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Impact of cultivation and sugar-cane green trash management on carbon fractions and aggregate stability for a Chromic Luvisol in Queensland, Australia

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Abstract

Technological advances in sugar-cane harvesting and processing is bringing about rapid changes in production systems which could impact on soil physical conditions. An increasing incidence of soil structural decline and depletion of soil carbon levels has increased the risk of soil erosion and crop yield reductions. Soil carbon (C) and aggregate stability were studied on a sugar-cane (*Saccharum officinarum* L.) green trash blanket trial that had been established on a Chromic Luvisol soil at Mackay, Qld, Australia in 1992. The experiment consisted of blocks with two blocks being harvested early and the remaining two blocks harvested late in the crushing season. Within each block, treatment combinations of trash burnt or green trash blanket, which are either cultivated between rows or not cultivated after harvest, were included. Cropping and cultivation of the soil reduced the different C fractions in the surface 0–100 mm layer by 66–67% when compared to an adjacent uncropped reference soil. The labile C (C_L) concentration was 11% lower in the burnt treatment compared to the trash returned treatment but the opposite was found for total C (C_T). After four years, the no cultivation treatment had higher concentrations of all C fractions measured, compared to the cultivated treatment. When compared to the uncropped reference soil, cropping resulted in marked reductions in aggregate mean weight diameter (MWD) and aggregates >250 μm and an increase in aggregates <125 μm determined by both immersion and tension wetting. The return of the green trash resulted in a 30% greater MWD and a 28% increase in aggregates >250 μm and an 18% reduction in aggregates <125 μm compared to the burnt treatment when immersion wetting was used. Four years of cultivation reduced the MWD, as determined by immersion wetting, by 26% compared to the no cultivation treatment. No significant correlations were found between any measured C fraction and aggregate stability. This study indicates that sustainable sugar-cane cropping systems will likely be those where cultivation is kept to a minimum and trash is retained in the system.

Keywords: Soil organic matter; Labile carbon; Cultivation; Residue burning; Structure

1. Introduction

It has been well documented that the cultivation of soils results in decreased concentrations of soil organic matter (SOM) and in structural degradation. SOM is one of the major soil constituents involved in binding individual soil particles into aggregates, particularly in lower clay content soils and the stability of soil aggregates increases with increased levels of SOM (Tisdall and Oades, 1982; Chaney and Swift, 1984; Dutartre et al., 1993; Haynes, 1993). Oades (1993) suggested that repeated cultivation of soils, combined with limited SOM inputs, would

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eventually lead to major aggregate disintegration leaving the soil vulnerable to erosion and compaction. Many farming practices such as burning or removing stubble, using conventional tillage practices and fallows remove organic matter from the system. Karlen and Cambardella (1996) contended that changing management practices such as residue retention, reduced and no-till techniques, the use of green manure crops and pasture leys, or the application of organic materials resulted in numerous beneficial effects on soil physical properties and fertility.

Sugar-cane production is of major agricultural importance in Qld, Australia where much of the cane land has been developed from forest or natural grassland. The continuous cultivation of these soils and the burning of crop residues have led to reduced concentrations of SOM (Blair et al., 1995a). Similar results were reported in sugar-cane by Ball-Coelho et al. (1993) in northeast Brazil. The development of green cane harvesting, where the green leaf and dry leaf sheaths are mechanically removed from the cane stalk and deposited on the soil surface in situ has the potential for increasing soil C concentrations and improving soil structure on these soils. Blair et al. (1998) found significant increases in the labile C fraction (determined by oxidation with 333 mM $KMnO_4$ (Blair et al., 1995a)) in green trash treatments compared to the trash burnt treatments in the surface soils of two green trash management trials located at Ayr and Tully in Qld, Australia. In the study of Blair et al. (1998) no measurements were made of soil physical properties but studies with other soils (Blair and Daniel, 1996; Bell et al., 1998) have shown relationships between labile C and soil aggregate stability. In another study Skjemstad et al. (1999) found substantial amounts of charcoal, of pre-cane origin, in both uncropped and soils used for sugar-cane production in Queensland.

This study was undertaken at Mackay, Queensland to investigate the combined effects of trash management and cultivation in a sugar-cane cropping system on surface soil C concentrations and on soil physical properties as determined by aggregate stability. These results were compared to an adjacent uncropped pasture (reference soil) area of a similar soil type. Relationships between soil C fractions and aggregate stability were also investigated.

2. Materials and methods

2.1. Experimental site and environmental conditions

A sugar-cane (*Saccharum officinarum* L.), green trash blanket trial was established at the Central Sugar Experiment Station, Mackay, Qld, Australia on a Chromic Luvisol (non-calcic brown soil, Stace et al., 1972). The soil at the experimental site contained 570 g kg^{-1} sand, 240 g kg^{-1} silt and 180 g kg^{-1} clay and the clay mineralogy was predominantly kaolinite, quartz and illite with a small amount of halloysite.

The mean daily temperature of Mackay is 21.9°C and the average annual rainfall is 1681 mm (source: Australian Bureau of Meteorology, Met Access). The trial was planted in 1992 on a site that had previously grown sugar-cane for more than 20 years. The trial was set-up in a block design consisting of four blocks with two blocks being harvested early in the crushing season, which is generally early to mid-June and the remaining blocks harvested late during the last two weeks of crushing, mid- to late-November. The plots were 6 m (4 rows 1.5 m apart) wide and 18 m long and there were two replicates within each block (i.e., a total of four replicates). Treatment combinations consisting of trash burnt or green trash blanket which were either cultivated between rows after harvest or not cultivated. The cane was harvested green and burnt as a trash blanket fire on the ground for the burnt treatments but left on the soil surface for the green trash treatments. The trash was burnt within two weeks of harvest as soon as it had dried sufficiently to burn. Cultivation, to a depth of approximately 150 mm, was carried out between the rows within one week of burning. The disc implement used partially inverts the soil and burnt or green trash. Urea, at a rate of 180–200 kg ha^{-1}, was applied annually by a stool splitter to a depth of 150 mm. In 1996 and 1997, 70 mm of supplementary irrigation was applied during the season.

2.2. Soil sampling and preparation

Soil samples were collected in June 1997 just prior to the early harvest of the fourth ratoon crop. Two cores of soil, 80 mm diameter and 100 mm deep, were collected from between the second and third rows of each plot for determination of wet aggregate stability, dry aggregate size distribution and total (C_T) and labile (C_L) C concentrations. Cores of soil were also collected from an adjacent area, with the same soil type, that had grown pasture for more than 20 years. This was termed the reference sample. The two cores from each plot were bulked, air dried and large clods were gently broken by hand.

The air dried soil samples were broken down to pass through a 4 mm sieve using a metal roller on a board that had 4 mm high ridges on the sides. This prevented total disruption of the sample and ensured that each soil sample received similar energy input.

2.3. Wet aggregate stability

Wet sieving was undertaken through a set of five sieves of 2000, 1000, 500, 250, 125 μm sizes, with the diameter of the sieves being 100 mm, using a modification of the Yoder procedure (Whitbread, 1996). For immersion wetting, 30 g of air dried soil was placed onto the top sieve and immersed in distilled water at approximately 22°C for 30 s before being sieved for 10 min through an amplitude of 17 mm at 34 cycles min^{-1}. For tension wetting, the soil was wetted on a sand pad at a tension of 0.4 kPa before being immersed in distilled water at approximately 22°C and sieved as for immersion wetting. Following sieving, the sieves were drained and the soil was dried at 40°C for 24 h and MWD and the percentage of aggregates >250 and <125 μm were calculated. No measurement was made of sand content in each fraction as this was assumed to be a constant between treatments.

2.4. Dry aggregate size distribution

A dry sieving technique was used to measure the aggregate size distribution after the soils had been crushed as described in Section 2.2. A 30 g soil sample was placed on the 2000 μm mesh sieve of the set of sieves used for wet sieving. The soil was sieved through the set of sieves for <1 min, with minimum energy input, to get as close as possible to the dry aggregate size distribution of the soil prior to wet sieving. The amount remaining on each sieve size was weighed and MWD, percentage of aggregates >250 and <125 μm were calculated.

2.5. Total and labile carbon and the derivation of the carbon management index

Carbon measurements were made on soil samples ground to <0.5 mm. Total C (C_T) was determined by catalytic combustion on a Carlo Erba NA1500 carbon/nitrogen/sulphur analyser. Labile C (C_L) was determined by oxidation with 333 mM $KMnO_4$ according to the method of Blair et al. (1995a). Carbon oxidised by 33 mM $KMnO_4$ (the more easily oxidisable C (C_{33})) (Lefroy et al., 1993) was also determined. This followed the same method as for C_L except the weaker strength $KMnO_4$ was used and the dilution step was only a 1:25 dilution rather than 1:250. Non-labile C (C_{NL}) was determined by the difference between C_L and C_T.

The C management index (CMI) derived by Blair et al. (1995a) was calculated using the values for the reference soil to calculate the lability index (LI), C pool index (CPI) and CMI for all treatments.

The calculation is as follows:

1. Firstly a C pool index (CPI) was calculated as

$$\mathrm{CPI} = \frac{\text{sample total C (mg g}^{-1})}{\text{reference sample total C (mg g}^{-1})} = \frac{C_{T\ \text{sample}}}{C_{T\ \text{reference}}}$$

2. Then an LI was calculated

$$\mathrm{LI} = \frac{\text{lability of C in sample soil}}{\text{lability of C in reference soil}}$$

where lability of C $(L) = C_L/C_{NL}$

3. The CMI was then calculated as follows:

$$\mathrm{CMI} = \mathrm{CPI} \times \mathrm{LI} \times 100$$

2.6. Oxidation of charcoal and calcium carbonate by neutral $KMnO_4$

Because of the presence of charcoal and calcium carbonate in some soils, a study was also undertaken to examine if neutral $KMnO_4$ oxidised these forms of essentially non-active C. In order to test if charcoal and calcium carbonate were oxidised by neutral 333 mM $KMnO_4$ a 25 ml aliquot was added to 15 mg of activated charcoal or $CaCO_3$ alone, or in the presence of soil in a centrifuge tube and placed on an end-over-end shaker for 1 h. The tubes were then centrifuged at 815 g for 5 min and a sample of the $KMnO_4$ diluted and poured into a cuvette and the optical density read at a wavelength of 565 nm. The amount of C oxidised was calculated knowing that 1 mM of $KMnO_4$ oxidised is equivalent to 9 mg C (Lefroy et al., 1993).

2.7. Statistical analyses

Data were analysed by analysis of variance as a split-plot factorial experiment with harvest time as the whole plot and cultivation and trash management treatments as sub-plots. The reference soil was not included in the analyses because there was no true replication. Treatment means were compared using Duncan's multiple range test (DMRT) at the 5% level of probability. Regression analyses were undertaken using Excel 97.

3. Results

3.1. Carbon fractions

There was no significant difference in the amounts of $CaCO_3$ or charcoal oxidised by the 333 mM $KMnO_4$ when added alone or in the presence of soil. A mean of 0.08% of the $CaCO_3$ and 5.14% of the charcoal were oxidised by the 333 mM $KMnO_4$.

The impact of cropping and cultivation on soil C concentration is shown by the mean decrease of 67% in C_{33} and C_L and of 66% in C_{NL} and C_T, compared with that of the reference site (Table 1). Burning resulted in an 11% reduction in C_L compared to the green trash treatment, however there was an opposite effect for C_T and C_{NL} (Table 1). The lability (*L*) of the carbon, the LI and the CMI were all significantly higher in the green trash retention treatment than for the burnt treatments, while the CPI followed the same trend as C_T (Table 1). The different trash treatments had no significant effect on C_{33} (Table 1). There were no significant differences between the early and late harvests for any of the parameters measured.

Cultivation following harvest resulted in a reduction in C_{33}, C_L, C_{NL} and C_T of 22, 16, 18 and 18%, respectively, compared with that of no cultivation (Table 2). There was also a significant reduction in the CPI and CMI (Table 2). There were no significant interactions between trash management and cultivation.

3.2. Aggregate stability

Cropping and cultivation also impacted on the wet aggregate stability of this soil, with the greatest change being in the per cent of aggregates <125 µm, where cropping increased these by 538% (immersion wetting) and 832% (tension wetting) when compared with that of the reference soil (Table 2). For immersion wetting, the MWD was 30% greater in the green trash

Table 1
C fractions, *L*, LI, CPI and CMI for the cultivation and trash management treatments and reference soil from Mackay, Queensland

C fraction[a] and indices	Cultivation effect		Trash management effect		Reference soil
	No cultivation	Cultivation	Green trash	Burnt	
C_{33} (g kg^{-1})	0.76a[b]	0.59b	0.70n	0.66n	2.04
C_L (g kg^{-1})	1.99a	1.68b	1.94n	1.73m	5.63
C_{NL} (g kg^{-1})	10.47a	8.54b	8.61n	10.40m	27.87
C_T (g kg^{-1})	12.46a	10.22b	10.55n	12.13m	33.50
L	0.20	0.20	0.23n	0.17m	0.20
LI	0.98	0.99	1.13n	0.84m	1.00
CPI	0.37a	0.31b	0.32n	0.36m	1.00
CMI	35.4a	29.9b	35.3n	30.0m	100.0

[a] C_{33}=C oxidised by 33 mM $KMnO_4$; C_L=C oxidised by 333 mM $KMnO_4$; C_{NL}=C not oxidised by 333 mM $KMnO_4$ (C_T-C_L); C_T=total organic C.
[b] Numbers in the same row within cultivation and trash management followed by the same letter are not significantly different according to DMRT at P=5%.

Table 2
MWD, percentage of aggregates >250 μm, percentage of aggregates <125 μm for immersion and tension wetting and for dry sieving for the cultivation and trash management treatments and reference soil from Mackay, Queensland

Aggregate size class	Cultivation effect		Trash management effect		Reference
	No cultivation	Cultivation	Green trash	Burnt	
Immersion wetting					
Mean weight diameter (mm)	0.487a[a]	0.359b	0.479n	0.368m	1.682
Aggregates >250 (%)	33.6a	25.6b	33.2n	26.0m	85.2
Aggregates <125 (%)	48.5b	53.7a	45.8n	56.4m	8.0
Tension wetting					
Mean weight diameter (mm)	0.763a	0.609b	0.801n	0.571m	2.578
Aggregates >250 (%)	58.5a	53.5b	61.7n	50.4m	95.6
Aggregates <125 (%)	26.2b	30.2a	24.1n	32.3m	2.9
Dry sieving					
Mean weight diameter (mm)	1.471	1.629	1.620n	1.480n	1.776
Aggregates >250 (%)	80.1a	84.8b	84.1n	80.7n	89.5
Aggregates <125 (%)	12.1b	9.3a	9.5n	11.9n	5.6

[a] Numbers in the same row within cultivation and trash management followed by the same letter are not significantly different according to DMRT at $P=5\%$.

treatments than in the burnt treatments (Table 2). A similar increase was found for the percentage of aggregates >250 μm, while there was a 19% decrease in the percentage of aggregates <125 μm (Table 2). When tension wetted, the MWD and percentage of aggregates >250 μm increased by 40 and 22%, respectively, for green trash retention compared to burning the trash, while the percentage of aggregates <125 μm was decreased by 55% (Table 2). For dry aggregate size distribution there were no significant differences found between treatments for MWD, percentage of aggregates >250 μm or percentage of aggregates <125 μm (Table 2). There were no significant differences between the early and late harvests for any parameters measured.

Cultivation resulted in a 26% reduction in MWD and a 24% decrease in the percentage of aggregates >250 μm for immersion wetting compared to the no cultivation treatment, with corresponding decreases of 20 and 8%, respectively, for tension wetting. In contrast, cultivation resulted in an 11 and 13% increase in the percentage of aggregates <125 μm for immersion and tension wetting, respectively (Table 2). There were no significant effects of cultivation or trash management on the MWD for the dry aggregate size distribution, however, cultivation resulted in a decrease in the percentage of aggregates >250 μm and an increase in the percentage of aggregates <125 μm (Table 2). Trash management and cultivation showed no significant interactions. There were no significant relationships between any carbon fractions and any factors of aggregate stability measured for this soil.

4. Discussion

4.1. Carbon fractions

The term labile C has been used to describe that fraction of soil C oxidised by neutral 333 mM $KMnO_4$ (Blair et al., 1995a). Results from the study of the oxidation of $CaCO_3$ and charcoal presented here confirmed that these two rather inert components of soil C were not significant contributors to labile C as measured by oxidation. The 4.4% recovery of powdered activated charcoal added to soil would likely be greater than the charcoal contained within micro-aggregates, which would be less likely to be oxidised by $KMnO_4$ because of clay protection.

In the present study the four years of cultivation resulted in a decrease in all C fractions compared to the no cultivation treatment (Table 1). Tisdall and Oades (1982), Sparling et al. (1992) and Lefroy et al. (1993) also found that cultivation resulted in a decline in the organic matter concentration of soils.

Syers and Craswell (1995) suggested that such a decline was due to an increase in the decomposition rate caused by the shattering of macro-aggregates, mixing of surface soil and increases in the intensity and number of wetting and drying cycles.

Cropping and cultivation has resulted in a similar decline in the different C fractions (66–67% averaged over all treatments) (Table 1). The burning of crop residues not only has detrimental effects on SOM and soil structure, but farmers are also under increasing environmental pressure not to burn residues. The retention of green trash resulted in an increase in C_L but a decrease in C_T, compared to the burning of trash (Table 1). This indicates that the green trash was releasing more active labile C from the crop residue than the burnt treatments. This contrasts to the findings of Blair et al. (1998) who found increases in both C_T and C_L as a result of green trash retention at Ayr and Tully, Queensland. The results of the present study also contrast with that reported by Weir (1998) who suggested that the application of sugar-cane trash to soil generally increased total SOM by 20% over a 20 year period. In the present study, the sugar-cane was harvested green and then burnt as a trash blanket fire on the ground. This resulted in a slower burn and more of the ash remained on the soil surface than if the cane was burnt standing. Normal practice, prior to green trash blanketing, is to burn the standing cane prior to harvest, which results in a hotter fire and much of the carbon is carried by updraughts into the atmosphere, leaving little residue on the soil surface and contributing to elevated atmospheric CO_2 concentrations. The burnt residue of the sugar-cane trash remaining on the soil surface most likely had a higher lignin content and a lower decomposition rate than the higher quality, readily decomposable, green trash. It may also contain more C in the inert form of charcoal that may not be oxidised by potassium dichromate, which is used in many SOM studies. This method of burning and the presence of charcoal could result in the higher amounts of C_T observed in the burnt compared to the green trash returned treatment. However, over time, the results may be reversed as more of the labile C becomes protected in soil aggregates and enters the non-labile pool.

In a sugar-cane green trash management trial in Brazil, Blair et al. (1998) reported no significant change in C_T but a significant increase in the C_L concentration in the top 7.5 cm of the soil following green trash returned, compared to the trash burnt treatments. In a similar trial at Tully in northern Queensland, C_L was significantly higher in the top 1 cm of the soil under the green trash management treatment than the trash burnt treatment but there was no difference in C_T (Blair et al., 1998). However, Blair et al. (1998) found no significant differences between treatments for C_T or C_L in the 1–25 cm layer. Burning of crop residues generally results in less organic matter return to the soil. Ladd et al. (1994) showed that the return of crop residues whether incorporated, or retained on the soil surface, increased soil organic C compared to the burning of residues.

Even though green trash management returns large amounts of residues to the soil following each crop (50–60 Mg ha^{-1} of dry matter), it is difficult to increase SOM quickly, as the high rainfall and warm temperatures result in rapid breakdown of organic materials, particularly when it is of high quality. Blair et al. (1995b) suggested that in tropical climates, where mineralisation rates are potentially high, the use of rotations with plant residues of lower quality and hence slower breakdown rates had the highest potential for increasing soil C content.

4.2. Changes in C lability and CMI

The green trash management treatment increased the lability of the C compared to the burnt treatment (Table 1). Blair et al. (1998) also found an increase in the lability of the C in the 0–1 cm layer, but not in the 1–25 cm layer, as a result of green trash return at Tully, northern Queensland. The decrease in all C fractions as a result of cultivation has resulted in no change in the lability of the C between the cultivated and non-cultivated treatments (Table 1).

The CMI was designed to give an indication of the C dynamics of the system. The value itself is not important but the changes reflect how different management strategies are affecting the systems (Blair et al., 1995a). The green trash returned treatment has increased the CMI compared to the burnt treatment and there has also been a similar change as a result of no cultivation following harvest. Although there was no significant interaction between cultivation and trash management after four years, continuation of green trash management and reduced cultivation may have the potential to increase the CMI by increased inputs and lower losses. At Tully in northern Queensland Blair et al. (1998) found that there was a significant increase in the CMI in the 0–1 cm layer following green trash management but not in the 1–25 cm layer. They found a higher CMI value for the green trash treatment than for the reference site (100 by definition) in the 0–1 cm layer. However, if the measurement had been done on the 0–10 cm layer, as in the present experiment, this may not have been the case.

Carbon compounds particularly the more labile fractions provide energy for soil organisms and stimulate their activity, which contributes to nutrient release from plant and animal residues and the synthesis of humic substances that affect both soil physical and chemical fertility. Conteh et al. (1999) found a close correlation between C_L and both labile and total polysaccharides in soil which indicates that the C_L pool substantially represents microbial substrate.

Addition of organic matter to soil usually increases microbial activity which can result in improved soil structure and fertility (Hodges, 1991). The maintenance of soil C levels, particularly the more labile fractions, is important for maintaining both soil chemical and physical properties and fertility.

4.3. Aggregate stability

The decline in wet aggregate stability, as a result of cropping and cultivation, when compared to the reference soil, is similar to the findings of Tisdall and Oades (1980), Dormaar (1983), Cook et al. (1992), Cambardella and Elliot (1993), Bridge and Bell (1994) and Whitbread et al. (1998). This may be partly associated with the decrease in C_L and C_T found in the cropped soils (Tisdall and Oades, 1980). Cultivation also breaks up roots and fungal hyphae which also positively influences the stability of soil aggregates (Tisdall, 1991). The large increase in the percentage of aggregates <125 μm may cause problems with surface sealing. Loch (1994) contended that the percentage of particles of this size had the greatest influence on surface sealing of dry-land cropping soils when determined followed by wetting with simulated rainfall. Tisdall and Oades (1982) reported that the aggregates most susceptible to breakdown from agricultural practices were those >250 μm. The stability of these aggregates is also important for water flow and air entry in soils. The breakdown of the larger aggregates can lead to pore blockages through the soil, reducing infiltration and leading to an increased erosion risk. MWD and percentage of aggregates >250 μm for the reference soil was higher and the percentage of aggregates <125 μm lower, following tension wetting and sieving than for the dry aggregate size distribution (Table 2). This soil took 5 days to wet up at 0.40 kPa tension compared with 15 min for the cropped soils. This indicated that the organic matter in the reference soil was highly hydrophobic making the soil slow to wet and the soil aggregates very stable to wetting as a result of the slower entry of water into the aggregates. The soil wet under tension was very cohesive and the mechanical action of the sieving was unable to destabilise this cohesiveness, resulting in a higher stability following tension wetting than for dry sieving.

The improvement in all measurements of wet aggregate stability following green trash retention reflects the increases in the labile C fractions. In the experiment of Whitbread (1996), residue retention in a wheat cropping system at Warialda in northwest NSW also improved wet aggregate stability. Soils rely on organic C compounds for stability against rapid wetting and mechanical forces (Oades, 1984). Residue retention and the subsequent increase in organic C compounds leads to stronger aggregation in these soils. The four years of no cultivation has also improved all measures of aggregate stability. This is once again reflected by an increase in the measured C fractions. Cultivation not only decreases aggregate stability by depleting soil C (Oades, 1993) and breaking up of aggregates by roots and fungal hyphae (Tisdall, 1991), but also by the shattering of aggregates during the cultivation process (Syers and Craswell, 1995). The uncultivated soil was more friable and easier to breakdown than the cultivated soil resulting in a significant decrease in the percentage of aggregates >250 μm and an increase in the percentage of aggregates <125 μm in the uncultivated soil following determination of dry aggregate size distribution (Table 2).

5. Conclusions

This investigation shows the difficulty in increasing SOM levels facing intensive agricultural industries such as sugar-cane production, in tropical areas. Although a significant increase in C_L was evident when green trash was returned to the soil and the soil was left uncultivated after harvest, the increase did little to return the size of the soil C pools to those of the reference soil. The rapid breakdown of the large amounts of organic inputs as a result of high temperatures and high rainfall in many tropical areas makes it a slow process to rehabilitate SOM concentrations back towards the original concentrations in these environments.

However, with correct management strategies, such as green trash retention and reduced cultivation, there is a potential to achieve some degree of rehabilitation of soil C and consequently improve soil structure. This will result in increased infiltration, better soil water relations, reduced surface sealing and erosion which should lead to increased crop yields. The improvement and maintenance of soil C and soil structure is necessary for sustainable agricultural systems and protection of the soil resource.

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