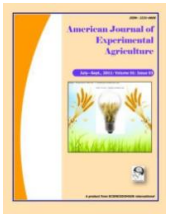

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Effect of Shelterbelt and Land Management on Soil Carbon Sequestration in Shelterbelt-pasture System at Charles Sturt University, Orange Campus New South Wales Australia

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Authors' contributions

This work was carried out in collaboration between all authors. Author AB designed the study, wrote the protocol. Authors AB and CSK wrote the first draft of the manuscript. Authors CSK and AR reviewed the experimental design and all drafts of the manuscript. Authors AB, YLO and DSH managed the analyses of the study. Authors HIN, AB and YLO performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Measurements of soil organic carbon (SOC) levels were made on soils from 0.00–0.10m and 0.10-0.20m soil depth that were collected from three 12 - years old shelterbelts integrated with pastures in new South wales, Australia to determine whether there was any effect of shelterbelts on SOC

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levels in the adjacent pasture. The samples were collected in the spring (September 2011) and autumn (March 2012) at increasing distance from the midpoint of shelterbelts. To determine the SOC level in the sample, two permanganate oxidisable methods were used: the Total Organic Carbon (TOC) and labile carbon analysis method. Regression analysis of our result indicated no significant difference (P>0.005) in SOC along the sampling points in an increasing distance from the midpoint of the shelterbelts in both seasons. However, there was a significant difference (P<0.005) in SOC level between the two depths. During autumn at 0.00-0.10m depth the TOC was higher at Weston 1 (1.386%) than College 4 and Leeds Parade site with 1.146% and 1.11% respectively. For the same depth, Weston 1 had 0.061% labile C and 0.054% labile C for both College 4 and Leeds Parade sites. This may be attributed to the topographic difference among the sites.SOC was higher during autumn sampling than spring sampling in all three sites and at both depths due to microbial activity, higher vegetation and warmer climate in autumn.

Keywords: Oxidisable permanganate; integrated pastures; carbon sequestration.

1. INTRODUCTION

The importance of organic carbon with respect to the physical, chemical and biological aspect of soil quality is well established. In addition to organic carbon being a crucial sustainability factor in temperate, as well as tropical land use. Soil organic carbon (SOC) sequestration is also an efficient pathway for mitigating agricultural CO_2 emission and even in reducing anthropogenic emission of CO_2 [1]. Labile organic carbon is a critical component of SOC because of its intimate association with soil microbial respiration and role in the decomposition of resistant soil organic matter (SOM) [2].

All agricultural soils have been altered from their natural state by human interventions which are designed to maximizing production functions and which, to some degree, result in a loss of other ecosystem functions [3]. After the natural vegetation has been cleared to establish agricultural fields, all the major soil properties that describe its health are changed, largely negatively.

The decline in soil organic matter content starts immediately after clearing and the initiation of cultivation, after a period of continuous cultivation they reach a new dynamic equilibrium [4].

There is evidence that conservation practices, well-managed pasturelands, planted forests, and agroforestry systems can considerably reduce carbon loss, maintaining SOM levels or even increasing them [5]. Since SOM has no definite chemical composition, SOC has been measured to indicate soil health [6]. Soil organic carbon stock and pools are usually highly variable on both spatial and temporal scales [7]. The presence of SOC at any location is influenced by complex interactions among plant growth, climate, soil type or parent material, topography and site management.

Attributes such as increase water–holding capacity, higher infiltration rates and higher nitrogen availability arising from increased SOC can enable farming system to be more resilient to climate change [8].

It has been reported that the average SOC in the 0.00–0.5m layer within the shelterbelt was significantly greater than in cultivated fields, and this increase was as a result of organic inputs by tree litter and deposition of wind–blown sediments accumulating beneath the shelterbelt [9].

Storing carbon in soil (soil carbon sequestration) is a key process in relation to global warming and climate change, which is believed to be caused primarily by elevated concentration of atmospheric CO_2 with other greenhouse gases. Soil carbon sequestration restores degraded soils, enhances biomass production, purifies surface and ground waters, and reduces the rate of enrichment of atmospheric CO_2 by offsetting fossil fuel emissions [10]. Every tonne of carbon sequestered in the soil is a tonne of carbon reduced from the atmosphere, so good management of soil carbon is an important tool in the reduction of greenhouse gases in the atmosphere. Soil carbon sequestration is vital in agricultural systems and it is gaining global attention because of the growing concern to reduce the rapidly increasing atmospheric CO_2. [11] Estimated the potential carbon sequestration in pasturelands and rangelands in USA and concluded that half of the sequestration was derived from changes in pasture management,

i.e. fertility management, application of manure, improved pasture species, and grazing management [11].

In Australia, pastures are important to extensive livestock industries and are vital to crop–rotation systems. Despite growing interest in the soil carbon sequestration in recent times and the importance of pastures in the mitigation of climate change, little information is available on the soil carbon–sequestration potential of pastures in New South Wales agriculture [12].

The present study examines shelterbelt and pasture management and the extent to which they can be used to sequester soil organic carbon. The objective of this study was to compare the quantity of labile carbon and total organic carbon in soils managed under long term pasture and adjacent soil under shelterbelt plantings of native species at different depths.

2. MATERIALS AND METHODS

2.1 Study Site and Experimental Design

The study was done at the Orange campus of Charles Sturt University (33º15'S; 149º07'E; 875 m above sea level (asl)) in the Central Tablelands of New South Wales. The Campus farm extends across two soil landscapes identified as North Orange and Macquarie. Soil is shallow, well-structured and well drained with clay–loam top soil texture. It ranges from red–brown silty clay loam dermosols along the mid–lower slopes to red chromosols along the upper slopes and ridges [13]. From the records of the weather station of the University Campus, the climate is characterized by cold—wet winters (2—10ºC) and mild summers (12—25ºC). Usually, rainfall occurs uniformly through the year (700—950 mm). Mean-monthly maximum temperatures in 2011 ranged from 15.1 to 18.4ºC in 2011 indicating that temperatures were warmer than the comparable 30-year average of 15.6ºC; average rainfall was 603.4 mm in 2011, nearly 90 mm more than the preceding 30-year [14].

Three shelterbelts (*Leeds Parade*, *College 4*, and *Weston 1*; hereafter referred to as Sites 1, 2, and 3, respectively), each about 100 m long and 15—25 m wide, established in 1998—2000 and situated within previously established pasture land, were used (Fig. 1). The mean above-sea elevations are 885m asl for Sites 1 and 2, and 907 m for Site 3. These sites were chosen for their similarity in being narrow, elongated shelterbelts with a northerly—southerly orientation, receiving the same easterly downwind, in which the sampling transects were constructed.

The principal purpose of establishing these shelterbelts with a mixture of seedlings of Australian native trees was to capitalize on the advantages the shelterbelts provide when occurring in a pasture ecosystem of perennial-pasture taxa. Populations of *Poaceae* and Fabaceaewere the principal species in the pasture. Population of *Boraginaceae*occurred in fewer numbers than the previously listed taxa of *Poaceae* and *Fabaceae*. Shelterbelt taxa include; *Myrtaceae, Mimosaceae, Casuarinaceae*, *Myrtaceae* and large native shrubs. Major tree and grass species found at the study site are listed in Table 1 to show the flora at the study sites.

Table 1. Types of trees and grass species at the study sites

Study site	Tree species	Grass species
Leeds Parade	*Eucalyptus blakelyi, Eucalyptus macrorrhyncha, Eucalyptus viminalis, Acaciaimplexa, Acaciavestita, Casuarina cunninghamiana, Callistemon sieberi.*	*Phalaris aquatic, Trifolium subterraneum, Vulpia bromoides*,
College 4	*Eucalyptus blakelyi, Eucalyptus melliodora, Eucalyptus pauciflora, Acacia dealbata, Acacia vestita, Callistemon sieberi*	*Lolium rigidum, Holcus lanatus, Trifolium repens, Echium plantagineum*
Weston 1	*Eucalyptus blakelyi, Eucalyptus macrorrhyncha, Acacia dealbata, Acacia implexa, Casuarina cunninghamiana, Leptospermum myrtifolium*	*Phalaris aquatic, Lolium rigidum, Lolium perenne, Hordeum glaucum*

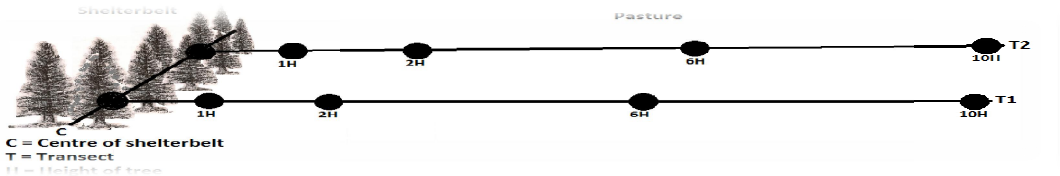

Fig. 1. Layout for soil sampling in each shelterbelt-pasture system (Not to scale)

Due to minor differences at the times of planting, the mean-tree heights of plants at Sites 1, 2, and 3 varied from 4.6 to 6.4 m. Therefore, average tree heights at each site were used as a pertinent measure to determine the distances for various sampling points to extract soil samples at two different depths. Tree heights were determined by obtaining average clinometric readings for randomly selected 15 trees, following the procedure described by [15].

Two parallel-running transects (T_1, T_2) situated at 90^o to the midline of the shelterbelt, separated by a distance of 30 m, were constructed at Sites 1, 2, and 3. Five sampling points, named Zero, 1H, 2H, 6H and 10H, starting from the midline of each shelterbelt were used (Fig. 1). The mean tree height at Site 1 was 4.6 m; that at Site 2 was 6.4 m, and that at Site 3 was 5.6 m; the sampling points — the distance variables — 1H, 2H, 6H and 10H, were calculated based on mean tree heights. Two of the five sampling points (zero and 1H) fell within the shelterbelt vegetated area; the remaining sampling points fell within the adjacent pasture (Fig. 1). A maximum of the equivalent of 10 tree heights was chosen as the most-distant sampling point, following [16].

2.2 Soil Sampling and Soil Organic Carbon and Total Organic Carbon Analysis

Sixty samples were collected(0.00–0.10 m and 0.10–0.20 m depth in each sampling point, 5 sampling points in each transect, two transects in each sites) in September, 2011 for spring sampling another sixty samples in March, 2012 for autumn sampling from three shelterbelt-pasture sampling sites. The vegetation and litter fall were removed from the sampling points and the soil samples were taken at 0.00-0.10m and 0.10-0.20m depth using a soil auger of 0.10m diameter. The soil samples were put in paper bags and labelled. The soil samples were crushed and rock and plant materials were removed before drying at 40ºC for 24 hr. in a desiccator. Additional soil sampling was done at every sampling point with soil cylinder to obtain intact soil core for bulk density measurements.

To measure different fractions of SOC: labile carbon and TOC in shelterbelt-pasture system at Charles Sturts University paddock in Orange Campus, the $KMnO_4$ oxidation methods of [6] and [17] were followed respectively. These methods have been found to effectively measure different fractions of soil organic carbon [6].

Following method of [6], 5g ofdried sieved soil was placed in screw–capped centrifuge tubes and 20.0 mL of 0.02 M $KMnO_4$ solution was added into each centrifuge tube. The tubes were shaken on a mechanical shaker for 2 min at 200 rpm. The tubes were then centrifuged (Avanti® J–E, Beckman Coulter Inc., USA) at 704.34 G for 5 min to separate soil particles from the solution. The clear supernatant (0.20 mL) was transferred to conical flasks and diluted with 10.0 mL deionized water. Absorbance was read at 550 nm using a UV–VIS spectrophotometer (Lambda 35 UV/VIS Spectrometer, Perkin Elmer Inc., USA) and absorbance readings were compared with a standard curve and the result carbon (mg/g) were reported as air–dried basis percentage carbon.

To measure the TOC, the method of [17] was followed. Two g of the sieved soil mentioned above was placed in a tube and 10 mL of 0.333 M $KMnO_4$ solution was added. The tubes were then shaken on a mechanical orbital shaker for 24 h at 12 rpm to be able to oxidize all TOC with $KMnO_4$. The content was then transferred to centrifuge tube and the polycarbonate tubes were washed with 10 mL of deionized water to minimize loss of materials. The tubes were centrifuged at 312 G for 5 min to separate the soil particles from the solution. After centrifuging, the clear supernatant of 0.2 mL was diluted with 25 mL deionized water and absorbance was read in the same UV–VIS spectrophotometer at 565nm. The absorbance readings were compared with standard curves and the quantity of carbon were converted to air dry basis percentage carbon.

2.3 Calculation of Carbon Percentage

The concentration of carbon in soil sample was calculated from the concentration $KMnO_4$ lost in the reaction base on the assumption that each 1.0 mM of MnO_4^- consumed 0.75 mM of carbon (or 9.008 mg of C) by reducing Mn^{7+}derived from $KMnO_4$ to Mn^{2+} [18] Therefore the concentration of labile carbon in soil sample for [6] method was calculated by the following formula:

C_{labile} (mg/g) $=\frac{(M_0-M_1)\times 20\times 9}{5}$, then C_{labile} (%) $=\frac{(M_0-M_1)\times 20\times 9}{5\times 10}$…….. (Equation 1)

Where:

M_0 = initial concentration of $KMnO_4$ (0.02)
M_1 = concentration of $KMnO_4$ after oxidation with carbon in the soil sample.
5 = dry weight of soil sample 20 and 9, are constants derived from the equation

Then the concentration of TOC in [6] method was calculated by the following equation:

TOC (mg/g) $=\frac{(M_0-M_1)\times 10\times 9}{2}$, then TOC (%) = $\frac{(M_0-M_1)\times 10\times 9}{2\times 10}$……..(equation 2)

M_0 = initial concentration of KMnO4 (0.333)
M_1 =concentration of $KMnO_4$ after oxidation with carbon in the soil sample.
2 = dry weight of soil

The mass of carbon (Mg ha^{-1}) was calculated following [19].

3. RESULTS AND DISCUSSION

Regression analysis for percentage of labile C and TOC were carried out using GenStat for Windows [20] for both spring and autumn samplings. For spring sampling, the TOC% showed no significant difference ($p>0.005$) between shelterbelt and pasture sampling points along transacts at 0.00-0.10m depth for all three sites (Leeds Parade, College 4 and Weston 1). Similarly, there was no significant difference ($p>0.005$) of TOC% along the transect for all sampling sites at the 0.10-0.20m depth. The TOC % ranged from 0.8% to 1.5% at 0.00-0.10m depth and from 0.2% to 1.3% at 0.10-0.20m depth with the mean of 1.1%, 1.1% and 1.4% at 0.00-0.10m depth and of 0.9%, 0.4% and 1.2% at 0.10-0.20m depth for Leeds Parade, Collage 4 [21]. The tree density at Leeds Parade shelterbelt was 20 plants per 250 m^{-2} and and Weston 1 respectively (Table 2). However, there was a slight increase of TOC% at 0.10-0.20m depth from shelterbelt to pasture (see Fig. 2).

The percentage of labile carbon showed similar trend as in TOC in spring sampling. There was no significant difference ($p>0.005$) of labile carbon percentage along the transect from the shelterbelt to pasture at 0.00-0.10m depth which varies from 0.05% to 0.06%. Moreover, there was no significant difference ($p>0.005$) of percentage labile carbon at 0.10-0.20m depth along transect from shelterbelt to pasture paddock which ranged from 0.03% to 0.06% (see Table 2). However, there were significant differences between both TOC% and labile C%, and sites ($p<0.001$), depth ($p<0.001$) and site-depth interaction ($p<0.001$) were also significant.

The seasonal difference between the mean value of TOC% and labile C%, indicates that the TOC% in autumn was higher than that of spring (see Fig. 2 and Fig. 3) and particularly Collage 4 site showed significantly lower TOC% in spring (mean 0.43%) than that of autumn (mean 0.97%) (Table 2).

From our result and analysis provided, it is clear that the TOC and labile C% did not change significantly along transects and hance the shelterbelt did not have significant effect on the mass of carbon in the adjacent pasture paddock. According to [21], the age and type of shelterbelt tree significantly affect the change in soil carbon down to 0.3m depth. The changes in soil C was found to be declining (-3.25%) under 7 years old trees, while 4.37% increased under 26 years old trees at 0.00-0.10cm depth. For 0.10-0.20cm depth, the change in carbon was 0.24% increased with 7 years old trees and 11.39% increased with 30 years old trees from around 100 observations [21]. Therefore, it is obvious that the trees in the shelterbelt under investigation were still young (10 years) to have effect on the mass of carbon sequestration in the shelter belts and pasture paddocks.

The effect of tree species is also an important factor to consider. For trees under 10years old, there was only a little change (0.23%) in soil carbon under eucalyptus compared to hard wood (4.67%) such as poplar (*Populous angustifolia*) and mahogany (*Swietenia mahagoni*) and decreased (2.39%) under pine (*Pinus radiate*) dominated by eucalyptus (50%) with larger canopy coverage, tree density at Collage 4 was 9

plants per 250 m^{-2} with pure eucalyptus (100%), and Weston 1 with 14 plants per 250 m^{-2} and dominated by acacia (70%) with understory shrubs. In addition to the shelterbelt species, the topography of the sites was also different: The mean above-sea elevations are 885 m (asl) for Sites 1 and 2, and 907 m for Site 3. Furthermore, the shelterbelts at Leeds Parade and Collage 4 are located down the hill, the transect therefore move towards the top of the hill unlike that of Weston 1 wherein the shelterbelt is located on top of the hill, and the transects moves down the hill.

From Table 3, it is clear that TOC ($Mgha^{-1}$) is higher at the 0.00-0.10 m depth than 0.10-0.20 m depth. Furthermore, at the 0.00-0.20 m depth, more TOC is recorded for the autumn sampling than the spring sampling for both Leeds parade and College 4 however, Weston 1 recorded a higher TOC in spring than autumn.

The shelterbelt species and topography might contribute to the significant difference of TOC% and labile C% at the three sites of the shelterbelt and pasture paddocks. The finding of [22] is consistent with our result due to the fact that the values of TOC in autumn were higher than that of spring when measured in a pasture. The result of lower carbon in 0.10–0.20m depth is consistent with the finding reported by [23] in New Zealand that 43.3 Mg ha^{-1} at 0.00–0.10m depth and 31.7 Mg ha^{-1} at 0.10–0.20m depth under pasture. From Table 3, the mean TOC at 0.00-0.10m depth for autumn sampling at college 4 transect 2 is 17.7 Mg ha^{-1} and the mean TOC at 0.10-0.20m depth is 14.9 Mg ha^{-1}.

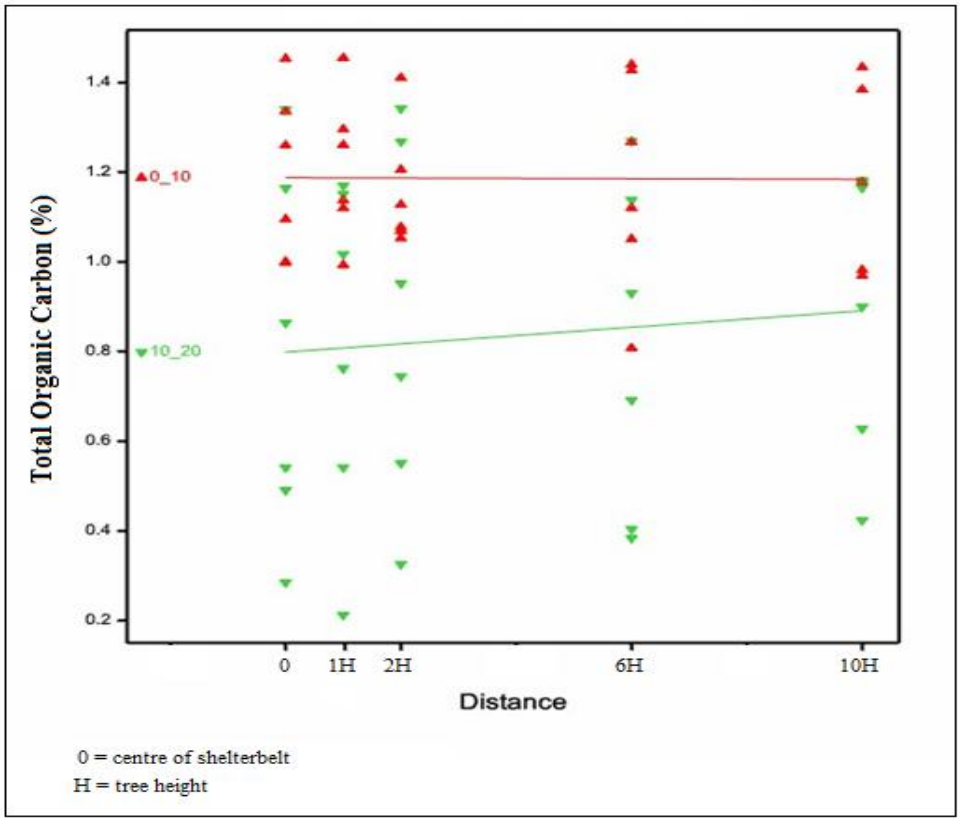

Fig. 2. GenStat output of fitted and observed relationship for TOC. (Spring sampling 2011)

Table 2. The mean and standard deviation of TOC% and labile C% for spring and autumn sampling

Site	TOC %				labile C %			
	Spring		Autumn		Spring		Autumn	
	0.00-0.10 m	0.10-0.20 m	0.00-0.10 m	0.10-0.20 m	0.00-0.10 m	0.10-0.20 m	0.00-0.10 m	0.10-0.20 m
Leeds Parade	1.083±0.062*	0.853±0.192	1.111±0.057	0.908±0.048	0.052±0.005	0.036±0.005	0.054±0.005	0.046±0.012
Collage 4	1.091±0.154	0.430±0.133	1.146±0.071	0.968±0.119	0.051±0.005	0.038±0.006	0.054±0.005	0.043±0.005
Weston 1	1.384±0.079	1.219±0.078	1.386±0.056	1.209±0.103	0.049±0.005	0.051±0.006	0.061±0.013	0.054±0.005

**Denote ± standard deviation*

Table 3. Mean and Standard deviation of TOC (Mgha^{-1}) for spring and autumn sampling period

Sampling period	Site	Transect	TOC (Mgha^{-1})		
			0.00–0.10 m	0.10–0.20 m	0.00–0.20 m
Spring 2011	Leeds	1	16.6±1.31*	13.92±2.94	30.52±3.84
	Parade	2	15.36±1.94	11.84±2.87	27.2±4.18
	College 4	1	20.6±1.64	6.32±3.13	26.92±4.08
		2	19.8±1.34	7.37±0.91	27.17±2.06
	Weston 1	1	20.7±2.25	17.6±1.81	38.3±3.91
		2	21.51±1.97	19.56±1.54	41.07±2.51
Autumn 2012	Leeds	1	16.01±2.13	12.63±0.99	28.64±3.09
	Parade	2	17.7±0.79	14.9±0.89	32.6±1.68
	College 4	1	16.85±1.22	14.49±2.19	31.34±3.23
		2	18.0±0.39	14.94±1.03	32.94±1.16
	Weston 1	1	18.52±3.18	16.04±3.34	34.56±6.47
		2	19.12±2.21	16.87±2.48	35.99±4.62

**Denote ± standard deviation*

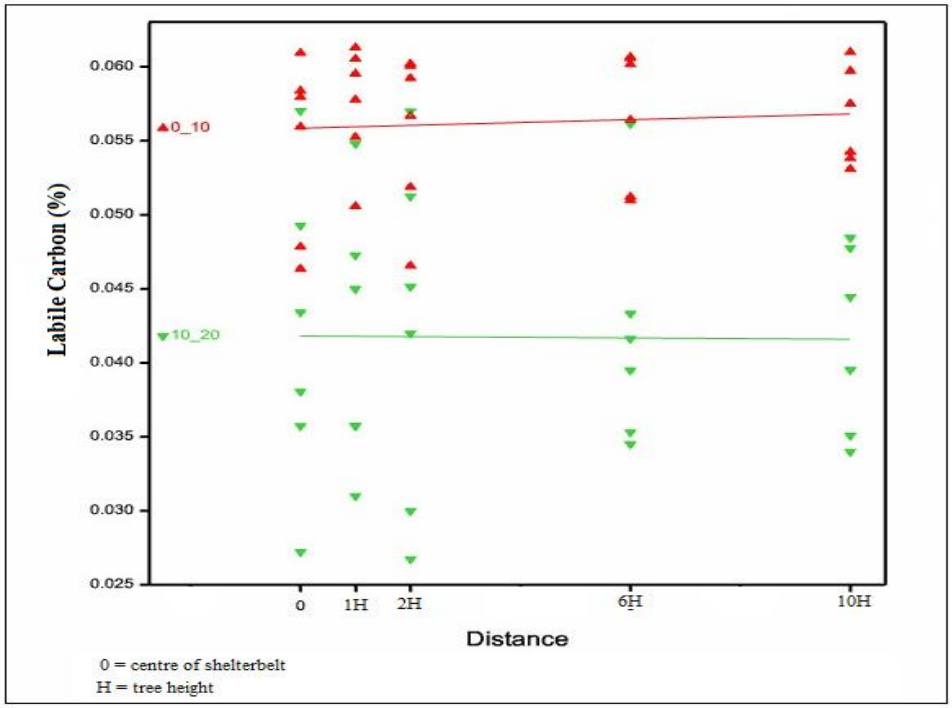

Fig. 3. GenStat output of fitted and observed relationship for labile carbon. (Spring 2011 sampling)

4. CONCLUSION

The TOC and labile-carbon has not changed significantly among sampling points along the transect as we move from the shelterbelt into the pasture paddock. However, both fractions of carbon decreased with depth. This is as result of the fact that SOC levels are dynamic and generally decline with depth because most sources of organic matter from which it is derived are either on the surface or near the surface of the soil and because plant roots are less dense as they grow deeper into the soil. Moreover, there was significant difference between sampling sites- Weston 1 site showed higher level of carbon than Leeds Parade and Collage 4. This may be attributed to topographic difference among the sites. The transect at Weston 1 moves down the slope while those for the other two sites move up the slope. In addition the proportion of carbon was higher in autumn sampling than spring sampling, which reflect the higher vegetation, microbial activity and warmer climate in autumn.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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