Plant and Soil **171**: 365–367, 1995.

Short communication

The influence of fertilizer nitrogen and season on the carbon-13 abundance of wheat straw

D.S. Jenkinson[1], K. Coleman[1] and D.D. Harkness[2]
[1]*BBSRC Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Herts., AL5 2JQ, UK and* [2]*NERC Radiocarbon Laboratory, NEL Technology Park, East Kilbride, Glasgow G75 0QU, UK*

Received 5 July 1994. Accepted in revised form 18 October 1994

Key words: carbon-13, carbon isotope fractionation, nitrogen fertilization, winter wheat

Abstract

Carbon-13 abundance, expressed as $\delta^{13}C$ in ‰, was measured in wheat straw grown between 1984 and 1989 on the Broadbalk Continuous Wheat Experiment at Rothamsted. In all six years, straw grown without fertilizer N contained less carbon-13 (i.e. $\delta^{13}C$ was more negative) than straw grown with fertilizer, although the magnitude of this difference varied with year. In a dry year, when dry matter response to fertilizer N was relatively small, there was a large difference between the $\delta^{13}C$ of straw grown with and without N. Conversely, in a wet year, when there was a marked response to N, there was little difference in the isotopic composition of N-fertilized and unfertilized straw. Over the six years, the *difference* between the $\delta^{13}C$ value of straw grown with and without nitrogen ($D^{13}C$, in ‰) was related to drought, measured as the calculated soil water deficit on 15 July (W_j, in mm), by the equation $D^{13}C = -0.299 + 0.01034\ W_j$ (r = 0.87).

Introduction

In this paper we examine the effects of season and of fertilizer nitrogen on the carbon-13 abundance of wheat (*Triticum aestivum* L.) straw, using archived crop samples grown on the Broadbalk Continuous Wheat Experiment at Rothamsted between 1984 and 1989.

Materials and methods

In the Broadbalk Continuous Wheat Experiment, wheat is grown year after year on the same (unreplicated) plots that receive the same annual applications of fertilizer - see the current Rothamsted Guide to the Field Experiments (Anonymous, 1991) for a detailed description. The straw samples used in this work all came from Section 1 of the Experiment; continuous winter wheat since 1843, apart from the 1926–1951 period, when this Section was fallowed one year in five to control weeds. The samples had been stored air-dry in sealed containers: all had been ground to pass a 1 mm sieve. To minimise errors due to sample inhomogeneity, samples for $\delta^{13}C$ measurement were reground in a knife mill, after cooling in liquid N_2. Plant samples were combusted in O_2, water removed by a trap cooled at $-80°C$ and the CO_2 finally collected in a liquid N_2- cooled trap. $\delta^{13}C$ was measured in this CO_2 using a Finnegan MAT (Model Delta E) mass spectrometer: values, expressed as ‰, are relative to the international PDB reference scale. All results are means of two independent combustions and analyses per sample. If duplicate $\delta^{13}C$ measurements differed by more than $\pm$ 0.1‰ they were discarded and the sample reanalysed. Crop yields are taken from 'Yields of the Field Experiments', published annually by Rothamsted Experimental Station. Details of the cultivars grown and of the different fertilizer applications are given in the footnotes to Table 1. Soil water deficits were calculated for the period 1 January -15 July of each year from daily meteorological measurements at Rothamsted: the calculated deficit was 138.0 mm for 1984, 72.2 for 1985, 113.6 for 1986; 71.5 for 1987; 48.1 for 1988 and 187.3 for 1989.

Table 1. $\delta^{13}C$ for straw from the Broadbalk Continuous Winter Wheat Experiment

Year of sampling[a]	Plot	Treatment[b]	Yield[c]		$\delta^{13}C$ in ‰ relative to PDB
			Grain	Straw	
			t ha^{-1}		
1984	051	PK	1.97	1.52	−27.09
1984	091	N_4PK	6.61	3.84	−26.38
1985	051	PK	1.54	0.84	−26.36
1985	091	N_4PK	8.21	4.78	−26.13
1986	051	PK	1.45	0.75	−25.52
1986	091	N_4PK	4.37	2.09	−24.32
1987	051	PK	0.97	1.41	−27.44
1987	091	N_4PK	4.00	6.18	−26.68
1988	051	PK	0.86	0.48	−26.04
1988	061	N_1PK	2.88	2.73	−25.82
1988	071	N_2PK	4.10	3.43	−26.14
1988	081	N_3PK	5.60	3.48	−25.69
1988	091	N_4PK	6.53	5.05	−25.95
1989	061	PK	1.12	0.30	−26.11
1989	051	N_1PK	2.34	0.80	−25.48
1989	071	N_2PK	4.40	1.00	−24.50
1989	081	N_3PK	4.06	0.94	−24.15
1989	091	N_4PK	4.55	1.46	−24.37

[a] Cultivars: Flanders (1984); Brimstone (1985–89).
[b] Inorganic fertilizers: P at 35kg P ha^{-1} yr^{-1}; K at 90kg K ha^{-1} yr^{-1}; N at 48 (N_1), 96 (N_2), 144 (N_3) or 192 kg N ha^{-1} yr^{-1} (N_4).
[c] Both straw and grain at 85% DM.

Results and discussion

In all six years, straw grown without fertilizer N contained less ^{13}C (i.e. $\delta^{13}C$ was more negative) than straw grown with 192 kg N ha^{-1}. The mean value of $\delta^{13}C$ for the six crops grown without fertilizer N was −26.4 ± 0.29‰, (SE); for the six crops given fertilizer N at 192 kg ha^{-1} yr^{-1} it was −25.6 ± 0.42. However, the size of this difference varied greatly from year-to-year, in one year being only 0.23‰, in another 1.74‰.

In Broadbalk the response to fertilizer N tends to be less in a dry year than in a wet year. Thus, for the six crop years 1984–1989 (Table 1) the yield response to N (i.e. grain plus straw in the crop receiving 192 kg N ha^{-1}, *less* grain plus straw in the crop receiving no N), is inversely (and significantly) related to the soil water deficit:

$$Rn = 11.76 - 0.0414\,W_j\,(r = -0.79)$$

where Rn is the yield response to N, in t ha^{-1} and W_j is the calculated soil water deficit on 15 July, in mm. This date was chosen as representing the beginning of crop senescence on Broadbalk.

There is an even closer direct relationship over the same six crops between calculated soil water deficit and $D^{13}C$, where $D^{13}C$ (in ‰) is defined as the *difference* in $\delta^{13}C$ between the plot receiving no fertilizer nitrogen and the plot receiving 192 kg N ha^{-1}.

$$D^{13}C = -0.299 + 0.01034\,W_j\,(r = 0.87)$$

The intercept in this equation is not significantly different from zero.
Similarly,

$$D^{13}C = 10.64 - 4.10\,Rn\,(r = 0.93)$$

Thus in a dry year, when the response to N is relatively small, there is a large difference between $\delta^{13}C$ in N-fertilized and unfertilized crops: conversely, in a wet year, with a marked response to N, there is little difference in the isotopic composition of N-fertilized and unfertilized crops. A similar observation was made for coniferous trees by Högberg et al. (1993): they found that leaf needles from N-fertilized plots had a higher ^{13}C abundance than those from unfertilized plots in dry years but not in wet.

Farquhar et al. (1982) derived an approximate expression relating the isotopic composition of a C-3 plant ($\delta^{13}C_p$) to the ^{13}C content of atmospheric CO_2 ($\delta^{13}C_a$):

$$\delta^{13}C_p = \delta^{13}C_a - a - (b - a)P_i/P_a$$

where a is the fractionation caused by the slower diffusion of $^{13}CO_2$ relative to $^{12}CO_2$ (about 4.4‰); b is the fractionation caused by discrimination of RuBP carboxylase against $^{13}CO_2$ (about 27‰), P_i the partial pressure of CO_2 in the intercellular leaf space and P_a the partial pressure of CO_2 in the (external) atmosphere. When, for example, drought causes closure of the stomata, P_i/P_a is small and discrimination is less, with $\delta^{13}C$ becoming less negative and tending towards the value determined by diffusion (4.4‰). If on the other hand, the stomata are fully open, P_i/P_a is near unity and discrimination increases, tending to approach values caused by carboxylation.

In a dry year on Broadbalk, stomatal conductance is presumably less in the water-profligate N-fertilized crop, with its dense canopy, than in the sparse unfertilized crop. Fractionation would tend to be markedly less in the crop with N than in the crop without N. In wet years, neither crop would be likely to run out of water and fractionation would be similar in both, at a level set by the growing season, rather than by the effects of N on leaf area index, canopy height, photosynthetic area, water use efficiency, etc.

Although the *difference* between the isotopic composition of crops grown with and without N ($D^{13}C$) is closely correlated with soil moisture deficit, there is no relationship between the absolute isotopic composition of a particular crop and moisture deficit. Thus for the same six crops grown without N:

$$\delta^{13}C = -26.60 + 0.0016\,W_j\,(r = 0.12)$$

We do not know why $\delta^{13}C$ varies so much from year to year in the unfertilized crops. Growing conditions (Bender and Berge, 1979) could be part of the answer, but so could fractionation between different parts of the plant (Winkler et al., 1978).

In 1991 Marino and McElroy published a paper in which they measured $\delta^{13}C$ in cellulose from stored maize samples grown over the last 40 years, and used these and other data to infer changes in atmospheric $\delta^{13}C$. They estimated that the $\delta^{13}C$ value of atmospheric CO_2 had fallen from $-6.4‰$ before 1860 to -7.8 in 1989. Our results (Table 1) show that the year-to-year variation of $\delta^{13}C$ in wheat straw is markedly greater than Marino and McElroy's estimate of the decrease in atmospheric $\delta^{13}C$ brought about by human activities over the last 130 years. There are good reasons why $\delta^{13}C$ varies much more from year-to-year in C-3 plants like wheat than in C-4 plants such as maize (Farquhar et al., 1989; Marino and McElroy, 1991). However, until we understand the factors that influence $\delta^{13}C$ in C-3 plants well enough to *correct* for annual variation, it is unlikely that the Rothamsted crop sample archives (which go back 150 years but contain no C-4 plants) can be used for precise measurement of long-term changes in atmospheric $\delta^{13}C$.

Acknowledgements

We thank the Terrestrial Initiative in Global Environmental Research (TIGER) authority for support under contract No 90/101. We also thank D W Lawlor for helpful advice.

References

Anonymous 1991 Guide to the Classical Field Experiments. Lawes Agricultural Trust. Harpenden. 31 p.

Bender M M and Berge A J 1979 Oecologia 44, 117–118.

Farquhar G D et al. 1989 *In* Stable Isotopes in Ecological Research. Eds. P W Rundel, J R Ehleringer and K A Nagy. pp 21–40. Springer Verlag, New York.

Farquhar G D et al. 1982 Aust. J. Plant Physiol. 9, 121–137.

Högberg P et al. 1993 Plant and Soil 152, 207–214.

Marino B D and McElroy M B 1991 Nature 349, 127–131.

Winkler F J et al. 1978 Z. Pflanzenphysiol Bodenkd. 87, 255–263.

Section editor: H Lambers