Is the atmospheric Suess-Effect reflected in arable soils of urban areas?

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INTRODUCTION & AIMS

Global atmospheric CO_2 concentration increased during the past four decades from 320 ppm (1961) to 370 ppm (2001) as a result of fossil fuel burning (Suess-Effect). This increase in CO_2 concentration led to a shift in stable carbon isotopes ($\delta^{13}C$) from approximately 6.9‰ V-PDB (1961) to 8.2-8.4‰ V-PDB in 2001, dependant of sampling site.

Changes in atmospheric CO_2 concentration in stable carbon isotopic value during photosynthesis will be transferred to plant biomass composition and the following questions arise:

- How fast and how intensive is the change in biomass composition reflected by soil organic matter (SOM) isotopic properties?

- Are specific differences between C3-plants (reacting upon changes in CO_2 concentration and $\delta^{13}C$) and C4-plants (reacting primarily upon changes in $\delta^{13}C$ of CO_2) recognizable in crop biomass and SOM?

- Do corrections have to be applied in turnover time determinations when using the natural isotopic labelling approach after C3-/C4-crop change?

Materials and methods

Samples: Archived soils from the ploughed horizons of the experimental "Eternal Rye" trial Halle/Germany with monoculture rye and silage-maize cropping.

Total organic carbon content (TOC) and stable carbon isotopic composition ($\delta^{13}C$) were determined after homogenization and decarbonatisation. Soil samples were extracted (ASE) and separated into several lipid fractions using two medium-pressure liquid chromatography (MPLC) procedures (Wiesenberg et al., 2004). Lipids were identified in the individual fractions using GC-MS, whereas quantification of individual lipids were performed via GC-FID.

CONCLUSIONS

Plant biomass isotopic value ($\delta^{13}C$) of crops grown on experimental fields in Halle were influenced by the CO_2 urban dome effect leading to an enhanced isotopic fractionation when compared to rural areas (e.g. Rotthalmünster site).

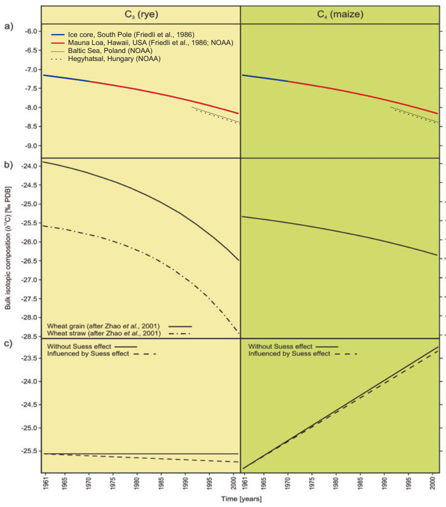
Rye cropped soil of Halle site showed a low isotopic depletion after four decades as a result of the atmospheric Suess-Effect. In addition to the atmospheric Suess-Effect isotopic composition of soils depends on cropping techniques and contamination by fossil fuel derived components. Thus, exact estimations of changes induced by the atmospheric Suess-Effect in soils are difficult. They would result in 0.5‰ for C3-cropped soils after four decades, when assuming an annual replacement of 0.5% of the total soil organic carbon with new biomass.

As a result of different biosynthetic processes in C3- and C4-plants, the isotopic fractionation within C3-plants is significantly larger than within C4-plants. After four decades a Suess-Effect induced isotopic difference of min. 0.2‰ between C3- and C4-cropped soils can be expected, when assuming an annual replacement of 0.5% of the total soil organic carbon with new biomass.

Ploughing depth modifications caused significant changes in the carbon concentrations and isotopic signatures of rye and silage-maize cropped soils from the Eternal Rye trial. The isotopic difference between both soils would be significantly larger (1.5 times) than the measurable difference, if ploughing depth would have been constant throughout the whole four decades.

Changes of stable carbon isotopic composition as a result of atmospheric Suess-Effect

Changes of stable carbon isotopic composition ($\delta^{13}C$) during four decades in the a) atmosphere, b) wheat plant parts (after Zhao et al., 2001) and maize plants (after Marino and McElroy, 1991) and c) soils of Eternal Rye trial, when postulating an annual replacement of 0.5% of total soil organic carbon by new plant biomass.

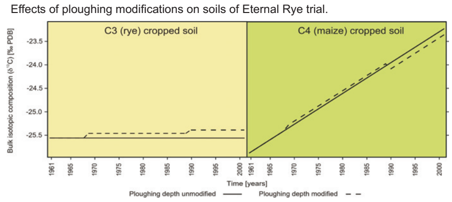


During the last four decades atmospheric carbon concentrations increased significantly as a result of fossil fuel burning, leading to an isotopic ^{13}C-depletion between 1.2‰ V-PDB for Hawaii and 1.4‰ V-PDB for sites across Europe. For urban sites no data of long-term CO_2 isotope studies exist. It is well documented that urban environments show a local enrichment in CO_2 concentration reaching 600-800ppmV (Idso et al., 2001, 2002), the urban dome effect.

Zhao et al. (2001) showed a larger isotopic depletion of C3-plants on atmospheric carbon changes as a result of increasing biosynthetic fraction. During four decades wheat plants got depleted by 2.5-3.0‰ V-PDB. For maize plants a direct reflectance of atmospheric carbon isotopic composition was shown by Marino & McElroy (1991). C3-crop plant biomass from the urban Halle site was $\delta^{13}C$-depleted by 2.1‰ V-PDB when compared to plant biomass of the rural Rotthalmünster site. Amongst other environmental factors (climate, crop genotype, etc.) this difference is attributed to the urban dome effect.

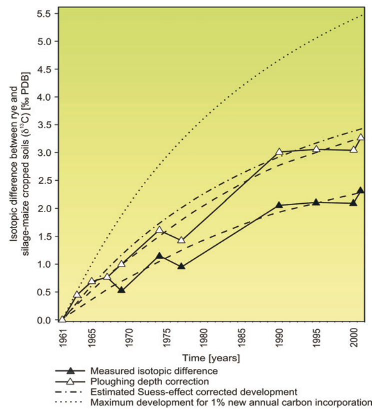
For soils of Eternal Rye trial an annual replacement of 0.5% of the total soil organic carbon could be determined. As a result of isotopic changes of plants induced by atmospheric Suess-Effect, in soils changes could be expected with a larger isotopic depletion in C3-cropped soils and a lower isotopic depletion in C4-cropped soils. Hence, a steady state system with a constant isotopic composition of the C3-cropped soil could not be assumed during long-term field experiments.

Effects of ploughing modifications on soils of Eternal Rye trial.



Ploughing depth was increased on Eternal Rye trial during the late 1960s and the early 1990s from 20cm to 30cm. Isotopically enriched and carbon depleted soil was added to the ploughed horizon from the underlying horizon, leading to an isotopic enrichment of the ploughed horizon of the C3-cropped soil, when assuming steady state conditions, without Suess-Effect induced changes. For maize cropped soil only minor effects induced by ploughing modifications could be expected.

Measured vs. expectable development of isotopic differences between rye and silage-maize cropped soils

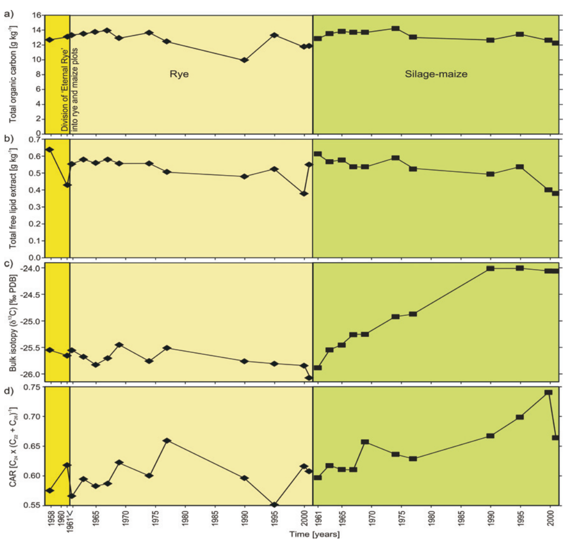


After four decades of parallel rye and silage-maize cropping an isotopic difference of 2.3‰ is measurable between both soils, corresponding to a maize derived carbon proportion of approximately 15%. This measurable difference represents only a fraction of the isotopic difference that would have occurred without additional perturbations of the soil ecosystem due to several factors, including: a) increases in ploughing depth, b) atmospheric Suess-Effect and the different biosynthetic reactions of C3- and C4-crops on this effect, and c) low biomass input due to silage cropping.

Increases in ploughing depth in the 1960s and the 1990s were excluded when calculating the extent of isotopic differences when correcting for ploughing depth modifications. Without ploughing depth modifications an isotopic difference of 3.2‰ V-PDB would be expected between C3- and C4-cropped soils of the Eternal Rye trial.

Atmospheric Suess-Effect and the resulting larger biosynthetic isotopic fractionation of C3-plants led to an underestimation of the isotopic difference between rye and silage-maize cropped soils of 0.2‰, when calculating assuming an annual replacement of 0.5% of the total soil organic carbon with new biomass and with isotopic changes observed for rural areas. Note that Friedli et al. (1986) used ice cores, Marino & McElroy (1991) showed results for Hawaii and Zhao et al. (2001) for Rothamsted for their determinations of CO_2-concentrations and isotopic composition. For urban areas no data were available, how the urban dome effect as observed by Idso et al. (2001, 2002) will influence the carbon isotopic composition of plants and soils. Thus, the isotopic difference induced by Suess-Effect seems to be underestimated for urban areas like Halle site.

If larger amounts of biomass would be incorporated into soils, e.g. an assumed annual replacement of 1% of total soil organic carbon the isotopic difference would be up to 5.5‰ V-PDB after four decades.



Development of different soil carbon parameters during four decades

a) Total organic carbon (TOC) contents slightly increased during the 1960s for rye and silage-maize cropped soils. Since the 1970s a TOC decrease could be observed due to monoculture cropping and dilution with carbon depleted material of underlying Axh horizons during ploughing-depth increases in the late 1960s and the early 1990s.

b) Total lipid extract yields showed less variations than TOC for both soils. Lipid extract yields consequently decreased during the whole period as a result of monoculture cropping and low biomass input.

c) Stable carbon isotopic values ($\delta^{13}C$) decreased during periods with monoculture rye cropping, while ploughing depth modifications in the late 1960s and the early 1990s resulted in an isotopic enrichment for rye cropped soil. Generally, an isotopic decrease of 0.5‰ V-PDB could be observed after four decades. The isotopic composition of maize cropped soil successively increased with the time of maize cropping. During the late 1960s and the early 1990s ploughing depth increases caused a stagnation of the soil carbon isotopic value. The stagnation of the isotopic value in the years 2000/2001 was most likely due to low biomass input (silage cropping) and a complete turnover of the fast or intermediate stable carbon pool.

d) The carboxylic acid ratio (CAR is the molecular ratio of long-chain *n*-carboxylic acids: $C_{26}/(C_{22}+C_{26})$) was found to be diagnostic for maize input in soils (large ratios and C_{24} contents = high maize-derived carboxylic acids in soils). The ratio showed variations for rye cropped soil as a result of natural soil heterogeneity. For maize cropped soil the ratio successively increased after the switch of the monoculture, interrupted by ploughing depth increases. Hence, increasing proportions of maize derived carbon changed composition of carboxylic acids in Eternal Rye trial.

Acknowledgements:
Prof. Dr. Merbach, Dr. Schmidt and Dr. Eisner provided samples from Halle site.
H. Cieszynski, B. Nabbefeld and B. Stapper provided excellent laboratory assistance.
This project was funded by DFG (German Research foundation) within the priority program 'Soils as sources and sinks of CO_2'.

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