NUKLEONIKA 2002;47(Supplement 1):S59–S61

Respiration and assimilation processes reflected in the carbon isotopic composition of atmospheric carbon dioxide

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Abstract This paper presents diurnal variations of concentration and carbon isotopic composition of atmospheric carbon dioxide caused by respiration and assimilation processes. Air samples were collected during early and late summer in 1998 in unpolluted area (village Guciow located near the Roztocze National Park, SE Poland) in three different environments: uncultivated field on a hill, a meadow in the Wieprz river valley and a forest. The effect is very strong during intensive vegetation growth on a sunny day and clear night. The largest diurnal variations in atmospheric CO_2 concentration and its carbon isotopic composition in June above the meadow were about 480 ppm and 10‰, respectively.

Key words atmosphere • carbon dioxide • carbon isotopes • delta-C-13 • respiration

Introduction

The terrestrial biosphere has a strong influence on the atmosphere. Interaction occurs mainly by exchange of gases during processes such as photosynthesis, respiration and transpiration. Especially evident are variations in atmospheric CO_2 concentration and its carbon isotopic composition. These variations are not uniformly distributed in space and time [2, 4, 6, 10, 11].

It is well known that all plants assimilate from the air $^{12}CO_2$ in preference to $^{13}CO_2$ (see for example: [5, 12, 13]). Diffusion of light molecule ($^{12}CO_2$) is faster than that of heavy molecule ($^{13}CO_2$). Carbon isotope fractionation factor is equal to 1.0044 if CO_2 gas diffuses in air [1, 3]. Enrichment of plant in light carbon isotope in comparison to atmospheric carbon dioxide (which has a $\delta^{13}C$ value of about -8‰) depends on photosynthetic pathways (C3, C4, CAM), stomatal conductance and is affected by environmental factors, such as temperature and atmospheric CO_2 concentration. Carbon isotopic composition ($\delta^{13}C$) of C3 plants (about 90% of all plants today) is in the range from -35 to -20‰ while C4 plants $\delta^{13}C$ have values of -16 to -9‰ [7].

CO_2 respired by plants has carbon isotopic composition, which is practically very close to that of plant tissue. Soil carbon dioxide originates from autotrophic root respiration and heterotropic microbial respiration in the rhizosphere and the bulk soil. It was found [1] that soil-CO_2 (gas occupying pore spaces in soil) is enriched in ^{13}C by about 4.4‰ or more relative to soil-respired CO_2, which represents the flux of soil-CO_2 to the atmosphere.

Plant respiration dominates over photosynthesis at night, whilst the reverse is true during daytime. At night higher CO_2 concentrations could be observed in the air above

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Received: 11 July 2001, Accepted: 30 October 2001

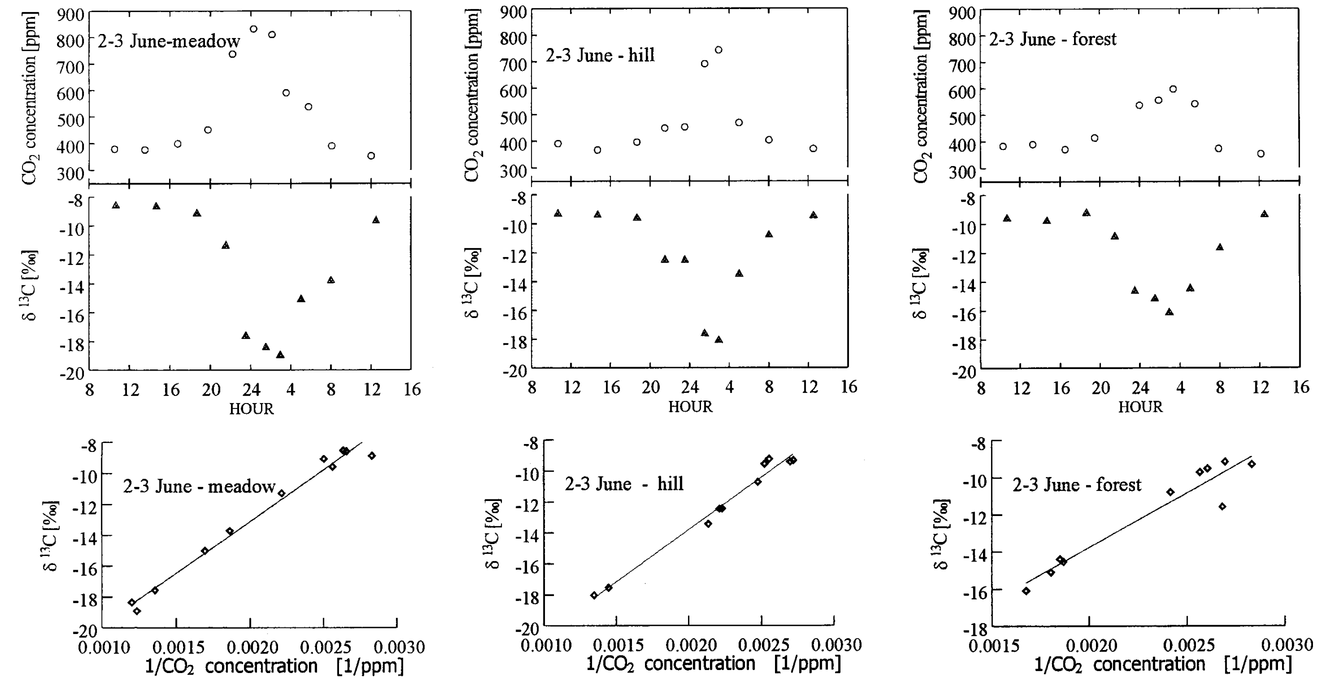

Fig. 1. Diurnal changes of CO_2 concentration and carbon isotopic composition of atmospheric CO_2. Linear correlation between $\delta^{13}C$ value and reciprocal CO_2 concentration is also presented (Guciow, 2–3 June 1998).

ground as a result of plant and soil respiration and decay and vertical mixing of the atmosphere.

Sampling sites and methods

Three different sites of sampling were chosen. The first one was situated on a wet meadow lying in the Wieprz river valley, near the river side. The meadow was overgrown with a thick and high grass. The height of the grass was about 0.6 m. The second site of sampling was situated on the top of hill ca. 20 m above the Wieprz river valley. The hill was overgrown with short grass. The third site of sampling was situated in coniferous forest 15 m above the Wieprz river valley. Its ground was overgrown with blueberries, lingenberries and surrounded by pines, the crowns of which reached 20 m high above the ground. All samples were collected 1.5 m above the soil surface.

Air was sucked into evacuated glass ampoules about 0.5 L in volume. The carbon dioxide from each flask was extracted separately by pumping the residual air through a trap cooled with liquid nitrogen at a pressure reduced to about 10 mbars. The condensate was purified from water vapor by

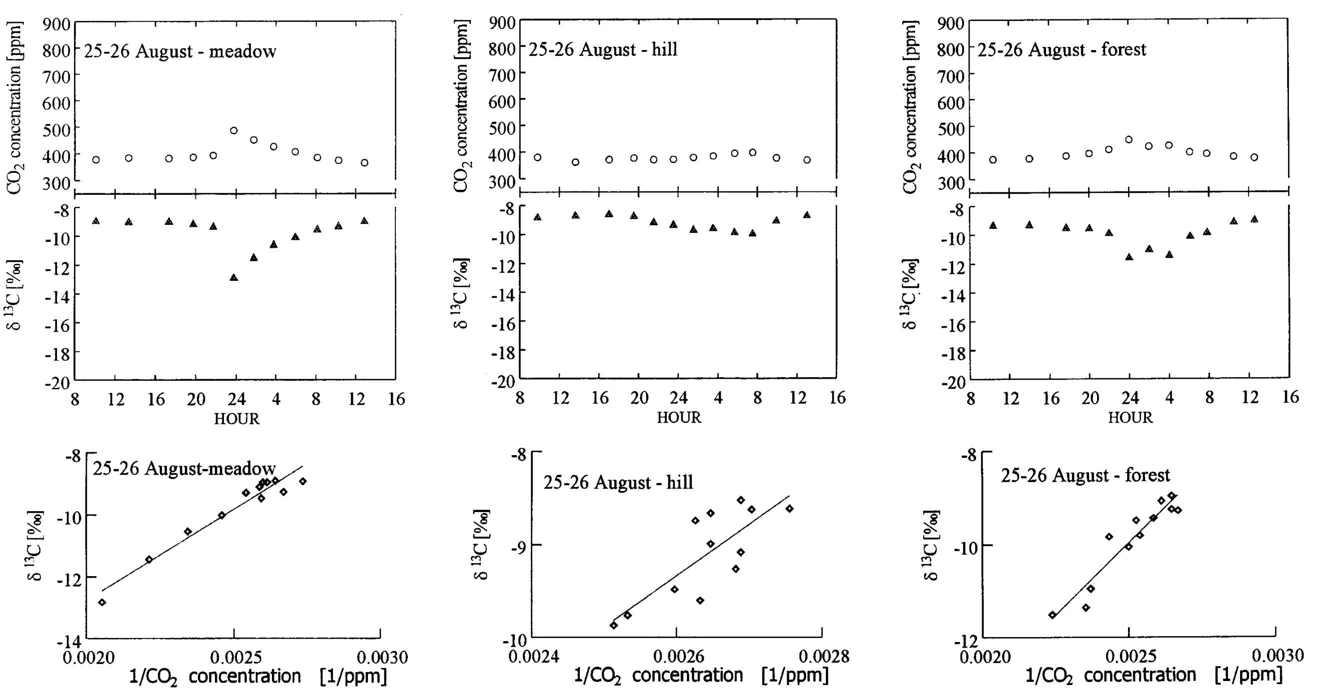

Fig. 2. Diurnal changes of CO_2 concentration and carbon isotopic composition of atmospheric CO_2. Linear correlation between $\delta^{13}C$ value and reciprocal CO_2 concentration is also presented (Guciow, 25–26 August 1998).

fractional sublimation at a temperature of -60°C. The absolute CO_2 concentration was determined mass-spectrometrically (with an accuracy of about ±1.5 ppm) by measuring the intensity of $^{12}C^{16}O_2^+$ ion beams for a given sample and known amount of CO_2 prepared for calibration. The carbon isotopic composition was measured with mean accuracy of 0.10‰ using the mass spectrometer arrangement for the isotopic analysis of nanomole gas samples [8, 9].

Results and discussion

The results obtained for samples collected at the three different places on a sunny day without wind in June 1998 are presented in Fig. 1, and for samples collected on a cloudy day in August 1998 are shown in Fig. 2. Variations in CO_2 composition above the meadow are greater than in those taken on the hill or in the forest.

During our field measurements in June, the temperatures at 1.5 m above the ground changed from 26°C (midday) to 11°C (night). On clear night, radiational cooling led to a strong surface temperature inversion. This inversion trapped the respired CO_2 close to surface. We observed an increase of CO_2 concentration in the atmosphere and a decrease of its $\delta^{13}C$ value. Maximum CO_2 concentration (811 ppm) and minimum $\delta^{13}C$ value (-18.9‰) were detected before the dawn above the meadow. CO_2 concentration dropped rapidly and $\delta^{13}C$ value became less negative after the sunrise as CO_2 was consumed by photosynthetic uptake and the air near the surface was mixed with the air from above. The air remained well mixed throughout the middle of day. The most striking effect was observed in the air above the meadow. This is obviously due to the highest biomass concentration.

On the overcast night in August, the variations of CO_2 concentration and $\delta^{13}C$ value were much smaller than on the clear night in June. The CO_2 concentration between day and night changed (above the meadow) from 370 to 487 ppm and $\delta^{13}C$ value from -8.9 to -12.8‰. Such small variations of CO_2 concentration might be caused by smaller amounts of CO_2 respired by vegetation and soil and by the lack of temperature inversion.

From the linear plots between the $\delta^{13}C$ value and the reciprocal of CO_2 concentration the carbon isotopic composition of CO_2 respired by plants and soil was found. For the samples collected in June the carbon isotopic composition of atmospheric CO_2 is very well correlated with the reciprocal concentration of CO_2, the correlation coefficient exceeds 0.99 for samples collected above the meadow and on the hill, whereas it is equal to 0.82 for CO_2 collected in the forest. The respective $\delta^{13}C$ values were: -26.5‰, -27.3‰ and -25.5‰. In August the correlation coefficients were lower (for the meadow and hill 0.97 and 0.81, respectively), whereas it was higher (0.95) for the samples collected in the forest. Respired carbon dioxide in August had less negative $\delta^{13}C$ values -25.4‰ (meadow), -23.7‰ (hill) and -24.6‰ (forest) than those in June.

Similar effects were observed by Szaran [14] in air above the meadow, the greatest variations were found in May, while during the winter (in February) no changes were observed.

Conclusion

Atmospheric CO_2 concentration and carbon isotopic composition show a strong dependence on the intensity of respiration and photosynthesis processes. The observed diurnal changes of CO_2 concentration and $\delta^{13}C$ value in June were larger than these in August for each place of sampling. It is due to the fact that biological activity is more intense in June than in August. The strongest changes of CO_2 concentration and $\delta^{13}C$ value were recorded for the samples of air, which were collected above the meadow ground. This was caused by a large concentration of the biomass. In the forest below the sampling point (1.5 m), the amount of CO_2 exchanged between the atmosphere and the biosphere is smaller than that in the case of meadow.

Acknowledgments Authors would like to thank to anonymous referees for their work resulting in improvement of consistency and language of this paper. This research was supported by University Maria Curie-Sklodowska project: Present development of environment of Central Roztocze.

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