Soil Organic Matter Changes towards an Equilibrium Level Appropriate to the Soil and Cropping System

By Johnny Johnston

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While soil organic matter (SOM) is an important aspect of soil quality it will never be easy to identify a critical level at which to maintain a soil. Nevertheless, the contribution of SOM to soil fertility, sustainable agricultural systems, and crop productivity cannot be over emphasized and every effort should be made to maintain, and if possible increase, SOM.

The amount of organic matter in soil varies greatly; in agricultural soils increasing from that under permanent tillage crops to that under permanent vegetation. What is not generally recognized is that the amount reaches an equilibrium level specific to a soil type and farming system. This level depends on the input of organic material and its rate of decomposition, the rate at which existing SOM is mineralized, soil texture, and climate. All four factors interact so that, under very similar climatic conditions, for any one cropping system, the equilibrium level in a clay soil will be larger than in a sandy soil; for any one soil type, the equilibrium value will be larger with permanent grass than with continuous arable cropping. SOM changes slowly in temperate climates, often over many decades, and more rapidly in warm conditions.

The living part of SOM, the soil microbial biomass, is vitally important although frequently less than 5% of soil C. The C content of SOM is typically 58%. The largest proportion of SOM is the end product of the microbial decomposition of added organic materials; consequently the ratio (by weight) of organic C to organic N is relatively constant for many soils, ranging from about 9:1 to 14:1. The C:N ratio of added material determines whether N is released to or taken from the soil mineral N pool during microbial decomposition.

SOM increases rapidly when large amounts of organic matter are added, but decreases quickly when additions cease. When 37.5 and 75 t/ha (fresh weight) of farmyard manure (FYM), biosolids, vegetable compost, and a compost of biosolids/straw were added to a sandy loam soil at Woburn, SOM increased rapidly **(Table 1)**. The size of the increase depended on the amount and type of material added, and there was a linear relationship between the amount of C added and the increase in soil C. However, large amounts of C were lost during microbial decomposition of the added manures, 75% of that in FYM after 25 years, and after 18 years, 64% of that in biosolids and 60% of that added in the composts. Once manure additions ceased, SOM declined. The uniformity of the SOM produced by microbial decomposition of these different manures is shown by the fact that the eight individual exponential C decay curves (not shown) could be shifted horizontally to form a single decay curve **(Figure 1)**.

SOM changes towards and/or remains at an appropriate equilibrium level depending on the input of organic matter. On a silty clay loam soil (about 25% clay) at Rothamsted where spring barley has been grown continuously since 1852, crop residues ploughed in each year are small on soils without annual additions of fertilizer, but are slightly larger with fertilizers. SOM declined a little initially, but has been at an equilibrium level of about 1.0% and 1.1% organic C, respectively, for about 100 years **(Figure 2a)**. The much larger annual input of organic matter from 35 t/ha FYM increased SOM rapidly at first and then more slowly towards an equilibrium level for that soil, cropping, and organic input. Where FYM was applied for the first 20 years, but not since, SOM increased initially but has then declined slowly towards an appropriate equilibrium level **(Figure 2a)**.

On a sandy loam soil (about 10% clay) at Woburn, with much smaller organic matter inputs after 1876, SOM declined **(Figure 2b)** towards a new, lower equilibrium value, and this value was smaller than that with similar cropping on the

Common abbreviations and notes: **N = nitrogen; C = carbon.**

Table 1. Effect of type and rate of organic amendment on the C content of a sandy loam soil, Woburn.

Amendment	Years applied	Fresh weight, t/ha/yr 37.5	75.0
		- - - - - - - - - % C* - - - - - - - - -	
Farmyard manure	25	1.46 (AD1)	2.17 (AD2)
Biosolids	18	1.93 (AS1)	2.92 (AS2)
Vegetable compost**	25	1.70 (ADC1)	2.25 (ADC2)
Biosolids/straw compost	18	1.77 (AT1)	2.38 (AT2)

*In parenthesis: identification for the initial organic C levels in Figure 1. Symbols with "B" in Figure 1 are from a duplicate set of plots.
** Vegetable compost for the first 18 years followed by seven years with farmyard manure.

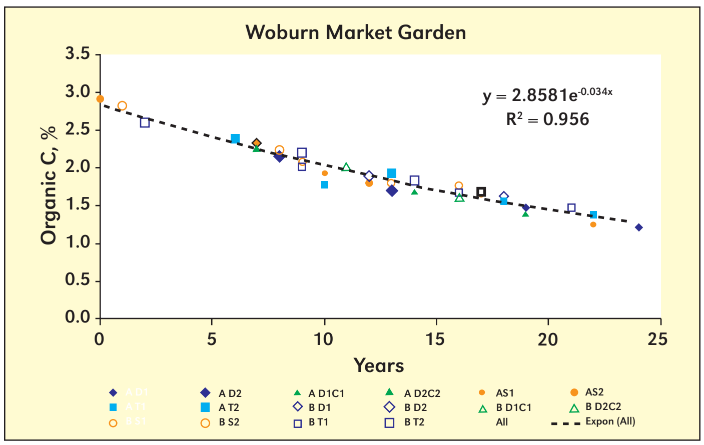

Figure 1. Regardless of the organic amendment, the decline in the resulting SOM due to microbial decomposition could be shifted horizontally to form a single decay curve.

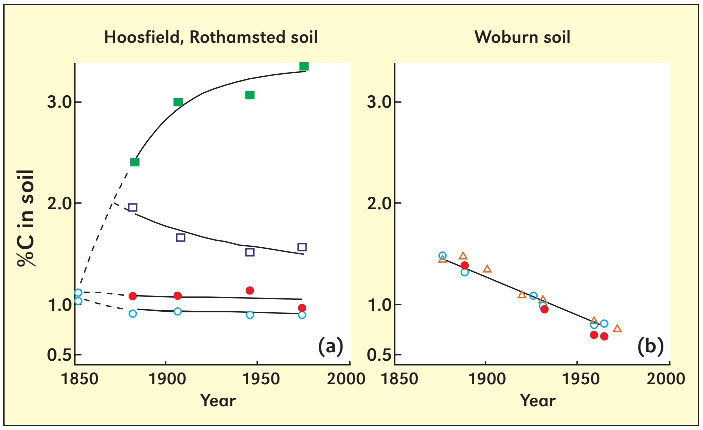

Figure 2. Changes in %C in the top 23 cm of soil at Hoosfield, Rothamsted (a) growing barley each year with annual treatments since 1852; unmanured ○, NPK fertilizers ●, 35 t/ha FYM ■, 35 t/ha FYM 1852-71, none since □; and Woburn (b). Cereals each year since 1876 unmanured ○, NPK fertilizers ●, manured 4-course rotation △.

silty clay loam at Rothamsted, where organic matter is held on clay particles.

SOM increases under permanent crops, partly because there is a greater turnover of roots, and with no soil cultivation and thus less aeration, microbial activity is less. On the silty clay loam at Rothamsted, the SOM equilibrium level where cereals are grown each year on soil that is ploughed to 23 cm is 1.0% organic C, while under permanent grassland for probably at least 400 years it is 2.7% C. Interestingly there are soils on the farm sown to permanent grass for various periods where SOM has increased and the data all fit on one curve **(Figure 3)**. This shows that when an arable soil is sown to permanent grass, it takes about 100 years for SOM to increase to that under permanent grassland. The increase in SOM was rapid initially then slower as a new higher equilibrium level was approached. It took about 25 years to get half the total increase in SOM.

On any one soil type, especially in temperate regions, farmers practice a wide range of cropping systems intermediate between the extremes of continuous arable and permanent grassland. Each farming system will have its equilibrium level of SOM and there will be slow changes when the cropping changes as illustrated in **Figure 4**. In 1938, an experiment comparing different 5-year cropping cycles was started on a sandy loam soil and changes in SOM in the top 25 cm soil were monitored for 60 years. Initially the soil contained 0.98% C, arable crops having been grown on the site for many years.

Where arable crops, wheat, barley, oats, potatoes, sugar beet and carrots, continued to be grown in rotation, SOM declined slowly to about 0.87% C (lower line in **Figure 4**). This decrease is probably due to deeper ploughing and more intensive cultivation.

The upper line in **Figure 4** shows SOM where the 5-year cropping cycle was 3 years grass with fertilizer N followed by 2 years of arable crops – a root crop and a cereal. SOM increased for about 40 years to reach an equilibrium level for that cropping system and soil type, and then remained unchanged at about 1.13% C for 20 years. In this second period, an equivalent amount of SOM accumulated during 3 years of growing grass was lost when arable crops were grown for 2 years.

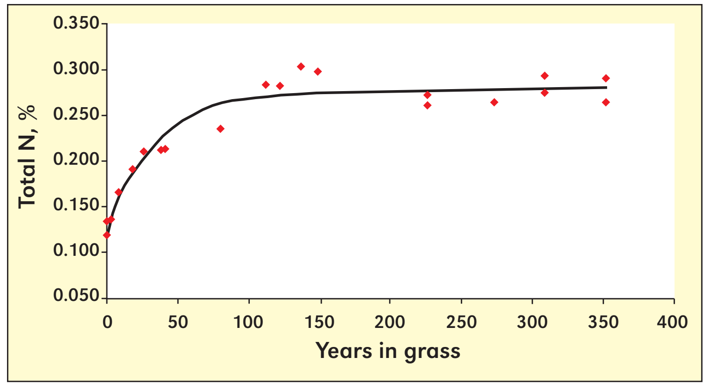

Figure 3. Increase in total soil N (as surrogate for SOM) under long-term permanent grassland, Rothamsted.

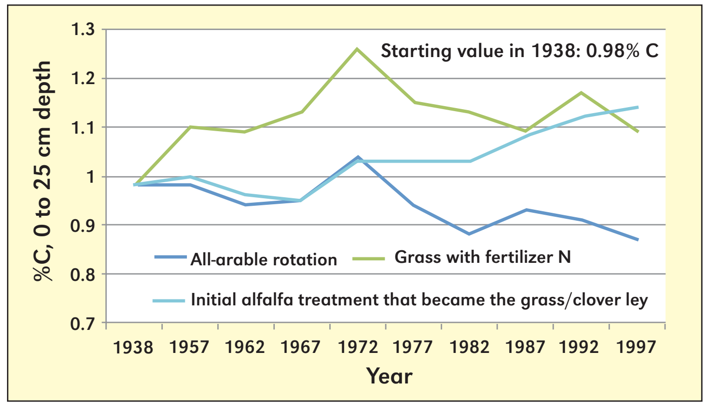

Figure 4. Changes in SOM in the top 25 cm soil within contrasted cropping systems over a period of 60 years.

The middle line in **Figure 4** is interesting because for the first 40 years the 5-year cropping cycle on this plot was 3 years alfalfa (lucerne) followed by two arable crops. Compared to the all-arable rotation (lower line) there was no increase in SOM from growing alfalfa for 3 years in each 5-year cycle. Then alfalfa was replaced by a 3-year grass/clover ley and SOM began to increase during the last 20 years and is now the same, 1.13% C, as in soils with 3 years of grass given fertilizer N.

There was another treatment (not shown) where in the last 30 years there was an all-arable rotation where no crop was grown for 2 of the 5 years of the 5-year cycle. The soil now contains 15% less SOM than the soil growing arable crops continuously.

Currently, there is a perceived need to remove carbon dioxide (CO_2) from the atmosphere to mitigate the effects of climate change, and that CO_2 can be stored in soil as SOM. However, there appears to be little awareness in these discussions that SOM does not increase above the equilibrium level specific to the local conditions of soil type, cropping, and fertilization; and that in temperate climates these changes often occur only slowly. BC

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