SOIL CARBON FRACTIONS AS INDICATORS OF SUSTAINABILITY OF COTTON CROPPING SYSTEMS

By

ABDUL RAHMAN CONTEH

Bachelor of Science in Education (Chemistry) (University of Sierra Leone)

Master of Science in Agriculture (Soil Science) (University of New England)

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DECLARATION

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree or qualification.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

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ABSTRACT

The cracking clay soils on which cotton is typically grown are prone to compaction, which can lead to a reduction in soil aeration, infiltration of water, and a condition where roots are unable to penetrate the dense layer of the soil. This in turn reduces yields and farm income, and in the longer term, will result in a reduction in soil quality and land value. Increasing public and grower concern about soil and environmental quality in relation to long-term sustainable cotton production has emphasised the need to develop and implement management strategies that maintain and protect soil resources.

The development of sustainable cotton cropping systems requires the identification, monitoring and management of those soil properties whose variability significantly influence the stability and resilience of the soil resource. Since sustainability is a systems issue, the sustainability of a cropping system can be appropriately assessed through the use of indicators, which are partial indices that estimate some aspect of the broader concept. The selection of such indicators can be achieved through a step-wise approach; by identifying a set of attributes that constitute components of a sustainable cropping system, and then develop techniques for monitoring these attributes. The organic matter content of a soil is a key indicator of a sustainable cropping system because of its influence on the physical, chemical and biological health of a soil. Because organic matter in soil exists in a wide diversity of forms with considerable variability in decomposition rates, the success of any organic matter management strategy will depend to a large extent on methods that can detect and monitor short-term changes in soil organic matter quantity and quality.

The primary concern of the work described in this thesis was to examine the potential value of a simple measurement of labile and non-labile carbon fractions to provide a sensitive monitoring indicator of organic matter changes under cotton cropping systems. The labile carbon is obtained by oxidation with a 333 mM $KMnO_4$ solution and the non-labile carbon obtained as the difference between the total and labile carbon. Based on the relative contents of labile and non-labile carbon in a cropped soil and a reference soil, a carbon management index is calculated. The study commenced with a general survey of the fertility status of soils used for cotton production. The specific objectives of the survey were to examine the soil test values in the main soils used for cotton production and compare these values between cropped and reference sites. Changes in soil organic matter due to cotton production were examined using the carbon fractionation procedure based on ease of oxidation. The relationships between the carbon fractions obtained by ease of oxidation and other common measurements of soil organic matter were also examined. The carbon fractionation procedure was then used to follow soil organic matter changes under different cotton stubble management systems and cotton rotation sequences.

The results from the soil survey showed that most of the soils used for cotton production in Australia are alkaline in reaction, with a considerable variability in soil test values. The ranges observed for most soil tests indicated adequate chemical fertility in these soils, but no significant relationships were found between soil test levels and nutrient responses under glasshouse conditions. The large number of significant responses to P and S under glasshouse conditions, inspite of the adequate soil test levels, suggests the need for future field studies to examine the role of these nutrients in cotton cropping systems.

The 333 mM $KMnO_4$ carbon fractionation procedure showed that cultivation of soils has led to a decrease in the organic carbon status of the cracking clay soils used in cotton production. The effect of cultivation was more pronounced in the labile carbon (C_L) and the carbon management index (CMI) than in the total carbon (C_T) and non-labile carbon (C_{NL}). The effect of cultivation on the ratio of C_L to C_{NL} (LI) was not as clear, since both increases and decreases were observed as a result of cultivation. The role of aggregates in the protection of soil organic matter from rapid decomposition was also demonstrated. It was shown that there was a higher concentration of both C_T and C_L in the microaggregates (< 250 μm) than in the macroaggregates (> 250 μm) indicating that the rates of decomposition of both C_T and C_L were higher in the macroaggregates than in the microaggregates. However, in all the aggregate sizes, the relative losses of C_L were higher than the relative losses of C_T. These observations also support the hypothesis that the $KMnO_4$-oxidisable carbon (C_L) is a measure of labile carbon in soil and can be used for monitoring short-term changes in organic matter under different cropping systems. The CMI generally declined during cultivation, with the exception of a few soils, and since the CMI incorporates the changes taking place in C_T, C_L and C_{NL}, the use of this index can provide very useful results in the monitoring of organic matter status of soils.

Since organic carbon in soils has been determined by a wide range of procedures, the carbon fractions obtained by ease of oxidation were compared with other common measurements of soil organic carbon. It was shown that C_L determined by ease of oxidation was significantly related to fulvic acid, soil polysaccharides and soil microbial biomass carbon. From ^{13}C NMR studies, it appears that the $KMnO_4$ oxidisable carbon mostly comprised of soil carbohydrates and some unidentified aromatic compounds. The association between C_L and fulvic acid, carbohydrates and microbial biomass carbon indicates that the term labile is appropriate for $KMnO_4$ oxidisable carbon, and that the un-oxidisable C_{NL} is related to soil humin and non-labile polysaccharides. Therefore, the partitioning of soil carbon into C_L and C_{NL} as shown in this study will allow the separation of active and less active soil carbon to be used for monitoring carbon dynamics of agricultural systems.

The carbon fractions obtained by ease of oxidation were then used to monitor organic matter changes under different stubble management systems and cotton rotation sequences in the field.

The results showed that management of cotton stubble significantly affects the organic matter status of Vertisols. Incorporation of stubble increased both the total carbon concentration and the Carbon Management Index while burning reduced the Carbon Management Index. Most of the increases in soil organic matter observed in a 3-year period were due to increases in the amount of light fraction. With regards to crop rotation options, it appeared that rotating cotton with wheat is a more sustainable option with regards to long-term improvement of soil quality than continuous cotton or legumes alone. The inclusion of legumes in the rotation sequence appeared to produce mainly short-term benefits, probably as a result of their rapid decomposition rates. However, since observations were only made for a relatively short time, subsequent monitoring of the organic carbon changes was recommended for a conclusive evaluation of the role of different rotation sequences on soil organic carbon status. In general, it can be concluded that for sustainable management of soil organic matter in Vertisols under cotton production, as much of the stubble produced in the system be returned to the soil rather than removed.

Since the continuity of supply of carbon in soil depends on both the total pool size and the decomposability, the carbon management index (CMI) can be considered to be a useful indicator of sustainable cropping systems.

Publications

The following papers, arising from this research project, have been published.

Conteh, A., Blair, G. J., MacLeod, D. A., and Lefroy, R. D. B. (1997). Soil organic carbon changes in cracking clay soils under cotton production as studied by carbon fractionation. *Australian Journal of Agricultural Research* **48**, 1049 - 1058.

Conteh, A., and Blair, G. J. (1998). The distribution and relative losses of soil organic carbon fractions in aggregate size fractions from cracking clay soils (Vertisols) under cotton production. *Australian Journal of Soil Research* **36**, 257 - 271.

Conteh, A., Blair, G. J., and Rochester, I. J. (1998). Soil organic carbon fractions in a vertisol under irrigated cotton production as affected by burning and incorporating cotton stubble. *Australian Journal of Soil Research* **36**, 655 - 667

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