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MICRO-GRADIENT EFFECTS ON CO2 EFFLUX IN BLACK WATER CONSERVATION ZONES: A COMPREHENSIVE STUDY

[1]Tameka Marie Johnson and [2]Joshua Samuel Thompson
[1]Assistant Professor, Southern University and A & M College, 801 Harding Blvd, Baton Rouge, LA 70807, United States
[2]Associate Director of Programs, Pennsylvania State University, State College, PA 16801

Abstract: *With the global human population rapidly approaching eight billion, the imperative to safeguard sensitive ecosystems has never been more critical for the planet's long-term survival. Wetlands, vital components of the Earth's ecological health, encompass approximately 6% of terrestrial land areas worldwide. In the United States alone, they span 274 million acres, constituting a remarkable 14% of the world's wetlands (Reddy & DeLaune, 2008). These ecosystems serve as crucial carbon reservoirs, estimated to store between 350-535 gigatons of carbon (Mitra et al., 2005). However, the looming specter of climate change, characterized by shifting global temperatures and erratic flood-drought cycles, poses an existential threat to wetlands. The potential desiccation of these fragile environments could result in the release of vast quantities of carbon back into the atmosphere. Elevated atmospheric temperatures have already triggered a reduction in surface and groundwater levels due to increased evapotranspiration. Consequently, climate change underscores the pressing need for wetland preservation while propelling innovation to create new wetlands capable of providing equivalent ecosystem services. This study makes a significant contribution by emphasizing the pivotal role wetlands can play in mitigating global climate change. It underscores the intricate relationship between soil moisture, temperature dynamics, and CO2 efflux, thereby enhancing our understanding of wetlands' potential in combating climate change.*

Keywords: *Wetlands, Climate change, Carbon storage, Ecosystem preservation, Soil moisture*

1. Introduction

As the human population grows, ecosystems are confronted with environmental pressures to maintain current production levels. With a global population of nearly eight billion people, the need to protect sensitive ecosystems is an essential part of the planet's long-term survival. Wetlands serve as a function to the health of the planet. Wetlands are vulnerable ecosystems, estimated to cover 6% of terrestrial land areas worldwide. The United States has about 274 million acres, which represents 14% of the world's wetlands (Reddy & DeLaune, 2008). Wetlands are estimated to store 350-535 gigatons of carbon (Mitra et al., 2005). The shift in global temperatures and sporadic flood and drought cycles are amongst the greatest threats to wetlands worldwide because of the potential of land drying up and releasing massive quantities of carbon back into the atmosphere. An increase

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in atmospheric temperatures has shown a decrease in surface and ground waters due to evapotranspiration. Climate change has induced a greater need for wetland protection while pushing innovation to construct new ones that provide equivalent services. The significant contribution of this study is an increased awareness of the importance of wetlands' potential in combating global climate change and the role that soil moisture and temperature play in CO_2 efflux.

1.1 Objectives

To better comprehend the value of wetland performance in urban areas, the main objectives of this study are to understand: 1) soil CO_2 effluxes within three wetland types, 2) the effects of soil moisture on soil CO_2 efflux, 4) and the effects of soil temperature on soil effluxes. We hypothesize that soil moisture will significantly affect CO_2 flux within the three land types and that temperature will have a significant impact on soil CO_2 efflux.

2. Materials and Methods

2.1 Study Area

The study area for this project is located in central East Baton Rouge Parish, Louisiana, adjacent to the Comite River. The Comite River serves as a westerly boundary line on the property. Blackwater Road serves as a boundary line to the east of the property, while Hooper Road defines the border on the south side.

On the north side of the study area, residential development sets the boundary line of the property. The study area has three distinctive land types that consist of bottomland hardwood wetland, upland hardwood, and scrub/shrub wetland. The bottomland hardwood (BLH) wetland portion of the study area was initially comprised of riparian forest. The soil in the bottomland area contains sand as a remnant of the former soil mining operation. During the initial investigation, the riparian zone was defined as 300 feet vicinity adjacent to the Comite River on either side. This definition was based on the North American Mink Habitat Suitability Model (Allen, 1986). Following the initial destruction of the site, the remnant BLH stand was located in the southwest corner, while a more extensive stand was located on the north side of the property. The BLH wetland presently extends from the southern boundary near Hooper Road to the northern residential boundary. From the Comite River, the BLH wetland progresses eastwardly across the property to the near center. According to the ecosystem restoration report, the typical tree species in this area include Sweetgum, Water Oak, American Elm, and Bald Cypress (Army Corps, 2000). The BLH wetland area is transitioned by the presence of some upland hardwoods. Due to the topography of the conservation area, the upland portion is dryer than BLH and scrub/shrub wetlands. The scrub/shrub wetland portion of the study site starts from the center of the property and expands eastward to the boundary at Blackwater Road. The inlet overflow from the Comite River keeps the scrub/shrub soil moist to support the vegetation. The vegetation in this area includes black willow, slash pine, wax myrtle, dewberry, cattail, plume grass, bluestem, softrush, and numerous other grasses, rushes, and sedges (Army Corps, 2000).

This 62.5-acre site, before restoration, was an abandoned soil mine. Before restoration, about half the site had 8-15 feet of soil removed. The remaining portion of the site, after mining, consisted of moderately mature forested systems. During an investigation conducted by the Army Corps of Engineers, it was discovered that the mined areas were low in fertility and had a pH of 5.4. After careful

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planning, the restoration project created two lakes on the property. This site includes 1.5 miles of walking trails, interpretive areas, and 8.5 acres of lakes for aquatic recreation. The southern lake is the largest at eight acres with a two-acre inland in the middle, providing habitat for many wetland species. The northern lake is two and half acres of aquatic habitat. Restoration planting in this area included: Loblolly Pine, Spruce Pine, Wax Myrtle, Bald Cypress, Tupelo Gum, Cherrybark Oak, Native Sweet Pecan, Blackgum, Willow Oak, Riverbirch, Cottonwood, Red Mulberry, Common Persimmon, Water Oak, Cow Oak, Live Oak, and Eastern Red Cedar (Army Corps, 2000).

2.1 Experimental Design

Stratified random sampling provides simplicity and reliability in collecting data that is representative of a population while separating population parameters. Using stratified random sampling, the study area was divided into three individual strata. The three distinctive land types within the Blackwater Conservation Area represent a single stratum. These land types include bottomland hardwood wetlands, upland hardwood, and scrub/shrub wetlands which were broken up into experimental units. Each area was separated into relatively homogenous sections by using

Light Detection and Ranging (LIDAR) to differentiate and distinguish the areas. The elevation, slope, and soil type were used to delineate the different wetland types. For each experimental unit, five random points were manufactured using ArchGIS. At each point, data was collected twice a week for the duration of twenty weeks.

2.2 Data collection

This study used the Li-Cor 8100 automated soil CO2 flux system with a 20 cm closed-chamber to measure soil respiration. The survey chamber uses a pressure/vacuum airflow system to adjust the chamber position up or down on the collar. The chamber was designed to with a pressure vent to prevent wind invasion and/or air seepage due to external and internal influences (Li-Cor, 2005). This system uses an infrared gas analyzer (IRGA) that records readings in one-second intervals. The automated soil CO2 flux system uses a rotary pump located inside the analyzer control to provide a continuous flow of air into the chamber. The airflow circulates without the use of fans to reduce the effects of pressure gradients. As the airflow from the chamber before it enters into the optical bench of the infrared gas analyzer to be measured for CO2 and H2O it must pass through a filter.

Soil respiration was measured twice a week over twenty weeks. PVC collars were placed in the field at least twenty-four hours before the first measurement was taken. The depth of the PVC collared varied but was not less than 6 cm deep. The collars were inserted until they had a solid foundation to maximize the reduction of lateral diffusion. Once the PVC collars were in place, the 20 cm respiration chamber was placed on top of it to initiate the measurement sequence. An integrated pneumatic system permits the chamber to lower and close during measurements. This allows the minimization of mechanical disturbance while sensitive measurements are in progress. To prevent changes in the chamber, CO2 measurements were limited to two minutes. This action reduced the potential of underestimation from changes in soil-atmosphere concentration gradients (Davidson et al., 2002).

Soil moisture and temperature were measured simultaneously using the Li-Cor 8100-202 EC-5 soil moisture probe and corresponding temperature probe connected to the auxiliary sensor interface. The mean for each stratum was calculated at the end of the study period. Statistical analysis was performed

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by using SAS software. The statistical model used to determine the differences between group means was the analysis of variance. In testing the analysis of variance, if the probability of the F-test was significant (i.e., $p < 0.05$) the means were compared using the TUKEY'S test.

3. Results and Discussion

3.1 Elevation Influence on CO2 Flux

Wetland productivity is in part determined by the soil characteristics and physical and biological processes. Elevation differences can impact wetland productivity by influencing soil moisture and temperature levels (Sousa Neto et al., 2011). Smith (2010) and Sousa Neto et al.(2011) studies were focused on soil temperature and moisture along large gradients. Sousa Neto et al. (2011) specifically examined the gradient change influence on the soil-atmosphere exchange on CO2. In this study, micro-gradient change was examined in relation to CO2 flux. Micro-gradient in this study is defined as the gradient of a small, specific place within an area as contrasted with the gradient of the entire area. The research question that was asked was how micro-gradients would affect soil CO2 efflux. The hypothesis was formulated that micro-gradient change will have no significant effect on soil CO2 efflux. Based on the findings, this hypothesis is rejected.

In studies with larger gradient differences, the soil temperature decreased as the elevation increase. In the findings of this study, the bottomland had the lowest elevation of 48.4ft (14.75m) and the lowest soil temperature, 24.3°C. The shrub/scrub area had the second-lowest elevation of 49.6ft (15.11m) but often had recorded the highest temperatures. The highest area was the upland, with the elevation of 56ft (17m), but the average temperature was not consistently higher than the shrub/scrub area (Figure 3). The reason for the temperature differences may be associated with the vegetation type found in each area. The upland and bottomland areas were more forested, with a greater canopy covering the sampling zones. In the Brazilian Atlantic study, the soil measurements were taking in forested areas. In the Deer Creek Experimental Watershed studies the measurements were taking in gradients ranging from shrub lands to evergreen forests. Both of these areas have some similarities in vegetation type to the Blackwater Conservation Area.

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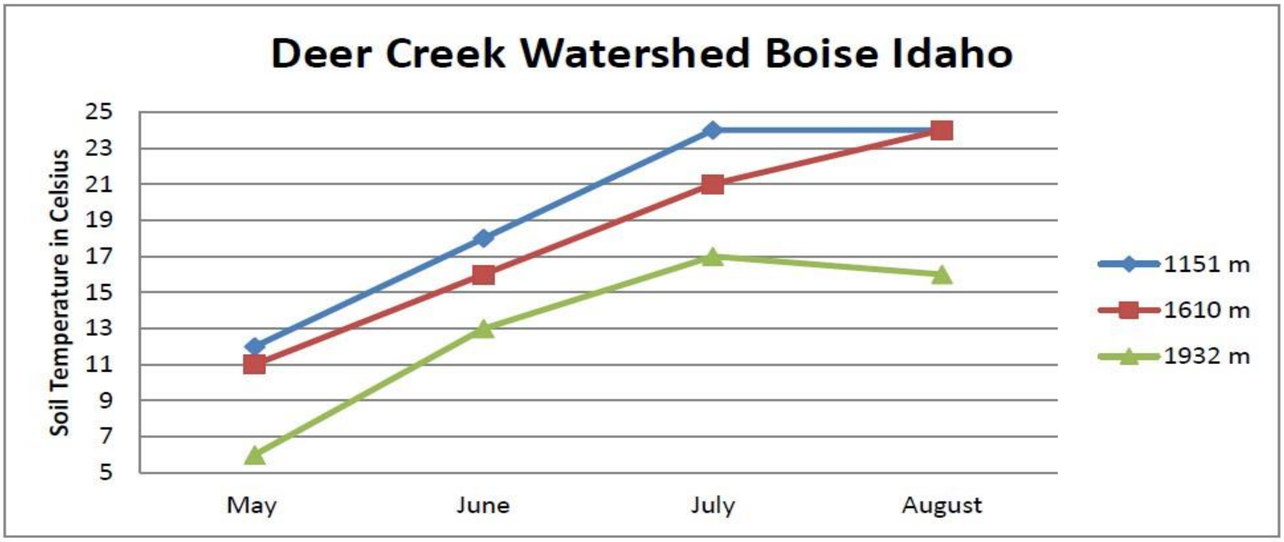

Figure 1. Deer Creek Experimental Watershed in Boise Idaho soil temperature decreases as elevation increase.

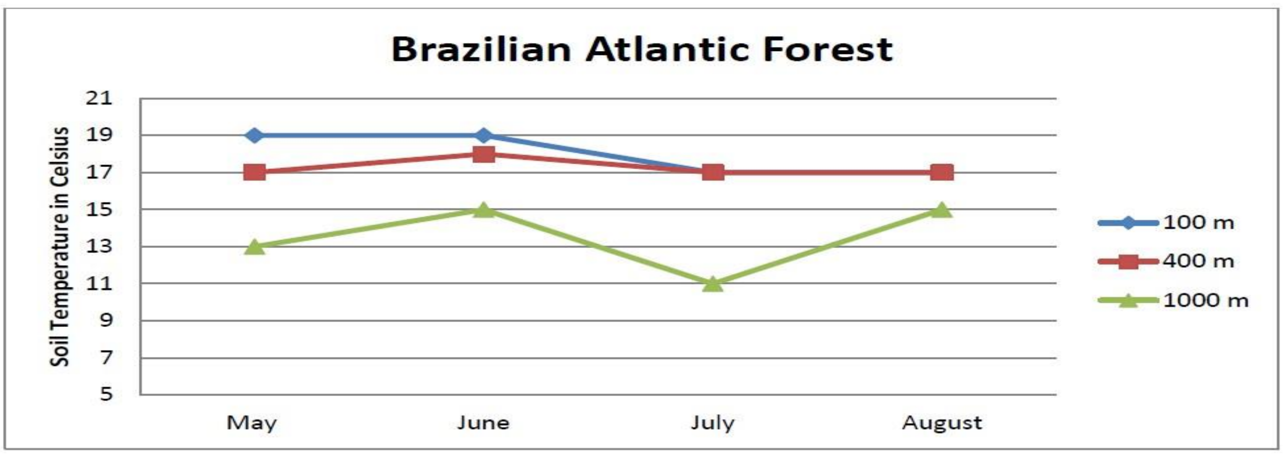

Figure 2. Brazilian Atlantic Forest soil temperature decreases as elevation increase along the gradient.

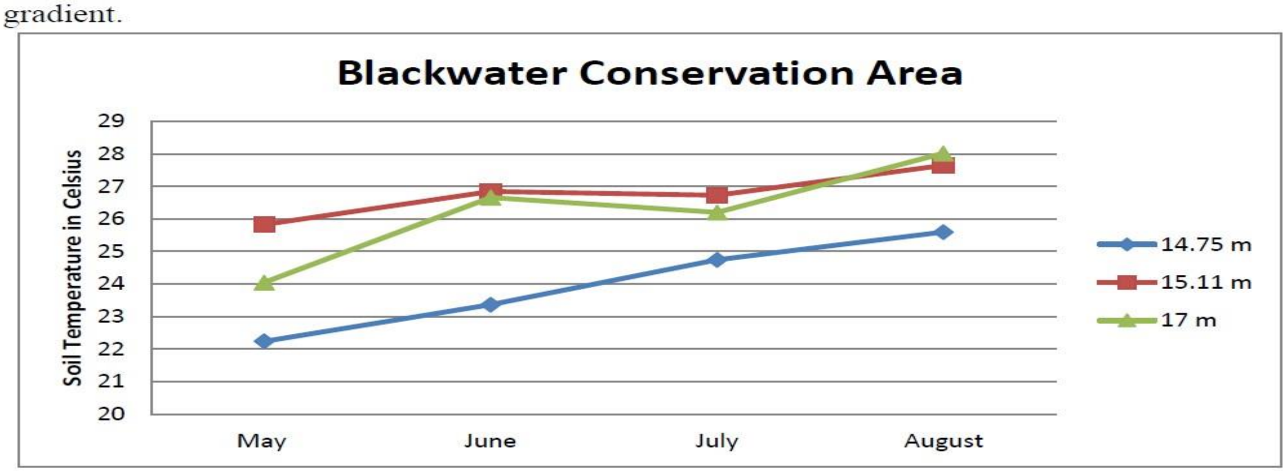

Figure 3. Soil temperature in the bottomland (14.75 m) is consistently lower than the upland (17 m) and

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Shrub/scrub (15.11) areas. The upland and shrub/scrub areas soil temperatures alternate positions in July and August.

3.2 Soil Temperature Influence on CO2 Flux

In earlier studies, soil flux has been shown to be positively correlated with soil temperature (Lloyd and Taylor 1994; Raich and Potter 1995). Nonetheless, in other studies, temperature responses have differed conditioned on ecosystem type and temperature range (Lloyd and Taylor 1994; Kirschbaum 1995; Winkler et al. 1996). It was hypnotized that soil temperature will have a significant effect on soil CO2 efflux. A wetland study in
2003 conducted by Zhaofu, Xianguo, and Qing showed a significant relationship between flux and temperature (Table 1). In this study, there was no significant relationship between soil temperature and CO2 flux in any wetland or land types (Tables 2 – 4). However, the temperature correlation with flux was positive in the bottomland and shrub/scrub but negatively correlated in the upland. This shows that responses to temperature differences in each ecosystem type. The shrub/scrub and upland's soil temperature were closely related, but the responses are different.

Table 1. Correlation analysis between soil CO_2 and soil temperature of D. angustifola wetland in China. **Correlation is significant at the 0.01 level (two-tailed), N=22

	Flux	0 cm	5 cm	10 cm
Flux	1.000	0.605 **	0.770 **	0.844**
0 cm		1.000	0.820**	0.777**
5 cm			1.000	0.995**
10 cm				1.000

Table 2. Correlation analysis between soil CO_2, soil temperature, and soil moisture in the bottomland study area. *Correlation coefficient significantly different from zero P<0.05

	CO2 Flux	Soil Temp.	Soil Moist.
CO2 Flux	1.00	0.13	-0.01
Soil Temp.		1.00	-0.29*
Soil Moist.			1.00

Table 3. Correlation analysis between soil CO2, soil temperature, and soil moisture in the shrub/scrub study area.

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*Correlation coefficient significantly different from zero P<0.05

	CO2 Flux	Soil Temp.	Soil Moist.
CO2 Flux	1.00	0.06	-0.04
Soil Temp.		1.00	-0.13
Soil Moist			1.00

Table 4. Correlation analysis between soil CO2, soil temperature, and soil moisture in the u pland study area.
*Correlation coefficient significantly different from zero P<0.05

	CO2 Flux	Soil Temp	Soil Moist
CO2 Flux	1.00	-0.18	0.37*
Soil Temp.		1.00	-0.24
Soil Moist.			1.00

3.3 Soil Moisture Influence on CO2 Flux

It was hypothesized that that soil moisture would have a significant impact on soil CO2 efflux. The results show that this was not the case for every wetland type. In the bottomland and shrub/scrub areas, the correlations were negative and not significant. The correlation of moisture with CO2 flux in the upland was positive and significant. In the upland area, water was a limiting factor in CO2. Figure 4. Shows the upland area spikes in soil moisture followed by larger moisture content inputs than the other wetland and land types. Feiziene et al. (2010) study show that soil moisture is an important factor in soil respiration. It also stated that microorganisms and root activity are reduced in drier conditions, resulting in lower soil CO2 efflux. In the weeks where soil moisture was not a limiting factor, the upland CO2 flux was higher (Figure 5). The moisture seems to have a lag effect on CO2. When water is available, the response is higher respiration rates. In the shrub/scrub and bottomland wetland types, soil moisture was not a limiting factor hence higher flux rates than the upland (Figures 6 and 7).

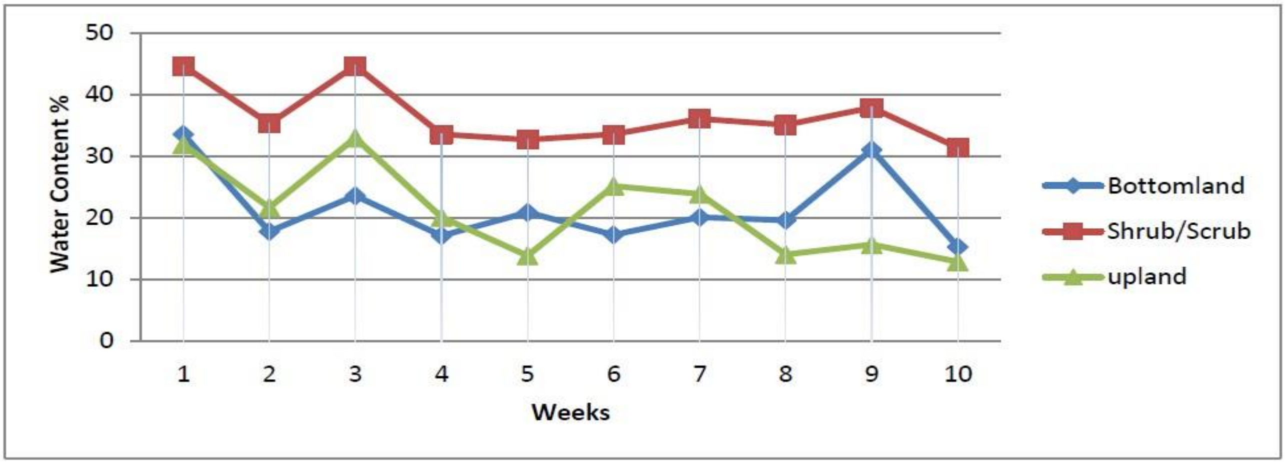

Figure 4. Soil volumetric moisture content of three wetland types over a ten-week period starting at week eleven in the Blackwater Conservation Area.

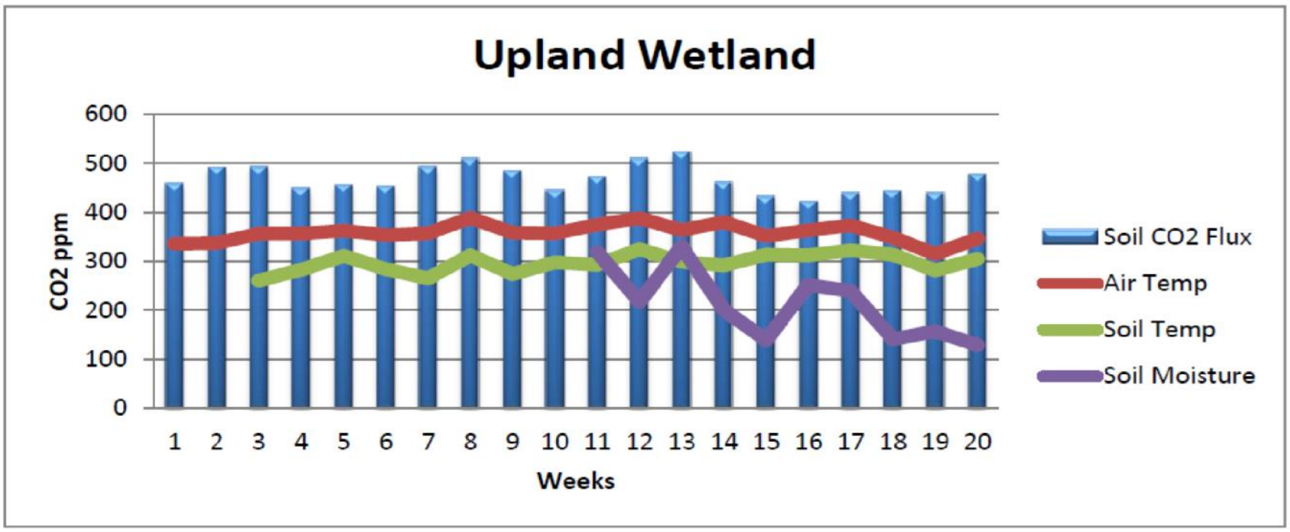

Figure 5. Soil CO_2 flux, air temperature, soil temperature, and soil moisture measured within the upland area over a twenty-week period. Air and soil temperatures were manipulated for thepurpose of graphing. The air temperature was multiplied by four and a half while the soil temperature was multiplied by eleven. The soil moisture was multiplied by ten.

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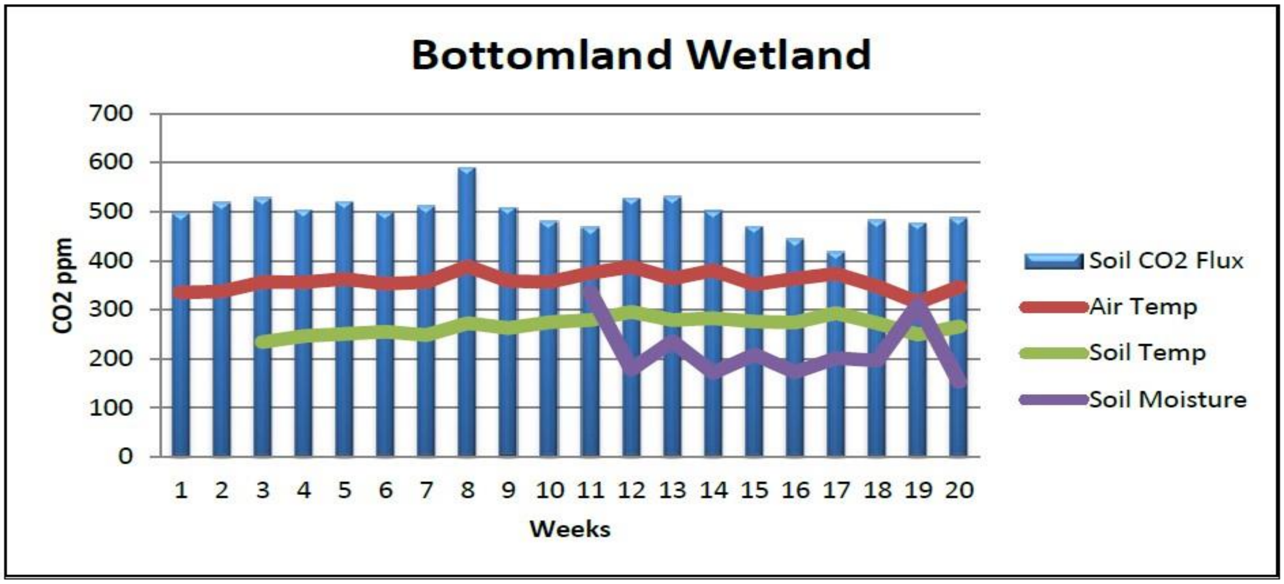

Figure 6. Soil CO2 flux, air temperature, soil temperature, and soil moisture measured within the bottomland area over a twenty-week period. Air and soil temperatures were manipulated for the purpose of graphing. The air temperature was multiplied by four and a half while the soil temperature was multiplied by eleven. The soil moisture was multiplied by ten.

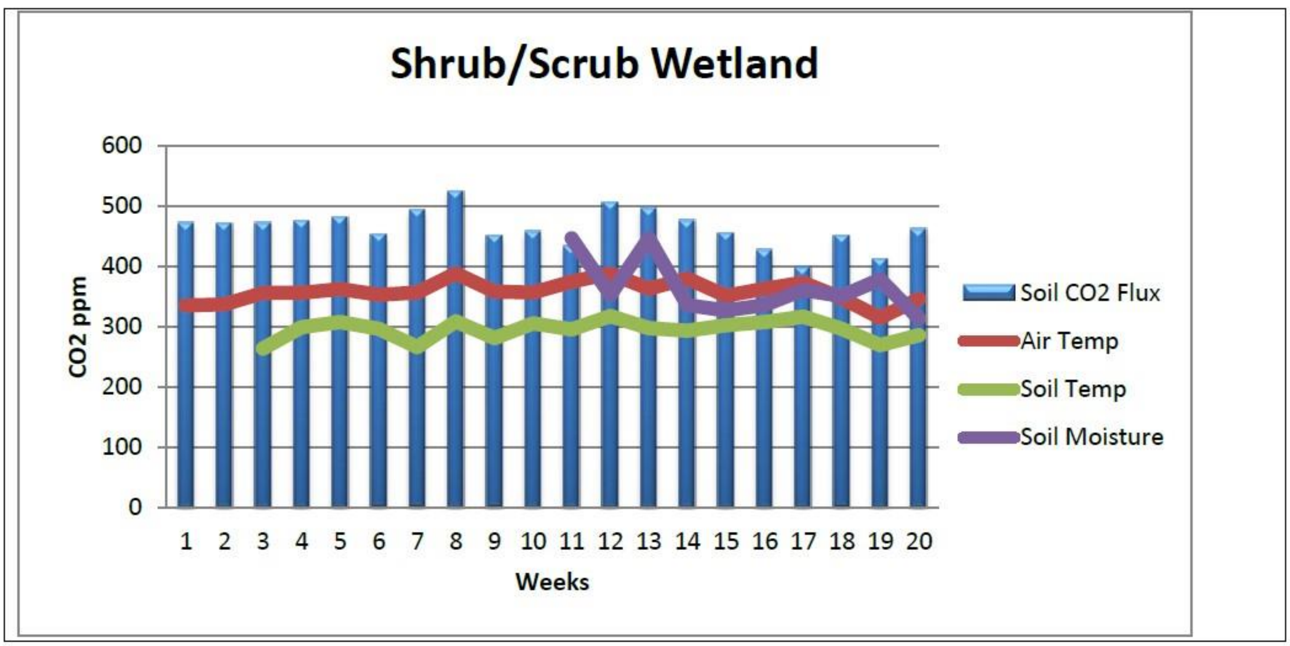

Figure 7. Soil CO2 flux, air temperature, soil temperature, and soil moisture measured within the shrub/scrub area over a twenty-week period. Air and soil temperatures were manipulated for the purpose of graphing. The air temperature was multiplied by four and a half while the soil temperature was multiplied by eleven. The soil moisture was then multiplied by ten.

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4. Conclusion

Many environmental factors influence soil gas exchange and respiration of CO_2 by soil organisms. Two factors, soil temperature and soil moisture play a role in soil microbial activity. From the results of this study, it appears that environmental factors like soil moisture and temperature have an important role in regulating CO_2 flux. Factors like bulk density can have an important role in drainage, which ultimately influences soil moisture, a regulator of soil CO_2 flux. With these findings, specific recommendations for the use of urban wetlands to combat global climate change cannot be offered due to the level of uncertainty of the influences of other factors outside of bulk density. There is a need for further research to understand other chemical and biological processes effects on soil gas flux. To understand the climatic implications of urban wetlands, other soil gas flux such as methane and nitrous oxide needs to be studied to understand the potential impact. In the efforts to combat carbon dioxide by using wetlands, methane emissions must be taken into consideration. Methane is one of the most important greenhouse gases in the atmosphere. The reason methane is an important greenhouse gas is because of its thermal absorption potential. Methane thermal absorption potential is 30 times greater than carbon dioxide.

On the contrary, CO_2 exist in the atmosphere at about 200 times the concentration (Bouwman, 1991). The increase in CH_4 over the past 200 years has drawn much attention in the scientific community because the concentration had doubled (Augenbraun et al., 1997). Wetlands are the largest producers of methane from a natural process. They account for about 20% of the global annual emissions of methane. Wetlands are largely disproportionate in contrast because wetlands only make up 5% of the earth's surface (Wang et al., 1996) (Adhikari et al., 2009). The other ways that methane is emitted naturally are from oceans and termites. Both ocean and termites make up a very small percentage of the overall picture. Collectively they make up about 7 to 10% of the total methane source. According to the 1997 global methane inventory, anthropogenic methane accounts for about 70% of the global methane (Augenbraun et al., 1997). The anthropogenic source comes from the mining of coal, oil, and natural gas. It is also derived from burning biomass, inputs from landfills, along with emissions from rice cultivation.

4.1 Future Considerations

Wetlands vary individually because of the array of environmental influences. Several factors must be taken into consideration when attempting to understand CH_4 emissions. Factor to be considered is carbon supplies, vegetation, pH, and the soil oxidation-reduction status just to name a few. Wetlands have an important role in the global carbon cycle because it stores about 10% of all globally stored carbon (Scheehle et al., 2002). The benefits of wetlands are tremendous, but the trade-off is that their anaerobic character causes carbon to be released back into the atmosphere in the form of CH_4 and CO_2 (Khoiyangbam et al., 2008). These gases are typically measured or monitored by a gas analyzer using a close chamber technique.

Wetlands within themselves are complex ecosystems, moreover in urban areas. The impact of anthropogenic inputs effects on urban wetland CO_2 flux is also an area that merits investigation. Each urban wetland land will differ from one to the other litter decomposition is another area that should be explored to better understand the productivity of urban wetlands.

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