DEVELOPING A SOIL SAMPLING PROTOCOL FOR THE OKLAHOMA CARBON PROGRAM

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DEVELOPING A SOIL SAMPLING PROTOCOL FOR THE OKLAHOMA CARBON PROGRAM

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Abstract:

Developing strategies to reduce carbon emission and/or sequester carbon at minimum cost is critical to the goal of mitigating climate change. The Kyoto protocol has opened doors for carbon markets to trade carbon emissions reductions and sequestration, though carbon markets came into existence a few years before the Kyoto protocol was ratified. Several schemes are emerging around the world to promote carbon markets. Oklahoma carbon program is one such initiative designed to establish carbon markets in Oklahoma. Currently, the program is focusing on carbon sequestration through conservation practices on agricultural soils. Agricultural soils can act as potential sinks for atmospheric carbon, but high spatial variation makes it difficult to monitor organic carbon mass (OCM) sequestered in the soil. Thus, methodologies are required to monitor change in OCM precisely. The present study focuses on three studies conducted in order to develop a soil sampling protocol to monitor carbon credits raised by farmers in their fields under no-till or grassland management systems: 1) to select a probe feasible for soil sampling in terms of cost and handling, 2) to evaluate the fixed depth and fixed mass method to remove any difference in OCM as calculated using three different probes, 3) to determine organic carbon mass and variation in different textured soils and to evaluate the role of organic carbon concentration and bulk density in organic carbon mass as well as in variation.

Findings and Conclusions:
The small diameter push probe tends to compress the soils and give higher bulk density measurements as compared to large diameter probes. A push probe appears to be feasible in terms of handling and cost to monitor carbon sequestration provided the OCM is calculated using fixed mass method. Sandy soils have minimum organic carbon mass and maximum variation as compared to loams, clayey and silty textured soils. Bulk density does not differ significantly among different textured soils. Standard deviation in bulk density explains appreciable variation in the OCM.

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CHAPTER I

LITERATURE REVIEW

Abstract:

Global climate change has raised concerns about elevated carbon dioxide concentrations in the atmosphere. Besides the industrial revolution and fuel combustion, deforestation and cultivation had an active role in increasing atmospheric carbon dioxide concentration. Tillage triggers the decomposition of soil organic matter by improving the conditions for microbes to decompose soil organic matter. However, the process of carbon loss from soils can be reversed by converting cropland to no-till croplands or grassland management. So, soil can act as both sink and source of carbon. This is why agricultural soils have been seen as potential sink of atmospheric carbon in Kyoto protocol. The Kyoto protocol has opened doors for carbon markets for carbon trading, though carbon markets came into existence a few years before the protocol was ratified. Several schemes have come up around the world to promote carbon markets. Oklahoma Carbon Program is one such initiative to establish carbon markets in Oklahoma for farmers. Spatial and temporal variation in organic carbon stocks creates difficulty in monitoring organic carbon stocks in the soil. Also, variation in the monitoring may arise from the sampling and analyzing methods. The present study focuses on developing a soil sampling methodology to monitor carbon credits incurred by farmers in their fields under no-till or grassland management systems. These studies concentrate on the variation in bulk density measurement in the soil samples as collected with different soil sampling probes, and evaluation of the fixed mass method to reduce this difference in carbon stock calculation among the probes. Further the study focuses on the variation in organic carbon mass in different textured soils.

Introduction:

Soil Organic Carbon and Global Climate Change

The increased temperature of the planet has raised scientists' concern over the expected drastic changes in the global climate. The main cause of increased temperature is the imbalance created by the anthropogenic transfer of carbon from terrestrial reservoirs to carbon in the form of carbon dioxide in the atmosphere which has taken place during last two centuries (IPCC, 2001). Carbon is distributed in five inter-related global carbon pools: Oceanic, Geologic, Pedologic, Atmospheric and Biotic. Table 1 gives the distribution of carbon in these five pools (Lal 2004a). The atmospheric concentration of carbon dioxide in 1750 was 280ppmv (Lal 2004a), which has become about 390 ppm in 2010(Moomaw, 2011).

Table 1: Different pools and carbon amount in them

Pool	Carbon Amount (Pg)
Oceanic Pool	38000
Geologic Pool	5000
Pedologic Pool	2500
Atmospheric Pool	760
Biotic Pool	560

Source: Lal 2004

Industrialization and burning of fossil fuel has been regarded as the major causes of the abrupt increase in CO_2 concentration in the atmosphere. Indeed, Industrialization and fossil fuel combustion have been the largest source of C contributed to the atmosphere since 1950, although land use change and soil cultivation emitted more carbon into the atmosphere than fossil fuel combustion prior to 1950 (Lal, 2004a). Analysis conducted by Ruddiman (2003) suggests a hypothesis that the increase in anthropogenic CO_2 began

8000 years BP (Before present), due to deforestation in Eurasian region by human beings. There is an estimated loss of 320 Pg carbon at a rate of 0.04 Pg/year lost during 7800 year period before the industrial era which is twice the amount released in the industrial era (which started in 1800 AD) which is 160 Pg carbon at the rate of 0.8 Pg/year (Rudiman 2003). The pre-industrial emissions were reported to be the result of deforestation and other forms of land transfer to agricultural production which occurred at a slow rate but for a much longer time compared to rapid land use change occurring in the industrial era. Houghton (1999), used the rate of land use change data to calculate net release of 124 Pg carbon due to land use change from nine potential emission regions across the globe (these regions are located in Asia, North America, Latin America and Europe) using a model. He reported a total 373 Pg of Carbon was released to the atmosphere due to landuse change during 1850-1990, including a contribution of 73 Pg from soil due to cultivation. However, 249 Pg of this release was recovered, out of which soil recovered 38 Pg of carbon due to abandonment of the cultivated lands, which restored the soil carbon content. The remaining carbon was assimilated into biomass on these abandoned lands. Additionally, 90% of the net release is from deforestation, 68% of which was for expansion of cultivated land. The rest of the net release was due to cultivation of grasslands.

Soil can act as a sink for atmospheric carbon. The role of soil as a source or sink depends on the input and output of carbon. The principle input of carbon to soils is above and below ground plant biomass (Prentice, 2001). The outputs are decomposition and erosion. Plants capture atmospheric carbon dioxide (270 Pg of carbon/year) by diffusion in leaf water through tiny holes on the leaf surface called stomata however most of the carbon dioxide escapes to the atmosphere without participating in the photosynthesis. In fact, 120 Pg of carbon is converted to carbohydrates through photosynthesis globally each year. This represents the gross primary productivity (of vegetation) of the earth. Almost half of this carbon is returned to the atmosphere through plant respiration. The difference between plant respiration and photosynthesis is referred to as net primary productivity (NPP) which assimilates approximately 60 Pg carbon in to the global biotic pool of carbon annually (Prentice 2001). In a steady state system the NPP is decomposed and released to the atmosphere. Deviations from steady state can result in CO_2 emission or sequestration.

Sequestration of carbon can occur when a previously disturbed terrestrial system is allowed to revert back to natural succession. Allowing a cultivated field to revert back to a forest or grassland provides an example in which carbon sequestration can occur until the system again reaches equilibrium. As previously mentioned, disturbances such as deforestation or the conversion of grasslands to cultivated crop production have released organic carbon from the soil system. Soil management that reverses this emission of CO_2 can result in a net sequestration of carbon in the form of soil organic matter.

The soil carbon pool of the planet is 3.3 and 4.5 times the size of the atmospheric and biotic pools respectively, with 2500 Pg carbon found in the soil (1550 Pg soil organic carbon(SOC) and 950 Pg soil inorganic carbon (SIC))(Lal 2004b). This suggests that relatively small changes in the pool of carbon found in soils could have a significant impact on the atmospheric carbon pool. Also, recall estimates that 73 Pg of carbon have been lost from soils through land use change. Again, suggesting that soil could play a significant role as a sink for atmospheric carbon with the reversal of this loss.

Additionally, estimates suggest that 103.2 Mg of organic carbon have been lost from Oklahoma soils since settlement (Oklahoma Conservation Commission, 2003). The findings of this report also suggest that reversal of this loss through conversion of cropland to no-till management and permanent grass could allow for sequestration of organic carbon.

Removal of native vegetation from and tillage of soils results in rapid loss of soil organic carbon. Tillage improves aeration, which enhances the microbial activity, mixes the plant residue in the soil and thus increases the respiration rate. Tillage makes soil prone to erosion and exposes the adsorbed organic matter to decomposition. The conversion of native vegetation to cropland decreases the input of organic matter to the soil system (Schlesinger and Andrew 2000). In contrast to conventional tillage, no till management can accumulate organic matter in the soil, improves soil quality, reduce erosion, and enhance water quality (Lal 2004a). Crop residues left on the soil surface hinder water loss from a no-till field (Reicosky 1999). Besides sequestering carbon in soil, no-till also decreases the emissions of carbon due to energy usage in the conventional tillage. The energy used for crop production in the form of fossil fuel for tillage, seed production, herbicides, insecticides, fungicides and fertilizer production, their packaging and transportation, and irrigation is generally higher for conventional tillage systems. Therefore, no-till emits less net carbon into the atmosphere than conventional tillage and reduced till. However this reduction depends on the crops, site and region. For example, a no till corn crop emits net carbon to the atmosphere that is nearly equal to emission when conventional tillage is used. In contrast, soybean and wheat emit less carbon under no till as compared to conventional tillage (West and Marland, 2001).

On the other hand, continuous removal of nutrients in the form of harvested grain or forage will result in depletion of essential nutrients from the soil such and N, P and K. Mining of these nutrients without fertilization will decrease productivity of the soil which reduces the input of organic matter in the form of crop residues. Data presented by Girma et al (2007) showed that the soil in a check treatment, receiving no fertilizer for 100 years after conversion from native grass to cultivated wheat in the U.S. Southern Plains, contained 1.17 % organic matter while the treatment receiving N, P and K fertilizer applications contained 1.58% organic matter. These differences in soil organic matter occurred while yields in the check treatment were approximately half that produced by the fertilized treatment for the last 70 years of the study.

Through implementation of conservation management, the soils in the world have a capacity to sequester 42-78 Pg of the atmospheric carbon (Lal 2004b). Therefore, soil has been seen as a potential sink of atmospheric carbon in the Kyoto protocol (UNFCCC 1998), with a vision that the maximum amount of the carbon should be sequestered with minimum investment such that it has both societal and economic benefits (UNFCCC 1998).

No till cropland management provides for the opportunity to sequester carbon while continuing to produce grain crops. Kimble (2007) reported the benefits of no-till that farmers from various regions incur are due to decreased labor, fuel, and machinery maintenance cost for tillage. However, these benefits can be offset by herbicide use in some no-till systems. Additional, no-till can improve yields; however, this affect is dependent on climatic and soil conditions. Some dry areas may observe increases in yields due to improved soil moisture conditions, but some wet areas may observe decreases in the yield or no difference in the yield with no-till. The most evident and certain benefit of no till is the reduced erosion, which reduces deposition of sediments in surface water resources thus reducing the cost of cleaning the water bodies. Lastly, farmers can realize secondary benefits by selling the carbon credits created through sequestration of carbon in soils by adopting no-till or planting grass in previously cultivated cropland. This vision led to the creation of agricultural carbon trading markets.

Carbon Trading:

Recognizing the danger of global warming, the United Nations Conference on Environment and Development created the United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janerio 1992. One of its aims was to "recognize the steps required to understand and address climate change which are environmentally, socially and economically most effective and based on relevant scientific, technical and economic considerations and continually re-evaluated in the light of new findings in these areas" (UNFCCC 1992). The focus is on reducing greenhouse gas emission and increasing their sequestration, especially CO_2; in order to decrease their atmospheric concentration in the future. Further, in 1997 during the third Conference of the parties (Nations participating in the UNFCCC) in Kyoto, Japan the Kyoto protocol was established (yu Ping and QinZehenman 2010). "The Kyoto protocol constitutes the first legally binding international environmental agreement that builds on market based instruments to determine cost-efficient methods for the greenhouse gas abatement" (Bohringer, 2003). Although, carbon trading was discussed about in the Kyoto protocol, it was not ratified until 2005. The first carbon market was established in Europe in 2002

(Johnson and Russell, 2004) which is currently the largest carbon trading scheme in the world (Perdan and Azapagic, 2011). Chemical and oil companies were the main participants in these markets. The use of soils as a sink for CO_2 to reduce greenhouse gas concentrations in the atmosphere was not recognized in these markets. Now, there are several emission trading schemes operating in different parts of the world with only one objective: to reduce net greenhouse gas emissions to the atmosphere at the lowest possible cost. Examples include the European Union Emissions Trading System, Regional greenhouse Gas Initiative, Tokyo Metropolitan Trading Scheme, and California's Cap and Trade Program (Perdan and Azapagic, 2011).

The United States has not ratified the Kyoto Protocol, thus cannot participate in the carbon markets set under Kyoto protocol treaty; however, under the protocol the US emission reduction target was 0.6 Pg below the projected level by 2010. U.S. croplands could have contributed in reducing 7% of projected increase of CO2 emission of the world and 30% of the emissions in the United States (Sandor and Skees, 1999). However, the US emissions of greenhouse gases increased by 10.5% from 1990 to 2010 (USEPA 2012). The Regional Greenhouse Gas Initiative (RGGI), the first emission trading scheme in the US was established in 2005 with a goal of reducing emissions by 10% within the period of 2009-2018. Ten North-eastern States of the US participated in the initiative including Connecticut, Delaware, New Jersey, New York, Maine, Maryland, Massachusetts, New Hampshire, Rhode Island and Vermont. The RGGI mainly covers the power sector with a limited scope in agriculture. Currently, the RGGI includes carbon sequestration through afforestation and CH_4 emissions reductions from agricultural manure.

The United States has already seen success in the reduction of SO_2 emissions through a cap and trade program (Sandor and Skees, 1999). Sulfur dioxide concentrations in the atmosphere were reduced by decreasing its emissions (Sandor and Skees, 1999). In contrast, both a reduction in the emission of CO_2 and its sequestration are required to decrease its concentration in the atmosphere (Sandor and Skees, 1999). Therefore, most trading programs allow for carbon credits to be generated by avoidance mechanisms as well as through sequestration.

Oklahoma Carbon Program:

Oklahoma Carbon Sequestration Enhancement Act was enacted in 2003, which created the Oklahoma Carbon program. The Oklahoma Carbon program is the first voluntary program to be run by a state agency with statutory authority to verify carbon offsets. The program encourages people to take part in improvement of the State's environment by adopting conservation practices such as no-till cultivation. The Oklahoma carbon program includes the major sectors forming the State's economic backbone i.e. agriculture (30 million acres), Forestland (9 million acres), Natural gas (more than a trillion cubic feet) and oil production (more than 83000 wells), thus, making Oklahoma a hotspot for carbon sequestration and a carbon market (Oklahoma Conservation Commission, 2012,).

The program includes buyers, state approved aggregators, verifiers and producers. The aggregators are the middle men between producer and the buyer; they hold contracts with the producers to adopt carbon sequestration practices such as no-till for a specified time period. The cropland producers generate carbon credits by sequestering carbon in the soil after adoption of no-till or the planting of perennial grass. The buyer will buy the carbon amount fixed in the soil after sequestration at a set market price. The soil carbon sequestration protocol currently used by the Oklahoma carbon program is a process/practice based protocol. Therefore, producers currently agree to follow specific requirements for no-till management. Verifiers simply conduct on farm visits to verify that management is in compliance with the carbon contracts. This increases certainty regarding management compliance, however many buyers want more certainty regarding the rate of sequestration. Specifically, a sampling protocol is needed by which aggregated acres can be sampled such that the average sequestration rate can be measured. Such a protocol must allow for hand collection of samples and provide carbon density values per unit of aggregated area that are independent of the type of probe used to collect the soil sample. The variability in carbon density will influence the number of samples required to measure significant sequestration of organic carbon. Therefore efforts are needed to assess factors that influence sample variability.

Variation in Carbon Analysis:

For trading purposes the accurate measure of the carbon content in the soil is very important. But soil organic carbon varies both spatially and temporally. Spatially, soil organic carbon variation takes place on small (cm-m), medium (m-km) and large scale (>km) (Vandenbygaart 2005). This variation makes it difficult to monitor soil carbon sequestration.

Since, the amount of organic carbon in the soil is determined by the rate of its addition and decomposition in the soil system, which further depends on the climate, physical and biological factors; different factors come into play at different scales. Tillage, mode of input and soil bioturbation affects variation at small scale. Landform, landscape soil moisture, erosion and redistribution affect variation at medium scale, and interaction of climate, vegetation and soil type affects the variability of soil organic carbon at large scale (VandenBygaart 2005). Further, variation can arise due to errors occurring during measurement of variables such as soil moisture, bulk density, and carbon concentration. Also, different persons taking samples from the same field with same technique at different times can give erroneous measurement of change in soil properties (Kulmatiski 2003). Variation in soil is not only due to spatial heterogeneity or errors during analysis for a single variable, but can also be due to relative interactions of the errors in various variables which can lead to further propagation of error (Goidts et al., 2009; and Post et al, 2001). Even different methods used to determine the soil organic carbon SOC concentration of a soil give different levels of error. For example the coefficient of variation for carbon determined by the loss-on-ignition method range from 1.2- 15.8%, for Walkley and Black method it ranges from 1.6 to 4.2% and for the dry combustion method it ranges from 1.3 to 7.1% (Goidts et al., 2009)

Merry and Spouncer (1988) analyzed three sets of soils using dry combustion. The authors analyzed soils in duplicate with varying number of duplicates. They observed a CV of 7.1% in soils having a minimum mean C concentration of 0.478 % and 30 duplicates. The smallest CV was observed in soils with a medium C concentration when analyzed 189 duplicates. The variation in the analyses depended on the weight of the sample taken for combustion (Merry and Spouncer, 1988). They observed the interaction of sample weight, furnace temperature and carbon concentration for four different soils with contrasting carbon content. The range of sample weight was 0.25 – 2gm and temperature from 500-1200^o C. The low sample weights resulted in high CV's because of inadequacy in obtaining a uniform subsample. The high sample weights had higher CV due to saturation of the detector in high carbon content (Merry and Spouncer, 1988). Further, authors report removal of total carbon from a sample at 1000^{o}C or more. A large sample (= 0.5 gm) is suitable for a soil having low organic carbon concentration and small sample (= 0.1 gm) should be taken for soils having high organic carbon concentration (7 % and above); however the coefficient of variation increased in both cases (Carr, 1973). The suitable weight for majority of the soils is 0.2-0.3gm (Carr, 1973). Sutherland (1998), made carbon determinations using dry combustion of 1356 samples divided into 6 grain size classes (<0.063mm, 0.063-0.13mm, 0.13-0.25mm, 0.25-0.50mm, 0.50-1.00mm, 1.00-2.00mm) and found CV for organic carbon ranging from 0.9 to 2.8%, where the minimum CV of 0.9% was observed for the <0.063mm class and maximum CV of 2.8% was observed for the 0.25-0.50mm class. Kalembasa and Jenkinson (1973) obtained a CV of 1.32% from their analysis of 22 soils using a LECO induction furnace. Soon and Abboud (1991) determined a CV of 4.9% through quadruplicated analysis using dry combustion of eight soils with the organic carbon concentrations that ranged for 10.8-70.1 mg/g.

The form of organic matter found in soils can influence variation in the measure of organic carbon. Organic matter in the soil can be broadly classified into two fractions: light and heavy. The light fraction (also particulate organic matter) is easily decomposable and possesses greater variation. The heavy fraction is clay/silt sized and is resistant to decomposition, such that the turnover requires decades (Post et al, 2001).

Janzen et al (1992) in their study on light fraction on three different sites in Canada observed the amount of light fraction was affected by fallow period, crop rotations, crop type, climatic conditions and fertilizer application. They observed that the light fraction decreased during fallow periods but increased in continuous cropping system, fertilizer enhanced the productivity of the system and therefore the amount of light fraction added to the soil and climatic conditions favorable for microbial activities reduced the light fraction.

Variation in Bulk Density Analysis:

Intergovernmental Panel on Climate Change has set guidelines to measure the soil organic carbon in C mass per unit area, also called the spatial coordinate system/fixed depth method. The method requires measurement of bulk density, which is difficult due to its dynamic nature (Wilson et al, 2011). In this approach the surface of the soil is assumed to be fixed, but the soil surface elevation changes due to erosion, deposition of the material, drainage of wetlands, swelling and compaction (Gifford and Roderick, 2003). High bulk density measurements lead to high C mass and vice versa (Ellert et al, 2002). Further, variation in bulk density and depth of sampling gives variation in the measurement of the soil organic carbon (Goidts et al, 2009).

Ellert and Bettany (1995) proposed a fixed mass approach to measure the carbon mass in the soil. In this method the mass of the soil is fixed instead of using a fixed depth. Ellert et al. (2002) applied coal dust (3.64 Mg C ha-1) on small plots to evaluate carbon recovery. In addition, a check plot was also studied which received no coal dust. Samples were taken at initial time (before addition of coal) and subsequent time (after addition of coal). Carbon stocks were quantified for each plot using fixed depth and fixed mass methods and recovery of coal dust carbon was determined by difference between samples collected prior to and after coal application as well as by comparing the stocks found in the check plot to that of the treated plot after application. The authors found that the fixed mass approach recovered 91 to 106 % of the applied coal when the difference between the pre-application and post application was used to assess carbon differences. In contrast, the fixed depth approach recovered 62 to 84 % of the carbon applied to the treated plots. These ranges in recovery varied with depth/mass of soil used for comparison. Additionally, when check plots were compared to treated plots, carbon stocks were not significantly (α=0.10) different at cumulative depths greater than 30 cm or cumulative masses greater than 4500 Mg ha^{-1}, indicating that while the fixed mass method can improve recovery it does not fully overcome the impact of spatial variability in small plot research that causes difficulty in using differences among treatments to estimate carbon sequestration.

Sixty percent of Oklahoma soils contain more than 35% montmorillonite clay, thus are prone to shrink and swelling. Wilson et al (2011), studied the variation in bulk density of a silt loam soil at different moisture levels. Wilson et al (2011) took samples three times in 18 days up to a depth of 90cm. During the first sampling, soil was in the driest condition, wettest on second and at intermediate moisture during the third sampling. No significant difference in mean bulk density was observed in the surface 30cm. But the bulk density was lower in driest condition as compared to wet conditions. This change in the bulk density gave significant difference in the measurement of total carbon mass, when there should be minimal or negligible change in the carbon mass during such short time. However, equivalent mass method gave no significant change in the total mass of carbon.

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CHAPTER II

Assessment of Soil Sampling Methods for Carbon Credit Monitoring

Abstract:

Soil sampling equipment and calculation methods are crucial for measuring soil properties such as soil organic carbon mass. This study observed the impact of different soil sampling probes on bulk density (BD) and consequently on soil organic carbon mass (OCM) as calculated with fixed depth and fixed mass methods. Three probes were tested in this study; push probe (PP), slide hammer probe (SH) and hydraulic probe (HP) with cutting edge diameter of 2.26cm, 4.8cm and 3.98cm respectively. 19 fields were sampled across western Oklahoma. Twenty soil samples (ten with HP, five with PP and five with SH) were taken within a randomly selected 3m radius circle in each field. Samples were taken up to 30 cm depth and divided in three segments 0-10 cm, 10-20 cm and 20-30 cm. The soil sample was weighed and then a subsample was used to determine soil moisture gravimetrically and both these parameters were used to determine BD. Samples were dried in oven at 65 ^{o}C and then ground to pass through 2 mm sieve. Total carbon concentration (TCC) was determined through dry combustion, pH was measured using 1:1 soil to water ratio and samples with pH higher than 7.2 were analyzed for inorganic carbon (IC) using the Pressure-Calcimeter method. Inorganic carbon (IC) was subtracted from TCC in order to obtain organic carbon concentration (OCC). Bulk density (BD) as

measured with PP was significantly higher than BD measured with SH and HP at the surface 0-10cm layer. Organic carbon mass (OCM) in 0-30cm depth for PP as calculated using the fixed depth method was significantly higher than OCM with SH and HP. In the fixed mass method OCM was calculated in fixed mass of ~3690 Mg ha^{-1}. The fixed mass method eliminated the difference of the OCM among the probes.

Introduction:

Increased temperature of the planet associated with elevated CO_2 levels in the atmosphere has raised scientists' concern over the potential changes in the global climate. The atmospheric concentration of carbon dioxide in 1750 was 280 ppmv (Lal 2004a), which has become about 390 ppm in 2010 (Moomaw, 2011). Industrialization and fossil fuel combustion have been the largest source of carbon (C) contributed to the atmosphere since 1950, but land use change and soil cultivation emitted more carbon into the atmosphere than fossil fuel combustion prior to 1950 (Lal, 2004a). Removal of native vegetation from and tillage of soils results in rapid loss of soil organic carbon. The conversion of native vegetation to cropland decreases the input of organic matter to the soil system (Schlesinger and Andrew 2000). Estimates from Ruddiman (2003) suggests emission of 320 Pg C into the atmosphere due to land use change and cultivation during the 7800 year period before industrialization which started in 1800 and emitted 160 Pg C during last two centuries. Houghton (1999) on the other hand reported a total release of 373 Pg C in atmosphere in which soil cultivation contributed 73 Pg C, However, net 249 Pg C was recovered by forests after afforestation and abandonment of cultivated land, Thus, soil can also act as a sink for atmospheric carbon.

The role of soil as a source or sink depends on the input and output of carbon, where plant residue is the principle input and its decomposition is the major output. Tillage improves conditions favoring decomposition and in contrast no-till accumulates organic matter, improves soil quality, reduces erosion and enhances water quality (Lal, 2004). Thus, soils have been seen as a potential sink for atmospheric carbon in the Kyoto protocol. This concept that soils can serve as a sink for atmospheric carbon has led to efforts to create carbon markets that pay land managers to alter management to sequester CO_2. The first carbon market was established in Europe in 2002 even before ratification of Kyoto protocol (Johnson and Russell, 2004) which was reported as the largest carbon trading scheme in the world by Perdan and Azapagic (2011). However, it did not recognize soils as sink for CO_2 due to lack of methods to monitor changes in soil OCM accurately.

For trading purposes accurate measure of the carbon content in the soil is very important. But soil organic carbon varies both spatially and temporally, which makes it difficult to monitor soil organic carbon sequestration. Spatially, soil organic carbon variation takes place on small (cm-m), medium (m-km) and large scale (>km) (Vandenbygaart 2005). Further, accumulation and decomposition of soil organic carbon depend on the climate, physical and biological factors; different factors come into play at different scales. Tillage, mode of input and soil bioturbation affects variation at small scale. Landform, landscape soil moisture, erosion and redistribution affect variation at medium scale, and interaction of climate, vegetation and soil affects the variability of soil organic carbon at large scale (VandenBygaart 2005). Further, variation can arise due to errors occurring during measurement of variables such as soil moisture, bulk density, and carbon concentration (Kulmatiski, 2003).

The Intergovernmental Panel on Climate Change has set guidelines to measure the soil organic carbon using a spatial coordinate system or fixed depth method. Fixed depth eliminates the variability due to depth, thus leaving bulk density and soil organic carbon as main sources of variation.

Four variables are required to measure soil organic carbon indirectly i.e. organic carbon concentration, bulk density, percentage of fragments >2mm and thickness of the soil layer (Panda et al 2007, Goidts et al 2009, Akala and Lal 2001). Soil organic carbon is calculated by the fixed depth method with the following expression (Akala and Lal, 2001):

$$SOC\ (Mgha^{-1}) = [\%OC \times\ \rho_b(Mgm^{-3}) \times d(m) \times 10^4 m^2 ha^{-1}]/100$$

Where SOC is the soil organic carbon in Mg ha^{-1}, %OC is the organic carbon concentration, d is the thickness of the layer (meters) in which SOC is to be calculated. Rock mass can also be included in the above equation if soil contains rock fragments.

The method requires measurement of bulk density, which is difficult due to its dynamic nature (Wilson et al, 2011). In this approach the surface of the soil is assumed to be fixed. However, the soil surface elevation changes due to erosion, deposition of the material, drainage of wetlands, swelling and compaction (Gifford and Roderick, 2003). Akala and Lal (2001) reported that time and depth has significant effect on bulk density. Authors in their study on reclamation of mineland soils by pasture forest plantation, found reduction in bulk density with time due to root system development which loosened the soil, reduced anthropogenic activity, improved soil structure and increased porosity. Additionally, Goidts et al (2009) reported that bulk density has highest influence on the variability of soil organic carbon in cropland as well as grassland.

Ellert and Bettany (1995) proposed a fixed mass approach to measure the carbon mass in the soil. In this method the mass of the soil is fixed instead of using a fixed depth. Ellert et al. (2002) applied coal dust (3.64 Mg C ha^{-1}) on small plots to evaluate carbon recovery. Carbon stock measurements or recovery can be improved by using fixed mass method, but it does not overcome spatial variability. Wilson et al (2011) reported significant changes in soil organic carbon mass using fixed depth method in just 18 days due to changes in bulk density. However, the fixed mass method resulted in no significant change in the soil organic carbon mass during this period of time. Although, the fixed mass method reduces error due to the dynamic temporal nature of bulk density; bulk density is still required to measure the soil mass.

One of the challenges in developing sampling protocols to monitor soil carbon sequestration in fields under contract for carbon credits is variability resulting from measurements in bulk density. As mentioned, measured soil bulk density can change as a result of many processes. In addition, the measured bulk density may be influenced by the type of soil probe used to collect samples.

Therefore one objective of this study was to determine the impact of probe type on measured bulk density, organic carbon concentrations, and organic carbon mass in cropland soils of the U.S. Southern Plains. A secondary objective was to evaluate the utility of the fixed mass method in reducing variability in measured organic carbon mass.

Materials and Methods:

Three probe types were used in this study. The first was a tractor mounted hydraulic probe (HP) (diameter 3.98 cm) the hydraulic probe used in this study was a Giddings #25-TS Model HDGSRTS. The second probe is referred to as the push/hand probe (PP) (diameter 2.67 cm). This probe is commercially available from AMS Inc. as the 1 1/4" x24" plated replaceable tip soil recovery probe. This push probe can be fitted with a hammer head cross handle allowing for sample collection during dry conditions. The third sampler evaluated is referred to as the slide hammer probe (SH) (diameter 4.8cm). This sampler is also commercially available from AMS Inc. as the 2" x 12" soil core sampler. These samplers were selected because they include solid recovery tubes that will prevent contamination as the core is extracted. They also allow sampling to 30 cm.

Nineteen fields participating in Oklahoma Carbon Program were sampled. These fields were located in four Oklahoma counties (Major, Garfield, Washita, and Caddo). The fields were cropland with wheat as the main crop. A wide range of soil types were included in this study. Legal descriptions of each field and management information were obtained from the Oklahoma Conservation Commission. Each field was assigned an alphabetic character for unique identification. Field boundaries were drawn in ArcMap 10 and the random point generator in the ArcToolbox was used to generate sample points within each field.

A 3 m radius circle was marked around each random point and samples were taken in that circle. In these fields, 10 cores were collected using the hydraulic probe, and 5 cores each were collected with the push probe and slide hammer probe.

Cores were extracted to a depth of 30 cm and cut into 0-10, 10-20, 20-30 cm segments. The segments were packed in zip lock plastic bags and placed in an ice chest until transported and stored in a refrigerator at 4 °C. Zip lock bags with wet soil were weighed and a subsample (~20 g) was weighed into a weighing tin. This subsample soil was dried at 110 °C for 24 hours and then weighed to determined moisture content. The soil remaining in the zip lock bag was transferred to a paper bag and allowed to dry a 65 °C for one week and then ground and sieved through a 2 mm sieve. Moisture content was used to determine dry soil mass in the zip lock bag and further to determine bulk density. The sieved soil was analyzed for total carbon using the dry combustion method (Kalembasa and Jenkinson, 1973) in a Leco CN analyzer after weighing 0.2400-0.2500 g into a tin foil cup. Inorganic carbon was determined using a Pressure Calcimeter (Sherrod et al., 2002) for samples with pH greater than 7.2. Soil pH was determined on a 1:1, soil:deionized H_2O mixture after a 30 min equilibration period.

The organic carbon concentration of samples was calculated as the difference between the total carbon and inorganic carbon. The organic carbon mass (OCM) in each depth was determined by multiplying the concentration by the bulk density.

The following method of Gifford and Roderick (2003) using linear interpolation to allow for variation with depth in both the mass fraction of C and bulk density was used to calculate the organic carbon mass on an equivalent mass basis. Specifically, The total length of the core was represented by z_b and the surface subsection is represented by z_a with the cumulative dry soil masses to the respective depths denoted by $m_s(z_b)$ and $m_s(z_a)$ and the cumulative mass of soil C, $c_s(z_b)$ and $c_s(z_a)$. The target or 'standard' cumulative mass of dry soil is denoted by $m_s(t)$ and the corresponding cumulative mass of soil C that we are looking for is denoted as $c_s(t)$. Through linear interpolation, the resulting equation is

$$c_s(t) = c_s(z_a) + \frac{c_s(z_b) - c_s(z_a)}{m_s(z_b) - m_s(z_a)} \left(m_s(t) - m_s(z_a)\right)$$

Soil mass up to 30 cm depth for each core was calculated. Minimum soil mass among the cores was selected as fixed mass which was ~3690 Mg ha^{-1}. This fixed mass was compared to soil mass up to 20 cm depth of every other core, to make sure fixed mass is greater than 0-20 cm soil mass of all the other cores. So soil mass of 0-20 cm depth of every other core is subtracted from fixed mass. The resulting number is the required mass in 20-30 cm depth for achieving fixed mass in each core. For example, in a field first core gives ~3690 Mg ha^{-1} (fixed mass) soil and second core in the same field gives 4130 Mg ha^{-1} soil mass in 30 cm depth. We want to fix soil mass of second core to 3690 Mg ha^{-1}. So knowing that soil mass of the second core 20 cm depth is 2696 Mg ha^{-1}. This 0-20 cm of the core will be subtracted from fixed mass value which gives required mass of 994 Mg ha^{-1} soil mass. Adding 2696 Mg ha^{-1} and 994 Mg ha^{-1} gives fixed mass for the second core. Organic carbon mass was calculated in soil mass of 0-10 cm, 10-20 cm and in required soil mass of 20-30 cm layer using organic carbon concentration in each layer, respectively.

Sample points were considered replicates and the probe type was the treatment. The mean bulk density, organic carbon concentration, and organic carbon mass was calculated for each sample point and probe at each depth. The mean organic carbon mass for the cumulative depth of 30cm and cumulative mass of ~ 3690 Mg/ha was also calculated for each sample point and probe. The coefficients of variation around these means was then determined.

All the three probes were treated as treatments and fields as replications. So, Randomized complete block analyses of variance were performed using the SAS PROC GLM procedure (SAS Institute, 2001) to determine significant treatment effects on the analyzed variables and the average coefficient of variation for those variables. Fisher's protected LSD was used to separate significant differences.

Results and Discussion:

Table 1 shows the impact of probe type on the bulk density measurements. The average bulk density as measured with PP was significantly higher than HP and SH in the surface 10 cm. The probable reason for higher bulk density at surface 10 cm for PP would be the compaction caused by its small cutting edge diameter (2.26 cm), such that the cross sectional area of the PP's sample is less than half of the SH (4.8cm) and HP (3.98cm). The granular structure in the surface layer with low bulk density tends to be compressed easily. There was no significant difference among the average bulk density readings of all three probes at 10-20 cm and 20-30 cm depth.

Further, the average coefficient of variation (CV) in bulk density for each probe was not significantly different for the 0-10, and 20-30 cm soil layers. However, the average CV for PP was significantly higher than the SH at 10-20 cm depth, but not different from the HP.

Table 2 shows that the average organic carbon concentration was not significantly different among the three probes at any depth. The average CV for organic carbon concentration at 0-10 cm depth for HP was significantly higher than average CV for PP. However, the CVs were not significantly different among the probes at the remaining depths.

Despite the differences in bulk density in the 0-10 cm depth, there was no significant difference in the OCM among probe types at this depth or the lower depths. Also, there was no difference in the average CV of organic carbon mass among probe types. This indicates that the probes could be used interchangeably to determine carbon mass on a fixed depth basis. However, inspection of the data shows that the PP estimated 9.97 Mg OC ha^{-1} compared to 9.19 and 9.21 Mg ha^{-1} for the SH and HP in the 0-10 cm depth (averaged across all fields). The difference between the PP and remaining probes is approximately 0.77 Mg OC ha^{-1}, respectively. Although not statistically significant this difference is larger than the current estimated carbon sequestration rates(0.14-0.4 Mg OC ha^{-1}year^{-1}) used to calculate carbon credits for management of cropland in the area (OCC 2011). Therefore this difference is practically important and effort should be made to minimize it. This error might be reduced, if the initial carbon value was also determined using PP or if the error due to compression of the PP core can be removed from the analysis.

Table 3 shows that the cumulative OCM measured in the 0-30 cm depth with the PP is significantly higher than the OCM calculated with HP to a fixed depth. This shows that the elevated bulk densities (Table 1) of the PP at surface 10 cm resulted in significantly higher average total OCM. No significant difference was observed in the average %CV for each probe.

Table 3 also shows the average OCM measured to a fixed mass of 3690 Mg ha^{-1} using three different probes in all 19 fields. There was no significant difference in average OCM calculated from different probes. However, the coefficient of variation for the PP is significantly lower (Table 3) than the coefficient of variation of the SH and HP. This result is in agreement with the study of Wuest (2009). Wuest (2009) used square sampling probes of different cutting edge cross-sectional area for taking samples in tilled and compacted soils for water content measurement. Using fixed depth method both equipment gave different results, but use of equivalent mass eliminated the difference, although equipment effect on bulk density was not reported.

Wilson et al (2011), studied the variation in bulk density of a silt loam soil at different moisture levels. Wilson et al (2011) took samples three times in 18 days up to a depth of 90cm. During the first sampling, soil was in the driest condition, wettest on second and at intermediate moisture during the third sampling. No significant difference in mean bulk density was observed in the surface 30cm. But the bulk density was lower in driest condition as compared to wet conditions. This change in the bulk density gave significant difference in the measurement of total carbon mass, when there should be a negligible change in the carbon mass during such a short time. However, equivalent mass method gave no significant change in the total mass of carbon. This is consistent with the findings of the current study in that differences in measured organic carbon density resulting from differences in bulk density can be corrected regardless of the cause of the changes in bulk density. There are different ways of using fixed mass method. For example, Ellert et al. (2002) compared fixed depth and equivalent mass method of measuring carbon on none and coal (serving as carbon sequestered) amended plots. The equivalent mass method recovered 91-106% of applied coal as compared to 62-84% when the fixed depth method was used. They chose value of equivalent mass for each layer arbitrarily and authors reported that whatever value of equivalent mass is chosen does not have any effect on recovery of organic carbon.

On the other hand, Lee et al. (2009) adjusted the bulk density based on an assumption that tillage would consistently decrease the bulk density compared to a no-till system. They compared changes in soil carbon mass using adjusted bulk density under these systems with equivalent mass of each layer adjusted to minimum, maximum and original soil mass. Authors reported greater accuracy when using minimum soil mass where the bulk density increases such as in no-till and where the direction of change in bulk density is not known. The maximum mass was suitable for sites where bulk density was decreasing and original mass accurately known.

As described in the materials and method section in our study we have adjusted the soil mass of all cores to minimum cumulative mass found among the cores/samples. Thus, there can be different ways of using equivalent/fixed soil mass method. However, both studies presented above and our study resulted in a reduction of error or uncertainties in calculation of OCM due to uncertainty in bulk density measurements.

Summary:

This study shows that small diameter soil sampling probes can compress the surface layers of the soil, thus giving higher bulk density measurements. Difference in bulk density can impact soil organic carbon stocks when calculated with fixed depth methods. The fixed mass method eliminates the differences in carbon stocks due to difference in sampling probes. This is crucial where bulk density is involved in calculation of soil properties especially for monitoring temporal changes in soil organic carbon stocks since data collection may be conducted by different people and with different tools at different times.   Removal of difference in carbon stocks due to bulk density error by fixed mass enables the use of inexpensive push probe in places where tractor mounted hydraulic probe cannot be used or where funding restricts its use.

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Table 1: Measurement of average bulk densities at various depths (0-10, 10-20 and 20-30cm) in 19 fields, with all three probes with their percent coefficient of variation (% CV)

Depth	Probe Type†	Bulk Density	%CV
cm		g cm^{-3}	
0-10			
	PP	1.46a†	7.92a‡
	SH	1.32b	7.73a
	HP	1.33b	7.82a
10-20			
	PP	1.51a	7.00a
	SH	1.55a	4.77b
	HP	1.53a	6.09ab
20-30			
	PP	1.56a	6.51a
	SH	1.56a	5.33a
	HP	1.53b	5.18a

†PP, Push probe with cutting edge diameter of 2.26cm; SH, Slide Hammer probe with cutting edge diameter of 4.8cm; HP, Hydraulic probe with cutting edge diameter of 3.98cm.

‡Values within each depth with different lower case letters are significantly ($p<0.05$) different

Table 2: Average of organic carbon(OC) concentration and its coefficient of variation (%), and organic carbon mass (OCM) and its coefficient of variation (%) 0-10,10-20 and 20-30cm depth of samples taken from all 19 fields as measured with all the three probes using fixed depth method.

Depth	Probe†	OC	Avg %CV of OC	OCM	Avg %CV of OCM
cm		g kg^{-1}		Mg ha^{-1}	
0-10					
	PP	6.96a	13.07a	9.97a	13.24a
	SH	7.08a	15.11ab	9.19a	16.44a
	HP	6.96a	17.31b	9.21a	16.68a
10-20					
	PP	5.29a	14.94a	7.88a	16.75a
	SH	5.21a	12.32a	7.96a	13.54a
	HP	5.15a	14.94a	7.76a	16.81a
20-30					
	PP	5.17a	20.23a	7.81a	21.35a
	SH	5.14a	15.17a	7.88a	16.05a
	HP	5.01a	17.02a	7.48a	17.69a

†PP, Push probe with cutting edge diameter of 2.26cm; SH, Slide Hammer probe with cutting edge diameter of 4.8cm; HP, Hydraulic probe with cutting edge diameter of 3.98cm.

‡Values within each depth with different lower case letters are significantly ($p<0.05$) different

In parenthesis is the lsd value for corresponding variable and depth

Table 3: Average Organic Carbon Mass (OCM) as measured in 19 fields, with three different probes in using fixed depth and fixed mass methods

	Probe†	Average OCM	%CV
		Mg ha^{-1}	
Fixed Depth			
	PP	25.66a	8.90a
	SH	25.04ab	10.21a
	HP	24.46b	10.71a
Fixed Mass			
	PP	21.76a	8.44a
	SH	21.57a	9.80ab
	HP	21.29a	11.04b

†PP, Push probe with cutting edge diameter of 2.26cm; SH, Slide Hammer probe with cutting edge diameter of 4.8cm; HP, Hydraulic probe with cutting edge diameter of 3.98cm.

‡Values within each depth with different lower case letters are significantly ($p<0.05$) different

CHAPTER III

Evaluation of Variation in Organic Carbon Mass

Abstract:

Spatial variation is an obstacle to precise measurement of soil organic carbon mass (OCM) accurately. There are many factors which contribute to spatial variation in the OCM. This study focused on OCM and its variation in different textured soils as calculated using fixed mass and fixed depth methods. Influence of organic carbon concentration (OCC) and bulk density (BD) and their standard deviation (SD) on OCM and its SD was examined using regression analysis. Soil samples were collected from 47 fields across western Oklahoma. Ten soil samples were taken within a randomly selected 3m radius circle in each field using hydraulic probe having cutting edge diameter of 3.98cm. Samples were taken up to 30cm depth and divided in to 0-10, 10-20 and 20-30cm segments. Whole soil sample was weighed and soil moisture as measured gravimetrically to determine BD. Samples were dried in oven at 65 ^{o}C and then ground to pass through 2mm sieve. Total carbon concentration (TCC) was determined through dry combustion pH of each sample was measured using 1:1 soil to water ratio and samples with pH higher than 7.2 were analyzed for inorganic carbon (IC) using Pressure-Calcimeter method. Sandy soils had least OCM and OCC but highest coefficient of variation (CV) regardless of the calculating method. OCM was highly correlated with

OCC for both calculating methods. SD of BD explained 70% of the variability in the OCM when calculated with fixed mass method. Average BD and SD for OCC were not related to OCM.

Introduction:

Spatial variation is an obstacle to precise measurement of soil properties, especially for measuring soil organic carbon stocks for trading purposes. Soil organic carbon varies both spatially and temporally. Spatially soil organic carbon variation occurs on small (cm-m), medium (m-km) and large scale (>km) (Vandenbygaart 2005). Since, the amount of organic carbon in the soil is determined by the rate of its addition (from vegetation) and decomposition in the soil system, which further depends on the climate, physical and biological factors; different factors come into play at different scales. Tillage, mode of input and soil bioturbation affects variation at small scale. Landform, landscape soil moisture, erosion and redistribution affect variation at medium scale. Interaction of climate, vegetation and soil affects the variability of soil organic carbon at large scale (VandenBygaart 2005). Different sampling approaches are used to minimize this spatial variation, particularly by dividing soil into soil mapping units of similar properties to achieve maximum uniformity in the soil organic carbon data, which further affects final organic carbon stock determination (Chappell and Rossel, 2013). However, Chappell and Rossel (2013) showed that the variation across the field is more significant than variation in the similar sol type.

High variation in organic carbon density in space and low temporal variation makes it difficult to assess changes in soil organic carbon stocks with time (Post et al, 2001).

Burke et al (1989) reported that soil organic carbon decreases with increasing mean annual temperature. In addition, they reported increase in precipitation up to 80 cm increased plant productivity and consequently added to SOM. However, beyond 80 cm precipitation also contributed to decomposition of SOM (Burke et al, 1989). Soil texture had secondary effect, which affects water availability to plants and microbes for productivity and decomposition, respectively (Burke et al, 1989).

The organic matter in the soil can be broadly categorized into two major pools: active and passive (Burke et al, 1989). Active consists of light fraction organic matter (density < 1.8g/ml) that is free from mineral matter and particulate organic matter (size > .053mm) (Gossing and Parsons, 2013). Light fraction and particulate organic matter can be distinguished by method of their extraction from soils. The particulate organic matter is obtained by size fractionation and light fraction is obtained by density as the light fraction (Gosling and Parsons, 2013). However, Köbel and Kögel (2003) referred to the fraction of organic carbon obtained by density method as particulate organic matter. Post et al, (2001) also, refers to light fraction as particulate plant and animal residues. The light fraction and particulate organic matter decompose easily, whereas clay sized fraction or heavy fraction is clay/silt sized and is either resistant or hindered to decomposition, such that turnover requires decades (Gosling and Parsons, 2013 and Post et al, 2001).

Light fraction and particulate organic matter are newly added plant residues Janzen et al (1992) in their study on light fraction on three different sites in Canada, observed the amount of light fraction was affected by fallow period, crop rotations, crop type, climatic conditions and fertilizer application. They observed that the light fraction decreased during fallow periods but increased in continuous cropping system. Fertilizer enhanced the productivity of the system and therefore the amount of light fraction added to the soil and climatic conditions favorable for microbial activities reduced the light fraction.

Although light fraction and particulate organic matter are newly added residues and are susceptible to decomposition; yet they can survive for long times if trapped in the aggregates where they cannot be reached by microbes (Christensen, 1996; Krull et al 2003). Tillage breaks these macro aggregates and exposes this fraction for decomposition by microbes. Clay sized organo-mineral complexes often show greater accumulations (Christensen, 1996). Soils with high clay fraction have more organic carbon in them as compared to coarse textured soils (Sorensen, 1981; Gosling and Parsons, 2013; Meersmans 2008; Parton et al. 1987).

Variation in soil organic carbon is not only due to spatial heterogeneity or errors during analysis for a single variable, but can also be due to variation in measurement of variable required to obtain carbon mass or relative interactions of the errors in various variables which can lead to further propagation of error (Goidts et al., 2009; Post et al, 2001). Even different methods used to determine the SOC concentration of a soil give different levels of error. For example the coefficient of variation for carbon determined by the loss-on-ignition method range from 1.2- 15.8%, for Walkley and Black method it ranges from 1.6 to 4.2% and for the dry combustion method it ranges from 1.3 to 7.1% (Goidts et al., 2009)

Texture does influence the carbon stocks (Gosling and Parsons, 2013; Meersmans, 2008). Different amount of sand, silt and clay affect the retention of organic carbon fractions where clay tends to retain organic carbon. Soil texture also influence rate of organic matter decomposition (Sorensen, 1981; Chritensen, 1996; Hassink, 1993).

Despite the body of work that has evaluated individual sources of variability in soil carbon concentrations and stocks, few examples are available to assess variability at multiple scales or to evaluate possible mechanisms responsible for variability. The development of soil sampling protocols for the monitoring of carbon stocks for the trading of carbon stocks require that these sources of variability be assessed and determinations made as to the minimum number of samples required to effectively monitor carbon in soils contracted for carbon credits. Therefore, the purpose of this study is to 1) determine if SSURGO data can be related to the measured carbon stocks and variability in those measurements, 2) finding the minimum number of samples required to measure expected significant change in carbon stocks, 3) determine if the fixed mass method for calculating carbon stocks can reduce variability resulting from variability in bulk density.

Materials and Methods:

Sampling and Sample Preparation:

The study was conducted on 47 fields in Alfalfa, Major, Caddo, Garfield, Greer and Washita counties of Oklahoma. Out of 47 fields, 32 fields are under no-till cropland systems and 15 fields are under grasslands management. Winter wheat dominates the no-till cropping systems in the region and is generally planted two or more years in a row. If crop rotation is practiced the producers generally utilize sorghum, canola, or cotton in a 1 crop per year system. However, most fields had been in continuous wheat since initiation of no-till management. The grass fields represented Bermuda grass as well as native mixed grass. A list of producers participating in the Oklahoma carbon program was obtained from the Oklahoma Conservation Commission. Participation means that the producers agree to maintain the fields in permanent no-till or planted grass during the contract period and will receive a carbon credit payment annually. Producers were contacted and asked if they would allow the collection of soil samples from the contracted fields. When producers agreed to sample collection, the legal descriptions and management information were obtained from the Oklahoma Conservation Commission. Field boundaries were drawn in ArcMap (ESRI, data) 10 and the random point generator in the ArcToolbox was used to generate sample points within each field.

At each sample point a 3m radius circle was marked around the random point and 10 cores were taken in that circle with tractor operated hydraulic probe. The tractor operated hydraulic probe (cutting edge diameter of 3.98cm) used in this study was a Giddings #25-TS Model HDGSRTS (Giddings Machine Company, Windsor, CO). The GPS location at which each core was extracted was recorded using a Trimble GeoXH GPS receiver. Precise GPS data was collected so that spatial analysis could be conducted to determine if small scale trends could be identified in the carbon data.

Cores were extracted to a depth of 30 cm and cut into 0-10, 10-20, 20-30 cm segments. The segments were packed in zip lock plastic bags and placed in an ice chest until transported and stored in a refrigerator at 4 ◦C. Zip lock bags with wet soil were weighed and a subsample (~20 gm) was weighed into a weigh tin. This subsample soil was dried at 110 ˚C for 24 hours and then weighed to determined moisture content. The soil remaining in the zip lock bag was transferred to a paper bag and allowed to dry at 65

°C for one week and then ground and sieved through a 2 mm sieve. Moisture content was used to determine dry soil mass in the zip lock bag and further to determine bulk density. The sieved soil was analyzed for total carbon after weighing 0.2400-0.2500g into a tin foil cup using the dry combustion method (Kalembasa and Jenkinson, 1973) in a Leco analyzer. Inorganic carbon was determined using Pressure Calcimeter (Sherrod et al., 2002). Soil pH was determined on a 1:1, soil:deionized H_2O mixture after a 30 min equilibration period.

Measured values of carbon stocks were pooled by various mapping unit variables from the SSURGO data to determine if SSURGO data could be used to estimate carbon stocks and the variability expected. Lastly, power analysis was used to determine the minimum number of samples required to observe significant change expected to occur if sequestration is occurring at the current estimated rate.

Calculation of Carbon Stock:

Previous research has shown that variation in the measurement of bulk density can cause significant errors in the quantification of soil carbon density (Wilson, 2011; Ellert and Bettany 1995; Ellert et al 2002). Gifford and Roderick (2003) proposed the cumulative mass method as an alternative to the fixed depth method. The cumulative mass method calculates carbon density found in a constant mass of soil instead of a constant depth and therefore may reduce errors associated with changes in bulk density. In this method, depth varies so that each sample contains the same dry mass per unit area.

In order to find the cumulative mass of soil carbon, Gifford and Roderick (2003) used linear interpolation to allow for variation with depth in both the mass fraction of C and bulk density. This is accomplished by dividing the core into two sections, for example, a core taken to 40 cm would be divided into one section of 0-20 cm and another of 20-40 cm. The total length of the core is represented by z_b and the surface subsection is represented by z_a with the cumulative dry soil masses to the respective depths denoted by $m_s(z_b)$ and $m_s(z_a)$ and the cumulative mass of soil C, $c_s(z_b)$ and $c_s(z_a)$. The target or 'standard' cumulative mass of dry soil is denoted by $m_s(t)$ and the corresponding cumulative mass of soil C that we are looking for is denoted as $c_s(t)$. Through linear interpolation, the resulting equation is

$$c_s(t) = c_s(z_a) + \frac{c_s(z_b) - c_s(z_a)}{m_s(z_b) - m_s(z_a)}\left(m_s(t) - m_s(z_a)\right). \quad (1)$$

The fixed mass of soil used in this calculation was ~3478.14 Mg. This mass of soil was selected because it was the smallest mass in a depth of 0-30 cm found among the sample points. Here, the 0-20 cm soil mass should not be greater than minimum cumulative soil mass. Required mass of the 20-30cm layer was calculated by subtracting 0-20 cm soil mass from this minimum mass. Thus, normalizing the soil mass. Carbon mass in soil mass in 0-10 cm, 10-20 cm and required soil mass was calculated using organic carbon concentration in respective layer.

It is expected that use of the cumulative mass method will reduce variability in the carbon density resulting from variability in bulk density measurements. Thereby decreasing the standard deviation and minimizing the number of samples required to measure carbon sequestration over time.

The soil texture data was obtained from SSURGO. SSURGO data for each county involved in this study was downloaded from USDA Soil Data Mart (Web Soil Survey). Each soil mapping unit in SSURGO data has multiple soil series however most of the mapping units involved in this study were consociations except one which was complex.

Therefore, soil texture for the major soil series in the mapping unit was used. Since there is variation in depth of different horizons in a single soil series, the depth of horizons were averaged. Major soil series in most of the mapping units had average A horizon depth more than 30 cm. For those which had average A horizon depth less than 30 cm, the texture of subsequent horizons was evaluated. In those soils having an A horizon less than 30 cm, the texture of the horizon immediately below the A horizon was not different from the A horizon.

Statistical analysis:

The PROC MIX procedure in SAS was used to calculate difference of least squares means for mean separation presented. The PROC POWER procedure in SAS was used to determine the fractional N total (cores required) based on the standard deviation of means calculated for each sample location and the pooled standard deviations. A nominal power of 0.80 was used to set the type II error at 0.20, the type I error was set at 0.05 for all power analysis. The pooled standard deviation for the data set was calculated as the square root of the mean squared error term in ANOVA generated by the PROC GLM procedure in SAS. These power analysis were conducted for soil organic carbon mass as calculated on a fixed depth (30 cm) and fixed mass (3478 Mg soil) basis

Results and Discussion:

Samples were collected from a wide range of soil types containing broad range of organic carbon mass (OCM) in the surface 30 cm (Table 1). The average OCM as calculated using the fixed mass method found in two Grandfield loamy sand soils was 3.83 Mg C ha^{-1}. In contrast an Aspermont silt loam contained 27.95 Mg C ha^{-1}. This difference demonstrates the diversity in OCM represented within this study. A wide range in the amount of variability in OCM is also presented in Table 1. The coefficients of variation (CV) presented were as little as 3.38% for one Abilene silt loam and as large 29.77%, which was the average CV for the two Grandfield loamy sand soils. When OCM was calculated on a fixed depth basis (Table 2) the relative difference among the soil series did not differ, however the OCM were higher for the fixed depth method. Standard deviation for OCM as calculated with fixed mass method was lower or slightly lower than the standard deviation of OCM calculated with fixed depth method. On the other hand, CVs for the fixed mass method are higher (with few exception) than those calculated with fixed depth method. It should be noted here that the mass selected for the fixed mass calculation was the minimum among the cores and all other cores were truncated to achieve it, such that the lower OCM values in fixed mass calculation were expected. Although, lower CVs resulting from the fixed mass calculation were expected due to decreased influence of bulk density error on OCM measurements; the decrease in average OCM and slight change in standard deviation did not bring large change in the relative error/CV in fixed mass.

The variation observed between soil types as well as within sample locations presents challenges to efforts to monitor organic carbon stocks and provide useful estimates of carbon sequestration or loss. Therefore an effort was made to determine if SSURGO data and land management information could be used to categorize the soil types into those that may allow for easier monitoring of carbon stocks and those that present challenges.

The effect of land management can be observed in Table 3. In this study there were 15 grass fields and 32 no-till cropland fields. The OCM, standard deviation (SD), and CV were not affected by management system (table 3). It should be pointed out again that the grass fields were previously cultivated. Some fields were planted to improved grasses for hay production and others were planted as a result of enrollment in the conservation reserve program. The common practice in the area is to plant grass to those cropland fields that are low in grain crop productivity or highly erodible. Therefore the results of this analysis are likely confounded by crop history and soil type. However, the diversity in soil types did not allow for analysis of management within each soil type.

Table 4 shows the effect of texture category on OCM and CV. When using both the fixed depth and fixed mass method the soils containing > 60% sand had significantly lower OCM than the remaining texture categories. The remaining textural classes were not significantly different from each other. Our results are in agreements with findings of Gosling and Parson (2013) and Meersmans et al (2008) who reported that soils with large amounts of sand have lower OCM when compared to those containing higher clay contents. Meersmans et al (2008) used Belgian textural triangle where clay soils have > 30% clay. Goslings and Parsons (2013) (for Great plains of US), and Meersmans et al. (2008) (for soils in Belgium) in their separate studies reported a significant effect of texture on total soil organic matter. Clay and silt appears to retain the heavy fraction of soil organic matter by protecting it in micro-pores out of the reach of microbes or by forming organo-mineral complexes with clay minerals (Christensen, 1996, Hassink, 1992, Schimel, 1985, Sorensen, 1981). Soils having more clay fraction have a higher proportion of micropores of diameter <0.2micro meter (Hassink, 1992; Hassink, 1993), which does not allow microbes to decompose the organic matter/biomass trapped in these pores. Similarly, soils with higher clay content due to their higher aggregation capacity, trap the organic matter in aggregates or encapsulate it; thus protecting it from decaying by micorbes (Kölbl and Knabner, 2004; Krull et al 2003). In contrast, Hassink (1994) did not find any relation of carbon decomposition with soil texture. In addition, Epinset et al (2013) reported that texture along with precipitation influences decomposition rates, where sands have higher rates of decomposition than clay for a given amount of precipitation. The available water capacity of soil influences net primary productivity, where the available water capacity increases with silt content of the soil (Burke et al 1989). However, there is a feedback mechanism with respect to the impact of precipitation which supports productivity as well as enhances decomposition of soil organic matter (Burke et al 1989).

In addition to containing the lowest OCM, the soils with > 60% sand (Soil type 5, Table 4) had the highest average CV, regardless of calculation method. In fact it was significantly higher than all other textural categories except for soil type 2 containing < 10 sand, > 60 silt, and > 30 clay. Those texture categories with < 25% clay and < 35% sand (soil types 1 and 4, Table 4) had the lowest CV's. This indicates that loam soils have lower levels of variability within a sample site compared to sandy and clayey soils.

The organic carbon concentration (OCC) follows the same trend as OCM with respect to the impact of texture (Table 5) The OCC in soils containing >60% sand was significantly lower than in the remaining textural classes. The CV's for the OCC values were lowest in the soils containing <35% sand (soil type 4) and <25% clay (soil type 1). This suggests that the relative variation, as indicated by CV, in OCC influences the relative variation in carbon stock measurements.

The bulk density was not significantly affected by soil texture (Table 6); however soil texture had a significant effect on the CV for bulk density (Table 4). The bulk density CV's were lowest for the soils containing >60% sand but only significantly lower than the CV for the soils containing >30 % clay and >60% silt.

The variation in OCC was highest in low OCC sandy soils followed by soils with >30% clay. This is in agreement with findings of Merry and Spouncer (1988), who reported an increase in CV of carbon concentration with decrease in carbon concentration. Merry and Spouncer (1988) analyzed the interaction of sample weight, furnace temperature and carbon concentration for four different soils. They observed a maximum CV of 7.1% in soils having a minimum OCC of 4.78 g kg^{-1}. The high CV is a result of being near the detection limit of the analysis (dry combustion method). They also found elevated CV in high concentrations soils (~150 g kg^{-1}) due to incomplete combustion when large sample sizes are used or due to sample heterogeneity when small sample weights are used. In contrast, the soil with maximum amount of organic carbon concentration in our results had minimum CV. The second highest CV was observed in soils with > 30% clay content, most of these clayey contained carbonates. The average total carbon concentration in soils with >30% clay was 13.29 g kg^{-1}, which almost double of the soil with maximum organic carbon concentration. Thus, the higher total carbon concentration (organic carbon + inorganic carbon) in soils containing carbonates might have elevated CV. The suitable weight for majority of the soils is 0.2-0.3 g (Carr, 1973), which has been used in this study. Current study shows high variation in sandy soils with lowest organic carbon concentration and in soil with highest total carbon concentration.

Table 7 simplifies the data by presenting OCM found in 3 texture classes and the average standard deviation (SD) and CV for both calculation methods. It should be noted that originally there were two categories of soils with clay > 30% (Soil type 2 and 3), in this table soil 2 has been treated same as soil 3 for its > 30% clay content. This presentation shows that the absolute error as indicated by the SD is similar for soils containing > 60 % silt or sand which have lower SD than compared to the soils containing > 30% clay. In contrast, because the soils containing > 60% silt have OCM values equivalent to the soils containing > 30 % clay the CV for the silt soils approximately is half of that found for the sand and clay soils.

Assessment of Tables 4, 5 and 6 suggests that the relative variability in OCM as evaluated using CV is dominated by variability in the OCC as indicated by the fact that the effects of texture class on the CV values for OCM and OCC were similar and that the CV in bulk density did not follow a similar trend. In order to fully understand how measured organic carbon concentrations and bulk density values influenced both relative and absolute error in the OCM estimate, regression analysis was used to determine if the average OCC or average bulk density in the 0-30 cm sample depth were related to the average SD values for the OCM values calculated using fixed mass and fixed depth. In addition, the SD values for OCC and bulk density for each depth and the average across depths were also regressed against the average SD and average CV values for OCM values calculated using fixed mass and fixed depth. The coefficients of determination (r^2) presented in Table 8 show that OCM was highly correlated with the OCC. The relationships between OCC and OCM for fixed mass and depth methods are graphically represented in Figures 1 and 2. These strong relationships suggest that OCC is the dominate factor resulting in differences among sample sites.

Table 8 also shows that the standard deviation for the OCM values was not related to the OCC, suggesting that although the OCC has a great impact on OCM, its impact on the variability in OCM is negligible. This is counter to the analysis of CV’s mentioned earlier in the first sentence of this paragraph. However, recall that CV provides a measure of relative variability whereas SD evaluates absolute variability.

Table 9 shows that the SD for OCC values was not related to the OCM. However, the SD for OCC was well related to the SD for OCM. This indicates that the within sample site variability in OCM measurements is dependent on variability in OCC. Furthermore, the relationship between the SD for OCC and SD for OCM is improved when OCM is calculated on a fix mass of soil. This of course results from removing error due to variability in bulk density measurements.

Tables 10 and 11 show that neither the average bulk density nor the SD for bulk density the OCM or the SD for OCM. This result is not surprising based on data presented earlier in Table 6 showing that bulk density was not significantly different among texture categories.

Summary:

The analysis shows that OCM is influenced by soil texture and that the variability in OCM increases in sandy soils due to low concentrations of OCC which decrease the reproducibility of the laboratory method. The dominate factor influencing within site variability at 6 m scale and therefore ultimately the number of samples required to successfully monitor carbon stocks is the variability in OCC.

The fact that bulk density was not significantly influenced by texture and is not a major contributor to variability suggests that perhaps a single/constant bulk density value may be used along with OCC analysis to monitor carbon stocks. This may be particularly true if the goal of monitoring is to determine the rate of change in a large land base such as the aggregated acres in a carbon program. However, the procedure is likely insufficient if monitoring is meant to determine the impact of soil type and or management on carbon sequestration. Further analysis is required to determine how using a fixed bulk density may influence carbon monitoring for carbon sequestration.

The data clearly illustrates the utility of using the fixed mass method to decrease variability in carbon stocks. In fact, the average standard deviation for OCM across all the 47 sites was 2.31 Mg ha^{-1}for the fixed depth method. Power analysis found that 188 samples would be required to provide a 90% confidence that 1.1 Mg C ha^{-1} change in OCM would be found significant at the 0.05 probability level, which represent the amount of carbon sequestered in no-till soils after three years based on current sequestration estimates used by the Oklahoma carbon program. In contrast, the fixed mass method reduces the average standard deviation across all the 47 fields 1.86 Mg ha^{-1} which decreases the sample requirement to 123 samples to measure a change of 1.1 Mg C ha^{-1}. It is simply not feasible to collect that many cores from each site, simply based on its impact on the integrity of the site for future sampling. Therefore, continued analysis will be conducted to determine the minimum number of sample sites required if 10 cores are sampled per site as was done in this study. Using a pooled standard deviation would allow for the high sample number required to be confident that a real change in carbon mass will be observed without collecting a detrimentally high number of samples from one site. It will also provide for likely opportunity to assess differences in the rate of accumulation between sites as they develop over time.

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List Figures:

Table 1: Average organic carbon stock per hectare (OCM) in different soil series1 and their corresponding average coefficient of variation (CV) as calculated using fixed mass method

Soil Series[1]	N	Avg. OCM (Mg/ha)	SD	CV
Abilene Silt Loam	1	22.50	0.75	3.38
Aspermont Silt Loam	1	27.95	0.98	3.50
Burford-Tillman complex	1	20.62	5.03	24.41
Carey Loam	2	21.94	1.02	4.74
Grandfield Loamy Sand	2	3.83	1.07	29.77
Grant Silt Loam	1	25.65	3.24	12.63
Lovedale Fine Sandy Loam	1	14.82	1.55	10.49
Meno Loamy Fine Sand	4	10.10	1.58	17.13
Minco Sandy Loam	3	19.53	2.36	12.37
Nobscot Fine Sand	3	11.02	1.78	17.79
Obaro Silty Clay Loam	2	20.55	2.69	14.93
Pond Creek Silt Loam	1	23.30	1.62	7.04
Port Silt Loam	1	15.79	0.57	3.58
Reinach Very Fine Sandy Loam	1	11.25	2.50	22.18
Renfrow Silty Clay Loam	2	27.10	4.03	14.90
St. Paul Silt Loam	8	24.50	1.67	6.16
Tillman Clay Loam	2	26.38	1.74	12.13
Westview Silt Loam	1	27.32	1.71	6.27

[1] Soil series used is the major series in the mapping unit. Most of the mapping units are consociation with major series occupying more than 75% of the area, except Burford-Tillman complex system

Table 2: Average organic carbon stock per hectare (OCM) in different soil series1 and their corresponding percent coefficient of variation (CV) as calculated using fixed depth method

Series[1]	N	OCM (Mg/ha)	SD	CV
Abilene Silt Loam	1	27.75	1.22	4.41
Aspermont Silt Loam	1	30.48	1.32	4.32
Burford-Tillman Complex	1	24.97	7.32	29.31
Carey Loam	2	26.59	1.35	4.65
Grandfield Loamy Sand	2	4.23	1.07	27.14
Grant Silt Loam	1	29.99	4.62	15.42
Lovedale Fine Sandy Loam	1	17.54	1.94	11.04
Meno Loamy Fine Sand	4	10.89	1.70	16.69
Minco Sandy Loam	3	25.79	2.43	9.47
Nobsco Fine Sand	3	13.16	2.35	19.20
Obaro Silty Clay Loam	2	25.13	3.21	14.03
Pond Creek Silt Loam	10	27.18	1.90	7.06
Port Silt Loam	1	18.07	0.53	2.95
Reinach Very Fine Sandy Loam	1	13.16	2.55	19.39
Renfrow Silty Clay Loam	2	32.13	4.10	12.77
St. Paul Silt Loam	8	31.01	2.66	8.66
Tillman Clay Loam	2	32.82	2.17	6.45
Westview Silt Loam	1	32.11	1.53	4.76

[1] Soil series used is the major series in the mapping unit. Most of the mapping units are consociation with major series occupying more than 75% of the area, except Burford-Tillman complex system

Table 3: Average organic carbon mass (OCM), average standard deviation(SD) and average coefficient of variation (CV) under grassland and no-till system as calculated through fixed depth and fixed mass method.

Method	Management System	OCM (Mg C/ ha)	SD	CV
Fixed Depth				
	Grass (N = 15)	22.11a	2.37a	13.85a
	No-till (N = 32)	25.09a	2.28a	10.16a
Fixed Mass				
	Grass	19.10a	2.12a	14.76a
	No-till	20.76a	1.74a	9.53b

Table 4: Average of Organic Carbon Mass and Coefficient of variation in soils with different proportion of Sand, Silt and Clay

Method	%Sand	%Silt	%Clay	Soil type	Number of Sites	OCM[†] (Mg/Ha)	Avg. %CV[‡]
Fixed Depth							
	<15	>60	<25	1	26	28.69b	7.69a
	<10	>60	>30	2	2	25.13b	14.02ab
	<30	<40	>30	3	5	30.97b	13.55b
	<35	<45	<20	4	2	24.02b	4.40a
	>60	<25	<15	5	12	11.28a	19.02b
Fixed Mass							
	<15	>60	<25	1	26	23.78b	7.30ab
	<10	>60	>30	2	2	20.55b	14.93bcd
	<30	<40	>30	3	5	26.68b	13.23c
	<35	<45	<20	4	2	19.95b	4.32a
	>60	<25	<15	5	12	9.86a	19.32d

[†] Average Organic Carbon Mass

[‡] Average Coefficient of Variation

Table 5: Organic carbon concentration (OCC) and percent coefficient of variation (CV) in soil with different proportion of sand, silt and clay.

% Sand	% Silt	% Clay	Soil type	Number of Sites	Avg. OCC (g/kg)	% CV
<15	>60	<25	1	26	6.74a	7.54a
<10	>60	>30	2	2	5.92a	14.52ab
<30	<40	>30	3	5	7.53a	14.36b
<35	<45	<20	4	2	5.79a	4.54a
>60	<25	<15	5	12	2.65b	19.57b

Table 6: Bulk Density (BD), its Standard Deviation (SD) and percent coefficient of variation (CV) in soil with different proportion of sand, silt and clay.

% Sand	% Silt	% Clay	Soil type	Number of Sites	Avg. BD (Mg/m^3)	CV
<15	>60	<25	1	26	1.44a	3.63b
<10	>60	>30	2	2	1.42a	5.65c
<30	<40	>30	3	5	1.41a	3.54ab
<35	<45	<20	4	2	1.39a	2.95ab
>60	<25	<15	5	12	1.48a	2.79a

Table 7: Average organic carbon (OCM) mass as calculated in soils with different dominating textural components and their average standard deviation (SC) and percent coefficient of variation(CV)

Method	Textural component	% in Soil	OCM (Mg/ha)	SD	CV
Fixed Depth					
	Clay	>30	29.30b	3.75b	13.69b
	Silt	>60	28.69b	2.20a	7.69a
	Sand	>60	11.28a	1.90a	19.02c
Fixed Mass					
	Clay	>30	24.93b	3.14b	13.72b
	Silt	>60	23.54b	1.70a	7.84a
	Sand	>60	9.86a	1.63a	19.32c

Table 8: Coefficients of determination for the linear relationship between average OCM and the corresponding average standard deviation for the OCM and the average Organic carbon concentrations found in each sampled depth and the average concentration in the 0-30 inch

Method		Ave. OCC (g/kg)			
		0-30cm	0-10cm	10-20cm	20-30cm
Fixed Mass					
	OCM (Mg/ha)	0.9939	0.8577	0.9371	0.8223
	OCM SD (Mg/ha)	0.0461	0.0357	0.0467	0.0398
Fixed Depth	Fixed depth				
	OCM (Mg/ha)	0.9748	0.7816	0.9206	0.8648
	OCM SD (Mg/ha)	0.0924	0.0237	0.1121	0.1071

Table 9: Coefficients of determination for the relationship between average OCM and the corresponding average standard deviation for the OCM and the average standard deviation of the organic carbon concentration found in each sampled depth and the average standard deviation in the 0-30cm

Method		Ave. Stdev of OCC (g/kg)			
		0-30cm	0-10cm	10-20cm	20-30cm
Fixed Mass					
	OCM (Mg/ha)	0.0559	0.0294	0.0048	0.0425
	OCM SD (Mg/ha)	0.697	0.4208	0.372	0.3108
Fixed Depth					
	OCM (Mg/ha)	0.0864	0.0236	0.0099	0.1165
	OCM SD (Mg/ha)	0.7555	0.1256	0.2723	0.7283

Table 10: Coefficients of determination for the relationship between average OCM and the corresponding average standard deviation for the OCM and the average bulk density found in each sampled depth and the average bulk density in the 0-30cm

Method		Ave. Bd (g/cm3)			
		0-30cm	0-10cm	10-20cm	20-30cm
Fixed Mass					
	OCM (Mg/ha)	0.1621	0.1238	0.1096	0.1427
	OCM SD (Mg/ha)	0.0014	0.0029	0.0133	0.0044
Fixed Depth					
	OCM (Mg/ha)	0.0801	0.0517	0.0497	0.0868
	OCM SD (Mg/ha)	0.0042	0.0019	0.0123	0.0003

Table 11: Coefficients of determination for the relationship between average OCM and the corresponding average standard deviation for the OCM and the average standard deviation of the bulk density found in each sampled depth and the average standard deviation in the 0-30cm

Method		Ave. Stdev. of Bd (g/cm3)			
		0-30cm	0-10cm	10-20cm	20-30cm
Fixed Mass					
	OCM (Mg/ha)	0.1491	0.0208	0.187	0.1515
	OCM SD (Mg/ha)	0.0451	0.0161	0.028	0.0529
Fixed Depth					
	OCM (Mg/ha)	0.1957	0.0426	0.2216	0.1817
	OCM SD (Mg/ha)	0.1366	0.1025	0.0685	0.1056

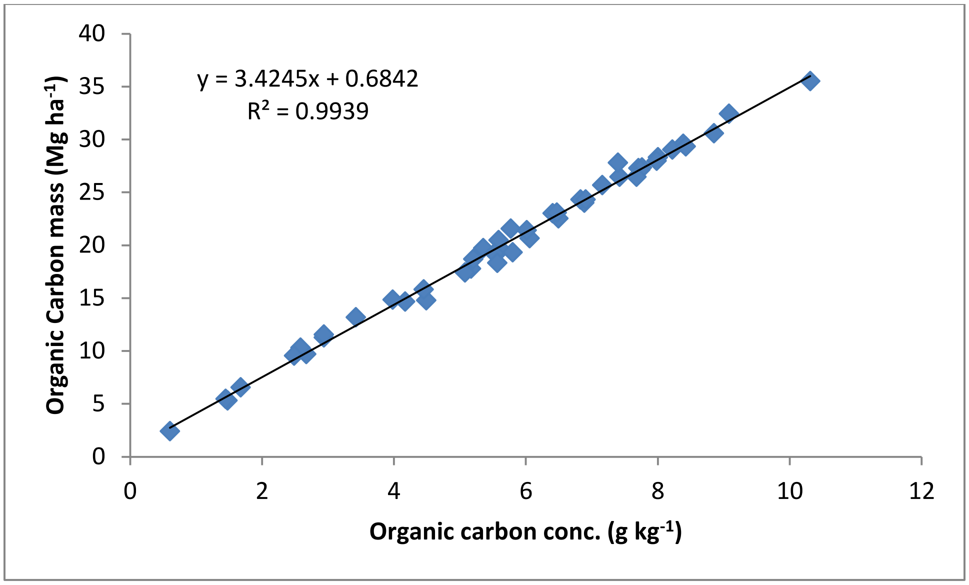

Figure 1: Relationship between the average organic carbon mass calculated with the fixed mass method and the average organic carbon concentrations found in the 0-30 cm depth in each of the 47 fields sampled

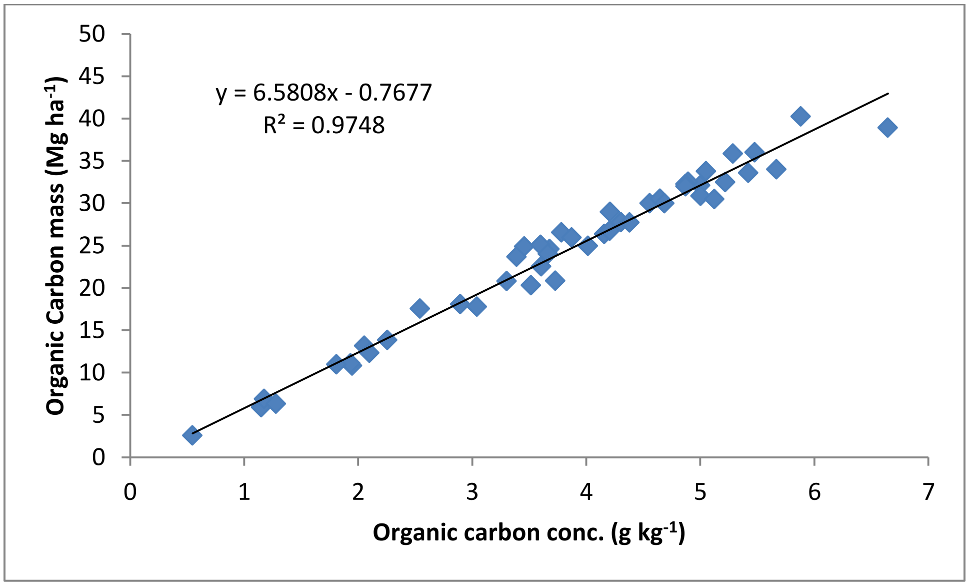

Figure 2: Relationship between the average organic carbon mass calculated with the fixed depth method and the average organic carbon concentrations found in the 0-30 cm depth in each of the 47 fields sampled

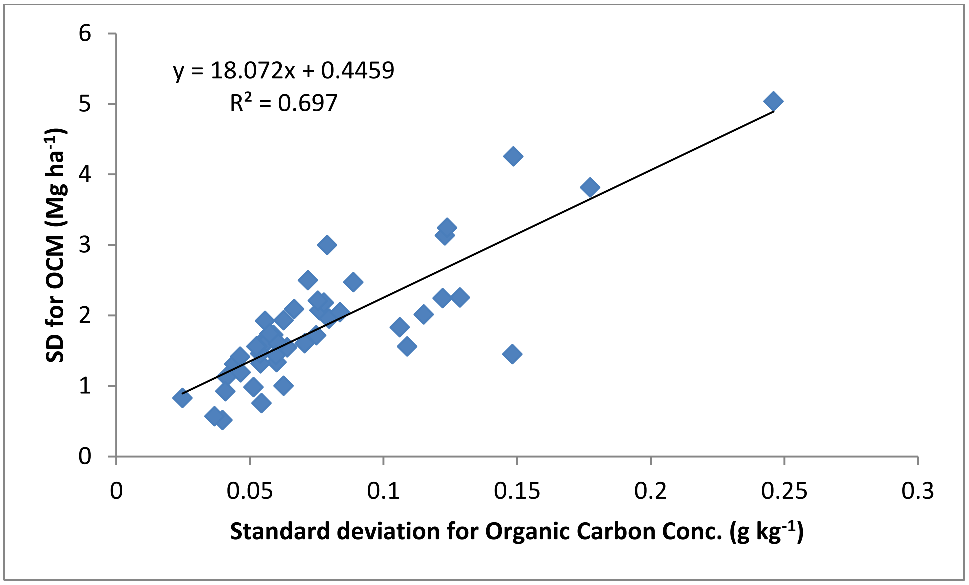

Figure 3: Relationship between the average standard deviation (SD) for organic carbon mass calculated with the fixed mass method and the average standard deviation for organic carbon concentration found in the 0-30 cm depth in each of the 47 fields sampled

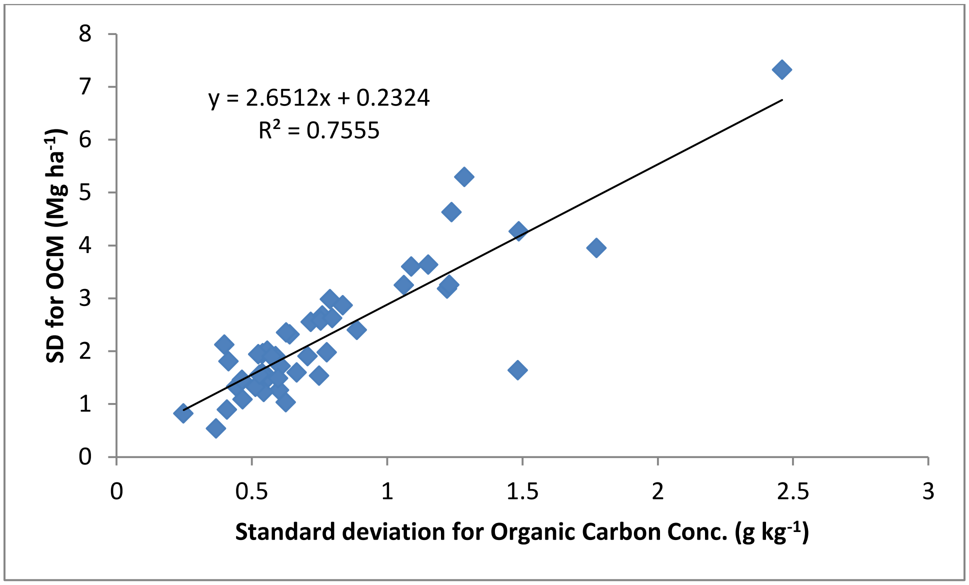

Figure 4: Relationship between the average standard deviation (SD) for organic carbon mass calculated with the fixed depth method and the average standard deviation for organic carbon concentration found in the 0-30 cm depth in each of the 47 fields sampled

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