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Long-term Trends in Fertility of Soils under Continuous Cultivation and Cereal Cropping in Southern Queensland. II* Total Organic Carbon and its Rate of Loss from the Soil Profile

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Abstract

The kinetics of organic C loss were studied in six southern Queensland soils subjected to different periods (0-70 years) of cultivation and cereal cropping. The equation: $C_t = C_e + (C_0 - C_e)\exp(-kt)$, where C_0, C_e and C_t are organic C contents initially, at equilibrium and at time t, respectively, and k is the rate of loss of organic C from soil, was employed in the study. The parameter k was calculated both for %C (k_c) and for weight of organic C/volume of soil (k_w), determined by correcting for differences in sampling depth due to changes in bulk density upon cultivation.

Mean annual rainfall largely determined both C_0 and C_e, presumably by influencing the amount of dry matter produced. Values of k_c and k_w varied greatly among the soils studied. For the 0-0·1 m depth, k_w was 0·065, 0·080, 0·180, 0·259, 0·069 and 1·224 year^{-1}, respectively for Waco (black earth — initially grassland), Langland-Logie (grey brown and red clays — brigalow), Cecilvale (grey, brown and red clays — poplar box), Billa Billa (grey, brown and red clays — belah), Thallon (grey, brown and red clays — coolibah) and Riverview (red earths — silver-leaved ironbark).

The k values were significantly correlated with organic C/urease activity ratio (r = 0·99***) and reciprocal of clay content (r = 0·97**) of the virgin soils. In stepwise multiple regression analysis, aggregation index (for k_c values) or exchangeable sodium percentage (for k_w) and organic C/urease activity ratio of soils were significantly associated with the overall rate of loss of organic C. It was inferred, therefore, that the relative inaccessibility and protection of organic matter against microbial and enzymic attack resulted in reduced organic C loss. Losses of organic C from the deeper layers (0-0·2 m, 0-0·3 m) were observed in Waco, Langlands-Logie, Cecilvale and Riverview soils, although generally rate of loss decreased with depth.

Introduction

Cultivation and cropping of soil affect its chemical, physical, and biological characteristics. In particular, cultivation of a soil previously supporting native vegetation or pasture generally leads to a reduction in its organic matter content (Haas *et al.* 1957). From long-term trends in soil fertility in the cereal-belt of southern Queensland, Dalal and Mayer (1986) observed that organic matter and its constituents, especially total organic C, organic C in the light fraction (<2 Mg m^{-3}), total N and mineralizable N were greatly reduced by cultivation. Organic matter exercises a vital role in most cultivated soils, for example, as a source of nutrient elements (such as N, P and S), in contributing to the maintenance of a favourable soil structure, in retention of cations, and in complexing micronutrient elements (such as copper, zinc and manganese), hence its rate of loss from the soil following cultivation is very important.

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The organic matter content in a soil depends upon the relative rates at which organic materials are added to the soil and lost from it through decomposition (Woodruff 1949), that is,

$$C_t = C_0\exp(-kt) + A/k[1-\exp(-kt)], \tag{1}$$

where C_0 and C_t are the organic matter contents initially ($t = 0$), and at a given time, t, A is the rate at which organic matter is returned to the soil and k is its rate of loss.

Where the organic matter is not homogeneous, but components decompose at different rates, equation (1) is modified (Woodruff 1949) to,

$$\begin{aligned} C_t = {} & C_1\exp(-k_1t) + A_1/k_1[1-\exp(-k_1t)] + \ldots \\ & + C_n\exp(-k_nt) + A_n/k_n[1-\exp(-k_nt)], \end{aligned} \tag{2}$$

where C_1, C_n refer to different components of organic matter (Jenkinson and Rayner 1977), and k_1, k_n refer to the rate of loss of individual components. When $t = 0$, equation (2) reduces to $C_t = C_1 + \ldots + C_n = C_0$, and when $t \rightarrow \infty$, $C_t = A_1/k_1 + \ldots + A_n/k_n = C_e$, which may be simplified to give $C_e = A/k$ (C_e is organic C content at equilibrium). Equation (2), therefore, can be approximated by equation (1) when organic matter has essentially reached an equilibrium after a long period of constant soil management (Woodruff 1949; Bartholomew and Kirkham 1960). Russell (1975) modified equation (1) to include the feed-back effect of crop yields on soil nitrogen. However, equation (1) has been widely used to study the rate of change in organic matter in arable soils (Jenny 1941; Gokhale 1959; Russell 1962; Hobbs and Thompson 1971; Greenland 1971; Jenkinson and Johnston 1976; Lathwell and Bouldin 1981). The parameter k is then the overall loss rate for the various organic matter components.

Using equation (1), the rate of loss of organic C in relation to the period of cultivation (0·5–70 years) was calculated for six major soils (Waco, Langlands-Logie, Cecilvale, Billa Billa, Thallon and Riverview) of the cereal belt of southern Queensland (Dalal and Mayer 1986). The rate constants, calculated on both weight and volume bases for the soil profiles, are reported in this paper. Soil properties that related to rates of loss of organic C are also reported.

Materials and Methods

The location of the study area, description of soils, crop and soil management practices, and soil sampling and analytical techniques were described previously (Dalal and Mayer 1986). Mean values of clay content, organic C content, pH and bulk density of the soils from virgin sites (0–0·1 m depth) are given in Table 1.

Briefly, soil samples were collected from farmers' fields that had been under cultivation for 0·5–70 years, and from the adjacent virgin area, by sampling 0·1 ha (25 m by 40 m) at each site on a 5 m by 8 m grid at 0–0·1, 0·1–0·2, 0·2–0·3, 0·3–0·6, 0·6–0·9 and 0·9–1·2 m depths with a 46 mm internal diameter tube. Five composite samples were obtained from each depth. Some of the sites on Waco and Langlands-Logie soils were re-sampled four years after to test the applicability of prediction equations based upon initial values.

Soil moisture content was determined by drying a subsample at 105°C for 24–48 h. Field bulk density was calculated from the oven-dried soil weight contained in the field volume of the soil sample. It was adjusted for 'normal' shrinkage up to the moisture content at field capacity (Berndt and Coughlan 1976; R. Berndt, personal communication). The remainder of the soil sample was dried at 25°C in a forced-draught oven, and ground to pass a 0·25 mm sieve for organic C determination by a spectrophotometric adaptation of the Walkley and Black method (Sims and Haby 1971).

Since bulk density increases with increasing period of cultivation (Dalal 1982), it was necessary to take this effect into account when comparing organic C content of soil at a given depth interval between virgin and cultivated sites. This was done by regarding each virgin site as a 'standard' for its set of corresponding cultivated sites, and using the measured values of bulk density at each depth in each profile to obtain for each cultivated site a sequence of 'equivalent' depth intervals, containing the same weight of soil as in the standard depth intervals at the virgin site. Then, from the organic C-depth distribution relationships at each cultivated site, organic C concentrations were estimated for each equivalent depth interval. A somewhat similar approach was adopted by Henzell *et al.* (1967) to correct the organic matter accretion under ley pasture by sampling at two depths only. Jenkinson and Johnston (1976) corrected for changes in depth upon bulk density changes in ley pasture systems by taking a sample from an additional depth. In the present study re-sampling to equivalent depth was made unnecessary by sampling the whole profile and then making adjustments to equivalent depths as described.

Table 1. Some characteristics of the soils (0–0·1 m depth): mean values from virgin sites

Soil series	Great soil group	pH (1:5, H_2O)	Organic C (%)	Clay (%)	Bulk density (Mg m^{-3})
Waco clay^A	Black earth	8·1	1·63	72	0·84
Langlands-Logie clay^B	Grey, brown and red clays (Brigalow)	7·4	2·23	49	0·99
Cecilvale clay^B	Grey, brown and red clays (Poplar box)	7·4	1·73	40	1·02
Billa Billa loamy clay^B	Grey, brown and red clays (Belah)	7·4	1·48	34	0·94
Thallon clay^B	Grey, brown and red clays (Coolibah)	7·2	0·77	59	0·96
Riverview sandy loam^C	Red earth	6·5	1·28	18	1·24

^{A}Typic Pellusterts. ^{B}Typic Chromusterts. ^{C}Rhodic Paleustalfs.

Results

Organic C Content of Virgin Soils

Organic C contents of the virgin soils (0–0·1 m) varied from 0·77% in Thallon clay to 2·23% in Langlands-Logie clay, and except for Langlands-Logie soil supporting brigalow (*Acacia harpophylla*), was closely correlated (r = 0·99***) with the mean annual (83–101 years) rainfall (Fig. 1). A close relationship (r = 0·97**) also existed for all soils after 20 years of cultivation, although the increase in organic C per mm increase in mean annual rainfall was about half of that in the virgin soils. The reduced effect of rainfall on the organic C content of cultivated soils may have been due to a reduction in the amount of organic matter returned to the soil, and/or more rapid organic matter decomposition, in cultivated soils.

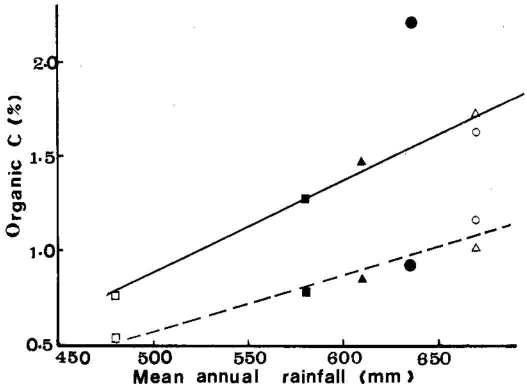

Fig. 1. Relationship between mean annual rainfall and organic C content of virgin soils (r = 0·99, $P < 0·001$) and adjacent soils cultivated for 20 years (predicted from equation 3) (r = 0·97, $P < 0·01$). The regression coefficients (% organic C/mm mean annual rainfall) are 0·0048 (——) and 0·0029 (– – –) for virgin (except Langlands-Logie) and cultivated soils, respectively. ○ Waco; ● Langlands-Logie; △ Cecilvale; ▲ Billa Billa; □ Thallon; ■ Riverview.

Among the soil properties (Dalal and Mayer 1986), organic C content of the virgin soils (n = 36) was significantly ($P < 0{\cdot}05$) correlated with total potassium (r = 0·57), total S (r = 0·35), electrical conductivity (r = 0·60), oxalate-iron (r = 0·42) and urease activity (r = 0·59). In a multiple regression analysis, however, total potassium, clay content, oxalate-iron and urease activity accounted for 84% of the variation in organic C content of the virgin soils.

Rate of Loss of Organic C from the Topsoil Layer (0–0·1 m Depth)

On assuming organic C content at equilibrium $C_e = A/k$, equation (1) when rearranged becomes:

$$C_t = C_e + (C_o - C_e)\exp(-kt). \qquad (3)$$

Equation (3) was used to estimate initial organic C values (C_o), equilibrium organic C values (C_e), rate of loss of organic C (k) and half-life ($t_{1/2} = (\ln 2)/k$) of organic C loss. Values expressed on a per cent basis (w/w) for the top layer (0–0·1 m) of the six soils are given in Table 2.

The values of C_o (calculated) were close to the mean organic C values of the virgin soil samples (measured), and so were closely correlated with mean annual rainfall, and presumably with the amount of organic matter produced by native vegetation. The C_e values were also positively correlated with rainfall (r = 0·91*), reflecting the amount of organic matter produced and returned to the soil as crop and root residues and residual material from original organic matter.

Table 2. Initial values (C_o), equilibrium values (c_e), overall rate of loss (k_c) and half life of loss ($t_{1/2}$) of organic C for the top layer (0–0·1 m) of six soils (on weight of organic C/weight of soil basis)

Soils	Period of cultivation (years)	C_o mean ± s.e. (%C)	C_e mean ± s.e. (%C)	k_c mean ± s.e. (year^{-1})	$t_{1/2}$ mean ± s.e. (year)	R^2
Waco	1–70	1·62 ± 0·03	0·97 ± 0·04	0·063 ± 0·013	11·2 ± 2·3	0·935
Langlands-Logie	0·5–45	2·26 ± 0·08	0·64 ± 0·13	0·060 ± 0·019	11·6 ± 3·7	0·902
Cecilvale	3–35	1·72 ± 0·03	1·00 ± 0·03	0·178 ± 0·037	3·9 ± 0·8	0·952
Billa Billa	0·5–25	1·48 ± 0·05	0·82 ± 0·10	0·161 ± 0·079	4·3 ± 2·1	0·785
Thallon	2–23	0·80 ± 0·02	0·34 ± 0·18	0·041 ± 0·021	16·9 ± 2·4	0·761
Riverview	0·5–20	1·30 ± 0·04	0·77 ± 0·04	1·211 ± 0·343	0·6 ± 0·2	0·877

The k_c *Values*

The rate of loss of organic C, on a per cent organic C basis (k_c), varied from 0·041 year^{-1} (Thallon soil) to 1·211 year^{-1} (Riverview soil). The value of k_c measures how rapidly the organic C content changes towards a new equilibrium level (Lathwell and Bouldin 1981). In Riverview soil, therefore, organic C was lost very rapidly from the top layer (0–0·1 m) (Fig. 2), and the new equilibrium level for organic C was attained quickly ($t_{1/2}$, 0·6 year, Table 2).

The k_c values were significantly correlated with the ratio of organic C/urease activity (r = 0·99***, Fig. 3) and with the reciprocal of clay content (r = 0·97***, Fig. 4).

In stepwise multiple regression analysis of the relation between properties of virgin soils, rainfall, temperature and cultural practices (Dalal and Mayer 1986) and

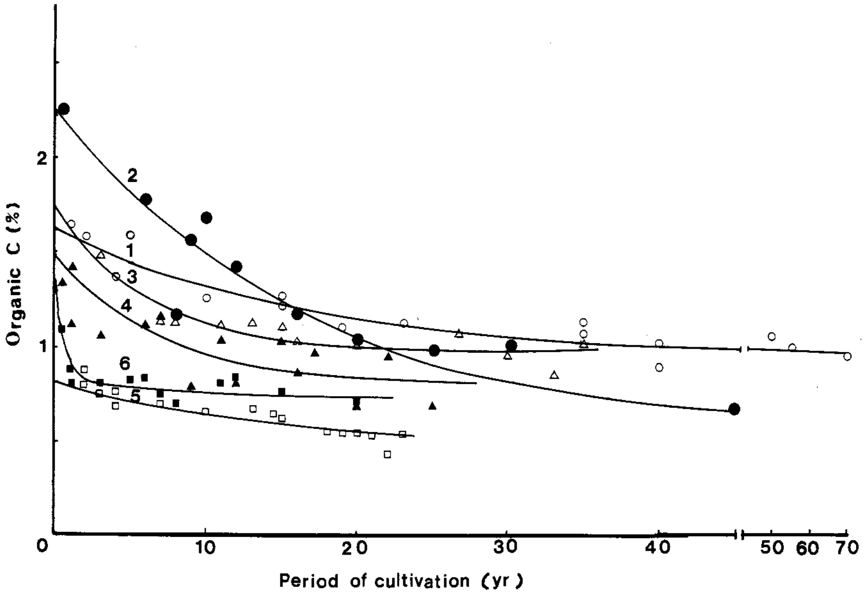

Fig. 2. Decrease in organic C in the top layer (0–0·1 m) with the period of cultivation. Curves are drawn according to equation (3) for each soil. 1, Waco. 2, Langlands-Logie. 3, Cecilvale. 4, Billa Billa. 5, Thallon. 6, Riverview. Symbols as in Fig 1.

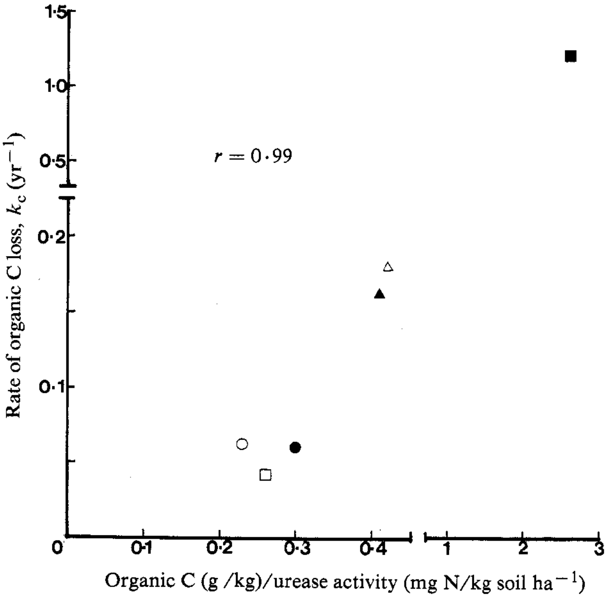

Fig. 3. Relationship between the rate of organic C loss, k_c, and organic C/urease activity ratio of virgin soils (0–0·1 m). Symbols as in Fig. 1.

k_c values, organic C/urease activity ratio and aggregation index explained 99·9% ($R^2 = 0{\cdot}999$, $P < 0{\cdot}001$) of the variation in the k_c values ($n = 6$):

$$k_c = 0{\cdot}319 + 0{\cdot}442^{***}x_1 - 0{\cdot}005^{*}x_2, \qquad (4)$$

where x_1 is the organic C/urease activity ratio (g organic C kg^{-1} soil/mg urea-N hydrolysed kg^{-1} soil h^{-1}) and x_2 is the aggregation index (Dalal and Mayer 1986).

The k_w *Values*

So that changes in organic C at different depths in the same soil series at different periods of cultivation and among soils can be compared, the kinetic parameters (equation 3) were calculated on the basis of weight of organic C/volume of soil for the equivalent of 0–0·1 m depth of adjacent virgin soil (Table 3). The k values were generally higher when calculated on weight/volume, k_w (Table 3) than on a concentration basis, k_c (Table 2), although large differences were found only in Billa Billa and Thallon soils, presumably because of the large increases there in bulk density upon cultivation.

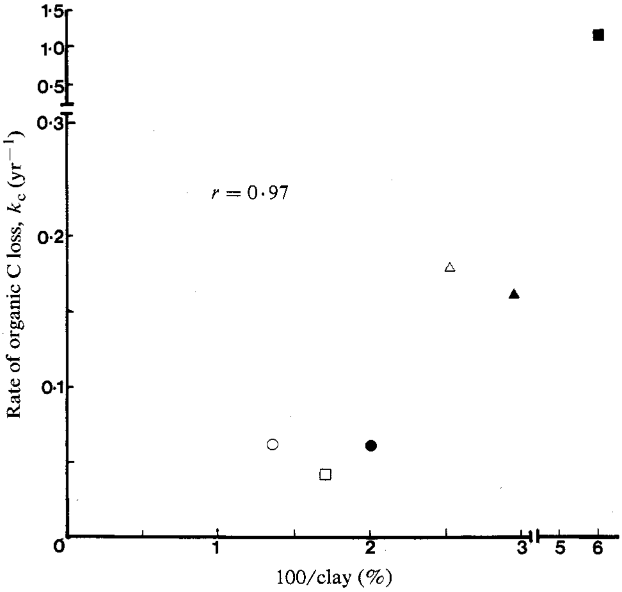

Fig. 4. Rate of organic C loss, k_c, and reciprocal of clay content in the top layer (0–0·1 m). Symbols as in Fig. 1.

Table 3. Initial values (C_0), equilibrium values (C_e), overall rate of loss (k_w) and half-life of loss ($t_{½}$) of organic *C* for the top layer (0–0·1 m) of six soils (on weight of organic C/volume of soil basis)

Soils	Period of cultivation (years)	C_o mean ± s.e. (t C ha^{-1})	C_e mean ± s.e. (t C ha^{-1})	k_w mean ± s.e. (year^{-1})	$t_{½}$ mean ± s.e. (years)	R^2
Waco	1-70	13·71 ± 0·22	8·26 ± 0·34	0·065 ± 0·013	10·6 ± 2·1	0·944
Langlands-Logie	0·5-45	22·07 ± 0·84	7·76 ± 1·83	0·080 ± 0·026	8·6 ± 2·8	0·876
Cecilvale	3-35	17·51 ± 0·28	10·18 ± 0·34	0·180 ± 0·036	3·9 ± 0·7	0·958
Billa Billa	0·5-25	13·64 ± 0·47	8·27 ± 0·56	0·259 ± 0·123	2·7 ± 1·2	0·792
Thallon	2-23	7·52 ± 2·18	4·41 ± 1·26	0·069 ± 0·025	10·0 ± 3·6	0·763
Riverview	0·5-20	15·69 ± 0·51	9·38 ± 0·39	1·224 ± 0·359	0·6 ± 0·1	0·870

The overall rate of organic C loss, k_w, varied from 0·065 (Waco soil) to 1·224 (Riverview soil) and mean half life, $t_{½}$, ranged from 0·6 to 10·6 years (Table 3). Like k_c values, k_w was closely correlated with organic C/urease activity ratio (r = 0·99***) and with the reciprocal of clay content (r = 0·98***). However, in a multiple regression analysis, exchangeable sodium percentage (ESP) instead of aggregation index, together with organic C/urease activity ratio, explained 99·9% of the variation in the k_w values ($n = 6$):

$$k_w = -0\cdot136 + 0\cdot496^{***}x_1 + 0\cdot033^{*}x_2, \qquad (5)$$

where x_1 is the organic C/urease activity ratio (g organic C kg^{-1} soil/mg urea-N hydrolysed kg^{-1} soil h^{-1}) and x_2 is the ESP of the virgin soils.

The Addition Term, A

The addition term, A, which equals the product of C_e and k_w, shows the amount of organic C required to maintain organic matter at equilibrium under constant soil and crop management practices. The amounts of organic C so required for the top layer (0–0·1 m) were 0·3, 0·5, 0·6, 1·8 and 2·1 t ha^{-1} $year^{-1}$ for Thallon, Waco, Langlands–Logie, Cecilvale and Billa Billa soils. Bartholomew and Kirkham (1960) pointed out the large errors involved in estimating A values and, therefore, these values can be used as a guide only. It is also likely that A value is the product of C_e and a low rate of loss of a residual organic matter component rather than one k value which represents the overall loss rate of various organic matter components (Woodruff 1949).

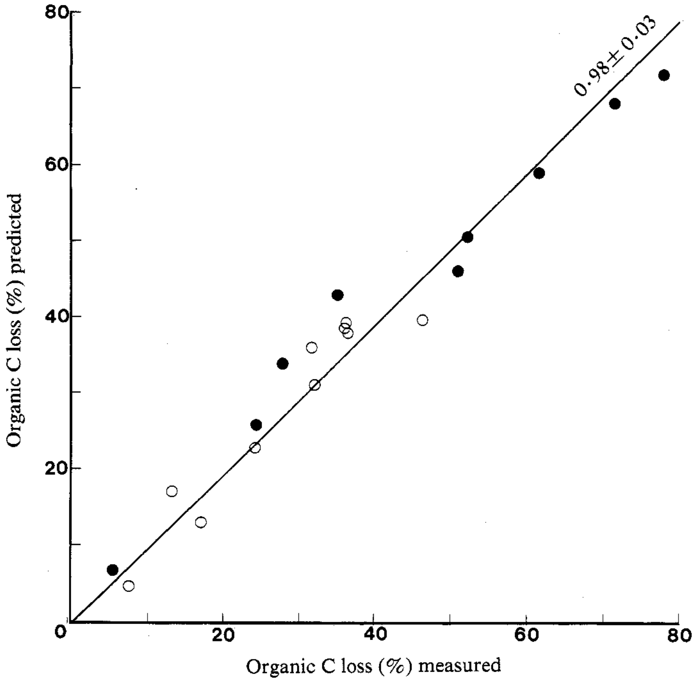

Fig. 5. Organic C losses in Waco (○) and Langlands-Logie (●) soils, measured by sampling the same sites 4 years later, and those predicted using values of parameters (equation 3) given in Table 2. $r = 0\cdot96$.

Prediction of Organic C Loss in Soil under Cultivation

Notwithstanding the limitations of A value, equation (3) described the level of organic C likely to occur in the long term under current cultural practices. A close relationship was obtained for Waco and Langlands-Logie soils between the measured organic C losses 4 years after initial sampling and those predicted (Fig. 5).

Loss of Organic C from the Subsoil Layers (0–0·2 m and 0–0·3 m Depths)

Loss of organic C was also detected from deeper layers (0–0·2 m and 0–0·3 m depth) in Waco, Cecilvale, Langlands-Logie and Riverview soils (Table 4). However, the k_w values generally decreased with depth. Hobbs and Thompson (1971) also found that a chernozem (Argiustoll) from Kansas, U.S.A., lost 352 kg C ha^{-1} year^{-1} from 0·18 to 0·51 m depth (65 kg C ha^{-1} year^{-1} from 0 to 0·18 m depth) in a fallow–wheat–sorghum rotation in the last 10 years of 50 years' cropping.

Table 4. Initial (C_0) and equilibrium (C_e) values and overall rate of loss (k_w) of organic C from different depths in four soils

Soil Series	Soil depth (m)	C_0^A (t ha^{-1})	C_e^A (t ha^{-1})	k_w^A (year^{-1})	R^2
Waco	0–0·1	13·7	8·3	0·065	0·94
	0–0·2	23·8	16·0	0·048	0·89
	0–0·3	32·6	23·0	0·039	0·87
Langlands-Logie	0–0·1	22·1	7·8	0·080	0·88
	0–0·2	36·6	17·4	0·092	0·85
	0–0·3	47·4	24·4	0·089	0·87
Cecilvale	0–0·1	17·5	10·2	0·180	0·96
	0–0·2	29·1	20·1	0·137	0·91
	0–0·3	39·4	29·2	0·132	0·85
Riverview	0–0·1	15·7	9·4	1·244	0·87
	0–0·2	25·0	16·7	0·969	0·83
	0–0·3	32·5	22·6	0·758	0·80

^{A}All values differ significantly from zero at $P < 0·05$.

Discussion

Organic C Content of Virgin Soils

In a virgin soil undisturbed for a long time, an approximate balance ($C_e = A/k$) is maintained between the rates of addition (A) of organic materials from dead and living roots, litter and residues of microorganisms and fauna and of depletion (k) by erosion, leaching and decomposition. The organic C content of virgin soils is a function of climate, vegetation, topography and parent materials (Jenny 1941).

Spain *et al.* (1983) have summarized the effects of temperature and rainfall, vegetation and soil type on the organic C contents of a number of Australian soils. Rainfall was found to be the most important of environmental factors and was positively correlated with the soil organic matter, in agreement with the results obtained in this study (Fig. 1). The effects of vegetation type on organic C contents, however, are inconclusive (Spain *et al.* 1983) because of the confounding effects of temperature and moisture on vegetation. Similarly, since soil properties are also affected by environment, vegetation and topography it is difficult to isolate the individual effects. Furthermore, a number of soil properties, such as organic C, urease activity and oxalate-iron, are interrelated.

The protective effect of clay on organic matter is well known (Sorensen 1981), although its effect would be modified by its mineralogy (predominantly montmorillonitic in Waco to predominantly kaolinitic in Thallon and Riverview soils; Dalal and Mayer 1986) and its interaction with iron oxides (Riverview soil) and aluminium oxides. The significant correlation between organic C content of the virgin soils and total potassium obtained in this study probably reflects the clay mineralogy effects on organic C, for it is known that montmorillonitic clays (low in total K) can protect organic substances better than illitic clays (high in total K) (Mortland 1970). Admittedly, the soil system is multivariate and interactive (Spain *et al.* 1983).

Organic C Content of Cultivated Soils

When virgin soils are brought under cultivation and cropping, organic C content generally declines because the amount of organic materials returned to the soil (*A* value) decreases sharply. This appears to be so in Fig. 1, where organic C/mm rainfall is about half after 20 years of cultivation as compared to the virgin soils. It is also likely that *k* values may be different in these two ecosystems, because of greater mixing of soil and exposure of new sites, more frequent and closer contact between organic and substrates and microorganisms, and larger changes in temperature and moisture regimes accompanying cultivation.

Kinetics of Organic C Loss from Soil

The *k* values reported in Tables 2 and 3 measure the overall rate of loss of organic C, and these values include losses due to erosion, leaching and decomposition. Erosion losses were probably minimal because most sampling sites were located on slopes rarely exceeding 1% (mostly on 0·1–0·5% slope). Leaching losses of organic C do occur but are rarely measured. It is assumed here that *k* values measure mainly the rate of organic C decomposition (mineralization) in these soils.

Lathwell and Bouldin (1981) summarized k_c values obtained under different cropping systems and environments. The *k* values varied from 0·024 (continuous corn) to 0·330 (maize and rice). In general, they were higher in the tropics than in temperate regions. Hobbs and Thompson (1971) got a k_c value of 0·062 under a wheat-fallow system in Kansas, U.S.A., for a cultivation period of 63 years. Russell (1981) found a k_c value of 0·049 for total N (0–0·1 m layer) of grey, brown and red clays (native vegetation — brigalow) under continuous sorghum in Queensland, and 0·022 for total N in red-brown earths under continuous wheat in the Mediterranean climate in South Australia.

Most of the *k* values mentioned above were obtained from the measurements of total N rather than organic C. They are not strictly comparable with the *k* values reported in Tables 2 and 3, since it is only in the later stages of decomposition that losses of soil N are proportional to the losses of organic C (Jenkinson 1966).

Another limitation in comparing the *k* values published in the literature is that most were calculated on a per cent N basis for samples obtained at different periods, but taken to the same depth (Jenkinson 1966). This procedure introduces errors because changes in organic matter content of soil generally are associated with changes in bulk density, and hence samples collected to the same depth at different periods are not strictly comparable (Campbell 1978).

Relationship between k *Values and Soil Properties and Cultural Practices*

The decomposition of organic matter occurs primarily through the action of proteolytic and other degradative enzymes produced mainly by microorganisms in soil. Any soil characteristic, environmental parameter or cultural practice that regulates enzymic production, persistence or protection, enzyme-substrate contact and enzymic inhibition would affect the rate of organic matter decomposition in soil.

Stubble retention reduces the rate of net organic matter loss by increasing inputs of organic materials through crop residues, affecting substrate accessibility and composition of substrates such as C/N ratio.

The soil properties significantly related to the k values were clay content, aggregation index, ESP and ratio of organic C/urease activity. Mortland (1970) summarized the possible mechanisms of organic matter protection by clays, including adsorption of organic C on clay surfaces and entrapment between clay particles. Moreover, clay may also exert direct influence on microbial activity and enzymes through adsorption and diffusion, thus retarding the enzyme-substrate contact. The clay is also involved in aggregate formation, and therefore its effect on k value would be interactive with bulk density, aggregation index, and possibly ESP. The latter may affect the stability and/or formation of aggregates (Emerson 1983), and hence diffusion of organic substrate and/or product or accessibility to the substrate by the degradative enzymes and microorganisms.

The ratio of organic C/urease activity is probably a measure of relative accessibility of organic C to proteolytic and other degradative enzymes. Pettit *et al.* (1976) postulated that extracellular urease may be stabilized in soil by bonding or entrapment in the organic matter matrix which renders it inaccessible to attack by soil proteolytic enzymes but may not exclude small molecular weight substrates (urea) and products (NH_4-N). Free urease, however, would be rapidly degraded by proteolytic enzymes or made inactive by physical and chemical denaturation. Ladd and Butler (1975) also postulated that some proteinases by becoming entrapped within or adsorbed to soil colloids may be completely stabilized against biological degradation.

The lower ratio of organic C/urease activity may, therefore, reflect greater protection afforded to the enzyme–organic matter complex, possibly through relatively less accessibility to the proteolytic and other degradative enzymes. If it is so, then the ratio of organic C/urease activity in a given soil series should decrease upon cultivation because relatively unprotected or easily accessible organic matter would be rapidly decomposed. In general, such a trend was noticed (4% decrease in Waco soil to 45% decrease in Billa Billa soil). Similarly, the ratio of organic C/urease activity generally decreased with depth and was closely correlated ($r = 0{\cdot}99^{***}$) with the k_w values at 0–0·1 m, 0–0·2 m and 0–0·3 m depths. The ratio of organic C/urease activity as an index of accessibility to or protection of organic matter needs to be confirmed, however, in different environments. A major difficulty lies in the apparently large effects of changes in temperature and moisture on urease activity in soil (Dalal 1985), although Zantua and Bremner (1977) showed that urease activity of soils (in the absence of recently added organic materials) reflects their capacity for protection of urease. In this study extracellular urease activity was measured in soils mostly collected during the May–July period.

Conclusions

Since the rate of loss of organic matter in the soils studied was associated with factors that affect its accessibility and stability to attack by microorganisms and proteolytic and other enzymes (clay content, organic C/urease activity ratio, aggregation and exchangeable sodium percentage), cultural practices that influence desirably some or most of these factors would assist in reducing the rate of loss of organic matter. The organic C contents at estimated equilibrium in the six soils studied (0·34–1·00%, Table 2) are much lower than the 2% organic C considered by Greenland *et al.* (1975) to be critical for the maintenance of satisfactory soil structure, although little is known about the required organic C levels for Vertisols. Also, these are generally less than the 1·16% organic C level claimed by Lucas *et al.* (1977) to be minimal for nitrogen supply to crops.

Although the rate of loss (k_W or k_C) of organic C reported in this study described organic C decline with period of cultivation successfully, the parameter probably encompassed a number of organic matter components which declined at different rates (Jenkinson and Rayner 1977). Russell (1981) has suggested the need to identify the easily determined and meaningful soil organic matter fractions from his simulation studies of long-term soil nitrogen change. This will be examined in subsequent papers.

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