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Recent Trends in Greenhouse Gases Levels in the Soils of the Coconino National Forest

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ABSTRACT

We have taken near-surface soil measurements of the gases CO_2, CH_4, H_2O and isoprene in several regions of the Coconino National Forest, Arizona, USA. Sets of measurements were taken both prior to the start of the seasonal monsoon season, in addition to while the monsoon season was underway. We have also compared the current monsoon season readings with readings taken at the same locations four years prior. For CO2, the relative level in the pristine forest soil is just under 3.7 percent lower than that measured in 2017, while the CO_2 relative levels for the thinned and logged sites are lower by 13.5 and 5.4 percent, respectively. Even accounting for small increases in forest vegetation, these lower readings appear to be correlated to lower overall soil H_2O concentrations. The pristine CH_4 relative concentration in 2021 is 9.6% higher and the thinned CH_4 level is 19% higher. For the logged region, the measured methane level is over 70% lower than in 2017, but still approximately triple the methane level as seen in the other forest areas. We conclude that this result also may also be correlated to lower measured H_2O levels in the soils.

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Introduction

Soil respiration in forest environments contributes a significant amount of the total atmospheric greenhouse gas flux attributed to the overall forest [1-5]. Studies show that in the case of carbon dioxide, or CO_2, soil respiration processes have been shown to contribute between 20% and 40% of all CO_2 released by forests worldwide and up to 70% of all CO_2 released in temperate forest environments. Several different factors may play a role in the respiration of CO_2 from these soils. Much of the CO_2 emission or absorption from soil environments is attributed to soil-based microbial activity. Factors that affect this microbial activity play a significant role in the overall CO_2 respiration. One factor that may affect soil microbial activity is short-term and long-term temperature variation [6, 7]. In these studies, a strong correlation with atmospheric temperature and soil CO_2 flux was observed, with maxima of flux and temperature being out of phase [8, 9]. Also, it was noted that atmospheric temperature and near-surface soil temperature were highly correlated, possibly indicating that soil CO_2 activity was occurring primarily in the very near surface regions of the soil.

The overall abundance of nitrogen in the soil may affect respiration of CO_2. Any factors that alter the amount of available nitrogen such as nitrogen deposition, litter decomposition, drought, fires, forest thinning, and other mechanisms may play roles in eventual CO_2 production [10, 11]. In soils where the nitrogen level is enhanced, overall microbial levels and activity are lowered, leading to reduced respiration and increased CO_2 sequestration. Here, the reduction in carbon emissions may be substantial, and near the same magnitude of carbon taken up by trees themselves owing to nitrogen fertilization [11]. Water content in the forest soils also affects overall CO_2 respiration. In studies focusing on ponderosa pine forested areas, CO_2 efflux was found to vary according to seasonal changes in soil moisture content as well as soil moisture content changes owing to forest thinning [12, 13]. A similar reduction in soil microbial activity and near-surface CO_2 concentration was also reported by us owing to forest thinning and logging activities with resultant soil moisture reduction [9]. It has also been reported that soil moisture conditions in which the soil water content is higher than optimal conditions may also result in a reduction of overall soil respiration [14]. Here, a negative correlation between high soil moisture content and soil temperature was observed. In studies comparing the availability of light fraction organic matter and overall levels of microbial activity and soil CO_2 respiration, it was reported that there exists a linear relationship between the availability of decomposing light biomass and soil CO_2 respiration [15]. Finally, levels of soil compaction were found to alter soil respiration rates, with coarse textured soils having more microbial activity that fine textured, compact soils [16].

Methane, or CH_4, is another very important atmospheric greenhouse gas in which forests around the world play a major role [17-20]. Forest soils may act as sources or sinks for CH_4, depending on a variety of environmental conditions. It has been shown that plant litter near soil surfaces may produce as much as 1-7 Tg/yr of methane in aerobic conditions on and near the surface of forest and other soils [21]. In another study, it was shown that CH_4 may be emitted by microbes contained within forest soils as they digest organic carbon made available by forest plant life [18]. Oxygen availability is needed and could vary substantially owing to changes in soil water content. In earlier studies, it has been shown that forest soils act as net producers of CH_4 as the topmost layers of the soil lose moisture. Here, it was argued that the oxidation of CH_4 was significantly reduced in the dryer soil layers, subsequently rendering inactive the largest process leading to CH_4 removal in the soils [22]. Possible explanations for this observation include reduced oxidation of CH_4 as a function of moisture loss and degradation of the bacteria, and more rapid diffusion of CH_4 out into the atmosphere because of water loss in the soils, ultimately resulting in less time for CH_4 oxidation by bacteria to occur [23]. Production of CH_4 and ethylene, C2H4, has also been demonstrated in laboratory experiments of forest soils under more anaerobic conditions [24]. In this set of experiments, soil bacteria consume forest litter near the soil surface resulting in direct CH_4 production.

Isoprene is another gas produced in abundance by forest plant and tree growth [25]. It is a volatile organic compound, or VOC, and a known greenhouse gas. Soils in forests and other environments may break down isoprene through the action of various bacteria in the soils, thus acting as isoprene sinks. Both Actinobacteria and Proteobacteria species have been found to break down isoprene in these environments. Overall, a wide variety of environmental processes occurring within the near-surface soils of forests contribute to respiration effects of carbon dioxide, methane, and isoprene.

Materials and Method

Field gas measurements were conducted using a portable, battery-powered quadrupole mass spectrometer designed and constructed by us [8]. Major components of this instrument include a miniature quadrupole residual gas analyzer (RGA), a diaphragm roughing pump, a high-vacuum turbomolecular pump, and a lithium-ion battery with associated DC-DC converter circuitry for overall system operation. Low and high vacuum pressure gauges are also attached to the mass spectrometer vacuum system. The full system is controlled by a laptop computer interfaced to the mass spectrometer through a serial port. The portable unit also is designed with a differentially pumped gas inlet orifice that enables real-time measurement of gases under fully ambient conditions. For a typical field measurement at a specific location, the system is placed on the ground and the roughing diaphragm pump is first turned on. After a few minutes of rough pumping the system is brought down to approximately 1-3 x 10-3 Torr. At this time, the turbomolecular pump may be initially turned on. The turbo pump is allowed to pump the system for 15-20 minutes, at which time the total system pressure is down in the low 10-6 Torr pressure range or better. After system pressure is in the 10-6 Torr range, the quadrupole RGA may be turned on, including the ionization filaments heated within the vacuum system.

After the quadrupole system is operational, gas measurements may be made at that specific location. The differentially pumped gas inlet system is configured with a low volume probe that is directly inserted into the soil, reaching a depth of approximately two inches. The probe may be used in moist, loose soils as well as dry compacted soils. After probe insertion, the system under measurement is allowed to come to equilibrium for a few minutes, with real-time monitoring of the gas concentrations in part-per-million or part per billion units enabled. Shortly after equilibrium is reached, typically in a few minutes, the gas concentrations are recorded. This process may be repeated at similar of different locations until the battery power is depleted, which is usually 2.5 – 3 hours of operation. The unit may then be plugged into a typical 115 VAC outlet to recharge itself.

Results and Discussion

In the current study, we measured the relative concentrations of CO_2, CH_4, and H_2O vapor at three different locations within the Coconino National Forest. The first area is referred to as pristine. Here, the forest is completely natural and untouched, with all plant and tree growth as well as soil conditions untouched or modified by any external means. Figure 1 shows a photo of the pristine forested area where measurements were taken. The types of trees that are contained within these areas include ponderosa pine, pinion pine, limber pine, aspen, Gambel oak, Douglas fir, white fir, sub-alpine fir, cork bark fir, Engelmann spruce, blue spruce, alligator juniper, rocky mountain juniper and Utah juniper. The dominant species within the Coconino National Forest is ponderosa pine.

Figure 1: Untouched Coconino National Forest location where "pristine" gas measurements were taken

The second area in which a set of measurements were taken is referred to as the W. L. Gore forest area. At this data collection location, the forest had been mechanically thinned in 2012 to reduce the probability of wildfires. As a result of this mechanical thinning process, small diameter trees are removed along with bushes, low-lying brush, and forest debris. The third area of quadrupole gas measurements is referred to as the Howard logged area. In the area, the forest was commercially logged in 2017. During the logging process approximately 80% of both large and small diameter trees were removed, along with much of other plants including bushes, grasses, and other forest debris. In this area, approximately 50% of the soil area was laid bare in 2017, with partial regrowth of some grasses, bushes and small trees observed four years later in 2021. For the current study, two sets of measurements were made at these three forest locations. The first set was obtained in May, prior to the Northern Arizona monsoon season. The second set of data was obtained in July of the same year, after rains had begun. Here, measured rainfall was recorded in approximately 5 of the 10 days prior to quadrupole data being taken. Figure 2 shows a photo of the thinned forest area, while Figure 3 shows a photo of the logged forest area.

Figure 2: Photograph of the Coconino National Forest W.L. Gore area that has been mechanically thinned in order to reduce the probability of wildfires

We also note that the measurements made during the monsoon seasons in 2017 and 2021 occurred with ambient temperatures within 1°C of each other, and within 1 hr of the time of day. In Table 1, we show the relative concentrations of CO_2, CH_4, and water vapor compared to the same gases measured outside of the soil approximately 5 minutes prior to the soil measurements. We use relative factors because while electron-impact quadrupole mass spectrometers are able to measure residual gases with part-per-billon sensitivity, calibrating these instruments in the field without the simultaneous use of exact calibration standards may be a source of many different types of errors. Here, by using ratios of gas concentrations taken a few minutes apart, we can best compare the effects of the soil environment with the ambient, above ground environment. The data shown in Table 1 contains measurements taken during the monsoon season, with damp soil and overcast atmospheric conditions.

Figure 3: Photograph of the commercially logged Howard Forest area

Table 1: Gas concentration ratios of in-soil measurements to ambient concentration measurements

	Carbon Dioxide	Methane	Water Vapor
Pristine Forest Soil	2.85	0.66	1.38
Thinned Forest Soil	2.30	0.47	1.32
Logged Forest Soil	2.10	1.51	1.31

We can compare these readings to previous, similar readings taken at the same locations in 2017. In 2017, the CO_2, CH_4, and H_2O relative readings were 2.96, 0.56, and 1.44 for the pristine location, 2.66, 0.42, and 1.41 for the thinned forest site, and 2.22, 5.1, and 1.37 for the logged location. For CO_2, the relative level in the soil is just under 3.7 percent lower than that measured in 2017, while the CO_2 relative levels for the thinned and logged sites are lower by 13.5 and 5.4 percent, respectively. Overall, the CO_2 levels at all three locations measured in 2021 are relatively consistent with the same measurements taken in 2017, albeit lower across all three locations. Observationally, we can report that the overall level of vegetation is observationally slightly higher in 2021 at the thinned and logged sites with tiny tree seedlings, grasses and weeds beginning to appear in greater quantities. While we note that the small increase in vegetation might otherwise result in a small increase in the production of CO_2, we also note that the relative soil water vapor concentration is lower in 2021 than it was in 2017. Much of the CO_2 emission or absorption from soil environments is attributed to soil-based microbial activity, thus factors that affect this microbial activity play a significant role in the overall CO_2 respiration. Some factors that may affect microbial activity include as nitrogen abundance, litter decomposition, drought, fires, forest thinning, and other mechanisms. Water content in the forest soils also affects overall CO_2 production and respiration [14]. Previous studies in ponderosa pine forested areas, CO_2 efflux was found to vary according to seasonal changes in soil moisture content and soil moisture content changes. Here, it is possible that the lower levels of moisture content in the soils measured have resulted in a concomitant decrease of soil microbial activity and subsequent CO_2 production. This effect may be considerably larger than CO_2 production from other effects, such as a slight increase in available biomass in determining the net CO_2 efflux observed.

In comparing the measurements on soil methane with those obtained in 2017, we refer again to Table 1. Here, we can see that the measured soil relative methane levels are higher than what was measured in 2017 for pristine and thinned forest areas and much lower than the 2017 value for the same logged area. The pristine CH_4 relative concentration in 2021 is 9.6% higher and the thinned CH_4 level is 19% higher. For the logged region, the measured methane level is over 70% lower than in 2017, but still approximately triple the methane level as seen in the other forest areas.

Forest soils may act as net producers of CH_4 as the topmost layers of the soil lose moisture. One possible mechanism is that the oxidation of CH_4 is significantly reduced in the dryer soil layers, subsequently rendering inactive the largest natural process leading to CH_4 removal in the soils [22]. Other possible explanations for this observation include reduced oxidation of CH_4 as a function of moisture loss and degradation of the bacteria, and more rapid diffusion of CH_4 out into the atmosphere because of water loss in the soils, ultimately resulting in less time for CH_4 oxidation by bacteria to occur. As was the case with CO_2, overall water vapor levels in the soil being less than what was observed in 2017 appear to be the dominating factor explaining our 2021 results. In the logged forest area, the measured CH_4 level is significantly lower, but as was the case in 2017 it is very high with respect to the methane levels measured in other forest areas. One possible explanation is that soil compaction owing to the logging process leads to higher anaerobic conditions within the soil, which has been shown to lead to enhanced CH_4 production by soil microorganisms and less diffusion of the methane out of the soil.

We can compare the relative values of these greenhouse gases as measured during the 2021 monsoon season with measurements taken at the same areas three months earlier, when drier conditions prevailed. In Figure 4, we show these relative levels. For the pristine, thinned, and logged forest areas, the measured water vapor levels in the soil are lower by 9.7, 20.0, and 12.0 percent, respectively. The relative levels of CO_2 are lower under drier soil conditions in each of the three areas measured, and the CH_4 levels are all higher. We do not have dry soil measurements from 2017 to compare with these results. The data do, however, point to soil water vapor content as potentially the most significant factor in determining the relative abundances of the gases CO_2 and CH_4 in these topmost soil regions. We feel that over the longer term, possibly decades, the availability of soil biomass will also be of very high relative importance, but for these sets of data taken over a four-year span, the effect of soil biomass quantity is more difficult to ascertain. Finally, we have taken initial measurements of isoprene in the near surface soil regions of the pristine, thinned, and logged forest areas. Table 2 below show this data.

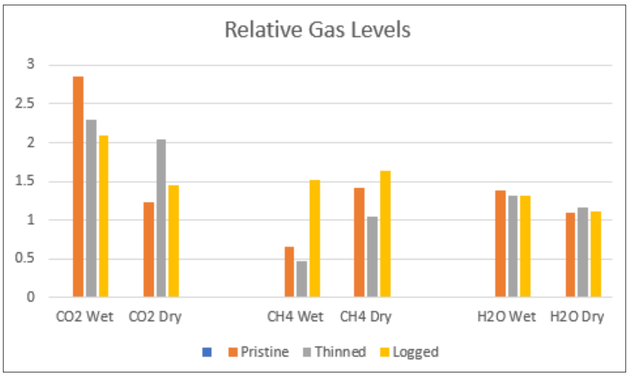

Figure 4: Relative values of greenhouse gases measured during the 2021 monsoon season compared with measurements taken at the same areas 3 months earlier when drier conditions prevailed.

Table 2: Relative amounts of isoprene gas in three forest areas during the 2021 monsoon season

	Pristine Forest	Thinned Forest	Logged Forest
Relative Isoprene	0.73	0.93	0.86

These relative isoprene levels, with respect to ambient air in the same areas, were taken during the 2021 monsoon season. It has been postulated that soils in forests and other environments may break down isoprene through the action of various bacteria in the soils, thus acting as isoprene sinks. Both Actinobacteria and Proteobacteria species have been found to break down isoprene in these environments. Here, we can see that is very possible that some sink effect owing to the soils may be in effect. Data on isoprene levels taken in future measurements will help to quantify this effect and may also help to provide a measuring tool for the overall bacterial activity levels in these soils.

Conclusions

Measurements taken in the forest soils of the Coconino National forest of Northern Arizona for the gases CO_2, CH_4, and H_2O show relatively consistent results with similar measurements taken in 2017. Differences in measured values for CO_2 and CH_4 over this span are mostly correlated with relative soil water vapor readings taken at the same times and locations. This result is also consistent with soil gas measurements taken in the dry season prior to the wet monsoon season at the same forest areas. While greenhouse gas respiration by forest soils is modified by several different factors such as temperature, biomass availability, nitrogen availability and other factors, the absolute concentrations of water vapor appear to be the predominant factor. In future studies, we can use baseline isoprene soil levels to further quantify the level of microbial activity present in the soils.

Competing Interests

The author declares that they have no competing interests.

References

1. Bond-Lamberty B, Thomson A (2010) Temperature Associated Increases in the Golbal Soil Respiration Record. Nature. 123: 99-117.
2. Davidson EA, Janssens LA (2006) Temperature Sensitivity of Soil Carbon Decomposition and Feedbacks to Climate Change. Nature.440: 165-173.
3. Gouklen ML, Munger JW, Fan SM (1996) Measurements of Carbon Sequestration by Long Term Eddy Covariance Methods in a Critical Evaluation of Accuracy. Global Change Biol 2: 169-182.
4. Law BE, Ryan MG, Anthoni PM (1999) Seasonal and Annual Respiration in a Ponderosa Pine Ecosystem. Global Change Biol 5: 169-182.
5. Raich JW, Schlessinger WH (1992) The Golbal Carbon Dioxide Flux in Soil Respiration and its Relationship to Vegatation and Climate. Tellus 44: 81-99.
6. Londo AJ, Messina MG, Schoenholtz SH (1999) Forest Harvesting Effects on Soil Temperature, Moisture, and Respiration in a Bottomland Hardwood Forest. Soil Society of America Journal 63: 637-644.
7. Parkin TB, Kaspar TC (2003) Temperature Controls on Diurnal Carbon Dioxide Flux. Soil Science Society of America Journal 67: 1763-1772.
8. Porter TL, Dillingham TR (2020) Measurement of Carbon Dioxide and Methane in Forest Soils Following Uncontrolled Wildfires in the Coconino National Forest. International Journal of Earth and Environmental Sciences 5: 176-184.
9. Porter TL, Dillingham TR (2018) In-Situ Measurement of Forrest Soil Gases using Quadrupole Mass Spectrometry. International Journal of Earth and Environmental Sciences. 3: 149-155.
10. 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.
11. Janssens IA, Dielaman W, Luyssaert S (2010) Reduction in Forest Soil Respiration in Response to Nitrogen Depletion. Nature Geoscience 3: 315-322.
12. Tang J, Qi Y, Xu M (2005) Forest Thinning and Soil Respiration in a Ponderosa Pine Plantation in the Sierra Nevada. Tree Physiology 25: 57-66.
13. Xu M, Qi Y (2001) Soil Surface CO_2 Efflux and its Spatial and Temporal Variations in a Young Ponderosa Pine Plantation in Northern California. Global Change Biol 7: 667-677.
14. 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.
15. Rui Y, Murphy DV, Wang X (2016) Microbial respiration, but not biomass, responded linearly to increasing light fraction organic matter input: Consequences for carbon sequestration. Scientific Reports 5: 1-9.
16. Six J, Connant RT, Paul EA (2002) Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. Plant Soil 241: 155-176.
17. Keppler F, Hamilton JTG, Brass M, et al. (2006) Methane

Emissions from Terrestrial Plants Under Aerobic Conditions. Nature 439: 187-191.
18. Megonigal JP, Guenther AB (2008) Methane Emissions from Upland Forest Soils and Vegitation. Tree Physiology.28: 491-498.
19. Zhang W, Wang K, Luo Y (2014) Methane uptake in forest soils along an urban-to-rural gradient in Pearl River Delta, South China. Scientific Reports 4: 1-6.
20. Sinha V, Williams J, Crutzen PJ (2007) Methane emissions from boreal and tropical forest ecosystems derived from in-situ measurements. Atmos. Chem. Phys. Discuss 7: 14011-14039.
21. Covey K, Megonigal JP (2019) Methane production and emissions in trees and forests. New Phytologist 222: 35-51.
22. Megonigal JP, Hines ME, Visscher PT (2004) Anaerobic Metabolism: Linkages to Trace Gases and Aerobic Processes. Biogeochemistry, ed. W.H. Schlesinger, Elsevier-Pergamon, Oxford 317-424.
23. Anderson BL, Bidoglio G, Leip A (1998) A New Method to Study Simultaneous Methane Oxidation and Methane Production in Soils. Global Biogeochem. Cycles 12: 587-594.
24. Jackel U, Schnell S, Conrad R (2004) Microbial ethylene production and inhibition of methanotrophic activity in a deciduous forest soil. Soil Biology and Biochemistry 36: 835-840.
25. McGenity TJ, Crombie AT, Murrell JC (2018) Microbial cycling of isoprene, the most abundantly produced biological volatile compound on Earth. The Multidisciplinary Journal of Microbial Ecology 12: 931-941.