Photoacoustic Measurements of \( \text{C}_2\text{H}_4 \) Production and Entrapment in Plants: A Comparison with Gas-Chromatographic Results

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**Introduction**

We compare the superior performance of the photoacoustic detection method to gas chromatography in measuring the \( \text{C}_2\text{H}_4 \) production of and entrapment in \( \text{Rumex} \) plants during submergence.

\( \text{C}_2\text{H}_4 \) is a well-known plant hormone. Already in 1935 [1] it was shown that many plant materials produce ethylene. \( \text{C}_2\text{H}_4 \) can e.g. stimulate the ripening of fruit, the wilting of flowers or the abscission of leaves.

In our experiment we measured the \( \text{C}_2\text{H}_4 \) production and \( \text{C}_2\text{H}_4 \) release of \( \text{Rumex palustris} \) plants. These plants grow in a zone near rivers, where they are flooded at irregular intervals when the water level in the river rises. They respond to this inundation by an enhanced growth of the petioles, a process triggered by an increased \( \text{C}_2\text{H}_4 \) production [2].

We have investigated plants under waterlogged and submerged conditions. The amount of entrapped \( \text{C}_2\text{H}_4 \) inside the plant tissue that had been submerged for 24 hours has been measured using the photoacoustic method. A large discrepancy was found with measurements using the gas chromatographic method.

**Experimental set-up**

As radiation source for our photoacoustic measurements we use an infrared \( \text{CO}_2 \) waveguide laser (9-11 \( \mu \text{m} \) wavelength). A small resonant acoustic cell is placed inside the laser cavity between the discharge tube and the output mirror [2]. Due to the small overall volume (35 cm\(^3\)) it can be used in low flow regimes (1 l/hour) and still have a fast response time. The total set-up has an absorption sensitivity of 1.8 \( \times \) 10\(^{-10} \) cm\(^{-1}\). For the strongest vibrational absorption of \( \text{C}_2\text{H}_4 \) on the 10P14 \( \text{CO}_2 \) laser line (949.479 cm\(^{-1}\)) we can reach a detection limit of 6 ppt (1 ppt = 1 \( \times \) 10\(^{-12}\)).

To measure the \( \text{C}_2\text{H}_4 \) production of plants the photoacoustic cell is connected to a flow-through system. Air from the plant cuvettes is stripped of \( \text{CO}_2 \) by a KOH-based \( \text{CO}_2 \) scrubber to prevent interference effects of \( \text{CO}_2 \) absorption on the \( \text{C}_2\text{H}_4 \) signal.

**Biological applications**

In figure 1 the \( \text{C}_2\text{H}_4 \) production of a single \( \text{R. palustris} \) plant is compared to that of a control plant. After an acclimatization period of 18 hours (with both production levels on 3-4 nanoliter per gram dry weight per hour (nl/g DW. h.) the plant is completely inundated (W) for a 24 hours period. In this period first a decrease
is measured of the C$_2$H$_4$ concentration in the air above the water level caused by the slow diffusion rate of C$_2$H$_4$ in water ($10^4$ x slower than in air). Afterwards the measured C$_2$H$_4$ level rises again due to the stress induced production of the plant.

When the water level is lowered from submergence to waterlogging a fast first peak of C$_2$H$_4$ occurred within 1 hour, followed by a second, gradual one with a maximum after 3-4 hours. The first peak is attributed to the entrapped C$_2$H$_4$ inside the plant tissue during submergence. Ethylene is released immediately after lowering of the water level. The width of this peak is given by the response time of the system (a combination of flow velocity through the cuvettes and the volume of the cuvettes, tube, photoacoustic cell etc.). The second peak is connected to the onset of ACC conversion (1-aminocyclopropane-1-carboxylic acid), yielding C$_2$H$_4$. During the inundation period ACC probably accumulates inside the root tissue, but cannot be converted into C$_2$H$_4$ since this conversion needs oxygen. After this second peak the C$_2$H$_4$ production remained higher for several days. Inspite of the continuous light and temperature regime a diurnal rhythm in the ethylene production is observed.

From the integrated first peak we calculate the total amount of C$_2$H$_4$ entrapped: for this specific plant 12 ppm. or 12 nanoliter per milliliter internal air volume. (The average internal air volume amounts to 0.35 ml.) This concentration is in contradiction to the results of gaschromatographic measurements which yield an average concentration of 0.5 ppm C$_2$H$_4$ inside the internal air volume of the plant[3]. Because concentrations of exogenous C$_2$H$_4$ become effective on the growth of petioles at a level of 5ppm[3] the gaschromatographic result appear to be doubtful.

The discrepancy between the two measurements can be explained by the difference in plant treatment. Before the C$_2$H$_4$ gas sample is injected into the gaschro-
Figure 2: The $C_2H_4$ release of $R. palustris$ plants is plotted against the exposure time to the atmosphere after a 24 hour period of submergence. The amount of $C_2H_4$ is normalized for its production rate and its internal volume. $C_2H_4$ release = $4.3(1-e^{-0.9t})$ nanoliter/plant.

matograph the plant is removed from the water, cut into pieces and put into an ammonium sulphate solution from where the internal air volume of the plant is collected by vacuum extraction[3]. During the treatment (which can take a few minutes) a large amount of $C_2H_4$ can escape from the plant.

In a separate photoacoustic experiment we have investigated the $C_2H_4$ release rate, lifting the plant above the water surface during a limited period of time. (Fig 2) and afterwards submerging it again. Just before the lifting of the plant the ethylene production rate (nl / plant h) was determined. The ratio of the mean $C_2H_4$ production rate ($n=36$) divided by each individual production rate was used to correct the ethylene release after de-submergence. High ethylene production rates will lead to high internal ethylene concentrations during submergence and thus to high release peaks after de-submergence. The ratio corrects for inter plant variation in ethylene production under water. The air exposure time varied from 2 till 360 seconds. From the concentrations in the air flow we calculated the total amount of $C_2H_4$ that was released during this period; corrected for the production ratio it is plotted in figure 2. From this figure we obtained a mean internal concentration of $4.1 ± 0.3$ ppm $C_2H_4$ in the plant tissue just before de-submergence. The $1/e$ release time is 25 seconds. This demonstrates that, unless the plants are handled very carefully the photoacoustic method is far more suitable for reliable measurements of $C_2H_4$ production and release than the gaschromatographic method.