

APPLICATIONS OF PHOTOACOUSTIC SPECTROSCOPY IN THE SERVICE OF SUSTAINABLE AGRICULTURE

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Agricultural activities are significantly responsible for the emission of anthropogenic greenhouse gases and the associated climate change. Besides carbon dioxide (CO₂) emissions related to production, fertilizer manufacturing, and intensive farming, we must also consider the emissions of methane (CH₄) and nitrous oxide (N₂O). Agriculture is the primary source of these two greenhouse gases. About 60% of methane emissions from human activities originate from agriculture, with the largest share coming from ruminant livestock. In the case of nitrous oxide, around two-thirds of anthropogenic emissions stem from fertilizer use, manure management, and microbial processes in soils. Additionally, fertilizer application leads to ammonia (NH₃) emissions, which, although having a minor direct greenhouse effect, contribute to environmental harm (e.g., biodiversity loss, nitrate contamination of groundwater, eutrophication, stratospheric ozone depletion, and health impacts) through interactions with other nitrogen compounds. For sustainability purposes, the first step in prevention and emission reduction is identifying the sources and their intensities. Infrared gas analyzers are the most suitable tools for determining concentrations and material fluxes between different media, with photoacoustic spectroscopy standing out among them. In this method, the target gas sample is excited with modulated laser light at a specific wavelength. During relaxation, a local temperature increase occurs, causing thermal expansion, pressure fluctuations, and the generation of an acoustic wave (sound), which can be detected by a sensitive microphone. Photoacoustic technology has several advantages, including linearity over a wide measurement range (from ppbv levels up to 100%), in-situ, non-destructive sampling with open chambers, and high selectivity. Photoacoustic methods can be applied in various agricultural areas to estimate emissions. Globally, it is known that half of the fertilizers are not utilized by crops but instead pollute the environment. Additionally, emissions related to fertilizer production could be reduced by improving efficiency. In our experiments, we analyze the nitrogen cycle in the soil – plant – atmosphere system for different crops, focusing primarily on detecting ammonia emissions after fertilization. We measure nitrogen flux using the relaxed eddy accumulation technique above the plant canopy, combining a quantum cascade laser-based photoacoustic spectrometer with an ultrasonic anemometer. We also plan to measure nitrous oxide emissions resulting from (de)nitrification using a similar approach. Furthermore, we have developed a model and simulations to estimate the ratio of stomatal and soil ammonia emissions and to determine the proportion of soil ammonia emissions recaptured by plants. Source identification is also conducted through laboratory incubation experiments, using the combined measurement of ¹⁵NH₄⁺, ¹⁴NH₄⁺ isotopologues, and ¹⁵N¹⁴N¹⁶O, ¹⁴N¹⁵N¹⁶O isotopomers. In both our field and laboratory incubation studies, we analyze the effects of climatic stress factors (heat and drought stress) on emissions. Regarding emissions from livestock farming, we measure methane emissions from ruminants at both the individual animal and barn levels. Additionally, ammonia, methane, and nitrous oxide emissions from excrement are primarily measured using chamber methods and photoacoustic spectroscopy. During the presentation, we will discuss the development of these measurement methods and our initial results.