Development of a Carbon-Based Sustainability Index for Ferrosols in Rainfed Cropping Systems

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Abstract

The amount of C oxidised by 33 mM $KMnO_4$ (C1) is shown to be a better predictor than total C for a range of chemical and physical properties of Ferrosol soils in the inland Burnett region of southeast Qld. Aggregate stability (measured as % aggregates <<0.125 mm after rain) was linearly related to infiltration rates of simulated rain, with variation in C1 able to account for 88% of the variation in aggregates in this size class. Effective cation exchange capacity was shown to be positively correlated with C1. The impacts of varying concentrations of C1 on pH buffer capacity, DECEC and the frequency of runoff events under different cropping systems were also investigated. The potential use of C1 as an indicator of the sustainability of various farming systems is discussed.

Keywords: Ferrosols, organic matter, sustainability index, rainfed cropping.

In their virgin condition, Ferrosols are generally regarded as fertile and well structured (4, 6). Many of the soil properties associated with these characteristics are controlled by soil organic matter, with the general decline in soil fertility of Ferrosols under a range of cropping systems often directly correlated with the extent of loss of soil organic carbon (2, 4, 6). Properties of particular concern to rainfed cropping systems in northern Australia include aggregate stability and rainfall infiltration, soil ECEC, pH buffer capacity, the ability to increase ECEC after liming and total reserves of N. While there is a general correlation between the levels of soil organic matter and most of these soil properties, there has so far been no successful identification of the labile soil organic matter pools which determine these properties.

Blair et al. (3) developed a carbon management index based on permanganate oxidisable C. This index was used to highlight differences between undeveloped and agriculturally developed sites in the lability of their soil organic matters. However, no attempt was made to relate changes in the index to changes in soil chemical and physical properties. To this extent, the management index offers no guidance as to the target levels of labile soil organic matter necessary for a desired level of soil productive capacity. Moody et al. (8) derived relation-ships between the C oxidised by different strengths of permanganate and several chemical properties of a wide range of acidic soil types, including a subset of Ferrosols. It is the aim of this paper to validate some of these relationships, and to develop relationships between C fractions and aggregate stability for the Ferrosols of the inland Burnett cropping area of south east Queensland. We then define the concentrations of permanganate oxidisable C which are associated with desirable levels of several soil properties, and compare several management systems in terms of their effects on the permanganate oxidisable C.

Materials and methods

Long term field sites have been established in the South Burnett area to examine the decline in soil fertility under continuous cropping, and to examine the role of tillage systems and pasture leys in maintaining soil productive capacity. The locations, cropping histories and soil types of these sites at Goodger and Coolabunia have been described elsewhere (1, 2, 4). Soil samples (0-10 cm) were collected from plots with varying managements at these sites during the 1996/97 summer season and analysed for various soil chemical and physical properties.

Samples for chemical analyses were oven dried (40^{o} C) and ground to <0.125 mm for C or <2 mm for other chemical analyses. Total C (TC) was determined by combustion in a Leco furnace, while the amount of C oxidised by 33 mM $KMnO_4$ (C1) was determined using the method described in (8). ECEC (sum of M NH_4Cl extractable cations and M KCl extractable acidity) and total N (micro-Kjeldahl digest) were also determined. Both pH buffer capacity (pHBC) and the increase in ECEC (_ECEC) with increase in soil pH were calculated from the equations derived by Moody et al. (8) viz.

pHBC = 2.2 - 0.037 * clay +1.799 * C1, ?and
DELTA ECEC = 0.55 + 0.021 * clay + 0.682 * C1

Aggregate stability was determined on unground, bulk samples of air-dried surface soil. Aggregates were loosely crumbled by hand, spread in trays 60 cm x 60 cm x 10 cm deep and placed under a laboratory rainfall simulator. Samples were subjected to high intensity rain (100 mm/h intensity, 29 $J/m^2/mm$) for a period of 30 min, with rainfall infiltration rates determined at the end of this period. Samples were then collected from the surface crust and analysed for aggregate size distribution using a modified Yoder wet sieving apparatus. Our data were used to explore the relationship between the proportion of aggregates <0.125 mm and rainfall infiltration rates, as proposed by Loch and Foley (5).

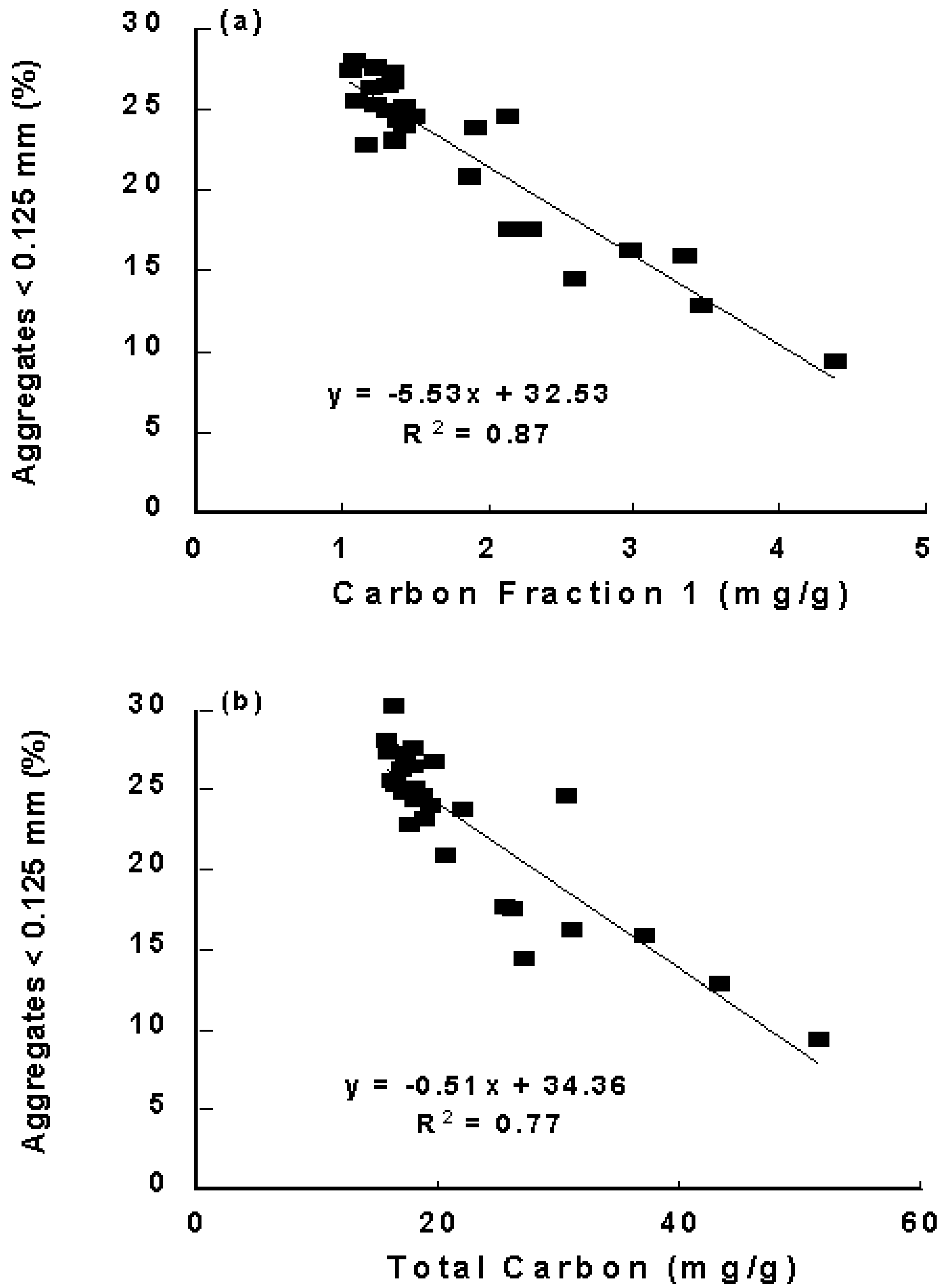
(a)
Aggregates < 0.125 mm (%)
Carbon Fraction 1 (mg/g)
y = -5.53x + 32.53
R 2 = 0.87
(b)
Aggregates < 0.125 mm (%)
Total Carbon (mg/g)
y = -0.51x + 34.36
R 2 = 0.77

Figure 1

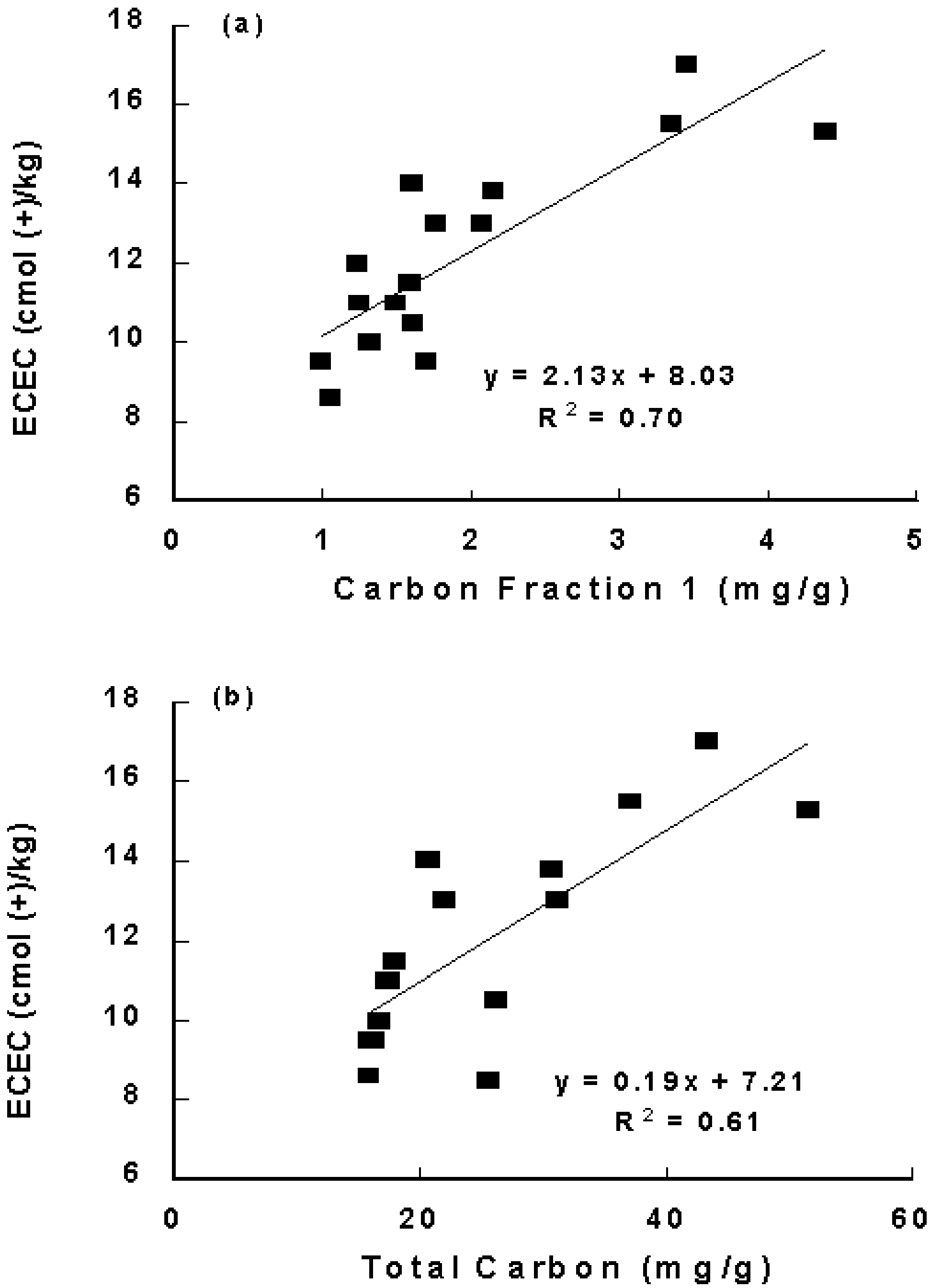

Figure 2

Results and discussion

The sites and prehistories in the data set provided a 3-fold range in both TC and C1, which corresponded to the range normally observed in developed Ferrosols (ie. excluding virgin scrub). There was also a marked clustering of soils under traditional management practices (conventional tillage, annual summer cropping) at the low end of the range in soil carbon content. Concentrations of C1 and TC were highly correlated (r = 0.95), with C1 representing 10.3% of TC.

Aggregate stability

The relationship between TC or C1 and the proportion of aggregates <0.125 mm in the soil crust after high intensity rain is shown in Fig. 1. While both measures of soil C were significantly correlated with this measure of aggregate stability, C1 accounted for a greater proportion of the variation than TC.

There was a highly significant (P100 mm/h, with most of the conventionally cropped soils in the 15-40 mm/h range.

Effective Cation Exchange Capacity

Soil ECEC was also strongly related to both TC and C1, with C1 again accounting for a greater proportion of the variation within the data set (Fig. 2). Most of the conventionally cropped soils had ECEC's of 8-12 cmol (+)/kg, with the derived relationships suggesting that the contribution from organic matter represented up to 30% of the measured ECEC.

pHBC and DELTA ECEC

The soils in this data set contained 60-65% clay. From the equations presented above, the impact of variation in the concentration of C1 on the ability of soils to resist the acidifying influence of the current cropping system [measured at 90 kg $CaCO_3$/ha/year (7)], and on the increase in ECEC per unit pH change (eg. as a result of liming) were calculated. These data clearly show advantages in maintaining a reasonable level of labile carbon, with the rate of pH change in particular being very sensitive to C1.

C1 levels for sustainable rainfed farming :

As the C1 fraction of soil organic matter was shown to be involved in determining a number of components of soil chemical and physical fertility, it was viewed as a potential indicator of the sustainability of the various cropping systems under investigation.

Water deficits are the single greatest limit to productivity in these rainfed production systems (1, 4), so the role of C1 in improving rainfall infiltration rates by prevention of surface sealing due to aggregate instability was deemed the most important indicator of sustainability of current farming systems. Using the rainfall intensity, frequency and duration statistics for a local catchment, the frequency of occurrence of 30 min rainfall events with varying intensities was determined. These data were combined with the relationship between the concentration of C1 and % aggregates <0.125 mm (Fig. 1a), and between the % aggregates <0.125 mm and infiltration rate at 30 min (data not shown), to derive a response surface describing the frequency with which runoff events would occur for varying levels of C1 (Fig. 3). For example, a C1 concentration of 1.5 mg/g would produce 24.2 % aggregates <0.125 mm during high intensity rain and an infiltration rate of 43.6 mm/h. A 30 min rainfall event exceeding that intensity falls at least once every year, so the frequency of a runoff event on such a soil is 100%. Indicative C1 levels from farms employing various management systems in the inland Burnett are also shown.

The management systems sampled produced a wide range in C1, suggesting considerable variation in the degree of sustainability of dryland cropping in those systems. However, no management system tested so far (with the exception of undisturbed pastures) consistently achieved C1 levels sufficient to substantially reduce the risk of runoff and erosion. These data show that in the absence of stubble cover, current conventional till and no-till systems are likely to experience runoff events at least on an annual basis. Pasture leys can reduce the frequency of these events (hence increasing water use efficiency and reducing soil loss), but even when combined with no-till management, runoff would still be expected to occur on a regular basis.

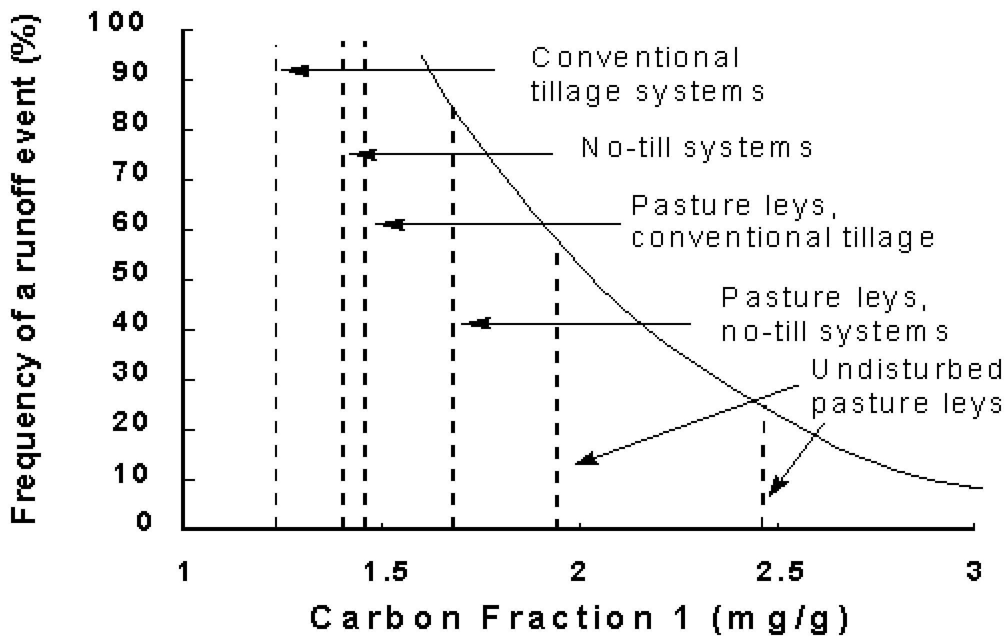

Figure 3

Conclusions

Carbon fraction 1 has been shown to be a determinant of a number of components of physical and chemical fertility in Ferrosols of the inland Burnett, and therefore has potential for application as an indicator of sustain-ability of various farming systems. The desired concentration of C1 will vary with land management due to changes in the relative importance of the various constraints to crop production. In the case of rainfed cropping systems, effects of C1 on aggregate stability and resulting rainfall infiltration were thought to be the most important determinant of continued productivity. Only no-till systems, combined with pasture leys, have produced a large enough change in C1 to markedly improve the efficiency of capture of commonly occurring, high intensity rainfall events.

Acknowledgments

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