Porter et al., Int J Earth Environ Sci 2023, 8: 205
https://doi.org/10.15344/2456-351X/2023/205

International Journal of
Earth & Environmental Sciences

Research Article Open Access

Carbon Dioxide, Methane, and Isoprene Concentrations in the Soils of Sustainable Organic Farmland

Timothy L. Porter*[1] **and Thomas R. Dillingham**[2]
[1]*Department of Physics and Astronomy, University of Nevada Las Vegas, Las Vegas, NV, 89154, USA*
[2]*Department of Applied Physics and Materials Science, Northern Arizona University, Flagstaff, AZ, 86011, USA*

Abstract

We have used a portable, battery powered quadrupole mass spectrometer to measure the relative concentrations of greenhouse gases CO_2, CH_4, and isoprene, along with water vapor concentrations in the soils of land practicing sustainable organic farming. Soils measured in this study show a reasonably strong correlation between greenhouse gas concentrations and soil water vapor content, similar to previous studies in natural forests. In this study, soil CO_2 concentration generally rises as water vapor content increases while CH_4 concentration increases as water vapor in the soil decreases. This is observed most strongly in the tilled soils and is likely the result of CH_4 oxidation decreasing as soil water content decreases. An exception to this trend for methane was observed in the fruit orchards. Higher relative CH_4 levels were measured along with high levels of soil isoprene. Here, isoprene producing bacteria are likely dominant, resulting in the higher CH_4 levels measured.

Publication History:

Received: January 04, 2023
Accepted: January 21, 2023
Published: Janaury 23, 2023

Keywords:

Carbon dioxide, Methane, Isoprene, Soil, Farmland, Quadrupole

Introduction

Soils throughout the world are large repositories of organic carbon. It is estimated that the topmost one meter of global soil contains between 3-4 times as much carbon as the entire planetary atmosphere [1-3]. For example, it has been measured that about 1500 Gt of organic carbon is stored in this top meter of soil with about 615 Gt stored in the top 20 cm alone [4, 5]. Farmland soils typically contain about 1-3 percent organic carbon. This compares to native forest soils which may have a 40 percent or more greater concentration of organic carbon [6], much of which is contained in the massive root structures of the large trees. In all types of soils, soil organic carbon (SOC) consists of live plant structures such as plant roots, and various forms of biomass that has worked into the soil from above ground plant structures. Soil respiration is the absorption or emission of gases from the soil owing primarily to the action of microbes living within the soil. Soil microbes feed upon decomposing soil biomass and depending on several factors may emit or absorb greenhouse gases such as carbon dioxide, methane, isoprene, and others. This process is highly dependent on soil biomass type and concentration, soil water vapor content, temperature and other factors [7-9].

According to the United States Environmental and Energy Study Initiative, sustainable farming, including the practice of no-till farming, greatly helps farmers adapt to climate change issues related to their profession. Conservation tillage, which includes no-till features, not only reduces the plowing or tilling of the farm soils, but leaves crop residues and plant litter atop the soil. It may also involve allowing the growth of other plant species or weeds in conjunction to the agricultural crops without the use of herbicides. It has been reported that soil organic carbon, or SOC, is greater in farm soils that practice no-till management [10]. Generally, natural forested areas or grasslands that are tilled and subsequently converted to agricultural land result in large declines in the concentrations of SOC [11]. Owing in part to the action of microbial species that exist in greater abundances in non-tilled soils, the amounts of SOC can be increased in these agricultural soils that practice conservation tillage [12, 13]. Even if the practice of no-till or sustainable farming results in greater sequestration overall of carbon in the soil, the flux of greenhouse gases owing to soil management is important in considering gas emission into the atmosphere from the soil.

Soil respiration generally refers to the mechanisms by which SOC is emitted into the atmosphere as carbon dioxide, CO_2. Soil Respiration represents the second largest carbon flux in the full terrestrial carbon cycle, releasing approximately 98 billion tons of carbon into the atmosphere every year (10). In the most general sense, soil respiration may also include the emission or absorption (sinking) of many gases, including CO_2, methane (CH_4), nitrous oxide (NO), isoprene (C_5H_8), and others. Several factors may affect the process of soil respiration, including soil temperature, water and soil water vapor, root structures, plant litter and decomposing species, soil bacterial load, soil pH, fertilization, and others [14-18].

Previously, we have used a battery-powered quadrupole mass spectrometer to obtain real-time measurements of CO_2, CH_4, water vapor, and isoprene in the near surface soils of the Coconino National Forest located in northern Arizona, USA [19,8,9]. The goal was to monitor the presence of these gases in pristine forests, forests that have been burned by wildfires, forests that have been commercially logged, and forest areas that have been mechanically thinned to reduce the future danger of wildfire. Over the span of many years, concentrations of these gases may help model soil respiration processes as burned forest areas or logged or thinned forest areas slowly recover to their natural state. In the current study, we use in-situ field quadrupole mass spectrometry to measure CO_2, CH_4, water vapor, and isoprene in agricultural areas that practice sustainable farming techniques, including no-till farming.

Materials and Method

The instrument used in this study is based upon a Micropole quadrupole mass spectrometer from Horiba, Inc. The basic design

***Corresponding Author:** Prof. Timothy L. Porter, Department of Physics and Astronomy, University of Nevada Las Vegas, Las Vegas, NV, 89154, USA; E-mail: tim.porter@unlv.edu

Citation: Porter TL, Dillingham TR (2023) Carbon Dioxide, Methane, and Isoprene Concentrations in the Soils of Sustainable Organic Farmland. Int J Earth Environ Sci 8: 205 doi: https://doi.org/10.15344/2456-351X/2023/205

has been described previously [8, 20]. In this study, the input section of the instrument has been modified with a 10 cm perforated probe that is fully inserted into the soil that is to be tested. This probe allows for the soil gases to rapidly come to equilibrium within the input section of the instrument during the warm-up period. The Micropole unit can measure masses in the range of 0-300 AMU and can measure partial pressures down to 10^{-10} Torr. The quadrupole analyzer itself measures 3.5 cm in length and is mounted on an MDC high vacuum mini-conflat flange. The system is powered by a a Li-Ion 24-Volt battery pack rated at 5 A-hr. Other components of this instrument include a diaphragm roughing pump, a 10 l/s high-vacuum turbomolecular pump, and a Pirani vacuum pressure gauge. The quadrupole instrument is interfaced to a laptop computer via a standard 9-pin serial port. The custom ambient air gas inlet components use two differentially pumped gas inlet orifices. For taking measurements at a given location, the system is placed on the ground and the roughing diaphragm pump is first turned on. After the system is rough pumped to approximately 1^{-3} x 10^{-3} Torr, the turbomolecular pump is initially turned on and the overall system pressure is brought down to the low 10^{-6} Torr pressure range. This warm-up process typically takes 20-25 min.

After gas equilibrium is reached, quadrupole measurements are taken and recorded. For this study, measurements were taken at Gilcrease Orchards, an 80-acre sustainable, organic farm located in Clark County, NV, USA. Crops grown on this farm include apples, peaches, cucumbers, green beans, radishes, pumpkins, and others. This sustainable farm practices sustainable, no-till farming and does not use pesticides or herbicides. On occasion, if a crop is to be rotated in a specific area of the farm, the soil may be tilled before planting. For this study, soil gas measurements were taken in no-till areas of the farm, except for specific soil measurements taken in tilled soil for the purposes of comparison with non-tilled soils. Also, these initial measurements were taken in the late summer season, while growing was still active, however some harvesting of crops was underway. Figure 1 below shows an image of the quadrupole instrument in the apple orchard during measurements.

Results and Discussion

Table 1 shows the “in-soil” relative concentrations of the gases CO_2, CH_4 and water vapor to their ambient air concentrations. Figure 2 shows the cucumber patch location at the farm. For each location, ambient gas concentrations were measured prior to the in-soil measurements. In table 1, relative gas concentrations are used as electron-impact quadrupole mass spectrometers only measure gas partial pressures (as low as the 10-10 Torr range). Calibrating these types of instruments in the field without the simultaneous use of exact calibration will likely result in potentially large errors. In this study, we are primarily interested in the soil relative values to ambient air.

We see that the relative levels of soil CO_2 are generally higher in the soils that contain the highest relative concentrations of water vapor. The lone exception is the soil from the area used for growing green beans. The correlation between soil CO_2 emission and water vapor has been studied previously [21] and also noted by us in studies of forest soils in the Coconino National forest. Soil microbial activity is decreased as the level of soil water vapor decreases if all other factors stay constant. Figure 3 shows a photo of the tilled soil area where measurements were taken. In addition to the effect of water vapor on soil CO_2 emissions, several other factors also play a role in the respiration of CO_2 and other gases. Soil biomass concentration

	Carbon Dioxide	Methane	Water Vapor
Apple Orchard	1.60 ± 1%	1.37 ± 1%	1.62 ± 1%
Peach Orchard	1.55 ± 1%	1.34 ± 1%	1.60 ± 1%
Cucumbers	1.49 ± 1%	1.15 ± 1%	1.41 ± 1%
Green Beans	1.51 ± 1%	1.18 ± 1%	1.58 ± 1%
Tilled Soil	1.03 ± 1%	1.43 ± 1%	1.22 ± 1%

Table 1: Soil gas concentration values relative to atmosphere in the farm areas indicated. These measurements were taken in September, late in the growing season.

Figure 1: Photo of the quadrupole instrument in the apple orchard during measurements. The small inlet probe can be seen curved over the instrument case top side in the instrument case.

Figure 2: Cucumber patch. Here, the cucumbers are watered using a drip system, so soil areas in-between rows do not show much wild plant growth. Soil gas measurements were taken in plant growth areas that receive water.

and litter decomposition [22], temperature variations [21, 23], and soil nitrogen concentration also play roles in soil respiration [24, 25]. In this study, we expect little or no temperature variation or soil nitrogen content variation between different areas of the same farm. Soil biomass and soil litter, however, will be somewhat different in the various types of vegetable or fruit growing areas of the farm.

Looking at the soil concentrations of CH_4, we see higher concentrations of methane over ambient air in all locations. The apple and peach orchards show the highest relative methane concentrations for growing areas, with the vegetable growing areas having about 15% lower soil methane levels. The tilled soil exhibits the largest soil methane concentration we measured on this farm. Soils normally act as net producers of CH_4 as the topmost layers of the soil lose moisture to the ambient atmosphere. This is because the largest natural process leading to CH_4 removal in the soils, oxidation of CH_4, is reduced as the soils dry out. In addition to the reduced oxidation of CH_4 that occurs as a function of water vapor loss and subsequent reduced bacterial activity, more rapid diffusion of CH_4 from deeper soil layers owing to water loss in the soils may also occur. These factors may explain the large methane concentrations measured in the tilled soils, but do not account for the larger levels of soil methane measured in the fruit orchards relative to the vegetable growing areas.

In table 2 below we show measurements of relative isoprene from different agricultural areas studied. Interestingly, we find higher than atmospheric levels of isoprene in the apple orchard and to a lesser degree the peach orchard. Isoprene (2-methyl-1,3 butadiene) is a highly volatile greenhouse gas that is produced in large amounts by growing vegetation. It is estimated that annual emissions of isoprene from all sources of vegetation are 503 Tg per year. Previously, it was thought that the atmosphere was the only large isoprene sink in the environment, however more recently soils have been found to act as another large net consumer of isoprene [26].

	Apple Orchard	Peach Orchard	Green Bean	Cucumber	Tilled Soil
Relative Isoprene	1.40 ± 1%	1.08 ± 1%	0.88± 1%	0.86 ± 1%	0.98 ± 1%

Table 2: Relative concentrations of isoprene at the tested farm locations indicated.

Many different types of microbes in the soil consume isoprene, including Arthrobacter, Nocardia and Rhodococcus genera. In addition, bacteria such as Actinobacteria and Alphaproteobacteria as well as some fungal species such as Sordariomycete and Eurotiomycete have also been found to consume isoprene in soils [27]. Certain bacteria found in soils may also produce isoprene. These bacteria include Proteobacteria, Actinobacteria, Firmicutes and Bacillus [28].

Figure 3: Photo of tilled soil patch. This soil has been tilled for approximately one year.

Citation: Porter TL, Dillingham TR (2023) Carbon Dioxide, Methane, and Isoprene Concentrations in the Soils of Sustainable Organic Farmland. Int J Earth Environ Sci 8: 205 doi: https://doi.org/10.15344/2456-351X/2023/205

In most situations, however, soils act as net sinks of isoprene. For example, in one laboratory study, soils were found to consume approximately 55% to 80% of the gaseous isoprene provided to the soils [27]. Total yearly removal of atmospheric isoprene by soils worldwide is estimated to be 20.4 Tg/yr. [29]. Here, we see that isoprene production from soil bacteria is relatively larger than isoprene consumption in the two fruit orchards, while isoprene consumption is larger in the two vegetable farm locations. We also note that we measured larger relative soil isoprene consumption in several forested areas in earlies studies by us [8, 19]. It may be possible that the larger levels of soil isoprene found in the fruit orchards is correlated to the larger relative levels of soil CH_4 found in the same orchards. In soils, anaerobic methanogenic bacteria are generally responsible for methane production, while aerobic methanotrophic bacteria, as well as anaerobic methanotrophic bacteria and archaea, are involved in methane consumption through oxidation [30]. Higher levels of soil water, which enhance soil CO_2, may be correlated with lower soil oxygen levels and greater anaerobic bacterial activity. This same combination of soil conditions that is resulting in larger isoprene production in the fruit orchards may also contribute to the relatively large CH_4 levels.

Conclusion

The concentrations of CO_2, CH_4, and isoprene in soils depend on many factors including water vapor content in the soil, temperature, soil biomass content and type, microbial and bacterial populations, nitrogen content, use of herbicides and pesticides, and others. Like previously measured soils in forested areas, the farm soils measured in this study show a reasonably strong correlation between greenhouse gas concentrations and soil water vapor content. Soil CO_2 concentrations generally rise as water vapor content increases while CH_4 concentrations generally show an inverse correlation to water vapor. This is observed most strongly in the tilled soils. An exception to this trend for methane was observed in the fruit orchards. Higher relative CH_4 levels were measured along with high levels of soil isoprene. Here, isoprene producing bacteria are dominant, and may also contribute to the higher CH_4 levels measured. Measurements of soil biomass types and other conditions that may lead to higher relative isoprene production will be undertaken in future studies.

Competing Interests

The authors declare that they have no competing interests.

References

1. Stockmann U, Adams MA, Crawford JW, Field DJ, Henakaarchchi N, et al. (2013) The Knowns, Known Unknowns and Unknowns of Sequestration of Soil Organic Carbon. Agriculture Ecosystems and Environment 164: 80-99.
2. Kirschbaum M (2000) Will Changes in Soil Organic Carbon Act as a Positive or Negative Feedback on Global Warming. Biogeochemistry 48: 21-51.
3. Powlson DS, Stirling CM, Jat ML, Gerard BG, Palm CA, et al. (2014) Limited Potential of No-Till Agriculture for Climate Change Mitigation. Nature Climate Change 4: 678-683.
4. Jobbagy EG, Jackson RB (2000) The Vertical Distribution of Soil Organic Carbon and its Relation to Climate and Vegetation. Ecol Appl 10: 423-436.
5. Guo LB, Gifford RM (2002) Soil Carbon Stocks and Land Use Change. Global Change Biol 8: 345-360.
6. Jenkins DS (1988) The Turnover of Organic Matter in Soil, in Russell's Soil Conditions and Plant Growth, A. Wild, Editor, Harlow. p. 564-607.
7. Parton W, Silver WL, Burke IC, Grassens L, Harmon ME, et al. (2007) Global-Scale Similarities in Nitrogen Release Patterns During Long Term Decomposition. Science 315: 361-364.
8. Porter TL, Dillingham TR (2020) Measurement of Carbon Dioxide and Methane in Forest Soils Following Uncontrolled Wildfires in the Coconino National Forest. Int J Earth Environ Sci 5: 176.
9. Porter TL, Dillingham TR (2018) In-Situ Measurement of Forrest Soil Gases using Quadrupole Mass Spectrometry. Int J Earth Environ Sci 3: 149.
10. Ogle SM, Alsaker C, Baldock J, Bernoux M, Breidt FJ, et al. (2019) Climate and Soil Characteristics Determine Where No-Till Management Can Store Carbon in Soils and Mitigate Greenhouse Gas Emissions. Nature Sci Rep 9: 11665-11672.
11. Davidson EA, Ackerman IL (1993) Changes in Soil Carbon Inventories Following Cultivation of Previously Untilled Soils. Biogeochemistry 20: 161-193.
12. Jastrow JD, Boutton TW, Miller RM (1996) Carbon Dynamics of Aggregate-Associated Organic Matter Estimated by Carbon-13 Natural Abundance. Soil Science Society of America Journal 60: 801-807.
13. Six J, Elliot ET, Paustain K (2000) Soil Macroaggregate Turnover and Microaggregate Formation: A Mechanism for C Sequestration Under No-Tillage Agriculture. Soil Biology and Biochemistry 32: 2099-2103.
14. Blevins RL, Thomas GW, Cornelius PL (1977) Influence of No-Tillage and Nitrogen Fertilization on Certain Soil Properties After 5 Years of Continuous Corn. Agron 69: 383-386.
15. Boone RD, Nadelhoffer KJ, Canary JD, Kaye JP (1998) Roots Exert a Strong Influence on the Temperature Sensitivity of Soil Respiration. Nature 396: 570-572.
16. Bowden RD, Nadelhoffer KJ, Boone RD, Melillo JM, et al. (1993) Contributions of Aboveground Litter, Belowground Litter, and Root Respiration to Soil Respiration in a Temperate Mixed Hardwood Forest. Can J Forest Res 23: 1402-1407.
17. Brumme R, Beese F (1992) Effects of Liming and Nitrogen Fertilization on Emissions of CO_2 and N_2O From a Temperate Forest. J Geophys Res 97: 12851-12858.
18. Dick WA (1983) Organic Carbon, Nitrogen, and Phosphorus Concentrations and pH in Soil Profiles as Affected by Tillage Intensity. Soil Sci Soc Amer J 47: 102-107.
19. Porter TL, Dillingham TR (2022) Recent Trends in Greenhouse Gases Levels in the Soils of the Coconino National Forest. Journal of Earth and Environmental Sciences Research 3: 1-5.
20. Porter TL, Dillingham TR, Cornelison DM, Venedam RJ, Williams G (2009) Design of a Portable, Battery Powered Quadruple Mass Spectrometer System for Real-Time Sampling of Materials. Proc Mat Res Soc 1169: 1169-Q06-10.
21. Davidson EA, Belk E, Boone RD (1998) Soil Water Content and Temperature as Independent or Confounded Factors Controlling the Soil Respiration in a Temperate Mixed Hardwood Forest. Global Change Biology 4: 217-277.
22. Rui Y, Murphy D, Wang X, Hoyle FC (2016) Microbial Respiration, but not Biomass, Responded Linearly to Increasing Light Fraction Organic Matter Input: Consequences for Carbon Sequestration. Scientific Reports 5: 1-9.
23. Davidson EA, Janssens LA (2006) Temperature Sensitivity of Soil Carbon Decomposition and Feedbacks to Climate Change. Nature. 440: 165-173.
24. Berg B, Matzner E (1997) Effect of N Deposition on Decomposition of Plant Litter and Soil Organic Matter in Forest Systems. Env Reviews 5: 1-25.
25. Janssens IA, Dielaman W, Luyssaert S, Subke JA, M. Reichstein, et al. (2010) Reduction in Forest Soil Respiration in Response to Nitrogen Depletion. Nature Geoscience 3: 315-322.
26. McGenity TJ, Crombie AT, Murrell JC (2018) Microbial Cycling of Isoprene, the Most Abundantly Produced Biological Volatile Compound on Earth. The ISME Journal 12: 931-941.
27. Gray CM, Helmig D, Fierer N (2015) Bacteria and Fungi Associated with Isoprene Consumption in Soil. Elementa Science of the Anthropocene 3: 53-58.
28. Kuzma J, Nemecek-Marshall M, Pollock WH, Fall R (1995) Bacteria Produce the Volatile Hydrocarbon Isoprene. Curr Microbiol 30: 97-103.
29. Cleveland C, Yavitt J (1997) Consumption of Atmospheric Isoprene in Soil. Geophysical Research Letters 24: 2379-2382.
30. Knief C (2019) Diversity of Methane Cycling Microorganisms in Soils and Their Relation to Oxygen. Curr Issues Mol Biol 33: 23-56.