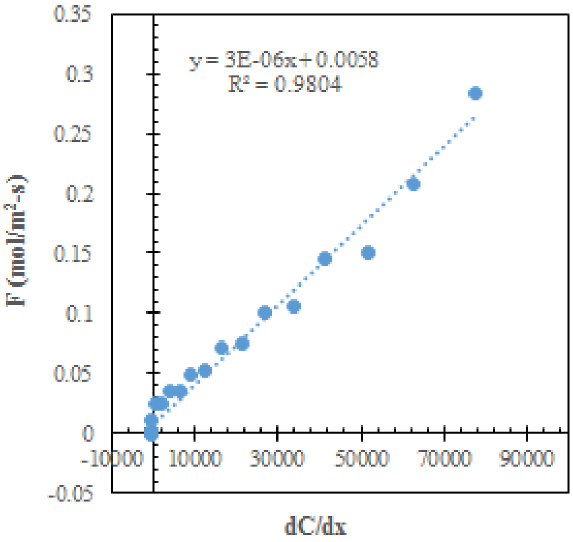

Figure 13. Soil CO_2 flux versus concentration gradient; VWC = 3.5%, replicate 2.

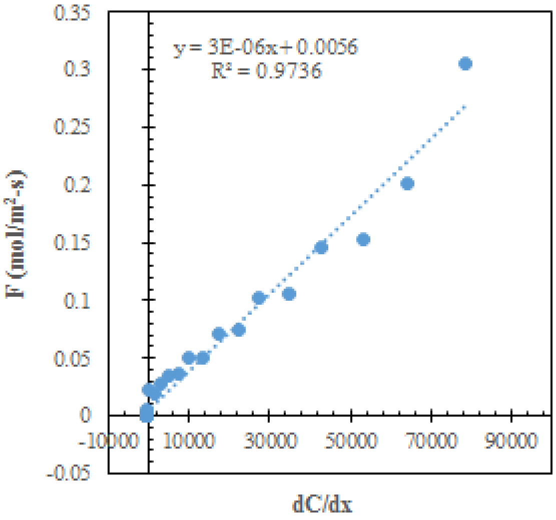

Figure 14. Soil CO_2 flux versus concentration gradient; VWC = 3.5%, replicate 3.

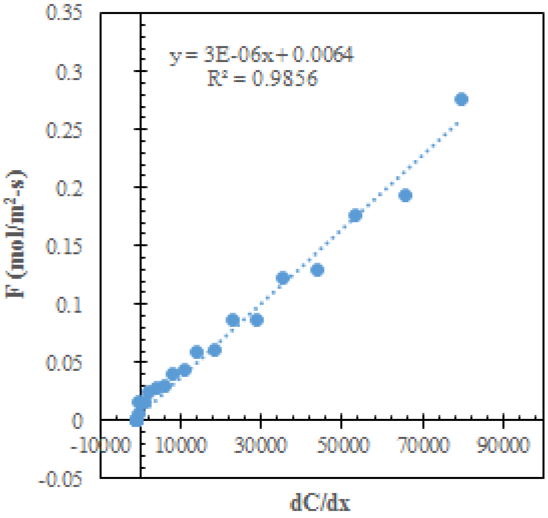

Figure 15. Soil CO_2 flux versus concentration gradient; VWC = 3.5%, replicate 4.

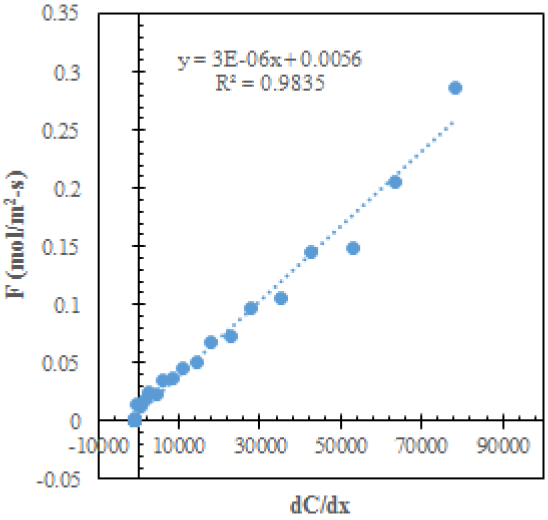

Figure 16. Soil CO_2 flux versus concentration gradient; VWC = 3.5%, replicate 5.

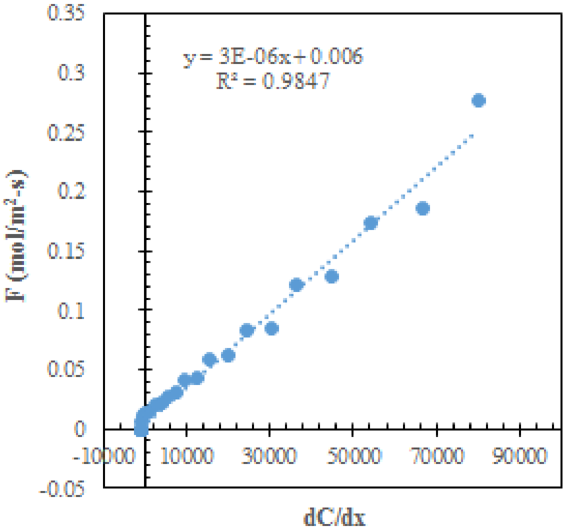

Figure 17. Soil CO_2 flux versus concentration gradient; VWC = 3.5%, replicate 6.

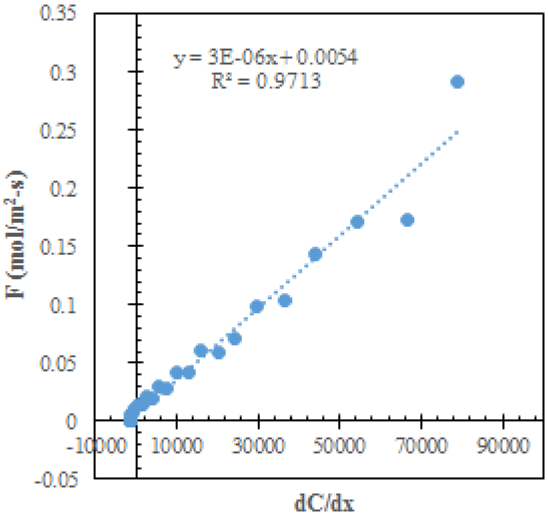

Figure 18. Soil CO_2 flux versus concentration gradient; VWC = 3.5%, replicate 7.

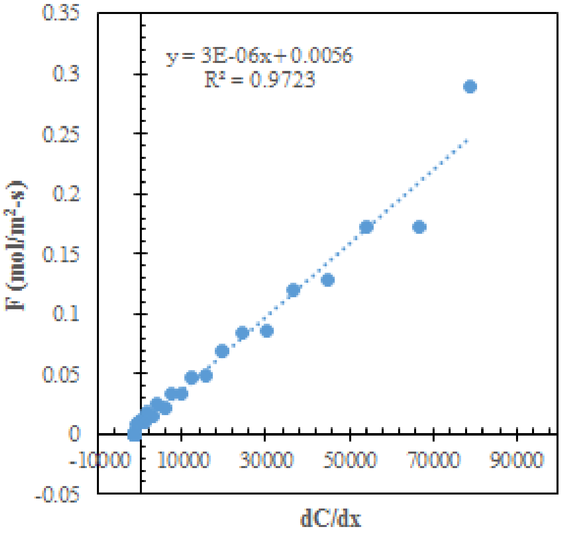

Figure 19. Soil CO_2 flux versus concentration gradient; VWC = 3.5%, replicate 8.

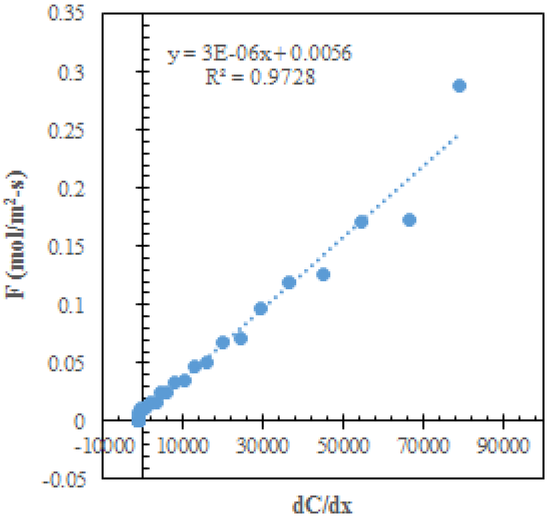

Figure 20. Soil CO_2 flux versus concentration gradient; VWC = 3.5%, replicate 9.

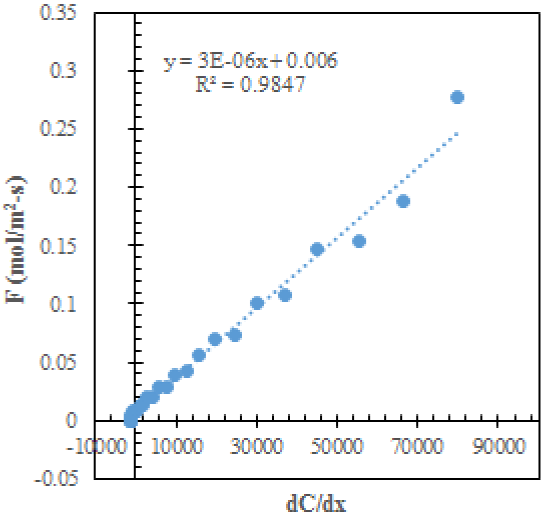

Figure 21. Soil CO_2 flux versus concentration gradient; VWC = 3.5%, replicate 10.

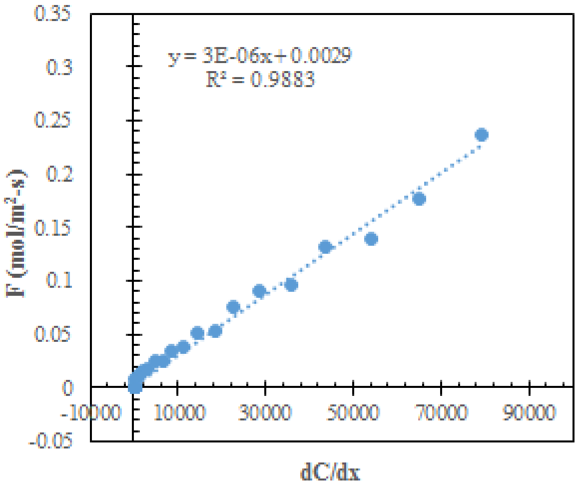

Figure 22. Soil CO_2 flux versus concentration gradient; VWC = 7.8%, replicate 1.

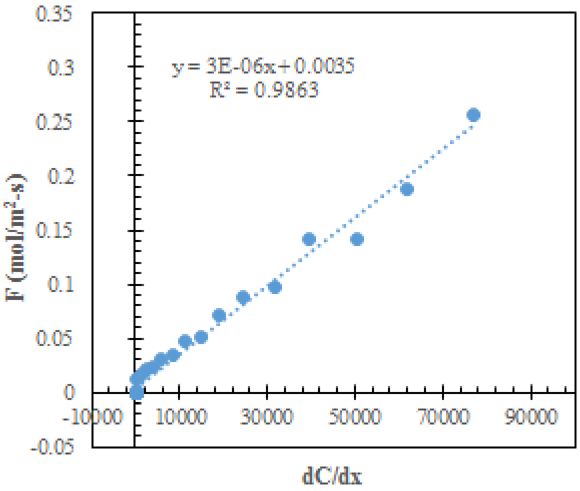

Figure 23. Soil CO_2 flux versus concentration gradient; VWC = 7.8%, replicate 2.

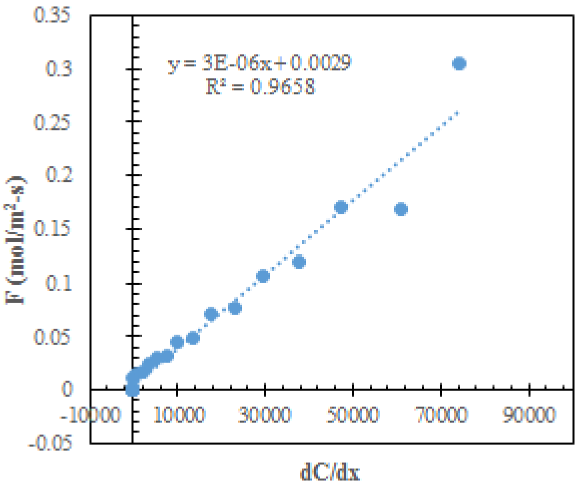

Figure 24. Soil CO_2 flux versus concentration gradient; VWC = 7.8%, replicate 3.

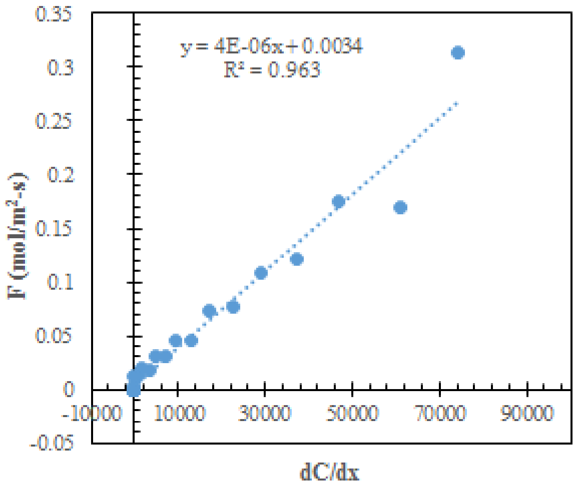

Figure 25. Soil CO_2 flux versus concentration gradient; VWC = 7.8%, replicate 4.

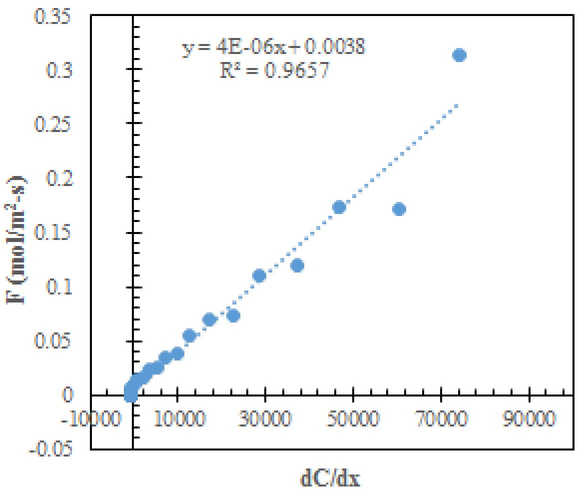

Figure 26. Soil CO_2 flux versus concentration gradient; VWC = 7.8%, replicate 5.

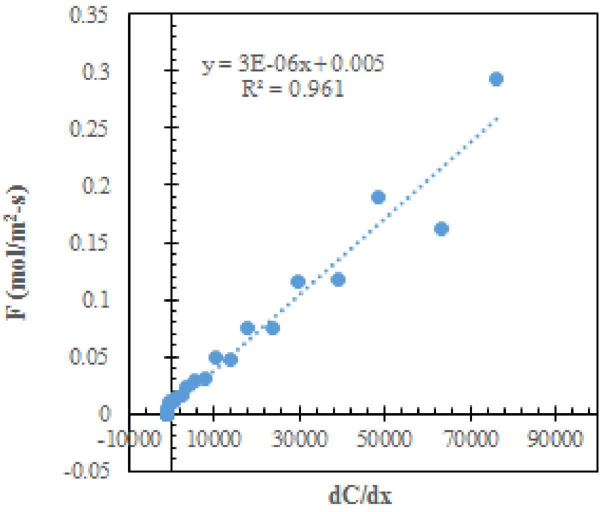

Figure 27. Soil CO_2 flux versus concentration gradient; VWC = 7.8%, replicate 6.

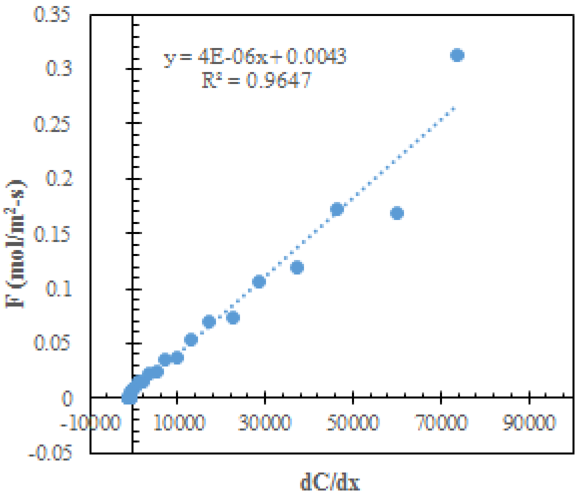

Figure 28. Soil CO_2 flux versus concentration gradient; VWC = 7.8%, replicate 7.

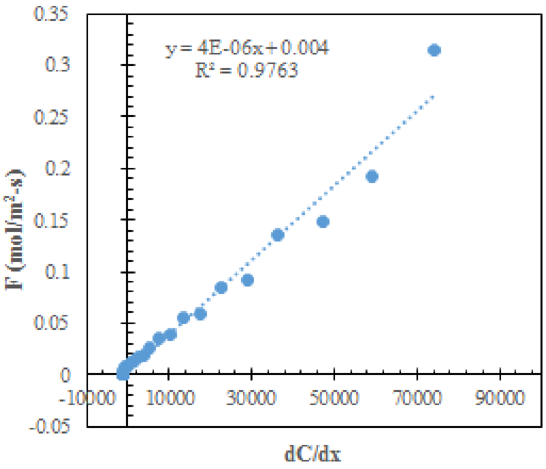

Figure 29. Soil CO_2 flux versus concentration gradient; VWC = 7.8%, replicate 8.

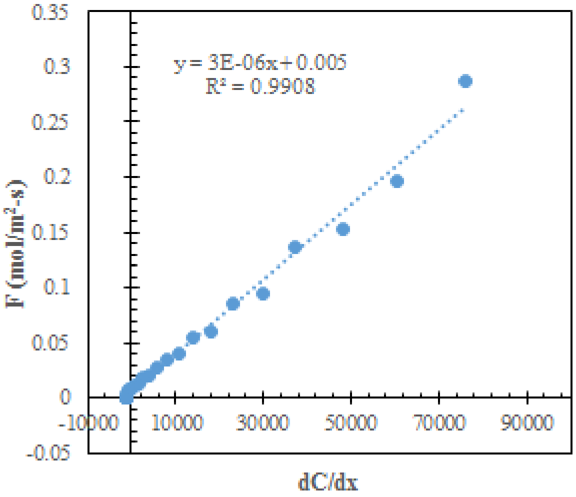

Figure 30. Soil CO_2 flux versus concentration gradient; VWC = 7.8%, replicate 9.

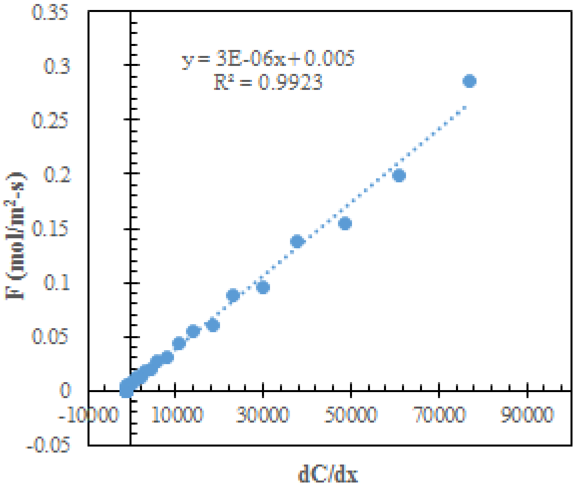

Figure 31. Soil CO_2 flux versus concentration gradient; VWC = 7.8%, replicate 10.

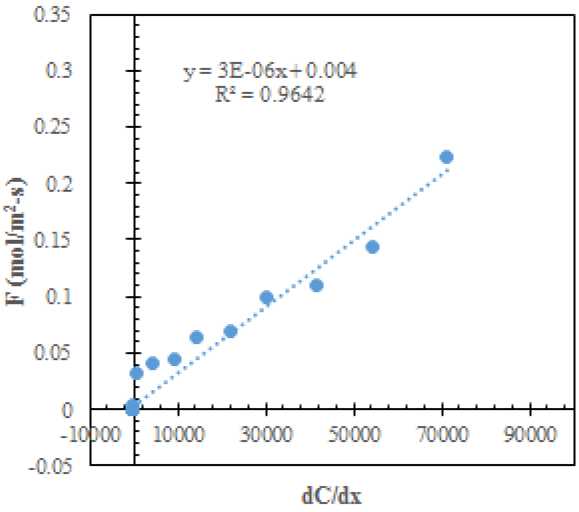

Figure 32. Soil CO_2 flux versus concentration gradient; VWC = 20.5%, replicate 1.

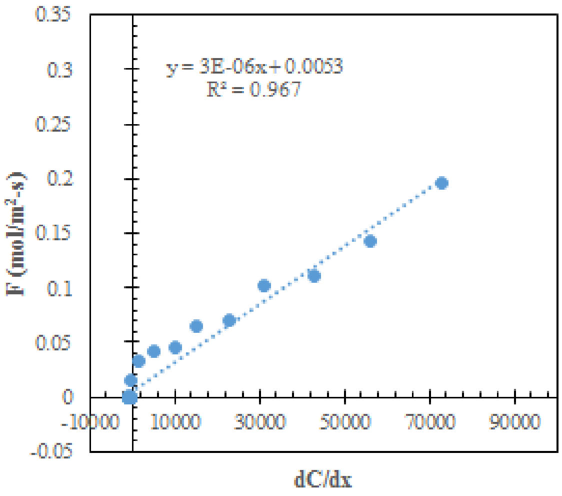

Figure 33. Soil CO_2 flux versus concentration gradient; VWC = 20.5%, replicate 2.

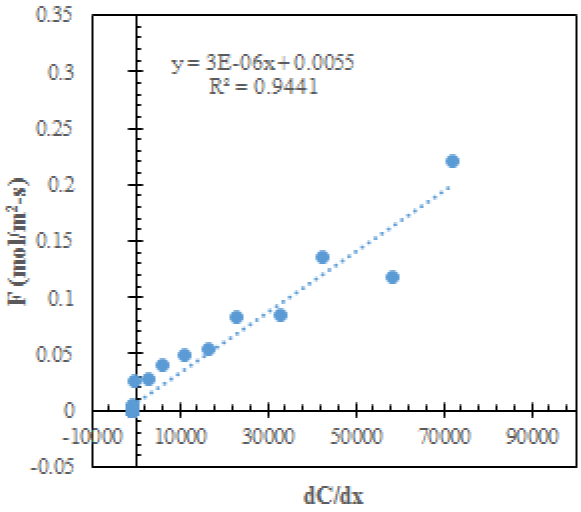

Figure 34. Soil CO_2 flux versus concentration gradient; VWC = 20.5%, replicate 3.

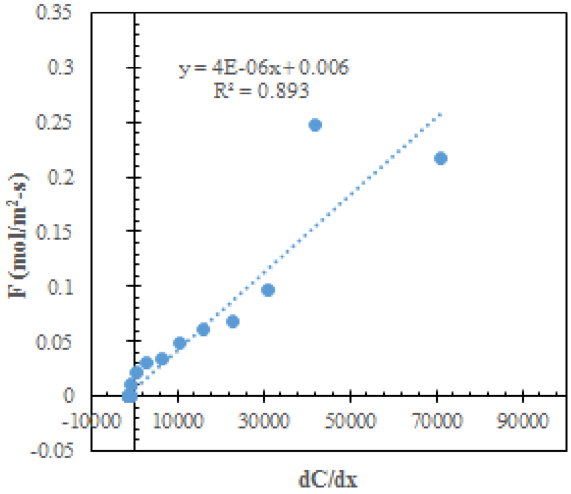

Figure 35. Soil CO_2 flux versus concentration gradient; VWC = 20.5%, replicate 4.

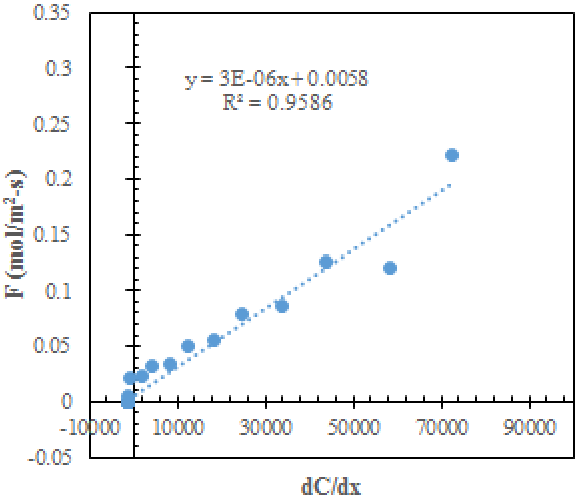

Figure 36. Soil CO_2 flux versus concentration gradient; VWC = 20.5%, replicate 5.

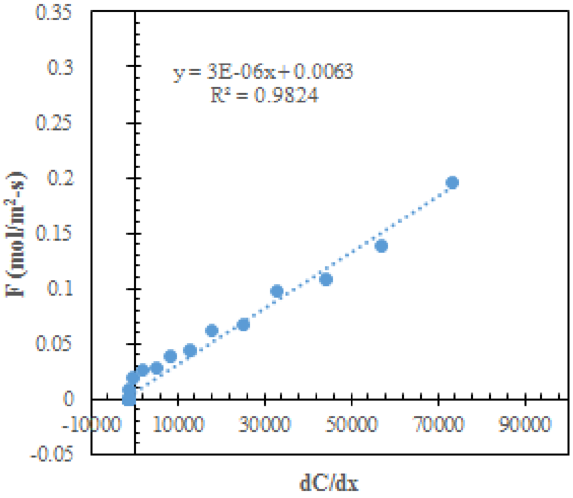

Figure 37. Soil CO_2 flux versus concentration gradient; VWC = 20.5%, replicate 6.

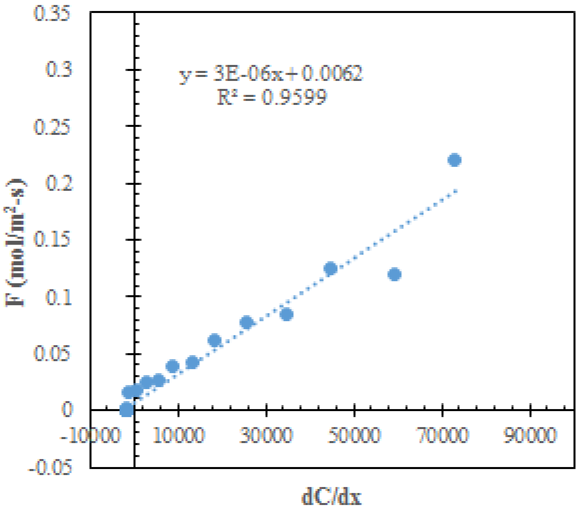

Figure 38. Soil CO_2 flux versus concentration gradient; VWC = 20.5%, replicate 7.

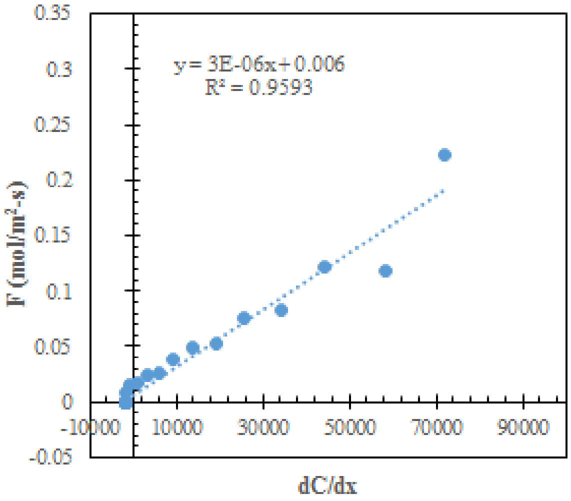

Figure 39. Soil CO_2 flux versus concentration gradient; VWC = 20.5%, replicate 8.

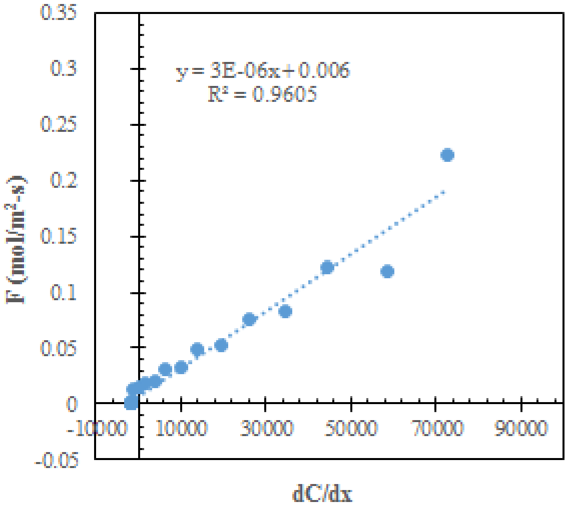

Figure 40. Soil CO_2 flux versus concentration gradient; VWC = 20.5%, replicate 9.

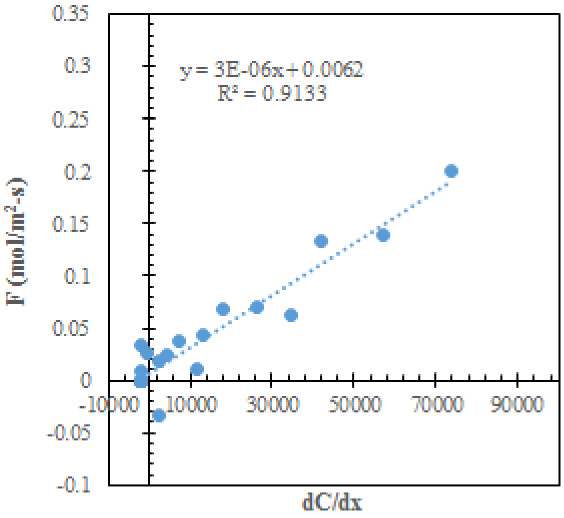

Figure 41. Soil CO_2 flux versus concentration gradient; VWC = 20.5%, replicate 10.

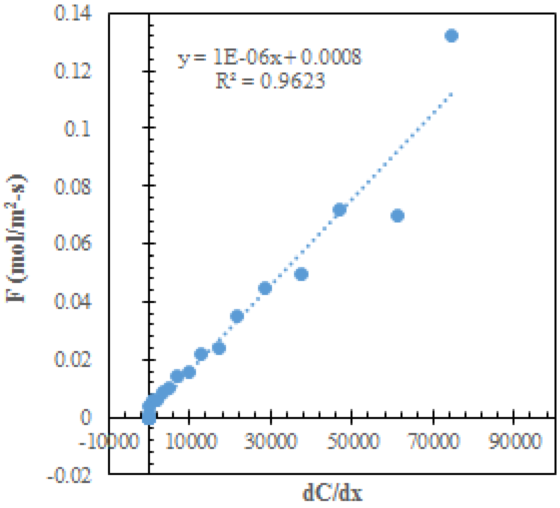

Figure 42. Soil CO_2 flux versus concentration gradient; VWC = 31.3%, replicate 1.

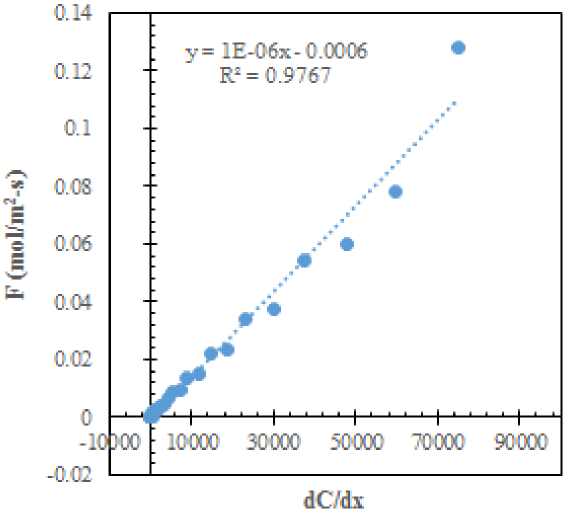

Figure 43. Soil CO_2 flux versus concentration gradient; VWC = 31.3%, replicate 2.

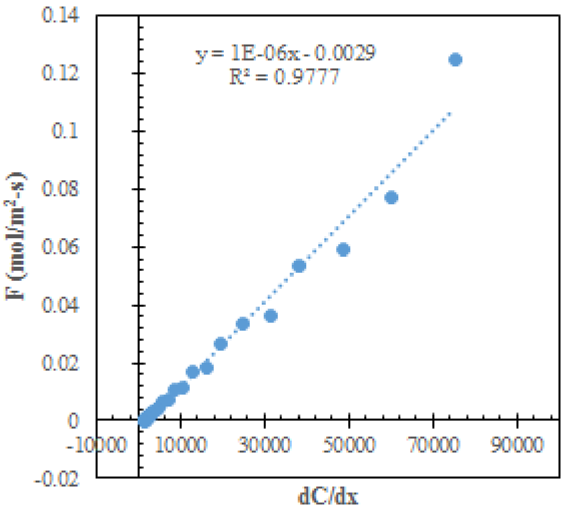

Figure 44. Soil CO_2 flux versus concentration gradient; VWC = 31.3%, replicate 3.

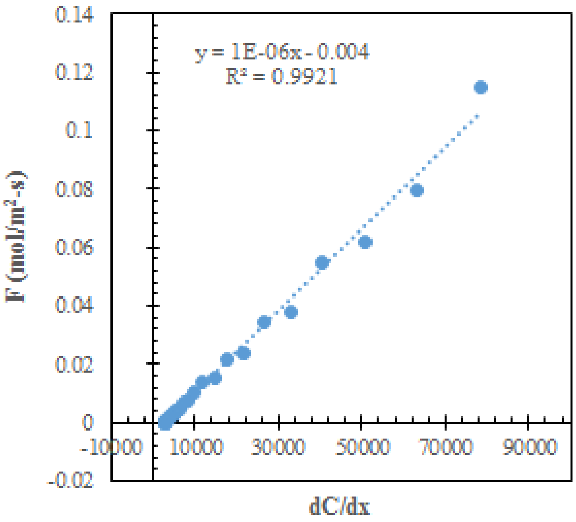

Figure 45. Soil CO_2 flux versus concentration gradient; VWC = 31.3%, replicate 4.

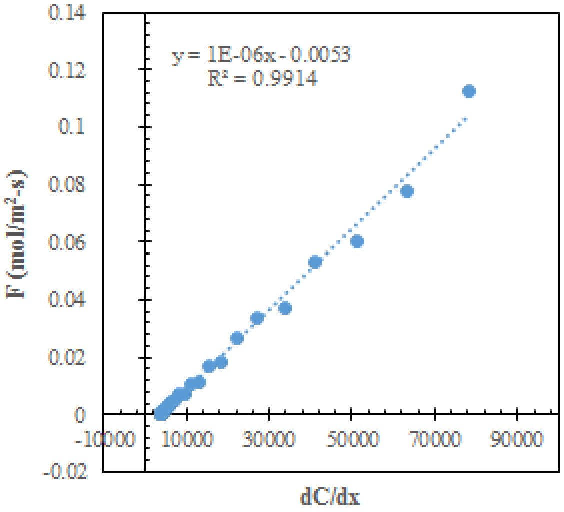

Figure 46. Soil CO_2 flux versus concentration gradient; VWC = 31.3%, replicate 5.

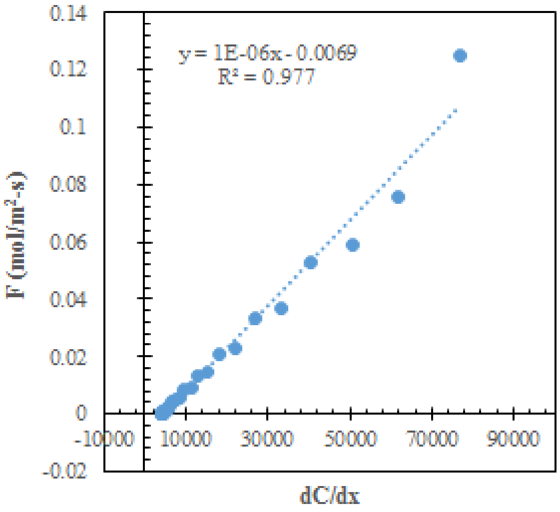

Figure 47. Soil CO_2 flux versus concentration gradient; VWC = 31.3%, replicate 6.

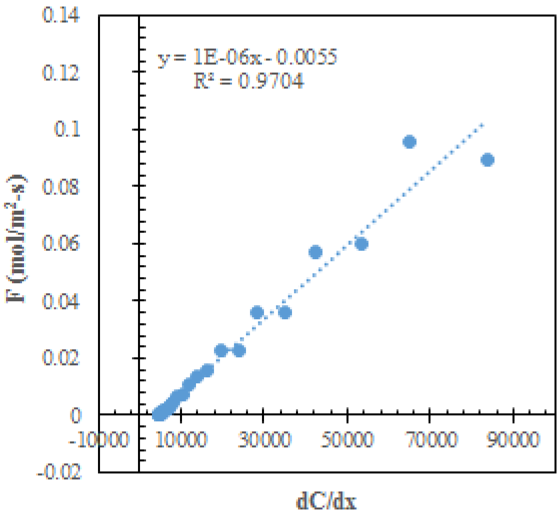

Figure 48. Soil CO_2 flux versus concentration gradient; VWC = 31.3%, replicate 7.

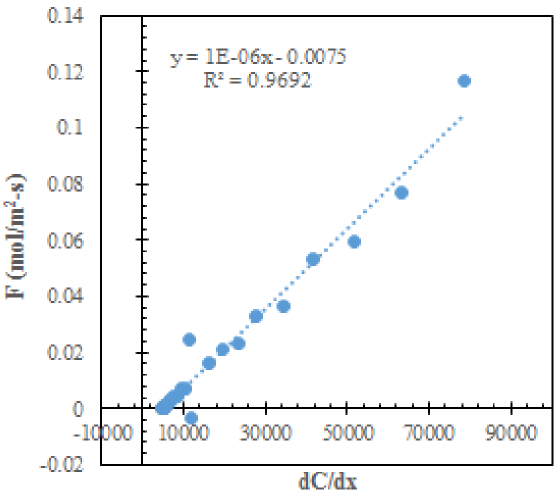

Figure 49. Soil CO_2 flux versus concentration gradient; VWC = 31.3%, replicate 8.

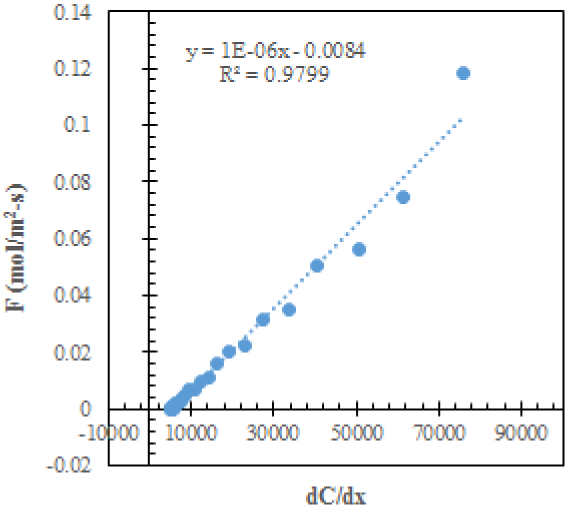

Figure 50. Soil CO_2 flux versus concentration gradient; VWC = 31.3%, replicate 9.

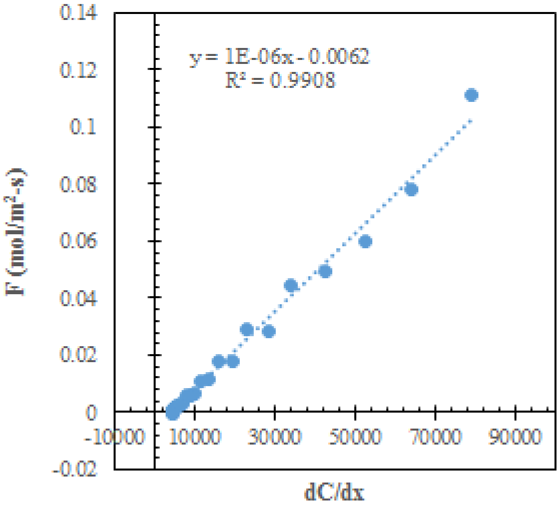

Figure 51. Soil CO_2 flux versus concentration gradient; VWC = 31.3%, replicate 10.

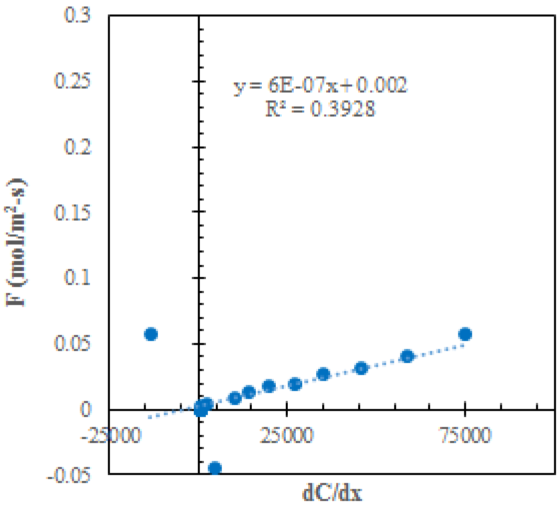

Figure 52. Soil CO_2 flux versus concentration gradient; VWC = 39.6%, replicate 1.

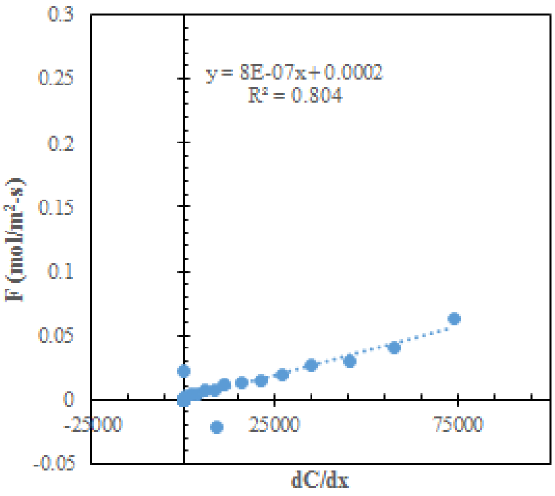

Figure 53. Soil CO_2 flux versus concentration gradient; VWC = 39.6%, replicate 2.

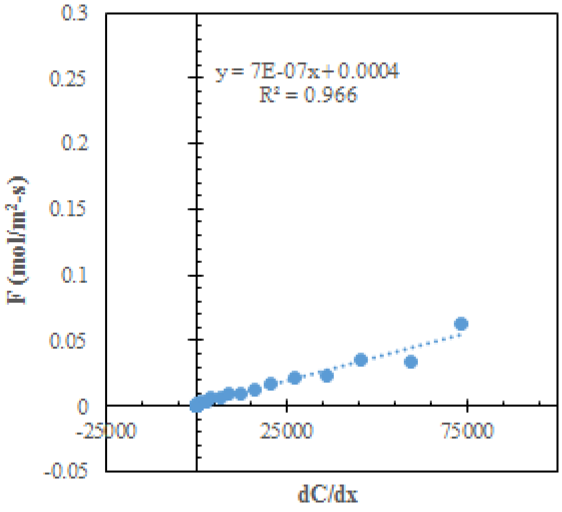

Figure 54. Soil CO_2 flux versus concentration gradient; VWC = 39.6%, replicate 3.

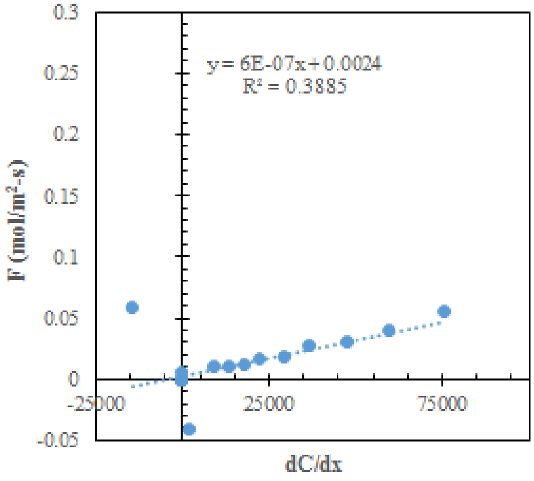

Figure 55. Soil CO_2 flux versus concentration gradient; VWC = 39.6%, replicate 4.

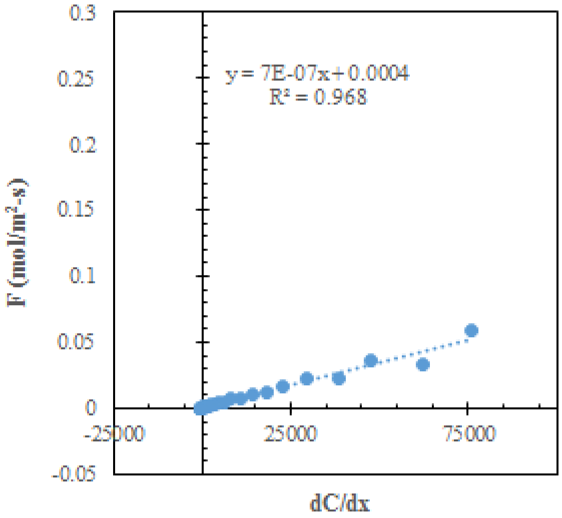

Figure 56. Soil CO_2 flux versus concentration gradient; VWC = 39.6%, replicate 5.

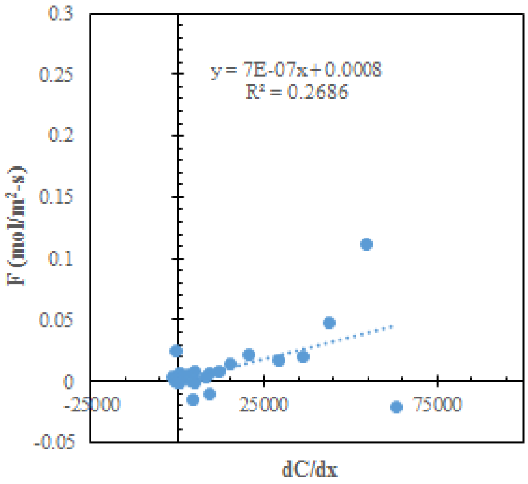

Figure 57. Soil CO_2 flux versus concentration gradient; VWC = 39.6%, replicate 6.

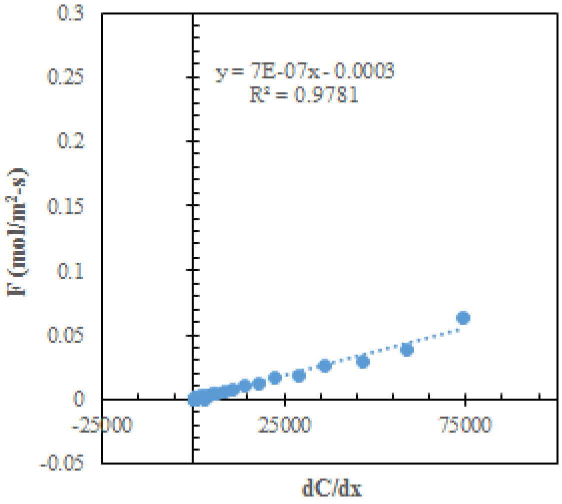

Figure 58. Soil CO_2 flux versus concentration gradient; VWC = 39.6%, replicate 7.

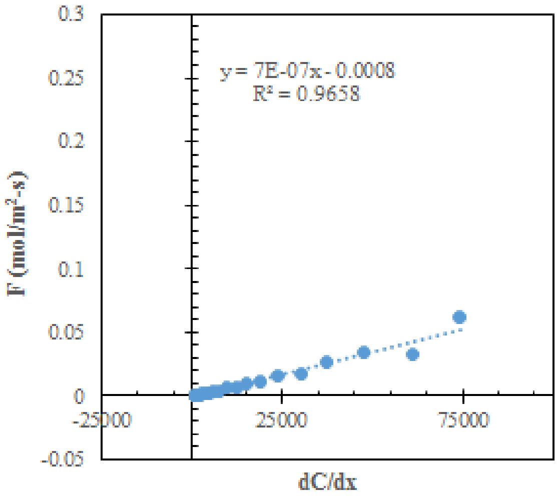

Figure 59. Soil CO_2 flux versus concentration gradient; VWC = 39.6%, replicate 8.

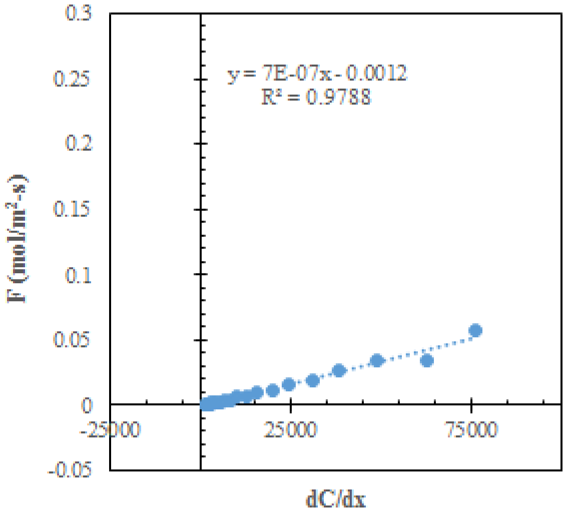

Figure 60. Soil CO_2 flux versus concentration gradient; VWC = 39.6%, replicate 9.

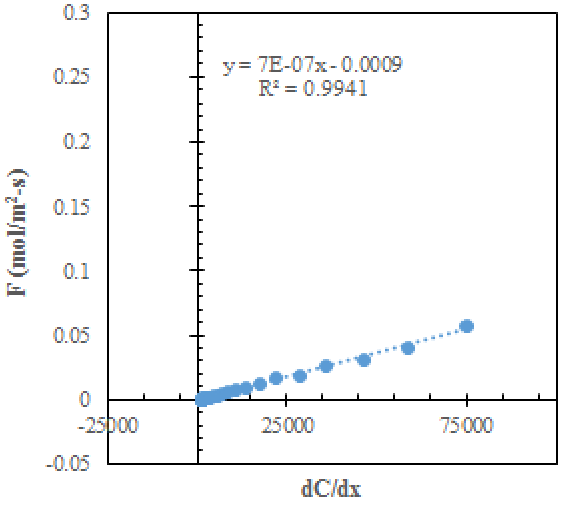

Figure 61. Soil CO_2 flux versus concentration gradient; VWC = 39.6%, replicate 10.

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ACADEMIC VITA

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EDUCATION

The Pennsylvania State University, *The Schreyer Honors College* University Park, PA
College of Agricultural Sciences *Graduation: May 2015*
Bachelor of Science in Environmental Resource Management
Minors in Environmental Engineering, Environmental & Renewable Resource Economics, and Watershed & Water Resources Management

RESEARCH EXPERIENCE

Kaye Biogeochemistry Laboratory University Park, PA
Undergraduate Researcher *May 2013-Present*

-Constructed soil-membrane probes to measure in-situ soil gas diffusivity

-Measured the effects of various cover crops on the nitrogen cycling of a cropland ecosystem through soil and water sampling, biomass analysis, and photo-acoustic spectroscopy

-Analyzed nitrogen concentrations in samples using CHNS combustion analysis, micro-plate spectroscopy, and LiCOR gas analyzer

Lake Champlain REU Program (University of Vermont) Burlington, VT
Undergraduate Researcher *June 2014-Aug 2014*

-Profiled pharmaceutical products of the highest threat to the aquatic ecosystem through literature and toxicity testing

-Isolated areas of highest concern within the Lake Champlain watershed using GIS software to map contaminant point sources and demographics within the basin

-Investigated pharmaceutical disposal policies state by state and made recommendations for intervention through public presentations and a written manuscript

PROFESSIONAL EXPERIENCE

Teaching Assistant University Park, PA
E R M 411: Legal Aspects of Resource Management *Aug 2014–Dec 2014*

-Provided assistance to the professor with grading of assignments, student aid in class, and organization of students' final project

-Conducted class for half of the student group during the class' final project period, working to guide student groups in the proper direction for the project and answering questions

LEADERSHIP EXPERIENCE

State of State Organization University Park, PA
Executive Project Coordinator *April 2014–Present*

-Coordinated a day-long symposium in which members of the community discussed local educational, social, and cultural issues and potential resolutions

-Cooperated with symposium speakers to organize outreach projects and to establish connections between speakers and appropriate community organizations

The Penn State Environmental Resource Management Society University Park, PA
Vice President *Aug 2013–Dec 2013*

-Assisted in the organization of the society in its first year, as well as drafting the society's official constitution

-Supported the president in running meetings and organizational tasks

COMPUTER/LANGUAGE SKILLS

SolidWorks
Conversational Spanish
ArcGIS
Wolfram Mathematica
Microsoft Office including Database, Excel, and Publisher
Minitab Statistics

HONORS/INTERNATIONAL EXPERIENCE

-Schreyer Honors College Academic Excellence Scholarship
-Ilene Glenn Scholarship in Environmental Resources
-John Danhouse Martz, Jr. Scholarship
-Dean's List: Spring '12, Fall '12, Spring '13, Fall '13, Spring '14
-Schreyer Honors College London Study Tour (London, United Kingdom)