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THE USE OF NATURAL AND ANTHROPOGENIC ^{14}C TO INVESTIGATE THE DYNAMICS OF SOIL ORGANIC CARBON

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ABSTRACT. Radiocarbon has been measured in two soil profiles, one of which has been covered by a building since 1956. A comparison of the $\Delta^{14}C$ values in horizons of each profile gives an estimate of the total input of atom bomb ^{14}C into the soil profile. From the $\Delta^{14}C$ and carbon density profile data, the carbon input rates, respiration rates, and diffusivity are calculated. The lack of vegetation on one soil affects the mobility and the respiration rate of the soil carbon in that soil. The data from this soil profile are also used to check the assumption, used in previous analyses, that there is a uniform distribution of 'old' carbon down the soil profile. The input rate, turnover time, and diffusivity parameters determined from the $\Delta^{14}C$ profiles in these soils are compared with other published data on pasture and forest soils.

INTRODUCTION

Previous studies showed that the measurement of ^{14}C, and particularly ^{14}C injected into the atmosphere from nuclear weapons tests is useful for indicating the uptake of organic carbon into soils (Rafter & Stout, 1970; Scharpenseel, 1973). More recent studies showed that the determination of atom bomb ^{14}C in the profiles of pasture soils can indicate the movement and turnover rate of organic carbon in these soils (O'Brien & Stout, 1978; O'Brien, 1984). These earlier studies indicated that the increasingly negative values of $\Delta^{14}C$ with depth can be accounted for by assuming there is an approximately constant density of very old carbon in these soils. This assumption was used in the past to estimate what the $\Delta^{14}C$ values would have been in the upper soil horizons if no atom bomb ^{14}C were present.

In this study two soil profiles were sampled. One profile was taken from beneath a house built in 1956; the other was taken on a lawn ca 14m from the first profile. Since, in the southern hemisphere, little ^{14}C was present in the atmosphere prior to 1956, the soil from under the house should not have been significantly contaminated with atom bomb ^{14}C (Rafter, 1965). This soil profile was used to investigate the hypothesis of a constant level of old carbon in the different soil horizons. The data from this profile are also used to estimate what ^{14}C values would be in the organic carbon in the lawn profile if there had been no input of bomb carbon. This is then used to determine input rates and turnover times for this organic carbon under the lawn.

MATERIALS AND METHODS

The two profiles were situated in the Hutt Valley north of Fairfield, ca 40m from the Waiwhetu Stream. This soil is very clay-like and very deep. Prior to 1956, the land had been used as dairy farm land (pasture).

Each profile extended down to 50cm and was sampled in 5cm layers. In the under-house profile, data were measured on each 5cm horizon, but for the lawn profile, adjacent horizons were combined and data were measured on 5 horizons, 10cm thick.

After drying, the soil densities were estimated. The soils were acid-washed to remove any carbon present as carbonate in the samples. The percent carbon present in each horizon was determined from the yield of CO_2 after complete ignition. The $^{14}C/^{12}C$ ratios were determined with respect to 0.95 NBS oxalic acid standard and were then normalized for isotopic fractionation using measured $^{13}C/^{12}C$ ratios which were measured against the PDB standard.

RESULTS

The measured data for each 10cm horizon of both profiles is shown in Table 1. It is apparent that the percent carbon present in the top three horizons under the house are almost equal, and also that in all cases the percent carbon in each horizon under the house is significantly below the corresponding values measured under the lawn. This would be expected if since 1956 there was no input of new carbon into the house profile, while at the same time, the carbon that was present in this profile in 1956 continued to respire back to CO_2. The constancy of the percent carbon in the top three horizons would also indicate that there is no nett transport of carbon between these horizons due to diffusive processes.

On the other hand, the percent carbon present under the lawn decreases with depth, indicating that here there is a downward transport of carbon from diffusive processes.

The $\Delta^{14}C$ values are also markedly different for these two profiles, particularly in the upper horizons. In the top horizon under the house, the $\Delta^{14}C$ value of −118 is much more negative than values measured previously in the top layer of any soils in New Zealand. The positive value of $\Delta^{14}C$ under the lawn indicates the presence of atom bomb ^{14}C, although the

TABLE 1
Distribution of organic carbon and ^{14}C in two soil profiles, meters apart, sampled 1985

Profile under house*					
Depth v ‰ (cm)	Density P	% carbon C	PxC	$\Delta^{14}C$ ‰	Estimated $\Delta^{14}C'$ in 1956 v
0–10	1.05	1.15	1.21	−118	− 54
10–20	1.04	1.08	1.12	−126	− 94
20–30	1.31	0.96	1.26	−148	−133
30–40	1.21	0.54	0.65	−206	−118
40–50	1.30	0.42	0.55	−236	−160
Profile under lawn					
Depth v ‰ (cm)	Density P	% carbon C	PxC	$\Delta^{14}C$ ‰	$\Delta^{14}C$-$\Delta^{14}C'$ ‰
0–10	1.06	2.5	2.65	+ 77	131
10–20	1.19	1.45	1.72	− 63	31
20–30	1.36	1.07	1.45	− 91	42
30–40	1.16	0.94	1.09	−110	—
40–50	1.23	0.62	0.76	−191	—

* Built mid-1956

value of +77 is smaller than reported for most other soil profiles (O'Brien, 1984).

Also shown in Table 1 are values of PxC, the product of the soil density and percent carbon. This gives the density of carbon per unit volume, and it can be seen that this is very constant in the upper three horizons of the profile under the house.

MODEL OF ORGANIC CARBON TRANSPORT

A steady state dynamic carbon transport model was developed by O'Brien and Stout (1978) to account for the organic carbon distribution in soils and to explain the ^{14}C activities of these soils. One observation made in that study was that values of $Cx\Delta^{14}C$, for each horizon, remained fairly constant with depth. The value of $(Cx\Delta^{14}C)/100$ is called the percent "old" carbon present in each soil horizon. The assumption that the percent old carbon present was constant with depth was used to estimate the pre-bomb values of $\Delta^{14}C$ in the upper horizons.

Values of the percent old carbon have been estimated for the two soil horizons of this study (Fig 1). The values for the profile under the house are fairly constant above 30cm at ca 0.14, but fall to ca 0.1 below 30cm. Values of 0.16 were measured on the Judgeford loam (O'Brien, 1984). The percent old carbon under the lawn is about the same as under the house for the soil in the 30 to 50cm horizon. Above this level the apparent percent old carbon under the lawn is much smaller due to the uptake of atom bomb ^{14}C into these upper horizons.

If the percent old carbon in each horizon of the soil under the house is assumed to be equal to that present under the lawn, it is possible to estimate what the $\Delta^{14}C'$ would be under the lawn, without any atom bomb ^{14}C being present. These estimated values of $\Delta^{14}C'$ are shown in the upper sixth column of Table 1. The value for the 0 to 10cm horizon is computed by dividing $\Delta^{14}CxC$ (135) by the percent carbon in the same horizon under the lawn (2.5). Assuming that these numbers also reflected the situation under

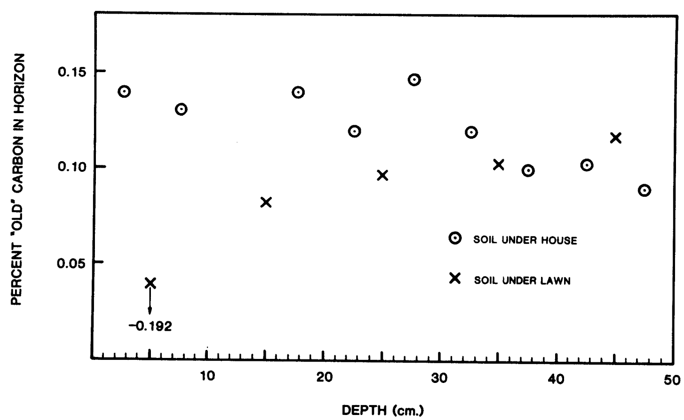

Fig 1. The percent of old carbon present in soil at different depths in two soil profiles

the lawn in 1956, it is possible to estimate the increase in $\Delta^{14}C''$ (*ie*, $\Delta^{14}C - \Delta^{14}C^{1}$) under the lawn as a result of atom bomb ^{14}C input. These values are shown in the lower right-hand column of Table 1. The total input of atom bomb ^{14}C can be represented by T_k, where

$$T_k = \Sigma_j l_j P_j C_j \Delta^{14}C_j'' \times 10^{-2}$$

where l_j is the thickness of horizon j in cm (O'Brien, 1984). Using the data from under the lawn in Table 1, T_k is estimated to be 46.1g ‰ cm^{-2}. From data given in the above reference, it is then possible to estimate the average input flux, F_o, of organic carbon to the soil. This is $F_o = 0.0048g\ cm^{-2}\ y^{-1}$.

The total organic carbon in the profile (down to 50cm) is $W = \Sigma_j l_j P_j C_j$. Under the lawn $W = 0.766g\ cm^{-2}$, while under the house it is $0.479g\ cm^{-2}$. The mean respiration time in lawn (W/F_o) is 160 years.

Assuming that in 1956 the soil under the house had the same total amount of organic carbon as now in the lawn profile, it is possible to estimate the loss rate of carbon in this soil due to respiration. Assuming that the change is from $0.766g\ cm^{-2}$ in 1956 to $0.479g\ cm^{-2}$ in 1985, and that it has decayed exponentially over these 29 years, the mean respiration time is then $\tau = 62$ yr. The initial decay rate would have been $0.0125g\ cm^{-2}\ y^{-1}$. If the initial organic carbon respiration rate was equal to the input flux rate of organic carbon in 1956 then this too would have been $0.0125g\ cm^{-2}\ y^{-1}$. It is surprising that this value is some 2.5 times that of the current input rate into the lawn soil profile. The mean depth of organic carbon under the lawn is given by $Z_o = 100\ W/C_o\ P_o$ (O'Brien, 1984), where C_o and P_o are the percent carbon and density in the top horizon. For the lawn this is estimated as 29cm. It is then possible to compute the diffusivity for organic carbon in this soil and this is $5.3cm^2\ y^{-1}$.

DISCUSSION

It is quite likely, from comparing these results with other pasture soils in New Zealand, that the organic carbon content in the upper horizons of the soil, prior to 1956, was greater than is currently the case under the lawn. This would have meant that the turnover time and input flux of organic carbon were even greater than 2.5 times that estimated for the lawn soil. The relatively low value estimated above for the lawn soil probably represents the fact that the lawn has been mowed regularly and the clippings have been collected and removed. Therefore, only a fraction of the herbage produced finds its way to the soil surface as litter and subsequent incorporation into soil organic matter. What is perhaps surprising is that the turnover time for organic carbon in the lawn is so much longer than that under the house. One possible reason for this difference could be that under the lawn the soil becomes water-logged for quite long periods during the winter, while in summer it tends to dry out excessively, sometimes becoming parched and cracked. However, under the house the soil moisture regime is more constant, being not too dry but relatively well aerated. There also may be other reasons related to the relative populations of earthworms and other animals under these two regimes.

Even if the organic carbon regime in the lawn soil is not yet in equilibrium, the differences in turnover time would seem to be real. Certainly the quantity of bomb carbon present under the lawn soil seems small compared with most other soils reported on (O'Brien, 1984), and this is probably explained by the removal of lawn clippings.

Future work embodying a comparison of this sort would be best done using a soil from under a building as compared with a nearby soil still under grassland which had not been disturbed or changed in any way. Such a comparison would not have some of the deficiencies and uncertainties noted above. Assumptions made in these studies that the old organic carbon remains fairly constant within this soil seems to need further investigation. The average value in the soil from under the house was ca 0.14% and this compares with a value of 0.16% measured on loess soil sampled at Judgeford (O'Brien, 1984) in 1977. Another reason for supposing this to be true is that in the deepest two horizons the percent old carbon present in both the lawn and house profiles is approximately the same, even though $\Delta^{14}C$ values differ considerably between these two profiles. If the old carbon was labile and respired at the same rate as the modern carbon then one would have expected the percent old carbon to have been less under the house.

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