Estimating permanganate-oxidizable active carbon as quick indicator for assessing soil quality under different land-use system of rainfed Alfisols

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Estimating permanganate-oxidizable active carbon as quick indicator for assessing soil quality under different land-use system of rainfed Alfisols

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ABSTRACT

The labile fractions of soil carbon, often termed as active carbon pool serve as sensitive indicators of initial changes in soils due to management practices. A simplified method in which dilute, slightly alkaline $KMnO_4$ reacts with the most readily oxidizable (active) forms of soil C was used to measure the labile fraction. The present investigation was undertaken in long-term experimental plots in Alfisols soil at Hyderabad. The different land-use systems evaluated were *Leucaena* (*L. leucocephala*) plantation, sorghum (*Sorghum bicolor*)–castor (*Ricinus communis*) rotation in cultivated land, *Cenchrus ciliaris* grassland and an undisturbed bare soil as benchmark. Shaking of air-dry soil in 0.01M $KMnO_4$ solution for 5 min. and addition of 0.1 M $CaCl_2$ for enhanced settling of the soil after shaking produced consistent and management sensitive results. Significantly higher active carbon content was noticed under *Leucaena* plantation, followed by grassland, undisturbed bare soil and cultivated land and the values varied from only 2.7 to 3.4% of organic carbon. Higher infiltration rate, lower bulk density, higher water stable mean weight diameter (MWD) of soil aggregates and higher organic carbon content were recorded under plantation and grassland soil compared to the cultivated and undisturbed bare soils. The active soil C measured by this procedure was closely related to other soil properties, such as infiltration ($r^2 = 0.71$), MWD ($r^2 = 0.60$), bulk density ($r^2 = 0.76$), dehydrogenase activity ($r^2 = 0.62$), microbial biomass carbon ($r^2 = 0.66$) and organic carbon ($r^2 = 0.53$). This procedure has a scope for developing a user-friendly field kit to measure active soil carbon, which would serve as a sensitive indicator for management-induced soil quality.

Key words: Alfisol, Soil organic matter, Field kit, Labile carbon, Potassium permanganate, Soil quality indicators

Soil organic matter (SOM) and related soil properties are probably the most widely acknowledged indicators of soil quality (Katyal *et al*. 2001, Weil *et al*. 2003, Manna and Sharma 2009). Since SOM has no definite chemical composition, soil organic carbon (SOC), the dominant elemental constituent of SOM is more commonly measured material to represent SOM. Small changes in SOC resulting from changes in soil management are often difficult to measure. It may take many years for contrasting soil management practices to cause measurable differences in SOC (Sikora *et al.* 1996).

Changes in small but relatively labile fractions of SOC may provide an early indication of soil degradation or improvement in response to management practices. The labile fractions of soil C are important to study as these fractions fuel the soil food web and therefore greatly influence nutrient cycles and many biologically related soil properties. The labile fractions of soil C are often termed the active C pool, to distinguish it from the bulk of the C, which belongs to a highly recalcitrant or passive C pool that is only very slowly altered by microbial activities. It is generally accepted that labile constituents decompose within a few weeks or months, whereas their stable counterparts can persist in the soil for years or even decades. Labile SOC fractions such as particulate C, microbial biomass C (MBC), mineralizable C, carbohydrates, and enzymes are highly responsive to changes in C inputs to the soil and will provide a measurable change before any such change in total organic matter and can serve as sensitive indicators of changes in management-induced soil quality (Islam and Weil 2000). In contrast, the passive or stable (humified) pools are probably the more appropriate and representative fractions for C sequestration characterization (Cheng and Kimble 2001).

Researchers, extension workers and farmers are increasingly interested in making simple assessments of soil quality in the field to help guide management decision (Liebig

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and Doran 1999, Wander and Drinkwater 2000). Determinations of labile C fractions such as particulate organic matter, extractable carbohydrates or rapidly mineralizable C are time consuming and require complex laboratory manipulations that limit their use.

Potassium permanganate, a powerful oxidizing agent can react a portions of SOC and deep purple permanganate colour is partially bleached to light pink to clear and can be used for reagent. The decrease in the intensity of deep purple colour of potassium permanganate is proportion to the reactive C oxidized. Blair *et al.* (1995) reported that only 0.333M $KMnO_4$ concentration was needed to distinguish labile soil C (oxidized by $KMnO_4$) from recalcitrant soil C (not oxidized by $KMnO_4$). Significant correlations have been reported between 0.333M $KMnO_4$ reactive C and several soil chemical and physical properties (Blair *et al.* 1995, Moody *et al.* 1997, Bell *et al.* 1998, Blair and Crocker 2000, Whitbread *et al.* 2000). However, at this high concentration, $KMnO_4$ reacts with a large fraction of the total SOC [(14-27% of the total organic carbon (TOC) in the 13 soils describe by Blair *et al.* (1995)], rather than the just labile fractions.

The 0.333 M solution may therefore be better suited as a simple estimate of total organic C than as an estimate of the labile C fractions associated most closely with soil quality. Bell *et al.* (1998) established relationships between fractions of soil organic C oxidized by 0.033M, 0.167M and 0.333M $KMnO_4$ solutions with other soil properties and reported that the soil organic C fraction oxidized by 0.033M $KMnO_4$ was most closely correlated with aggregate stability, infiltration rates and effective cation exchange capacity. Melero *et al.* (2009) reported that active soil carbon content determined by using 0.2M $KMnO_4$ solution was one of the most sensitive and consistent indicator for assessing the impact of conservation tillage in a sandy clay loam Entisol and clay Vertisol soils in semi-arid southwest Spain. The $KMnO_4$ oxidizable C was also used to asses the impact of long-term manuring and fertilization on soil organic carbon pools and sequestration rates in a typic Haplustept soils under maize–wheat–cowpea cropping system in semi-arid sub-tropical India (Purakayastha *et al*. 2008). Verma *et al*. (2010) reported $KMnO_4$ oxidizable SOC were more sensitive and consistent as an index of labile pool of SOC compared to MBC for monitoring changes in SOC pool under different tillage and nutrient management practices in rice–wheat, soybean–wheat, maize–wheat cropping system.

The present research work was an attempt to develop a rapid, reproducible user-friendly kit for measuring labile soil carbon that would be a sensitive indicator of management-induced soil quality changes under different land use systems. The role of active fractions of soil organic matter in physical and chemical fertility and in turn on the soil quality was also evaluated.

MATERIALS AND METHODS

Soil samples were collected during 2005–06 from a micro watershed of three hectares at Hayatnagar Research Farm (17°20´ N latitude and 78°35´ E longitude and an elevation of 515 m above mean sea level) of Central Research Institute for Dryland Agriculture, Hyderabad. Farm situation represents semi-arid tropical environment with hot summers and mild winters. Mean maximum temperature during summer months (March, April and May) varied from 35.6°C to 38.6°C. Mean minimum temperature during winter months (December, January and February) ranged between 13.5 and 16.8°C, and mean annual rainfall was 746.2 mm. Soils in the experimental micro-watershed were light textured red soil representing Alfisols (Typic Haplustalf).

Four land-use systems, viz cultivated field, grassland, plantation field and undisturbed bare soil were chosen for the present study. In cultivated field, since 1993 onwards, sorghum–castor was grown for two years rotation. The primary tillage, with tractor-drawn mould board plough, followed by tractor-drawn cultivator was imposed after onset of rainfall during monsoon. Castor and sorghum were sown in later half of June. Crops were grown under rainfed condition and no irrigation was applied. In grassland, Anjan (Buffel) grass (*Cenchrus ciliaris* L.), a perennial herbage has been growing since 1991. Cutting of grass was done once in every year in September. Subabul (*Leucaena leucocephala*), a multipurpose tree was adapted in the plantation field since 1991. Initially for two years the plants were allowed to grow without any prunning. Subsequently cutting and pruning was undertaken once in every alternate year. The girth and height of subabul trees varied from 12 to 20 cm and 20 to 25 m, respectively at the time of study. A nearby bare undisturbed plot, which was not at all under cultivation and less disturbed by human activity was taken as bench mark plot. Sparse weeds were there during the study in the bare/fallow plot.

Present investigation focused on to find a concentration of $KMnO_4$ solution that would react consistently with a management sensitive labile C fraction in soils and the bleaching of permanganate colour could be detectable easily even by naked eye for field kit preparation. To do so, a series of $KMnO_4$ solution ranging from 0.005 to 0.1 M (0.1, 0.05, 0.02, 0.01 and 0.005 M) adjusted to *p*H 7.2 were tested using a set of soil samples. The resulting solution after bleaching between concentration of 0.1 and 0.02M $KMnO_4$ were too dark in colour for absorbance reading as well as to detect through naked eye as proposed for the field kit method. The concentration of 0.01M $KMnO_4$ gave consistent result and found suitable for field kit preparation. Air dried soil (5 g) was passed through 0.5 mm sieve and was taken in a 150 ml conical flask, 20ml 0.01M $KMnO_4$ solution was added to it, followed by 0.3g $CaCl_2$ (equivalent to 0.1M $CaCl_2$ in 20 ml) to increase the settling of soil. The soil-$KMnO_4$-$CaCl_2$ suspension was shaken at 200 rpm for 5 min. After shaking the suspension was centrifuged at 3000 rpm for 5 min. to separate the soil particles from the solution and filtered through glass fibre filters. The bleaching of colour of $KMnO_4$ was measured by spectrophotometer at 550 nm light setting.

The standard curve was prepared with 0.0000, 0.0001, 0.0002, 0.0004 and 0.00075M $KMnO_4$ solutions.

The bleaching of the purple $KMnO_4$ colour is proportional to the amount of oxidisable C in soil. To estimate the amount of C oxidized, it is assumed according to Blair *et al.* (1995) that 1 mol MnO_4^- is consumed (reduced from Mn^{7+} to Mn^{4+}) in the oxidation of 0.75 mol (9000 mg) of C.

The reaction is $3C + 4KMnO_4 + 2H_2O = 4KOH + 4MnO_2 + 3CO_2$

Active C (mg/kg) = [0.01mol/l – (a + b × absorbance)] × (9000 mg C/mol) ×(0.02 l solution/0.005 kg soil)

where 0.01mol/l is the initial concentration of $KMnO_4$, 'a' is the intercept and 'b' is the slope of the standard curve. The numerical value 0.005 is the amount of soil in kg on oven dry basis.

In addition to the analysis of $KMnO_4$ reactive C soils were also analyzed for soil texture, infiltration rate, bulk density (BD), mean weight diameter (MWD) of soil aggregates. Bulk density was measured by the core method (Blake and Hartge 1986). Soil texture was determined using the bouyoucos hydrometer method (Gee and Bauder 1986). Water stable aggregate size distribution was determined by wet sieving (Yoder 1936). The values were expressed as mean weight diameter (MWD) after correcting for the sand particles retained on each sieve (van Bavel 1950). This was done by dispersing the oven-dried material from each sieve using a mechanical stirrer and sodium hexa-metaphosphate dispersing agent, and then washing the material back through the same sieve. The weight of oven-dried sand retained after the second sieving was subtracted from the weight of aggregates determined after the first sieving. The infiltration study was carried out using a double ring infiltrometer. Water was ponded to a depth of about 15 cm initially in both the inner and outer rings of double ring infiltrometer until a constant rate of infiltration was achieved. It took 45 to 60 min. to reach a constant infiltration rate. The organic carbon (OC) was determined by Walkley and Black's method (Jackson 1967). Microbial biomass determinations were made using chloroform fumigation (Jenkinson and Powlson 1976, Jenkinson and Ladd 1981). The dehydrogenase assay (DHA) was measured using tri-phenyl tetrazolium chloride (TTC) (Lenhard 1956). The data sets for variables were evaluated using a one-way analysis of variance (ANOVA) and Student's t comparison of means at $P = 0.05$.

RESULTS AND DISCUSSION

Soil physical properties and organic carbon

Leucaena plantation as well as Anjan grass had a distinct advantage in maintaining soil physical properties and organic matter (Table 1). Organic carbon content in forest, grassland and bare soils was 2, 1.4 and 1.1 times, respectively than that of the cultivated field. The soil colour was also recorded as dark grey in case of plantation field, while it was reddish in other three cases. The increase in organic carbon content resulted in reduction in bulk density of forest and grassland sites. The extent of reduction in bulk density in forest, grassland and bare soils was 0.25, 0.21 and 0.08 Mg/m^3, respectively over cultivated field. Leaf litter as well as root decay increased the total pore space, which in turn decreased bulk density of soil. The organic matter accumulation improved the soil structure, which was evident from higher values of water stable MWD of aggregates in plantation field and grassland soil. Water stable MWD was highest under grassland condition, followed by forest, bare soil and cultivated field, respectively. The fibrous roots of grassland might have contributed towards granular structure and that increased the MWD of water stable aggregates. The study revealed that plantation field and grassland soils had significantly higher infiltration rate (Table 1) when compared with bare and cultivated field. Amount of water that infiltrated through plantation field and grassland soils under ponding was 3 and 1.8 times higher, respectively than that of cultivated field. Even the undisturbed fallow showed higher ponded infiltration rate when compared to cultivated field. The relatively large contribution of water flow in plantation and grassland was probably due to combination of root channels, invertebrated burrows and the structural development of soil matrix materials (Mandal *et al.* 2005).

Table 1 Characteristics of soil under different land-use systems

Parameter	Undisturbed bare soil	Cultivated field	Grassland	Plantation field	LSD ($P = 0.05$)
Soil texture	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam	
Infiltration rate (cm/hr)	6.18	5.00	8.80	15.01	1.27
Bulk density (Mg/m^3)	1.54	1.62	1.41	1.37	0.065
Water stable mean weight diameter (mm)	0.275	0.226	0.516	0.586	0.071
Dehydrogenase activity (mg/g soil /hr)	1.76	1.5	3.63	5.03	1.13
Microbial biomass carbon (mg/g soil)	192.91	196.07	300.01	419.23	32.91
Organic carbon (%)	0.684	0.625	0.889	1.25	0.061

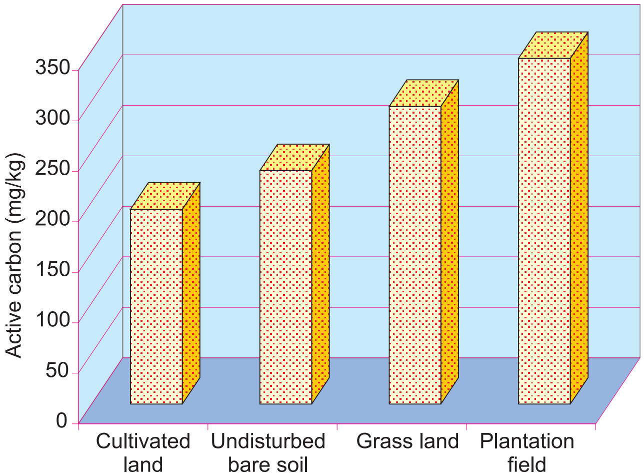


Fig 1 Permanganate oxidizable active carbon under different land-use systems

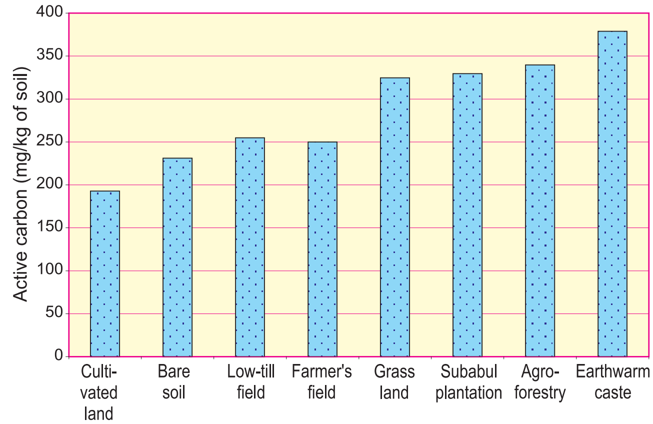


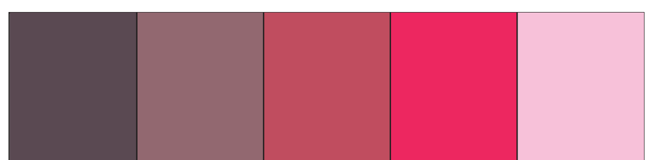
Fig 2 Labile or active carbon of soils collected under different land management

Active carbon and its relationship with other soil properties

The potassium permanganate oxidizable C (active carbon) was higher in plantation field, followed by soil in grassland, undisturbed bare soil and lowest in cultivated field (Fig 1). The active carbon contents were 2.7, 3.3, 3.4 and 3.1% of organic carbon content in case of plantation field, grass land, undisturbed bare soil and cultivated land, respectively. The one-way analysis of variance revealed that land-use systems differed significantly with regard to active C at 0.0005 level (F ratio = 19.2, P< 0.0005), where as for organic C; different land-use systems were significant at 0.024 level (F ratio = 5.54, P< 0.024). The active soil C measured by this procedure was closely related to other soil quality indicators, such as infiltration (r^2 = 0.71), MWD (r^2 = 0.60), bulk density (r^2 =0.76), dehydrogenase activity (r^2 = 0.62) Microbial biomass carbon (r^2 = 0.66), and organic carbon (r^2 = 0.53) (Table 2). The investigation revealed that active carbon by the proposed method was consistently and more closely related to other soil-quality properties than that of total OC.

Field kit preparation

The procedure has been tested with the soil samples collected from different cropping systems as well as in soil from the farmers' field (Fig 2) at Rangareddy district of Andhra Pradesh. Mandal *et al.* (2011) also used the same strength of $KMnO_4$ for analyzing labile carbon under different land use system in a watershed of semi arid tropical India and the values varied from 57 to 367 mg/kg of soil. The strength of $KMnO_4$ suitable for tropical soils having <1% organic carbon should be 0.01M. For developing field kit instead of using rotary shaker and centrifuge the experiment was carried out in test tube and the tubes were shaken vigorously for 5 min. The tubes were then allowed to stand in a rack for 5-10 min. to allow soil to settle and filtered through glass fibre filters. A colour chart (Fig 3) was developed based on the different levels of active carbon in the soils.



	<180	180-260	230-280	>280
Blank	Poor	Fair	Good	Excellent

Fig 3 Colour chart for estimating labile soil carbon (mg/kg)

Table 2 Correlation matrix for different soil quality indicators

Variable	Infiltration	MWD	BD	DHA	MBC	Active C	OC
Infiltration	1.00	0.73**	–0.78**	0.86**	0.85**	0.84**	0.90**
MWD	0.73**	1.00	–0.84**	0.86**	0.88	0.77**	0.47
BD	–0.78**	–0.84**	1.00	–0.84**	–0.81**	–0.87**	–0.54
DHA	0.86**	0.86**	–0.84**	1.00	0.91**	0.79**	0.66**
MBC	0.85**	0.88**	–0.81**	0.91**	1.00	0.81**	0.63*
Active C	0.84**	0.77**	–0.87**	0.79**	0.81**	1.00	0.73**
OC	0.90**	0.47	–0.54	0.66*	0.63*	0.73**	1.00

**P = 0.01, *P = 0.05

Higher active carbon in soil leads to more bleaching of $KMnO_4$ indicating better soil quality (Weil *et al.* 2003).

Relatively higher organic matter content in plantation field and grassland helped in improvement of soil structure, reduction in bulk density, increase in soil hydrological properties and increase in soil biological properties, than cultivated and undisturbed bare soil. The active carbon measured using potassium permanganate was closely related to other soil quality indicators. For measuring the active or labile carbon the strength of $KMnO_4$ suitable for tropical soils having <1% organic carbon should be 0.01M. This procedure has a scope of developing a user-friendly field kit to measure active soil carbon which is sensitive to management-induced soil quality.

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