Implication of tillage, texture and mineralogy on the sieving efficiency, physical-based soil organic matter and aggregate stability of some soils in Eastern Cape Province, South Africa

By

Peter, Prince Chinedu

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Department of Agronomy, Faculty of Science and Agriculture,
University of Fort Hare, Alice.

Supervisor: Professor Isaiah IC Wakindiki

March, 2015

DECLARATION

I, **Peter, Prince Chinedu** declare that the thesis hereby submitted for the degree of Doctor of Philosophy in Agriculture (Soil Science) at the University of Fort Hare is my work and has not been previously submitted to another university.

Sign:

Date: 2nd March, 2015.

Place: University of Fort Hare, Alice.

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CERTIFICATION

This is to certify that this work titled ‘Implications of tillage on some soil structure-associated physical properties in soils with different texture and mineralogy in Eastern Cape Province, South Africa’ is a research work carried out by **Peter, Prince Chinedu**, a Doctor of Philosophy degree in Agriculture (Soil Science) student in the Department of Agronomy, University of Fort Hare, Alice.

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Prof. Isaiah IC. Wakindiki	Dr. Charles S. Mutengwa
(Project supervisor)	(Ag. Head of Department)
Date………………..	Date…………………

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PREFACE

This work explored the factors that influence structural breakdown of soils in Eastern Cape Province. Accomplishing this task was with its share of challenges as well as great helps without which it would have been mission impossible.

My greatest thanks go to the almighty God who in His infinite mercy opened this door of opportunity and kept me through. This opportunity could not have been mine but for the kind gesture of Professor Isaiah IC. Wakindiki. He was the instrument God used to bring me to the University of Fort Hare, make me comfortable and ensured that against all odds, I completed this work in record time. I sincerely lack the right words to express my gratitude to this icon and his family whose humility, simplicity and thoroughness has made me understand life differently. He was not just my supervisor; he was my motivator, coach, and father. May God richly bless you and your family in Jesus name, Amen!

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Very importantly, I thank the Govan Mbeki Research and Development centre for providing the funding for this work through the supervisor linked bursary. As well as for the several trainings and workshops they conducted for students free of charge.

DEDICATION

This work is dedicated to God Almighty whose providence availed me this great privilege.

THESIS STRUCTURE

This thesis consists of four chapters. Chapter one provides the introduction and objectives of the study. Chapter two gives a general review of the literature relevant to the study. Chapter three covers the materials and methods used in this study. The fourth chapter reports the findings of the study, discussion of results, conclusions and recommendations.

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LIST OF ABREVIATIONS

ASC = Aggregated silt and clay

CDR = Clay dispersion ratio

CFI = Clay flocculation index

CT = Conventional tillage

DR = Dispersion ratio

MWDd = Mean weight diameter (dry sieving)

MWDw = Mean weight diameter (wet sieving)

NT = No till

PSDI = Potential structural deformation index

SCL = Sandy clay loam

SL = Sandy Loam

SOC = Soil organic carbon

SOM = Soil organic matter

WDC = Water dispersible clay

WDSi = Water dispersible silt

WSA = Water stable aggregate

ABSTRACT

Soil structure and its associated physical properties are essential soil components. Soil texture and mineralogy are inherent soil properties that influence soil management. This study assessed the implication of tillage, texture and mineralogy on soil sieving, aggregate stability indices and physical fractions of organic matter in soils of Eastern Cape Province of South Africa. An Iris FTLVH – 0200 digital electromagnetic sieve shaker (Filtra Vibración SL Spain), was used to determine settings for sieving efficiency. Mean weight diameter (MWD), water stable aggregate (WSA), state of aggregation (SA), dispersion ratio (DR), water dispersible clay (WDC), clay dispersion ratio (CDR), clay flocculation index (CFI), and potential structural deformation index (PSDI) were aggregate stability indices evaluated to check for sensitivity in evaluating aggregate stability of soils under two tillage systems and physical fractions of carbon and nitrogen in soils of Eastern Cape Province. The T4I3P2 and T4I4P3 settings were sensitive under tillage and T4I1P4, T3I4P3 and T4I4P3 were sensitive under mineralogical considerations for sieving efficiency.

The total carbon in soils under conventional tillage (CT) was 17.7 g/kg and in soils under no tillage (NT) it was 15.8 g/kg. The total carbon content in the clay fraction of soils under CT was 24.1 % higher than the total carbon content in the clay fraction of soils under NT. The total nitrogen content in the clay fraction of soils under CT was 5.4 % higher than the total nitrogen content in the soils under NT.

The total carbon in the sandy loam (SL) textured soils was 17.4 g/kg and in the sandy clay loam (SCL) textured soils it was 17.1 g/kg. The total nitrogen in SL soils was 3.7 g/kg and in SCL soils it was 3.7 g/kg. The clay fraction had higher total carbon than other fractions in Sl and SCL soils. The higher values of nitrogen were observed in the silt fraction for SL soils

and clay fraction for SCL soils. The total carbon in the soils dominated with kaolinite was 17.3 g/kg and in quartz dominated soils the value was 16.9 g/kg. The total nitrogen in the soils dominated with kaolinite was 3.7 g/kg and in the soils dominated with quartz the value was 3.7 g/kg.

For soils under NT the WDC was 135.8 g/kg and for soils under CT it was 139.7 g/kg. The ASC was 72.5 for soils under NT and 92.0for soils under CT. The DR was 0.9 for soils under NT and 0.8 for soils under CT. The CFI was 0.5 for soils under NT and 0.5 for soils under CT. The CDR was 0.5 for soils under NT and 0.5 for soils under CT. The MWDw was 1.6 mm for soils under NT and 1.4 mm for soils under CT. The MWDd was 4.0 mm for soils under NT and 4.0 for soils under CT. The % WSA > 0.25 mm was 61.7 % for soils under NT and 56.2 % for soils under CT. The PSDI was 55.2 % for soils under NT and 61.15 % for soils under CT. The SA was 43.2 % for soils under NT and 37.89 % for soils under CT. The WDC was 125.7 g/kg for SCL soils and 151.4 g/kg for SL soils. The CDR was 0.5 for both SCL and SL soils. The DR was 0.9 for SCL soils and 0.8 for SL soils. The CFI was 0.5 for both SCL and SL soils. The ASC was 56.2 g/kg for SCL soils and 115 g/kg for SL soils. The MWDw was 1.5 mm for SCL soils and 1.4 mm for SL soils. The MWDd was 3.6 mm for SCL soils and 3.6 mm for SL soils. The % WSA > 0.25 mm was 53.0 % for SCL soils and 62.5 % for SL soils. The PSDI was 59.2 % for SCL soils and 59.7 % for SL soils. The SA was 33.6 % for SCL soils and 45.2 % for SL soils.

The WDC was 313.3 g/kg for kaolinitic soils and 120.7 g/kg for quartz dominated soils. The CDR was 0.5 for kaolinitic soils and 0.5 for quartz dominated soils. The DR was 0.9 for kaolinitic soils and 0.8 for quartz dominated soils. The CFI was 0.5 for kaolinitic soils and 0.5 for quartz dominated soils. The ASC was 110.0 g/kg for kaolinitic soils and 101.7 g/kg

for quartz dominated soils. The WSA > 0.25 mm was 57.3 % for quartz dominated soils and 68.4 % for kaolinitic soils. The MWDw was 1.6 mm for quartz dominated soils and 0.8 mm for kaolinitic soils. The MWDd was 3.6 mm for quartz dominated soils and 3.4 mm for kaolinitic soils. The PSDI was 56.3 for quartz dominated soils and 76.0 for kaolinitic soils.

It was concluded that Tillage, texture and mineralogy influenced the result of the sieving operation using Iris FTLVH – 0200 digital electromagnetic sieve shaker (Filtra Vibración SL Spain). Sieving efficiency attained for these soils varied with tillage and mineralogy. The aggregate size composition and distribution in soils of these ecotopes are a function of mineralogy rather than tillage.

Tillage influenced Nitrogen in the physical fractions of these soils. Changes in nitrogen content due to tillage were expressed more in the silt fraction of the soils. Soils in these ecotopes showed tendency for slow nitrogen accumulation. Texture influenced the accumulation of carbon and nitrogen in these soils. Clay fraction was prominent in determining the amount of carbon and nitrogen in these soils.

Tillage influenced the sensitivity of different aggregate stability indices in these soils. The indices WSA > 0.25 mm, SA, and MWDw were sensitive to detect differences in macro aggregate stability among tillage system in these soils. Micro aggregate stability indices were generally not sensitive in detecting expected differences among tillage systems in these soils. The micro aggregate stability indices DR and ASC were more sensitive in soils of different texture. The macro aggregate stability indices MWDw, MWDd and PSDI were not sensitive to detect difference in stability with texture. The SA and WSA > 0.25 mm indices were sensitive to detect differences in the stability of the soils with texture. The micro aggregate stability indices DR and WDC were sensitive in soils of different mineralogy.

Clay fraction influenced the carbon content of these soils irrespective of mineralogy. The soils responded to different indices differently under different conditions of tillage, texture and mineralogy. Therefore caution must be exercised in adopting any index; it is however suggested to use the response of more than one index for any given conclusion. Further research on site specific measures to improve soil nitrogen retention in these soils is suggested to forestall green house gas emission. Also proper delineation of these ecotopes according to carbon response to tillage, texture and mineralogy for enhanced carbon sequestration measures is recommended.

CHAPTER ONE

1.0 INTRODUCTION

Soil tillage is an important factor in agriculture that affects soil physical properties (Stacy et al., 2015). Tillage is the physical manipulation of agricultural soil to enhance its structural rearrangement for agronomic purposes (Alam and Salahin, 2013). Tillage contributes to the breakdown of soil structure, often resulting in the formation of micro aggregates and individual soil particles (Munkholm and Schjonning, 2004). Destruction of soil structure lowers soil's quality (Liebig et al., 2004; Ball et al., 2007) because such soils become fragile and vulnerable to other forms of degradation e.g. erosion. In this regard, Eastern Cape Province contributes 28% of the total national soil loss in South Africa and about 37% of the province has moderate to extremely high rate of soil loss (Mandiringana et al., 2005). In Eastern Cape, soil erosion is so severe that some researchers like Murungu (2012) termed it "alarming". The land redistribution efforts of government has been faced with the problem of higher population density in productive areas, land abandonment and poor management (Fox and Rowntree, 2001)

Conventional tillage (CT) is widely practiced in Eastern Cape and has often been blamed for the low soil organic matter (SOM) (Mandiringana et al., 2005) and aggregate stability (Nciizah and Wakindiki, 2014). The extent of soil structure breakdown is determined by the aggregate stability (Barthès and Roose, 2002; Nimmo and Perkins, 2002), which in turn, depends on the soil texture and mineralogy (Wakindiki and Ben-Hur, 2002). Aggregate stability studies usually involve the sieving procedure to obtain aggregates of a particular size range (Barja, 2008). Sieving has traditionally been accomplished by agitating either a single or stack of sieves by hand (Ali et al., 2013). However shaking sieves by hand is a laborious process. Therefore, many researchers (Fernández-Ugalde et al., 2009; Cañasveras et al., 2010; Herath et al., 2013; Maki and Rota, 2014 and Miwa et al., 2014) used mechanical sieve shakers.

The Eastern Cape Department of Agriculture has established several initiatives to improve soil sustainability (Allwood, 2006). Some government initiatives include: Betterment planning programme, soil erosion and conservation programme, irrigation scheme and water conservation programme. However, some of these efforts either emphasised more on identification of the existing problems or are focus on short term crop improvement, neglecting soil physical properties. Research so far has been inadequate to meet the increasing challenge of soils in Eastern Cape. Several studies (Hoffman et al., 1999; Fairbanks et al., 2000; Hoffman and Todd, 2000; Hoffman and Ashwell, 2001; Wessels et al., 2004) dwell on a national over view with no specific details on individual Provinces. Other studies (Marco et al., 2011; Mandiringana et al., 2005) focused more on organic matter and plant nutrients. These have left much gap in the knowledge on soil structural conditions of fast degrading soils like soils of Eastern Cape Province. Therefore, the major objective of this work was to determine the implication of tillage, texture and mineralogy on selected soil structure-associated physical properties of soils in Eastern Cape Province.

The following were the specific objectives.

1) Determine the sieving efficiency of an Iris FTLVH – 0200 digital electromagnetic sieve shaker (Filtra Vibración SL Spain) using soils of different texture and mineralogy sampled from various parts of Eastern Cape.
2) Determine the implications of tillage, texture and mineralogy on physical-based soil organic matter fractions of soils sampled from various parts of Eastern Cape.
3) Determine the implication of tillage, texture, and mineralogy on aggregate stability of soils sampled from various parts of Eastern Cape.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil sieving and sieving efficiency

Soil sieving is an essential laboratory procedure in every soil investigation. The aim of soil sieving is to obtain aggregates of a particular size range (Naoki et al., 2015). Soil sieving traditionally was accomplished by agitating either a single or stack of sieves by hand (Ali et al., 2013), which is a laborious process compared to mechanical sieve shakers. In recent times, there are numerous scientific papers and reports based on mechanical sieve shakers such as those by Fernández-Ugalde et al., (2009), Cañasveras et al., (2010), Herath et al., (2013), Maki and Rota (2014) and Miwa et al., (2014). These reports underscore the importance of mechanical sieve shaking in soil investigations. Nweke and Nnabude (2014) used a mechanical sieve shaker for 10 min to separate an Ultisol into aggregate size fractions: 5 to 2, 2 to 1, 1 to 0.5, 0.5 to 0.25, and < 0.25mm. In that experiment, the authors reported that the 5 to 2 mm size fraction was dominant. Eccles and Ekwue (2008) reported that 100% of soil aggregates passed through a 4.75 mm sieve and 65% passed through 2.36 mm sieve after shaking the soil in a stack for 10 min with a newly constructed sieve shaker. Sainju (2006) used a Tyler Ro – Tap sieve shaker (Combustion Engineering Inc., Mentor, OH) to separate aggregates in soils from a semi-arid region in Eastern Montana and Western North Dakota into size fractions. Shaking for 3 min at 200 oscillations per minute, the author reported that the amount of aggregates retained on the different sieves decreased with decrease in the sieve aperture.

Many researchers using mechanical sieve shakers in soil investigations have suggested the implications of the settings of the mechanical sieve shaker such as time, interval and power on sieving result. These settings involve different combinations of various levels. For example, Diaz-Zorita et al., (2007) used a Fritsch vertical sieve shaker (Model Analysett-3, Idar – Oberstein, Germany) on a Typic Paleudalf and Typic Hapludalf for 15, 30, 60 and 120s at 2 mm amplitude and frequency of 50 Hz. The authors reported that the greatest change in the mean fragment size was detected between 15 and 30s of sieving, the maximum sensitivity to sieving duration was found in fragments > 16.00 mm and < 4.75 mm. The authors concluded that increasing sieving duration from 30 to 120 s resulted in greater fragmentation of the soil. Ali et al., (2013) experimenting with a Piarco sandy loam, Maracas clay loam and Talparo clay soils in Trinidad, used a combination of vibration frequencies of 1.25 Hz, 1.75 Hz, 2.25 Hz and sieving times of 5, 10, 15 min settings respectively. The authors reported that 15 min of sieving, 1.75 Hz frequency and 15 min sieving time setting was optimum combination for aggregate size separation.

Therefore, sieving time can influence the results (Diaz-Zorita et al., 2002; Jorge et al., 2013). Nahia et al., (2009) used a Retsch AS 200 Control Mechanical Sieve Shaker (Retsch Technology Düsseldorf Germany) for 2 min and amplitude of 1.5 mm to separate aggregates of a Dystric Regosol into size fractions and observed that soil aggregates > 2.00 mm were more than those < 2.00 mm. This result was attributed to the effect of tillage on macro aggregates. Furthermore, Nahia et al., (2011) working on a Typic Udorthents used the same setting and mechanical sieve shaker (Retsch AS200 Control, Retsch Technology Düsseldorf Germany) as Nahia et al., (2009) and reported that the 20 to10 mm aggregate size fraction was higher compared to other smaller aggregate size fractions. The authors attributed the effect to conventional tillage. However, Zhang et al., (2012) working on a Typic Hapludoll, used the same mechanical sieve shaker (Retsch AS200 Control, Retsch Technology Düsseldorf Germany) and settings as Nahia et al., (2009), but observed that the > 2.00 mm aggregate size fraction dominated in the no till (NT) system compared to the < 2.00 mm size fractions, while the 1 to 0.25 mm aggregate size fraction was predominant in soils under conventional tillage (CT) system. Jorge et al., (2013) in an experiment on beach and dune soil samples used 2, 5, 10, 15 and 20 min sieving times in a Ro – Tap sieve shaker (W.S. Tyler Industrial Group, Mentor, OH USA) operated at 2.6 rpm and 300 taps per min. The authors observed that at all sieving times, the 0.125 mm sieve size consistently retained more particles than other sieve sizes considered (>2.000, 2.000 to 1.000, 1.000 to 0.710, 0.710 to 0.500, 0.500 to 0.355, 0.355 to 0.250, 0.250 to 0.125, 0.125 to 0.063 and <0.063 mm). The authors concluded that sieving efficiency improved with sieving time and for the study, 10 min and 15 min were optimum for beach and dune samples respectively.

Sieving efficiency is the extent to which a sieving operation does not result to degradation of the soil aggregates. Degradation of soil aggregates occurs when the aggregates break into sizes that are lower than 0.25 mm, in which case they become soil particles that can easily be eroded (Nimmo and Perkins, 2002). During sieving operation using a mechanical sieve shaker, soil aggregates are broken into different aggregates of different sizes. The percentage of aggregates passing through the stack of sieves is used to measure the sieving efficiency of the sieving operation (Das, 2002). The machine setting at which a given percentage of the aggregates begin to pass through the sieve with the least aperture size is very important in sieving analysis. When sieving is done for soil aggregate analysis, the setting at which less than ten percent of the aggregates pass through the sieve with the least aperture (0.25 mm) in the stack of sieves is critical (Ali et al., 2013). But when sieving is done to separate the soil aggregates into constituent particles, the setting at which above ten percent of the aggregates pass through the sieve with least aperture size (0.25 mm) in the stack of sieves is critical. These critical points determine the sieving efficiency of the machine for specific soil analysis (Jorge et al., 2013).

2.2. Implications of tillage, texture and mineralogy on physical-based soil organic matter fractions

The physical manipulation of agricultural soils to enhance its structural rearrangement for agronomic purposes is the principle of CT (Alam and Salahin, 2013). Several benefits of CT such as improved ease of root penetration, hydraulic conductivity and water- holding capacity are well documented (Weiqiang et al., 2004). Equally, other studies have emphasized the negative effects of CT such as soil structural degradation and loss of SOM (Sundermeier et al., 2011; Asma et al., 2015). Furthermore, other studies have suggested conservation tillage practices such as no tillage (NT) or minimum tillage, crop residues deposition on the soil surface and crop rotation as alternatives to CT (Ali et al., 2013; Shangyu et al., 2015) especially with regards to soil organic carbon (SOC) management (Liebig et al., 2004; Sundermeier et al., 2011).

Soil physical fractionation is essential for understanding SOC stabilization by physical protection and organo-mineral interaction (Erika et al., 2015). The authors further stated that soil physical fractionation separates SOC associated with texture. Physical fractionation of SOC based on texture is directly related to the *in situ* fractions of SOC (Six et al., 2002; Fanqiao et al., 2014). The dynamics of SOC are influenced by soil texture (Fanqiao et al., 2014), although the relationship is not well understood (Francisco et al., 2008). For example a poor relationship ($r^2 < 0.05$) was reported between clay and carbon content in some New Zealand soils by Percival et al., (2000). McLauchlan (2006) observed a slight relationship between SOC and texture. While Six et al., (2000) opined that clay contents have a slight effect on SOC accumulation rate. Erika et al., (2015) concluded that SOC associated with sand fractions was the most sensitive to soil tillage systems in a short period compared to clay and silt fraction. But Francisco et al., (2011) had reported that sand size and its associated carbon are not always responsive to tillage change. Eusterhues et al., (2004) noted that SOC stabilization through aggregation is unlikely in sandy soils. The amount of SOC stored in the soil is influenced by mineralogy (Cordula et al., 2015).

Mineralogy influences soil properties because of the differences in surface area and charge of minerals (Gopi and Krishna, 2015). Clay minerals affect SOC retention and dynamics by particle-occlusion and sorption processes. In Mozambique, Wattel-Koekkoek and Buurman (2004) noted that upland, well-drained kaolinitic soils had much higher SOC than poorly-drained lowland montmorillonitic vertisols. Schaefer et al., (2004) reported that soils with kaolinite contents >800 g/kg clay have high bulk density, low macro porosity and low hydraulic conductivity. There are two opposing schools of thought; one suggesting that aggregation is controlled by texture and mineralogy (including Fe/Al oxides) (Schaefer, 2001), the other argues that SOC and biotic activity are the main aggregation factors (Van Breemen and Buurman, 2002). Both views are probably right for specific cases but wrong for general situations.

2.3 Implication of tillage, texture, and mineralogy on aggregate stability

2.3.0 Processes of aggregation and factors affecting aggregation

Soil aggregates are soil groupings formed by primary soil particles (sand silt and clay) which are bound together (Bast et al., 2015; Jatta et al., 2015). Soil aggregation is a key ecosystem process which results in the formation and stabilization of soil structure. The aggregation of soil is a complex process, regulated by a range of abiotic factors (e.g. texture). Soil aggregation is a major indicator of soil quality and the environmental sustainability of agricultural management practices (Todd et al., 2015). Macro aggregate (> 250 μm) formation is induced by organic matter inputs, while SOM decomposition within macro aggregates leads to the formation of micro aggregates (< 250 μm) (Six et al., 2000; Gale et al., 2000). Further more root length, microbial biomass, mycorrhizae and soil fauna have been reported to have positive effect on aggregation. Silt and clay particles are involved in micro aggregate formation, while microbial- and plant-derived polysaccharides as well as fungal hyphae play significant part in macro aggregate formation. (Zhang et al., 2012; Zhang et al., 2013; Todd et al., 2015)

2.3.1 Methods of measuring soil aggregation

Soil aggregate stability is a measure of soil structural stability or the extent to which soil aggregates resist break down by the destructive forces of water or wind (Ćirić et al., 2012; Ogban et al., 2013; Ondřej et al., 2015) or any other mechanical force. Consequently, aggregate stability is an important soil property that is used to evaluate the risk of soil structure deterioration (Martínez et al., 2015; Mohammad et al., 2015; Selen et al., 2015). According to Han et al., (2010) water stability test of aggregate is an indirect and discrete method for estimating aggregation and the effect of tillage on aggregation. Soil tillage is aimed to improve soil structure and quality (Takahiro et al., 2015). It is widely reported that water stable aggregates are a standard feature of soil structure that is sensitive to tillage practices (Sánchez-Marañón et al., 2002; Barthès and Roose, 2002; Green et al., 2005; Williams and Petticrew, 2009; Spohn and Giam, 2010). The degradation of soil structure should be balanced and/or exceeded by regeneration in order to have a sustainable soil use (Munkholm and Schjonning, 2004). Optimal soil structure supports plants, sufficient water supply, aeration and release of available nutrients (Alvarez et al., 2012).

Quantitative assessment of soil structural stability at discrete aggregate levels is fundamental to understanding the macro scale structural attributes of the whole soil (Blanco-Canqui et al., 2007). Studies on soil structure are many in literature and cover many soils in different environments (Six et al., 2002; Igwe and Stahr, 2004; Ball et al., 2007; Alvarez et al., 2012; Igwe et al., 2013; Antonio, 2014). Consequently, many indices have been proposed to measure soil structural stability (Mbagwu, 2003; Martínez et al., 2015) which depend on soil tillage practices and inherent properties like texture and mineralogy (Pinheiro et al., 2004, Erika et al., 2015; Chen-Yang et al., 2015).

2.3.2 Micro aggregate stability indices

The stability of soil micro aggregate opposed to its dispersion is a very important soil phenomenon that checks degradation (Trakoonyingcharoen et al., 2012). Some of the indices widely reported include: Water-dispersible clay (WDC), Clay flocculation index (CFI), Dispersion ratio (DR), (Igwe and Udegbunam, 2008), Aggregated silt and clay (ASC), Water dispersible silt (WDSi), and Clay dispersion ratio (CDR) (Trakoonyingcharoen et al., 2012).

The WDC refers to clay that can be easily dispersed by water (Paradelo, 2013), while CFI and ASC indices reveal the ability of the soil to resist dispersion in water. The WDC, WDSi and DR are indices that determine the clay and silt dispersibility in water. Higher WDC, WDSi, CDR and DR soils are weaker in their structure. These indices are inversely proportional to CFI and ASC indices, hence higher values of CFI and ASC imply greater soil aggregation at micro aggregate level (Igwe et al., 2006; Igwe and Nwokocha, 2006; Igwe and Udegbunam, 2008).

In general, soils with DR > 0.15 are more erodible while soils with DR < 0.15 are less erodible (Singh and Khera, 2008). Furthermore, Maharaj and Paige-Green (2013) reported that soils with DR > 0.5 were highly dispersive, soils with DR $= 0.3$ to 0.5 were moderately dispersive, soils with DR 0.15 to 0.3 were slightly dispersive and soils with DR < 0.15 were non dispersive.

2.3.3. Macro aggregate stability indices

Mean weight diameter from wet (MWDw) and dry (MWDd) sieving is an index that characterizes the structure of the macro aggregate by integrating the aggregate size class distribution into one number (Six et al., 2000). The MWDw indicate the effect of different tillage practices on soil structure and proportions of macro aggregates, it is directly proportional to structural stability (Igwe and Stahr, 2004; Adesodun et al., 2004; Martínez et al., 2015). High values of MWDd usually indicate lower stability of soil (Ćirić et al., 2012).

Percent water stable aggregates (%WSA) within aggregate size classes and in > 0.25 mm aggregate fraction index is a measure of the aggregates' resistance to breakage by water (Amezketa et al., 2003). Soils with high %WSA resist compaction but soils with low %WSA form surface crusts which can reduce both water infiltration and air exchange (Six et al., 2000).

State of aggregation index is the amount of naturally occurring discrete clusters or groups of soil particles that can only exist when the binding force exceed the force between adjacent aggregates (Igwe et al., 2013). State of aggregation correlates with soil binding agents and soils with high state of aggregation do not disperse easily (Igwe et al., 2013). Potential Structural Deformation Index (PSDI) measures the susceptibility of dry soil aggregates to disintegrate upon impact with water (Ogban et al., 2013).

Many studies have shown that soil aggregate stability is influenced by tillage (Shepherd et al., 2002; Williams and Petticrew, 2009; Stacy et al., 2015), texture (Wakindiki and Ben-Hur, 2002; Nciizah and Wakindiki, 2012; Bast et al., 2015) and mineralogy (Wakindiki and Ben-Hur, 2002; Lado et al., 2007; Nciizah and Wakindiki, 2012; Rabbi et al., 2015). However these studies only dealt with one or two indices and relate them often to tillage, organic matter or sesquioxides. This hinders useful information which could be generated when several indices are combined.

2.4 Effect of tillage on soil structure

Tillage operation on agricultural soils is a major factor involved in soil structure degradation, due to aggregate disruption (Garcia-Franco et al., 2015). Several authors (Barbera et al., 2012) (Lieskovský & Kenderessy, 2012) (Moraes et al., 2013) have reported on the effect of tillage practices on soil structure. Tillage modifies soil structure (Alvarez & Steinbach, 2009). Tillage promotes the breakdown of soil macro aggregates into micro aggregates and silt plus clay-sized particles (Eden et al., 2011). Minimum tillage practices, including no-till (NT) and reduced tillage (RT) improve soil structure (Jatta et al., 2015). However (Ferro et al., 2014) had observed that no tillage can create a soil structure stratification that negatively affects root-growth and root-induced parameters by modifying the soil structure within the soil profile.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Soil sampling

Soil samples were collected at 0 to 20 cm depths from thirteen sites in Eastern Cape Province of South Africa (Figure 1).

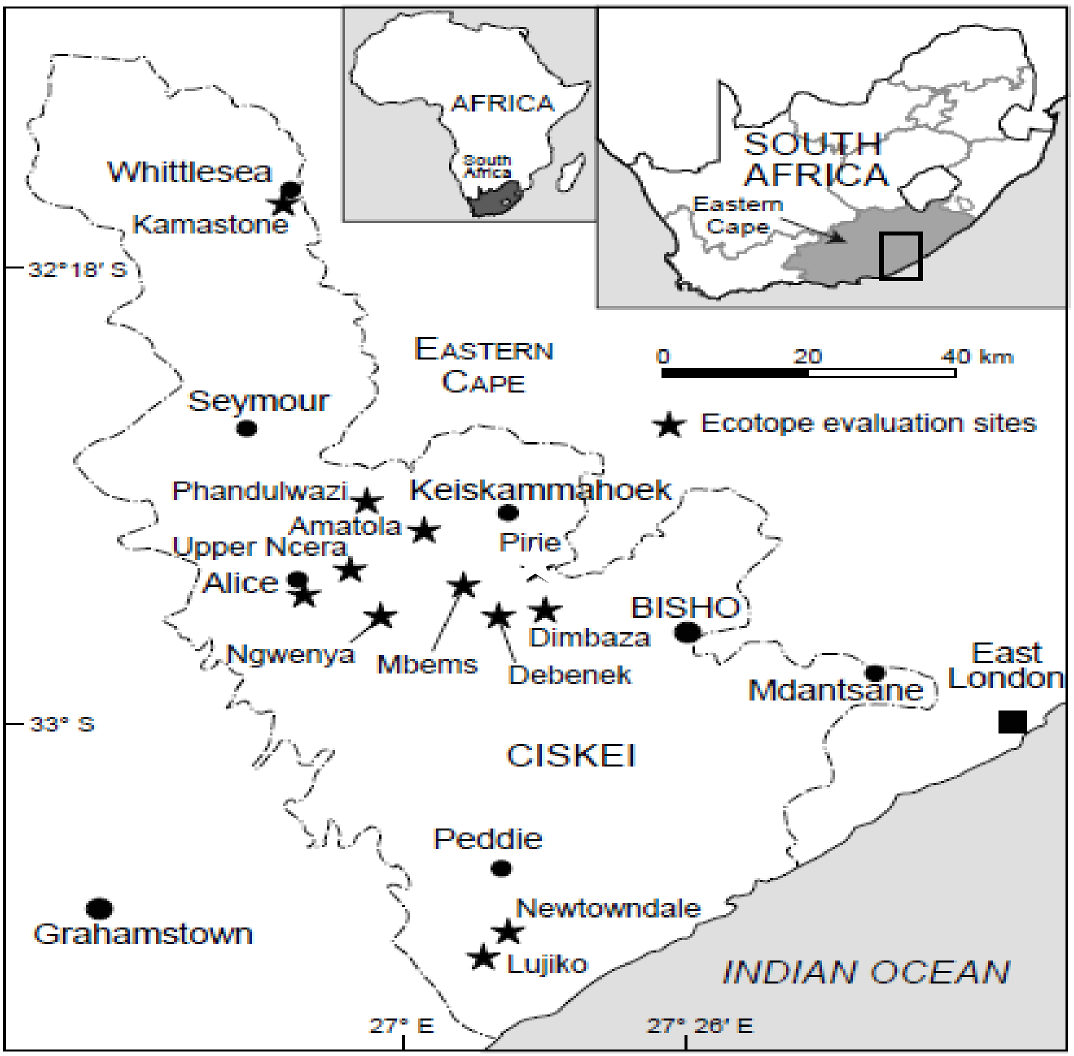


Figure 1. Sampling sites

(Source: Nciizah and Wakindiki, 2012)

Twenty samples were collected from each site making a total of two hundred and sixty samples. Samples from each site were bulked to form a composite sample. The locations were chosen based on similarity in climate, slope and soil, which were designated as Ecotopes (Nciizah and Wakindiki, 2012). The composite sample from each Ecotope was divided into three replicates, giving a total of thirty nine samples.

3.2 Implication of soil tillage and mineralogy on sieving efficiency of Iris FTLVH – 0200 digital electromagnetic sieve shaker (Filtra Vibración SL Spain)

3.2.1 Sieving operation

Each sub sample was passed through a 4.75 mm sieve, gently pressing the large aggregates by hand. Following the procedure described by Barja (2008), fifty grams of each sample, which passed through the 4.75 mm sieve was placed on a nest of sieves 2.0, 1.0, 0.50 and 0.25 mm, stacked top to bottom in descending order. The stack was placed on an Iris FTLVH – 0200 digital electromagnetic sieve shaker (Filtra Vibración SL Spain) to separate the soil into the different aggregate size fractions. The samples were subjected to 64 possible combinations of time (T), interval (I) and power (P) settings. The study was arranged as a factorial in completely randomised design with three replicates, with a total of 192 of sieving operation. The factors comprised four levels each: T1 (one minute), T2 (five minutes), T3 (15 minutes) and T4 (35 minutes); P1 (power level one), P2 (power level three), P3 (power level six), and P4 (power level nine); I1 (one second), I2 (three seconds), I3 (six seconds), and I4 (nine seconds). This was combined to fit into a statistical model for completely randomised factorial design using JMP®version 11 (SAS 2013). The aggregates on each sieve were carefully collected using a soft brush and weighed. The aggregate size distribution, percentage weight of aggregate retained on each sieve, percentage weight of aggregates passing through the stack and eventually the sieving efficiency were determined.

3.2.2 Sieving efficiency

The percentage weight of aggregates retained on each sieve was calculated using equation (1) described by Isavi and Mahmoudi (2013).

$$R_i\% = \frac{W_i}{W_t} \times 100 \qquad (1).$$

Where,

$R_{i\%}$= percentage weight of aggregates retained on the sieve i,

i = i^{th} sieve,

W_i= weight of aggregates on sieve i,

W_t = total weight of aggregates.

The percentage weight of soil aggregates (P_i) that passed through the sieve i was calculated using equation (2) as described by (Isavi and Mahmoudi, 2013).

$$P_i\% = 100 - \sum_{i=n}^{n} R_i \qquad (2).$$

Where,

R_i% is as described in equation (1),
n = number of sieves used = 4.

The setting at which > 10 % of the aggregates began to pass through the < 0.25 mm was considered as the sieving efficiency limit.

3.3 Soil Organic Matter in Soil Physical Fractions

Modified method described by Francisco et al., (2011) was adopted. Briefly, 100 g of soil sample was placed in a 500 mL capped plastic bottle containing 20 glass beads, 5 mm diameter, and 180 mL of deionized water. The suspension was allowed to shake on a rotary shaker for 16 h (100 cycles/min) after which the samples were poured unto a stainless steel pan, any floating material (Fw) was collected and placed in a labelled petri dish. The soil suspension was stirred and poured unto a 250 µm sieve and material retained on the 250 µm sieve (coarse sand fraction) was placed in a glass beaker and washed several times with deionised water. Soil materials that pass through the 250 µm sieve consisting of fine sand particles plus silt and clay were mixed together with the washed coarse sand fraction and re-suspended in 100 mL of deionized water. The suspension was poured into a stack of sieves (250, 106, 53 and < 53 µm), arranged in descending order of aperture size and using an Iris (FTLVH – 0200) digital electromagnetic sieve shaker (Filtra Vibración SL Spain) the soil samples were separated into coarse sand (> 250 µm), fine sand (106 to 250 µm), silt-size (53 to 106 µm) and clay-size (< 53 µm).

3.3.1 Soil carbon and nitrogen

The carbon and nitrogen concentration in Fw, particle-size classes (> 250, 106, 53, and < 53 µm) and whole bulk soil samples were determined using the TruSpec CNS analyser (LECO Corporation, USA). Determination of SOC by dry combustion converts all carbon in the presence of oxygen to CO_2 during a heating process (Krull et al., 2004). The relative percentage change of carbon and nitrogen in the whole soil and in the physical fractions of the soil samples was calculated using the relationship (equation 3 and 4) described by Francisco et al., (2011).

$$\%\Delta C = \frac{C_p - C_c}{C_p} \times 100 \qquad (3).$$

Where,

%ΔC = Percentage change in carbon

C_P = Percentage of the total carbon in the whole soil sample or in the physical fractions of soils under no tillage system,

C_C = Percentage of the total carbon in the whole soil sample or in the physical fractions of soils under conventional tillage system,

$$\%\Delta N = \frac{N_p - N_c}{N_p} \times 100 \qquad (4).$$

Where,

$\%\Delta N$ = Percentage change in nitrogen

N_P = Percentage of the total nitrogen in the whole soil sample or in the physical fractions of soils under no tillage system,

N_C = Percentage of the total nitrogen in the whole soil sample or in the physical fractions of soils under conventional tillage system.

3.4 Aggregate stability

3.4.1 Micro aggregate stability

The hydrometer method (Okalebo et al., 2002) was used to determine the micro aggregate stability. Fifty grams of the air dried < 2.0 mm soil sample was weighed into a 400 ml beaker and saturate with distilled water, 10 ml of 10 % calgon solution was added to the suspension as a dispersant. The suspension was allowed to stand for 10 min and transferred into a dispersing cup. About 300 mL of water was added before mixing the suspension for 2 min with an electric high speed stirrer. The suspension was transferred into a graduated cylinder and made up to mark with distilled water. The suspension was stirred with a plunger. Amyl alcohol was added to reduce foaming. A hydrometer reading was taken and recorded after 40 s, the suspension was again stirred with the plunger and allowed to stay for two hours before another hydrometer reading was taken and recorded. The procedure was repeated without calgon. The temperature of the suspension was taken before each hydrometer reading.

Micro aggregate stability was calculated using the following indices.

(i) Dispersion ratio (DR),

$$DR = \frac{a}{b} \qquad (5).$$

Where,

a = percent silt + clay in water-dispersed samples,

b = percent silt + clay in calgon dispersed sample.

(ii) Clay flocculation index (CFI),

$$CFI = \frac{b-a}{b} \times 100 \qquad (6).$$

Where,

a and b are as described in equation 5.

(iii) Clay dispersion ratio (CDR),

$$CDR = \frac{WDC}{TC} \qquad (7).$$

(iv) Aggregated silt and clay (ASC),

$$ASC = (TC + TS) - (WDC + WDS) \qquad (8).$$

Where,

TC = Percentage total clay obtained with calgon,

TS = Percentage silt obtained with calgon,

WDC = Water dispersible clay. Percent clay obtained using deionised water,

WDS = Water dispersible silt. Percent silt obtained using deionised water.

3.4.2 Macro aggregate stability

Wet sieving

Macro aggregate stability was studied using the method described by (Igwe et al., 2013). Fifty grams of < 4.75 mm air-dried soil was put in the topmost of a nest of four sieves of 2.00, 1.00, 0.50, and 0.25 mm mesh size and pre-soaked for 5 min in deionised water. Thereafter, the nest of sieves and its content were oscillated vertically in water 60 times using 40 mm amplitude at the rate of one oscillation per second. After wet-sieving, the resistant soil materials on each sieve and the unstable (< 0.25 mm) aggregates were transferred into beakers, dried in the oven at 105 °C for 24 hours.

Dry sieving

Following the method described by Zhang et al., (2012), fifty grams of the <4.75 mm air-dried soil samples were placed on a nest of sieves; 2.00, 1.00, 0.50, and 0.25 mm mesh size mounted on a Iris FTLVH – 0200 digital electromagnetic sieve shaker (Filtra Vibración SL Spain). The sieves were mechanically shaken to separate the dry aggregates into size classes > 2, 1 to 2, 0.5 to 1, 0.25 to 0.5 and < 0.25 mm. The data obtained were used in the following macro-aggregate stability indices.

(i) Mean-weight diameter (MWD),

The mean weight diameter for both water-stable and dry aggregates was computed using the relationship described by Igwe et al., (2013).

$$MWD = \sum_{i-1}^{n} x_i w_i \qquad (9).$$

Where,

MWD = mean weight diameter of stable aggregates (mm),

x_i = mean diameter of each size fraction (mm),

w_i = proportion of the total sample weight in the corresponding size fraction (g)

n = number of sieves used = 4.

(ii) Water stable aggregates (WSA).

The percentage of the aggregates in each sieve represented the water-stable aggregates (> 0.25 mm) and was calculated using the following relationship.

$$WSA = \frac{M_{a+s} - M_s}{M_t - M_s} \times 100 \qquad (10).$$

Where,

WSA = Percentage of water-stable aggregates,

M_{a+s} = mass of the resistant aggregate plus sand fraction (g),

M_s = mass of the sand fraction alone (g),

M_t = total mass of the soil sieved (g).

(iii) Water stable aggregate of different aggregate size fractions

The percentage ratio of aggregates in each sieve represented the water stable aggregate of aggregate size fractions 1 to 2, 0.5 to 1, 0.25 to 0.5 and < 0.25 mm.

(iv) State of aggregation (SA) (%)

$$SA = \frac{WSA > 0.25 - M_s}{M_t} \times 100 \qquad (11).$$

Parameters are as described in equation (10).

(v) Potential Structural Deformation index

The potential structural deformation index (PDSI) as described by Mbagwu (2003) was computed as follows:

$$PSDI = \left[1 - \frac{MWD_w}{MWD_d}\right] \times 100 \qquad (12).$$

Where,

MWDw = MWD from wet sieving,

MWD_d= MWD from dry sieving.

3.5 Soil Mineralogy

The Rietveld method for x-ray diffraction quantitative analysis as described by (Zabala et al., 2007) was used to determine the mineralogy of the soils. Briefly, milled soil samples were prepared according to the back-loading method. The samples were analysed with a PANalytical X'Pert PRO powder diffractometer with a X'celerator detector, variable divergence and fixed receiving slits with Fe-filtered Co-Kα radiation. The phases were identified using X'Pert Highscore Plus software. The relative phase amounts (weights %) were then estimated using the Rietveld method.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Tillage and soil structure-related properties

The tillage and soil structure-related properties are shown in Table 1. Two tillage systems (CT and NT systems) were common practices in these ecotopes. Under conventional tillage, soils were ploughed up to 20 cm depth during land preparation and preceding crops were harvested manually, removing the above ground biomass. In the case of NT the aboveground parts of the crop residues were cut after harvest and left on the soil surface. Sowing of the next crop was done by placing seeds into the holes drilled between the standing stubbles. These tillage systems have been practiced for at least five years prior to this study. Sites under NT were observed to be used for grazing livestock. The dominant textural classes are sandy clay loam and sandy loam. The mineralogy showed a predominance of quartz and Kaolinite while the SOM ranged from 24.0 g/kg to 66.1 g/kg. The percentage sand was higher than silt and clay for all soils. The soils were classified as Oakleaf (Soil Classification Working Group, 1991)

Table 1. Tillage and soil structure-related properties from the various soils

Ecotope/sampling site	Tillage system	Texture %			EC μ/ Sm	Textural class	Climate	pH	SOM g/kg	Soil Mineralogy (%)						
		Sand	Clay	Silt						H#	K	Mi	Mu	P	Q	S
Alice Jozini	CT	60	12	28	47.9	SL	SA	5.78	35.7	0.29	-	4.40	6.10	12.2	77.01	-
Amatola	CT	47	37	15	28.47	SCL	SH	5.80	66.1	1.91	32.4	4.36	2.74	9.29	28.88	14.7
Debenek	CT	56	18	26	49.23	SL	SA	5.79	24.0	0.30	2.10	4.59	8.50	84.5	-	-
Kamastone	CT	72	19	9	66.47	SL	SA	6.27	31.8	0.67	8.56	10.0	18.8	5.90	5.96	-
Lujiko Leeufontein	CT	68	19	11	52.23	SL	SA	5.45	38.2	0.63	-	8.61	5.14	10.4	75.14	-
Mamatha	CT	61	18	21	34.50	SL	SA	5.50	29.9	0.43	-	5.52	6.46	12.2	75.32	-
Mbems Koedosvlei	NT	56	21	23	55.17	SCL	SA	5.65	34.3	1.10	-	4.99	6.58	9.97	77.35	-
Mbems Koedosvlei	CT	56	22	22	80.97	SCL	SA	5.76	42.7	0.65	-	4.69	7.76	10.50	76.37	-
Ncera	CT	48	26	26	61.50	SCL	SH	5.08	41.9	1.12	9.30	4.48	3.12	8.23	61.90	9.9
Newtondale	CT	65	21	14	40.34	SCL	SA	6.25	51.4	0.76	-	10.5	7.83	8.11	72.74	-
Ngwenya Jozini	CT	72	18	10	41.27	SL	SA	6.49	36.4	0.56	-	8.83	5.78	16.60	68.22	-
Ngwenya Swertland	NT	67	21	12	53.57	SCL	SA	5.53	28.4	0.66	-	7.50	6.51	17.20	68.11	-
Phandulwazi	NT	58	21	21	37.80	SCL	SA	5.49	24.7	0.58	-	0.98	3.95	7.64	86.85	-

CT = Conventional Tillage, NT = No Tillage, SOM = Soil organic matter, $H^{\#}$= hematite, K = kaolinite, Mi = microline, Mu = muscovite,

P = plagioclase, Q = quartz, S = smectite

SC = sandy clay, SL = sandy loam, SCL = sandy clay loam

SA = semi-arid, SH = sub-humid

(Source: Nciizah and Wakindiki, 2012)

4.2 Implications of tillage, and mineralogy on the sieving of the aggregates

4.2.1 Percentage of aggregates retained on each sieve.

The percentage of aggregates retained on each sieve is shown in Table 2. Percentage aggregates retained on the sieves decreased with decrease in sieve aperture for both tillage systems and mineralogy considerations. About 70 % of the aggregates were retained on the 2 mm sieve. Hence these soils did not contain much micro aggregates (≤ 0.5 mm).

Under tillage system consideration, the highest percentage of aggregates retained on the sieves was 71.9 % on the 2 mm sieve in the soils under CT, and the least was 0.5 % on the 0.25 mm sieve in soils under NT. The percentage of aggregates retained on each sieve for soils under CT was higher compared to the percentage of aggregates retained on corresponding sieves for soils under NT. This is because of the breakdown and redistribution effect of tillage on soil aggregates. Similar report was given by Munkholm and Schjonning (2004).

Under mineralogy considerations the highest percentage of aggregates retained on the sieves was 86.0 % on the 2 mm sieve and the least 0.2 % on the 0.25 mm sieve. Both of these were in soils dominant in quartz. The percentages of aggregates retained on sieves < 2 mm aperture were comparatively higher in soils dominant in kaolinite than soils dominant in quartz. This result shows that kaolinite dominated soils were of smaller particle (< 2 mm) size than quartz dominated soils. Ramasamy et al., (2014) observed that quartz was of sand size while kaolinite was of clay size. This result implies that in these ecotopes, soils dominant in kaolinite would be less porous, prone to water logging and susceptible to high wind erosion. Ecotopes dominant in quartz are likely to show traits opposite to ecotopes dominant in kaolinite. Management strategies should aim at these factors for enhanced soil productivity.

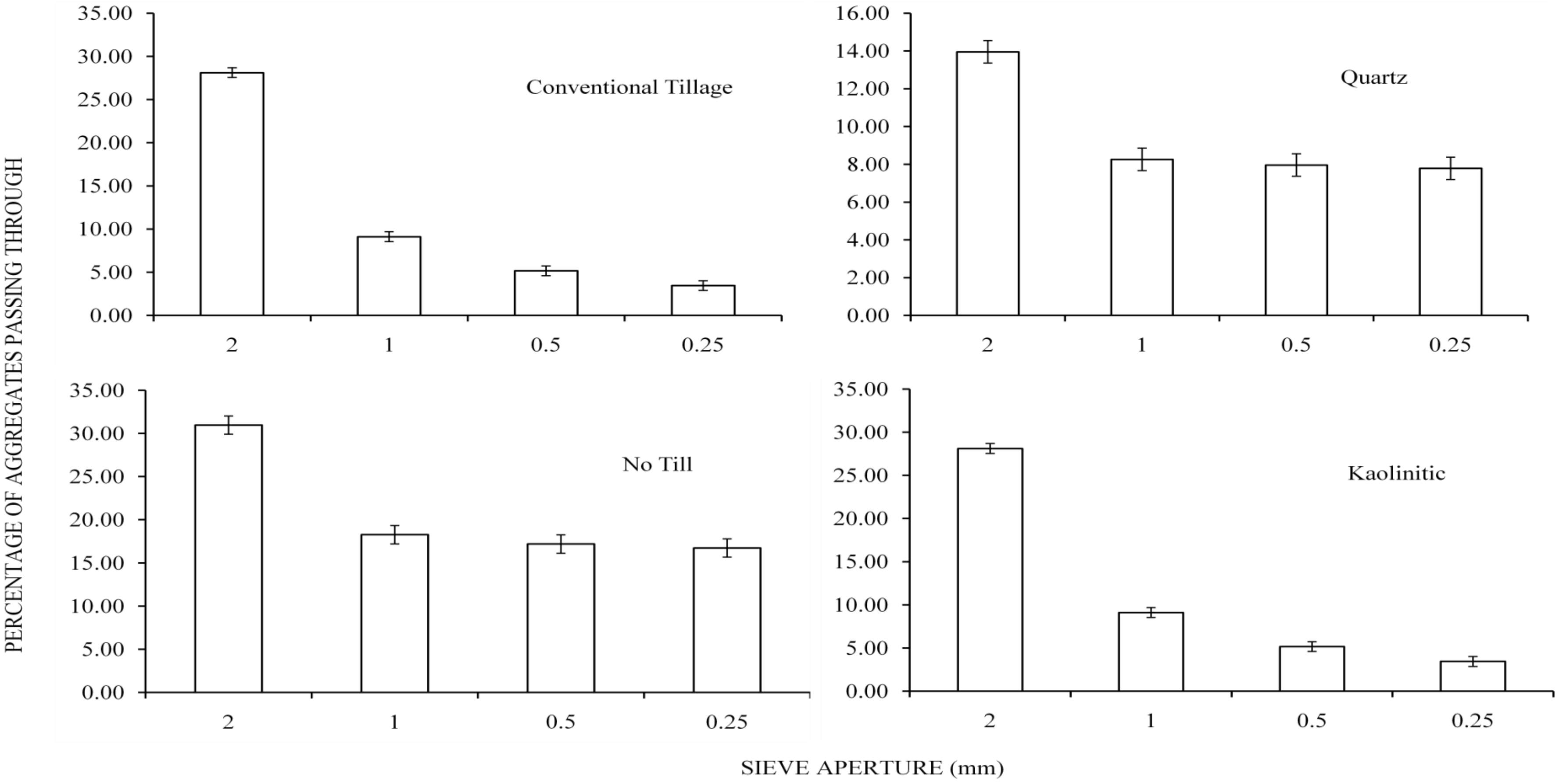
Table 2. The percentage of aggregates retained on each sieve after sieving

Sieve aperture (mm)	Percentage of aggregates retained on the sieves			
	Tillage System		Mineralogy	
	CT	NT	Quartz	Kaolinite
2.00	72	69	86	72
1.00	19	13	6	19
0.50	4	1	0.3	4
0.25	2	0.5	0.2	2

4.2.2 Percentage of aggregates which passed through each sieve aperture

The percentage of aggregates which passed through each sieve aperture is shown in Figure 2. The aggregate distribution decreased with decrease in sieve aperture for all considerations. The 2 to 4.75 mm aggregate class was predominant in soils under CT and soils under NT systems. Previous studies (Ćirić et al., 2012; Gajić et al., 2013) have noted the predominance of 1 to 2 mm size aggregates in top soils irrespective of tillage system. The decrease in aggregates with decrease in sieve aperture was more consistent in soils under CT than in soils under NT. The study showed that CT in these ecotopes affected aggregate size distribution.

The 2 to 4.75 mm aggregate class was dominant in soils with both kaolinite and quartz minerals. The 1 to 2 mm aggregates was higher in the kaolinitic soils than in the soils with quartz. Kaolinite dominated soils had stable 1 to 2 mm aggregate class than quartz dominated soils. The decrease in aggregates with decrease in sieve aperture was more consistent in soils dominant with kaolinite than in soils dominant with quartz. Quartz crystals are of sand size which influenced the aggregate size distribution in these soils. These results are in line with the aggregate hierarchy theory of Tisdall and Oades (2012) which showed the existence of soil aggregates in different size ranges.



Bars indicate standard error

Figure 2. Percentage aggregates distributed in various aggregate size classes.

4.2.3 Implications of tillage, texture, and mineralogy on sieving efficiency

The machine settings that affected the sieving of these soils are shown in Figure 3. Sieving for 35 min (T4) was critical for all significant distribution of aggregate size fractions result. Sieving for 35 min significantly affected the percentage of aggregates that were retained in the sieves irrespective of interval and power levels. For aggregates to pass through the 0.25 mm aperture the aggregates had to be broken into the constituent particles (sand, silt and clay). The 1.00 to 2.00 mm aggregate size was significantly broken when sieving was done for more than 15 min, with the interval and power kept above 6 sec and level 3 respectively.

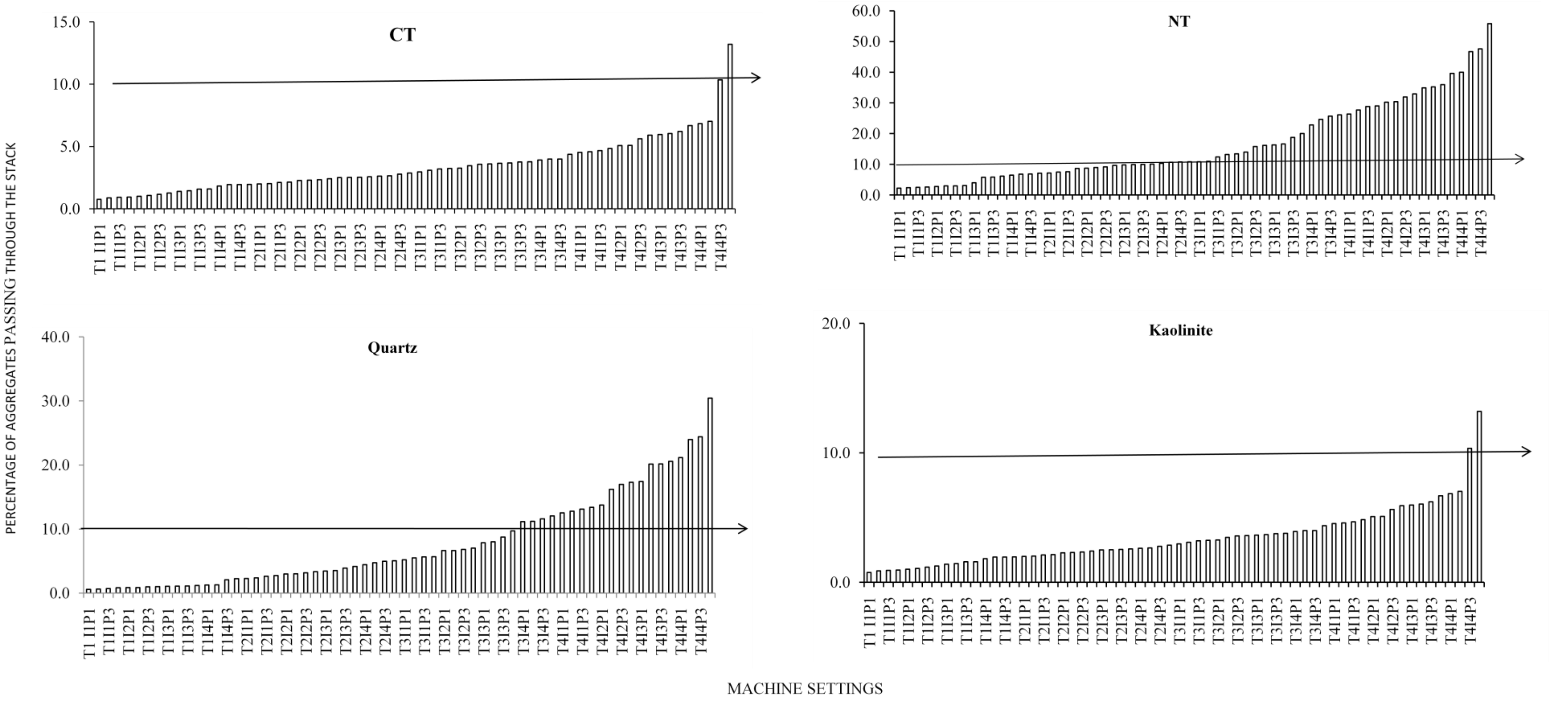
The T4I3P2 and T4I4P3 settings significantly ($p \leq 5\%$) influenced the 1.00 to 2.00 mm aggregate size distribution in the soils irrespective of tillage system (Figure 3). For soils under NT, sieving beyond 5 min at 9 sec interval and power level 6 caused the soil aggregates to be broken into constituent particles, but for soils under CT, sieving lasted up to thirty five minutes before aggregates were broken into the constituent particles. Nahia et al., (2009) working on some Dystric Regosol of the Atlantic area in the Basque Country reported similar findings. The authors attributed the result to the compaction effect of CT equipment on soil aggregates.

Increase in power level from P2 (level 3) to P4 (level 9) significantly influenced the percentage of aggregates retained on the 2.00 mm sieve for soils dominated with kaolinite. The > 0.50 mm aggregates responded either after sieving for 35 min (T4) or increasing both Interval and Power to (I3) 6 sec and (P3) level 6 respectively and sieving for 15 min (T3). The setting T4P4I1 (time 35 min, power level 9 and sieving interval 1 sec) significantly ($p \leq 5\%$) influenced the aggregates retained on the 0.50 mm sieve for quartz soils. The setting

T4I4P4 (time = 35 min, power = level 9 and sieving interval 9 sec) significantly ($p \leq 5\%$) influenced the percentage of aggregates passing through the stack for all the soils irrespective of mineralogy. As the setting levels increased the percentage of soil aggregates passing through the stack of sieves also increased. In a similar study Diaz-Zorita et al., (2007) studying a Maury silt loam and a Mc Afee clay loam in Kentucky USA concluded that increase in sieving time increased fragmentation. Hence increase in the percentage of aggregates passing through the stack of sieves.

More than 10 % of the aggregates passed through the stack of sieves at settings beyond T3I4P3 in quartz dominated soils while in kaolinite dominated soils > 10 % of the soil aggregates passed through the stack of sieves at settings beyond T4I4P3 (Figure 3). Therefore sieving beyond 15 min at 9 sec interval and power level 6 will cause aggregates of soils dominant in quartz to degrade into the constituent particles while sieving beyond 35 min at 9 sec interval and power level 6 will cause degradation in kaolinitic aggregates when using Iris FTLVH – 0200 digital electromagnetic sieve shaker (Filtra Vibración SL Spain) for aggregate analysis of these soils.

For soils under CT system sieving efficiency for aggregate analysis was achieved at T4I4P4. For soils under NT system the sieving efficiency for aggregate analysis was achieved at T2I4P3. Under mineralogy consideration, sieving efficiency was achieved at T3I4P3 setting in quartz dominated soils and at T4I4P3 setting in Kaolinite dominated soils when using Iris FTLVH – 0200 digital electromagnetic sieve shaker (Filtra Vibración SL Spain).



CT = Conventional Tillage, NT = No Till. Horizontal arrow indicates 10 % of aggregates mark

T1 = one minute, T2 = five minutes, T3 = 15 minutes, T4 = 35 minutes, I1 = one second, I2 = three seconds, I3 = six seconds, I4 = nine seconds

P1 = power level one, P2 = power level three, P3 = power level six, P4 = power level nine.

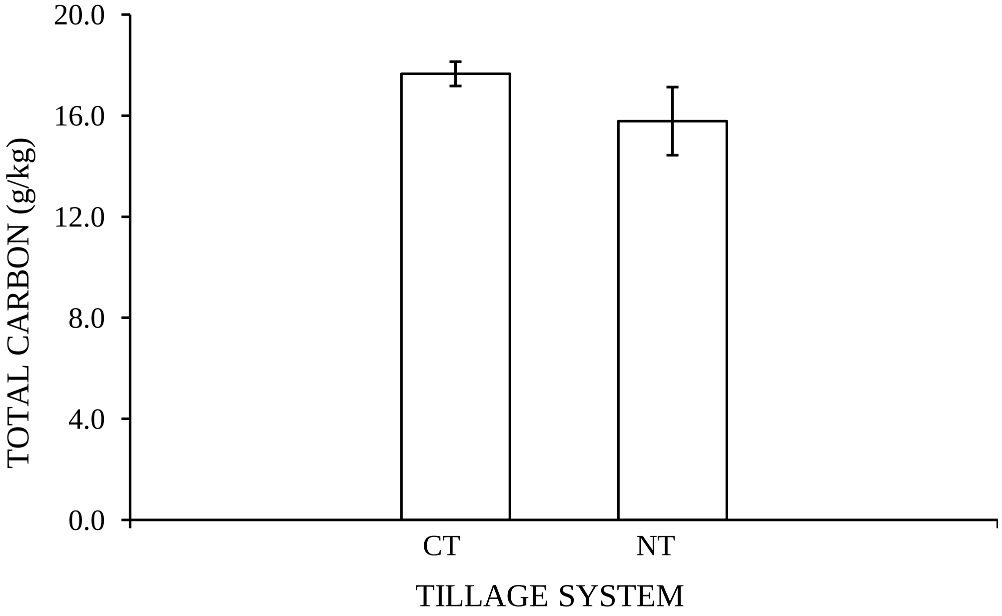
Figure 3. Percentage of aggregates passing through the stack of sieves at different machine settings

4.3 Implication of tillage, texture, and mineralogy on carbon and nitrogen in soil physical fractions

4.3.1 Implication of tillage on carbon and nitrogen in soil physical fractions

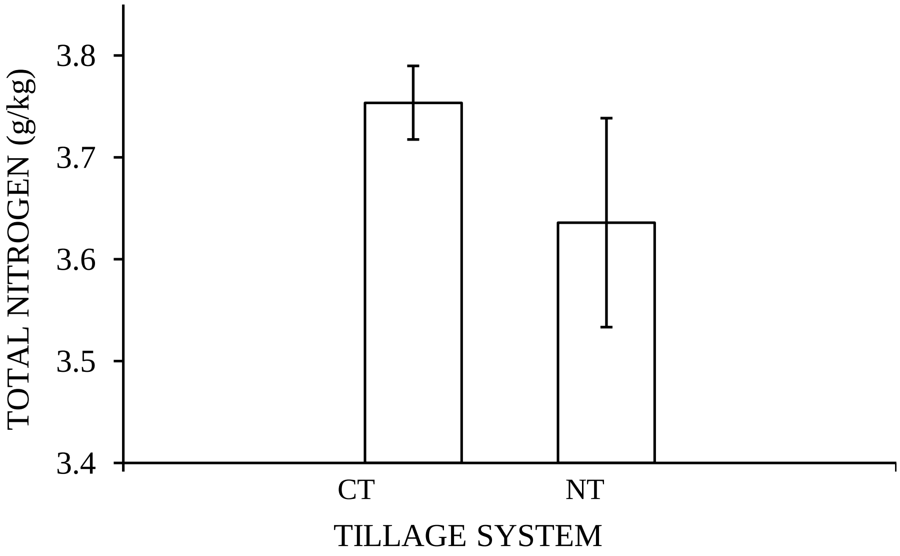
The total carbon and nitrogen content of the soils under different tillage systems is shown in Figure 4. The total carbon in soils under CT was 17.7 g/kg and the total carbon in soils under NT was 15.8 g/kg (Figure 4). The result shows that total carbon was higher in soils under CT. This is attributed to the incorporation of SOM by tillage. These incorporated SOM mineralise into SOC and are retained within soil aggregates. The soils under NT experienced reduction in total carbon due to grazing and wind action which remove plant materials from the soil. Similar finding was reported by Erika et al., (2015) who reported that tillage affected the carbon content in the 0 to 10 cm depth of a Brazilian Dystrophic Red Latosol (Typic Haplortox). The authors concluded that CT incoporated above and below ground crop residue.

The total nitrogen in the soils under CT was 3.8 g/kg and the total nitrogen in soils under NT was 3.6 g/kg (Figure 5). The results showed that total nitrogen in soils under CT was more than that in soils under NT. This trend is consistent with the result in total carbon. Shadrack et al., (2014) had reported similar finding and concluded that CT affected carbon and nitrogen content in the subsoil. Mineralization of SOM results in the release of both carbon and nitrogen. Tillage enhances SOM mineralization. Sources of nitrogen like inorganic fertilizer and leguminous crops were limited in soils under NT. The build up of nitrogen was slower than the rate of removal in soils under NT.



CT = Conventional tillage, NT = No tillage. Bars indicate standard error

Figure 4. Total carbon in the soils under contrasting tillage systems.



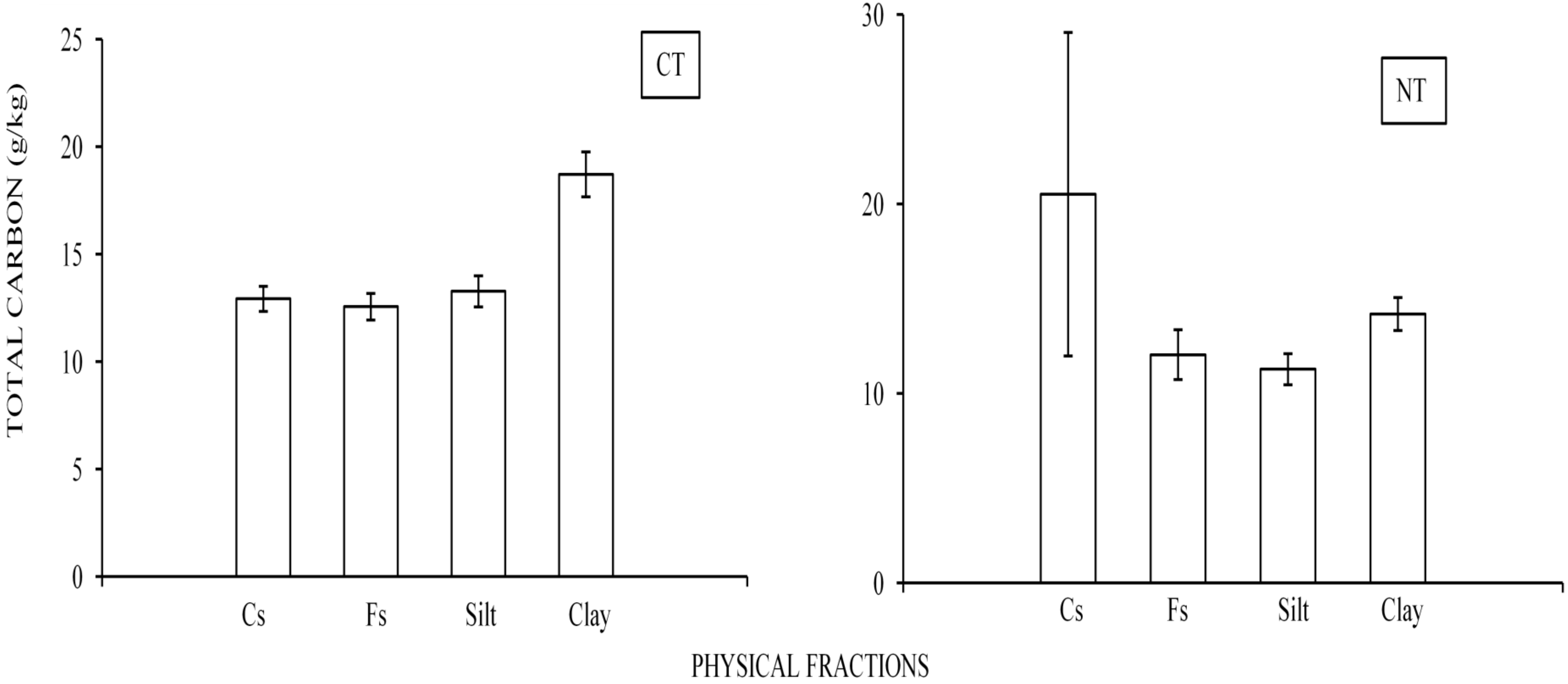
CT = Conventional tillage, NT = No till. Bars indicate standard error.

Figure 5. Total nitrogen in the soils under contrasting tillage systems.

The distribution of carbon in the physical fractions of the soils is shown in Figure 6. The total carbon content in the physical fractions of soils under CT increased with decrease in size of physical fraction. Total carbon content in the physical fractions of soils under NT did not show a consistent trend with size of physical fractions. The total carbon content in the coarse sand (Cs) fraction of soils under NT was 37.1 % higher than the total carbon content in the Cs fraction of soils under CT. The total carbon content in the clay fraction of soils under CT was 24.1 % higher than the total carbon content in the clay fraction of soils under NT.

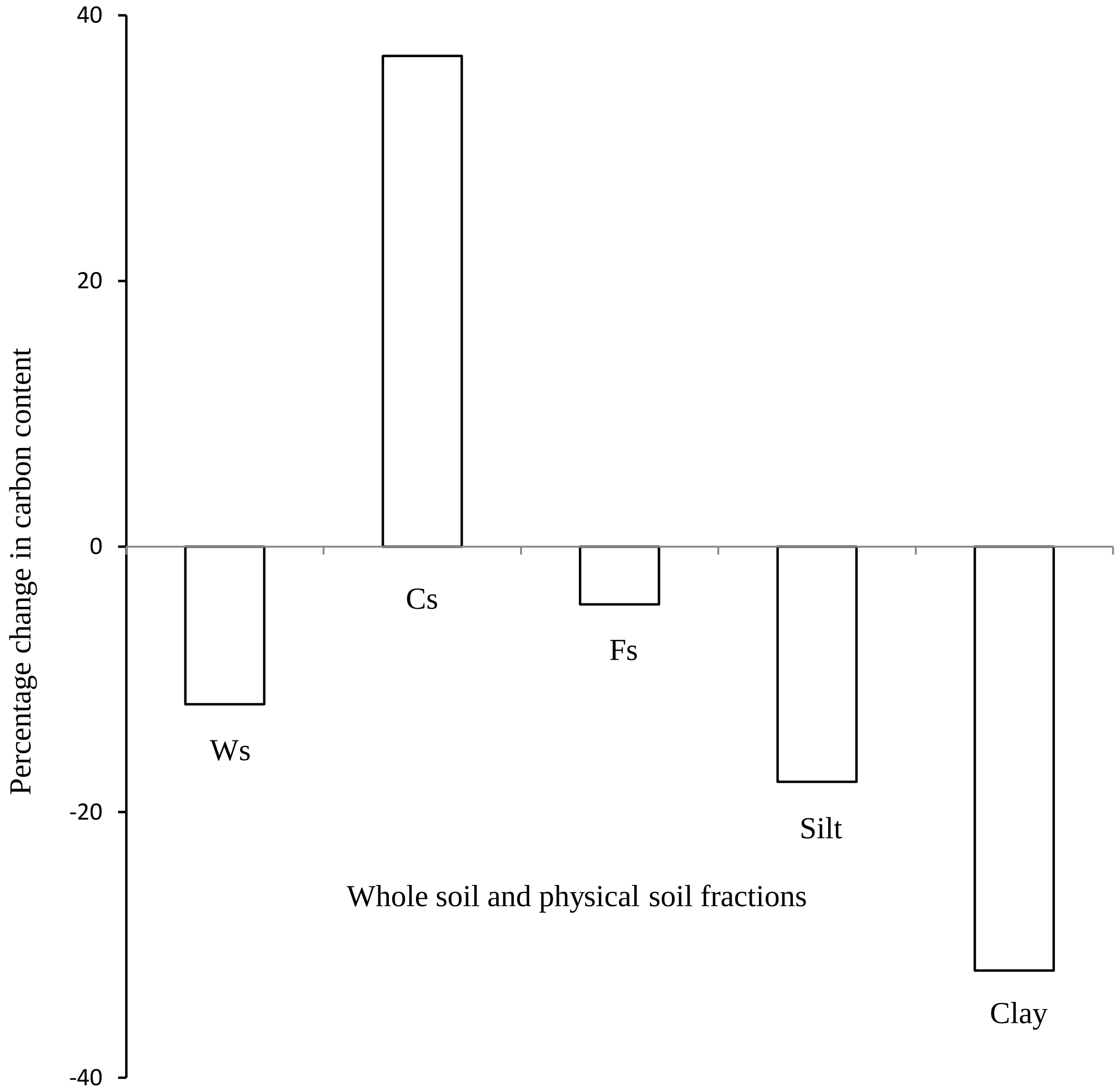
For soils under CT the total carbon content was 12.9 g/kg in the Cs fraction, 12.6 g/kg in the fine sand (Fs) fraction, 13.3 g/kg in the silt fraction and 18.7 g/kg in the clay fraction. While for soils under NT the total carbon content was 20.5 g/kg in the Cs fraction, 12.0 g/kg in the Fs fraction, 11.3 g/kg in the silt fraction and 14.2 g/kg in the clay fraction.

The results showed that CT influenced the total carbon content in the Clay fraction while NT influenced the total carbon content in the Cs fraction. This result was attributed to the redistribution of soil physical fractions and incorporation of SOM by tillage operations. The redistribution affected the carbon attached to these physical fractions. Erika et al., (2015) had reported similar finding and attributed the result to the linkage between organic matter and soil mineral fraction. The relative change in the carbon content in the whole soil and physical fractions of the soils with change in tillage system is shown in Figure 7. This figure shows that CT resulted to a loss in the total carbon content in the Fs, silt, clay fractions and whole soil. Also CT caused an increase in the total carbon of the Cs fraction of the soils.



CT = Conventional tillage, NT = No till, Cs = Coarse sand, Fs = Fine sand. Bars indicate standard error.

Figure 6. Total carbon in the physical fractions of the soils under contrasting tillage systems.

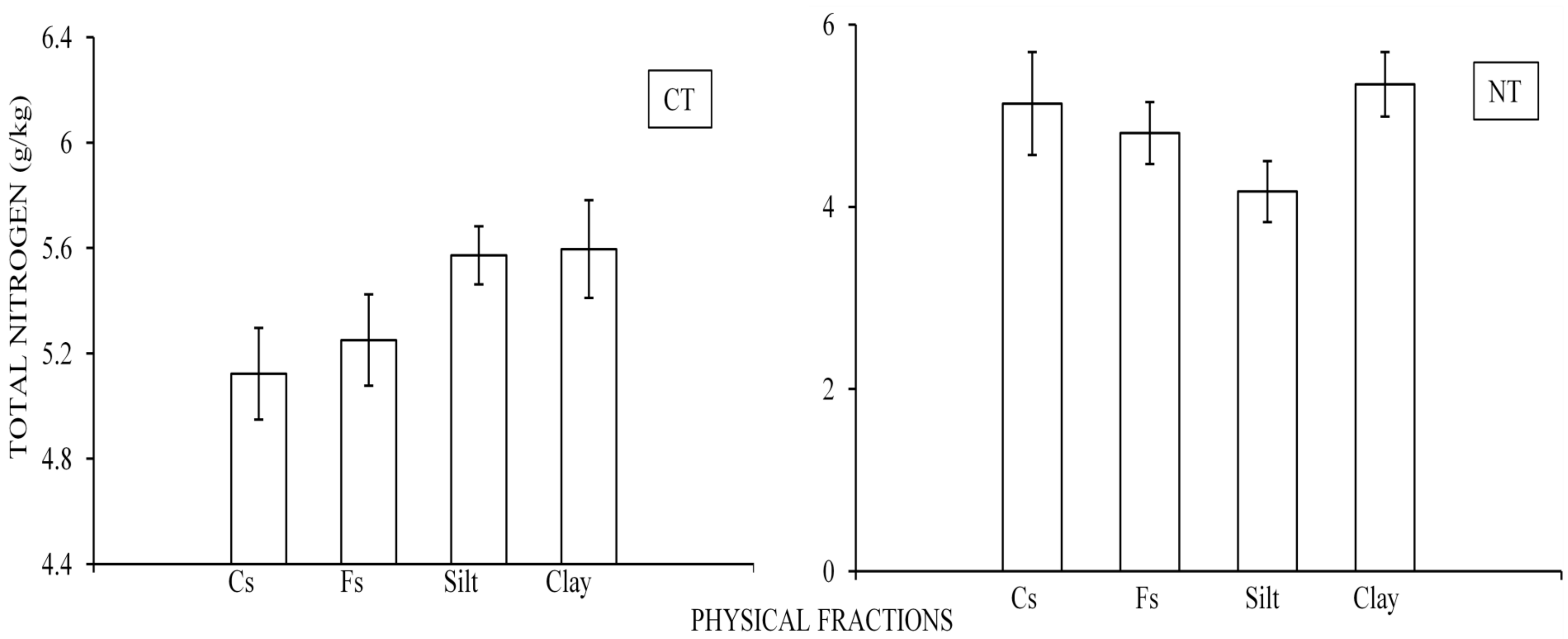


Ws = Whole soil, Cs = Coarse sand, Fs = Fine sand

Figure 7. Percentage change in carbon content in the whole soil and physical fractions.

The loss in total carbon increased with decrease in size of physical fractions (Figure 7). Similar observation had been made by previous authors who reported changes in the carbon content of sand fractions (Leifeld and Kögel-Knabner, 2005; Erika et al., 2015) silt and clay fractions (Gregorich et al., 2006). Francisco et al., (2011) concluded that such changes were sensitive indicator to land-use and ecological changes.

The distribution of nitrogen in the physical fractions of the soils is shown in Figure 8. The total nitrogen content in the Cs fraction (5.1 g/kg) was not influenced by tillage systems. For soils under CT there was increase in total nitrogen content in the physical fractions with decrease in the size of physical fraction. Total nitrogen was 5.1 g/kg in the Cs fraction, 5.3 g/kg in the Fs fraction, 5.6 g/kg in the silt fraction and 5.6 g/kg in the clay fraction of soils under CT. For soils under NT, the total nitrogen content was 5.1 g/kg in the Cs fraction, 4.8 g/kg in the Fs fraction, 4.2 g/kg in the silt fraction and 5.3 g/kg in the clay fraction.



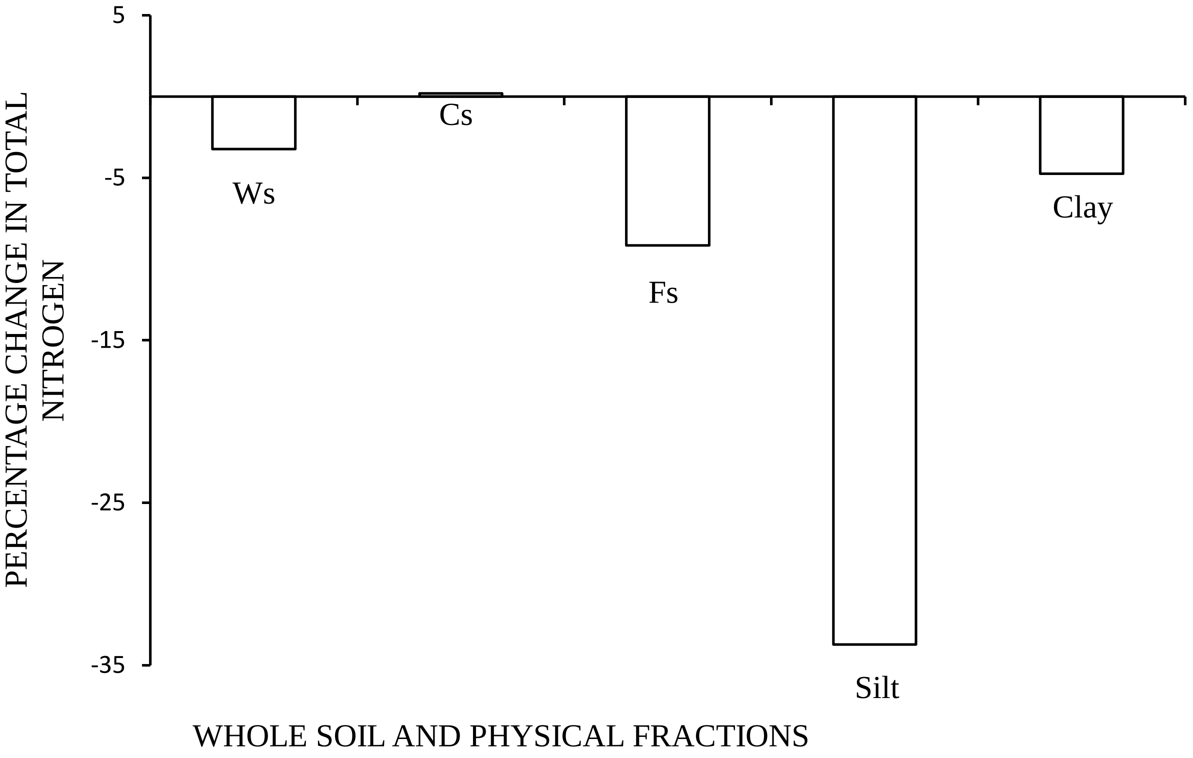
CT = Conventional tillage, NT = No till, Cs = Coarse sand, Fine sand. Bars indicate standard error. Scales on Y-axis vary

Figure 8. Total nitrogen in the physical fractions of the soils under contrasting tillage systems

The results show that the total nitrogen content in the clay fraction of soils under CT was higher than the total nitrogen content in the clay fraction of soils under NT by 5.4 %. The total nitrogen content in soils under CT and soils under NT was higher in the clay fraction compared to other physical fractions. Similar findings were reported by Solomon et al., (2000). The authors observed higher nitrogen content in the clay fraction of chromic luvisols in Tanzania. The authors attributed this to the association of SOM with silt and clay fractions. In their study however the authors observed that CT caused a decrease in nitrogen within three years of continuous cultivation. This result showed that beyond three years of continuous cultivation there would be a gradual build up of nitrogen in soils under CT.

The percent change in total nitrogen content in the whole soil and physical fractions is shown in Figure 9. The figure showed that CT resulted in a loss in total nitrogen in the whole soil, Fs, silt and clay fractions of the soils. There was an increase in total nitrogen in the Cs fraction of the soils under CT. The highest loss in total nitrogen occurred in the silt fraction.

This result is contrary to the findings of Francisco et al., (2011) who repoted an increase in the nitrogen content of the silt fraction with tillage. The authors studied soils classified as Ferrasols in Mexico which had been under continuous cultivation for nine years. This result suggests that the length of time under tillage affect the change in nitrogen content in the physical fractions of the soil.



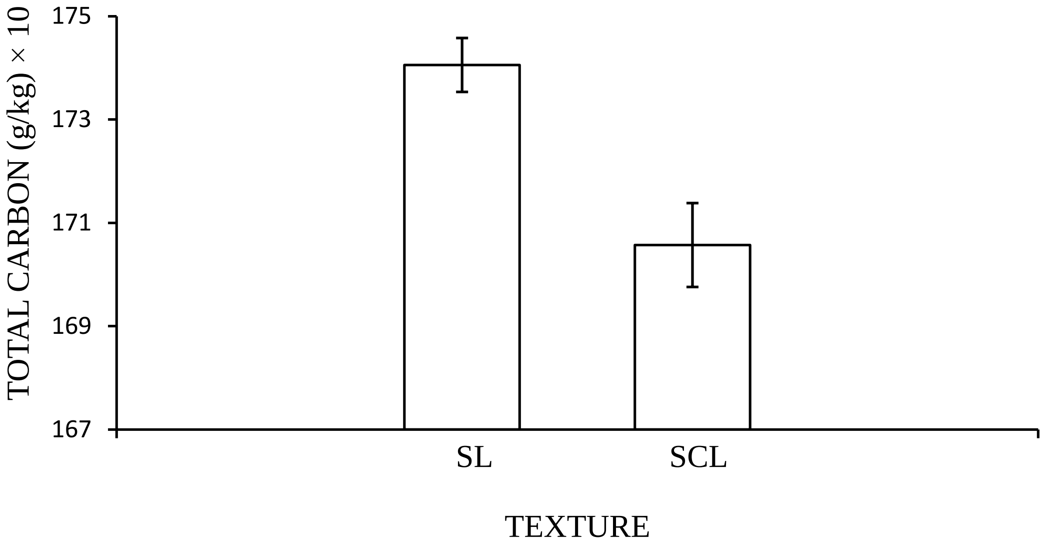
Ws = Whole soil, Cs = Coarse sand, Fs = Fine sand

Figure 9. Percentage change in total nitrogen in the whole soil and physical fractions

4.3.2 Implication of texture on carbon and nitrogen in soil physical fractions

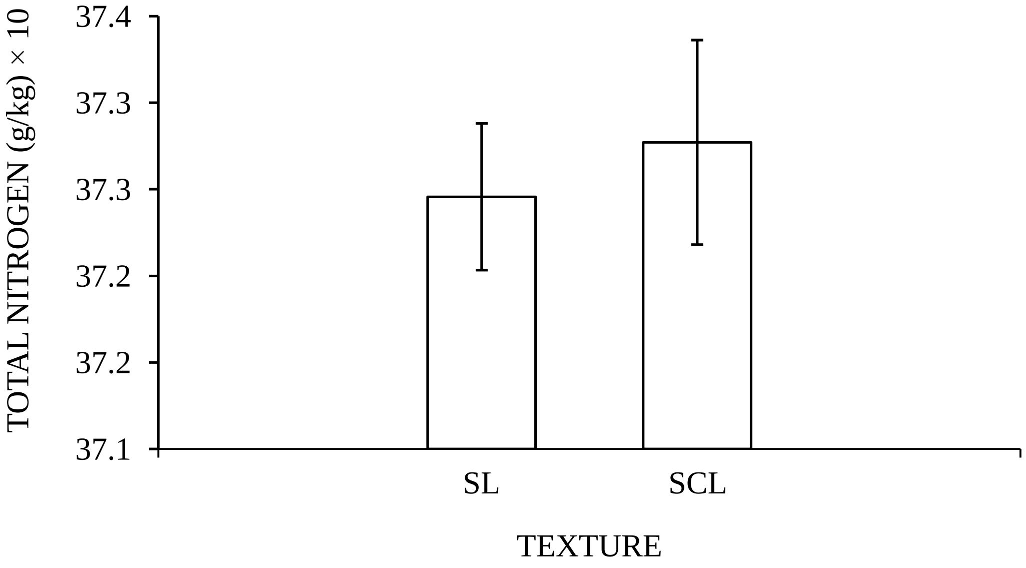
The total carbon and nitrogen content of the soils with contrasting texture is shown in Figures 10 to 13. The total carbon in the soils with sandy loam (SL) texture was higher than the total carbon in the sandy clay loam (SCL) textured soils (Figure 10). The total carbon in the SL texture was 17.4 g/kg and the total carbon in the SCL texture was 17.1 g/kg. The results showed that soils dominated with SL texture accumulated more carbon than soils dominated with SCL texture. This accumulation could be associated with depth of occurrence, mineralogy and tillage practice. Bayer, et al., (2000a) held similar views. The affinity of clay with carbon as reported by some authors (Plante et al., 2006 and Sakin, 2012), cannot be relied upon alone for these soils when considering soil carbon sequestration.

The total nitrogen in SL soils (Figure 11) was 3.7 g/kg and the total nitrogen in SCL soils was 3.7 g/kg. These results showed that the influence of texture on the nitrogen content of these soils was the same. This result was attributed to the high sand content of these soils. Nitrogen content is influenced by surface area of sand and the effect of texture on SOM (Six et al., 2002; Castellano et al., 2012, 2013). The implication of this result is that accumulation of nitrogen in these soils would be slow, and nitrogen attached to sand can be lost easily with sand due to erosion and leaching. Therefore measures to improve nitrogen content of these soil would have to involve both organic and inorganic measures.



SL = Sandy loam, SCL = Sandy clay loam. Bars indicate standard error

Figure 10. Total carbon in the soils with contrasting texture.



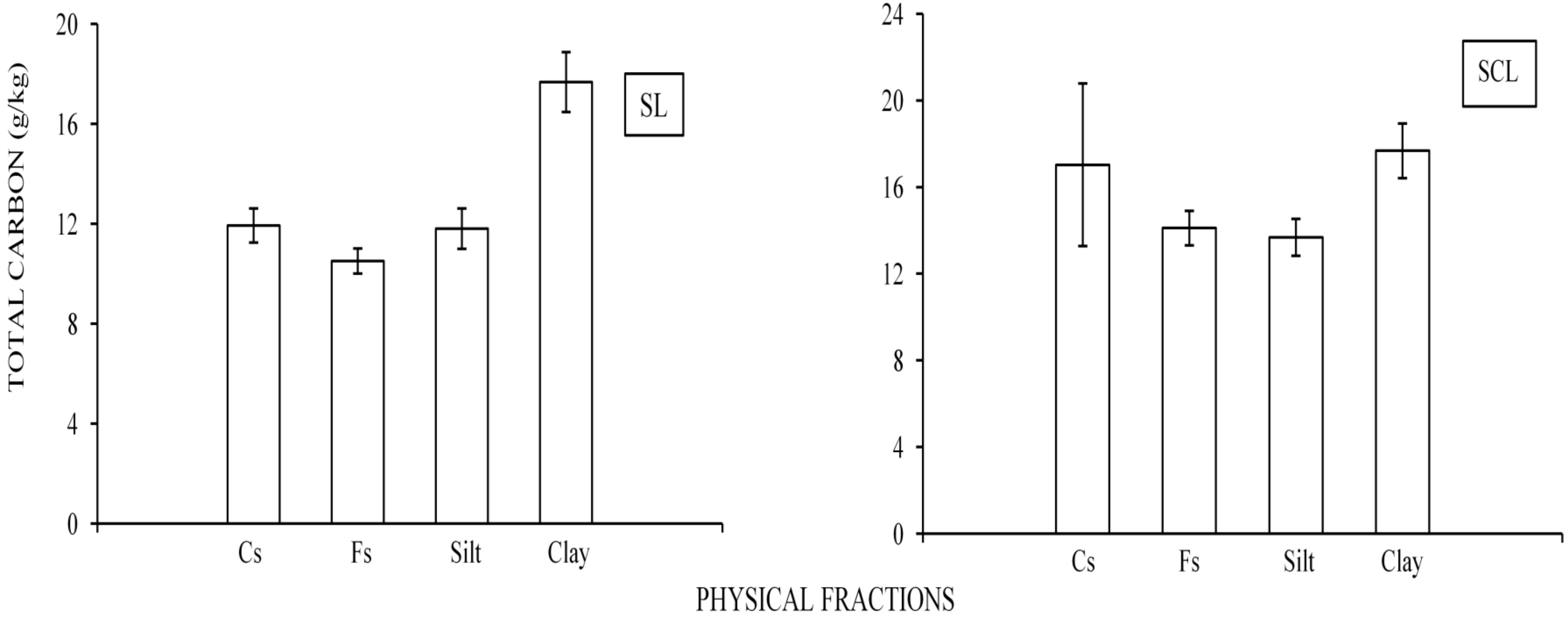
SL = Sandy loam, SCL = Sandy clay loam. Bars indicate standard error

Figure 11. Total nitrogen in the soils with contrasting texture.

The total carbon content in the physical fractions of the soils is shown in Figure 12. The highest (17.7 g/kg) value of total carbon was observed in the clay fraction of soils of SL and SCL textural classes. Therefore clay content in soils in these ecotopes will determine the amount of carbon contained in the soil. The distribution of total carbon across the physical fractions of the soils in both textural classes did not show any regular trend with size of physical fraction. This irregular trend in the distribution of carbon across the physical fractions of the soil can be attributed to other carbon regulating factors like tillage, climate, organic matter accumulation, and microbial activity.

The total carbon in the SL texture soils was 11.9 g/kg in Cs fraction, 10.5 g/kg in the Fs fraction, 11.8 g/kg in the silt fraction and 17.7 g/kg in the clay fraction. For SCL texture soils the total carbon was 17.0 g/kg in the Cs fraction, 14.1 g/kg in the Fs fraction, 13.7 g/kg in the silt fraction and 17.7 g/kg in the clay fraction.

This result showed that the interaction between carbon and physical fractions of the soils was more in the clay fraction. Similar result was reported by Sakin (2012). The author reported higher significant relationship between SOC and clay compared to other fractions for Harran plain soils in South Eastern Turkey. The author attributed the relationship to the organo-mineral complexes formed when Clay combine with SOC in soil. This affinity of clay with carbon and the high clay content of these ecotopes makes these soils potential carbon sink. Further research on carbon saturation limit will enhance the adoption of carbon sequestration strategies in these ecotopes.

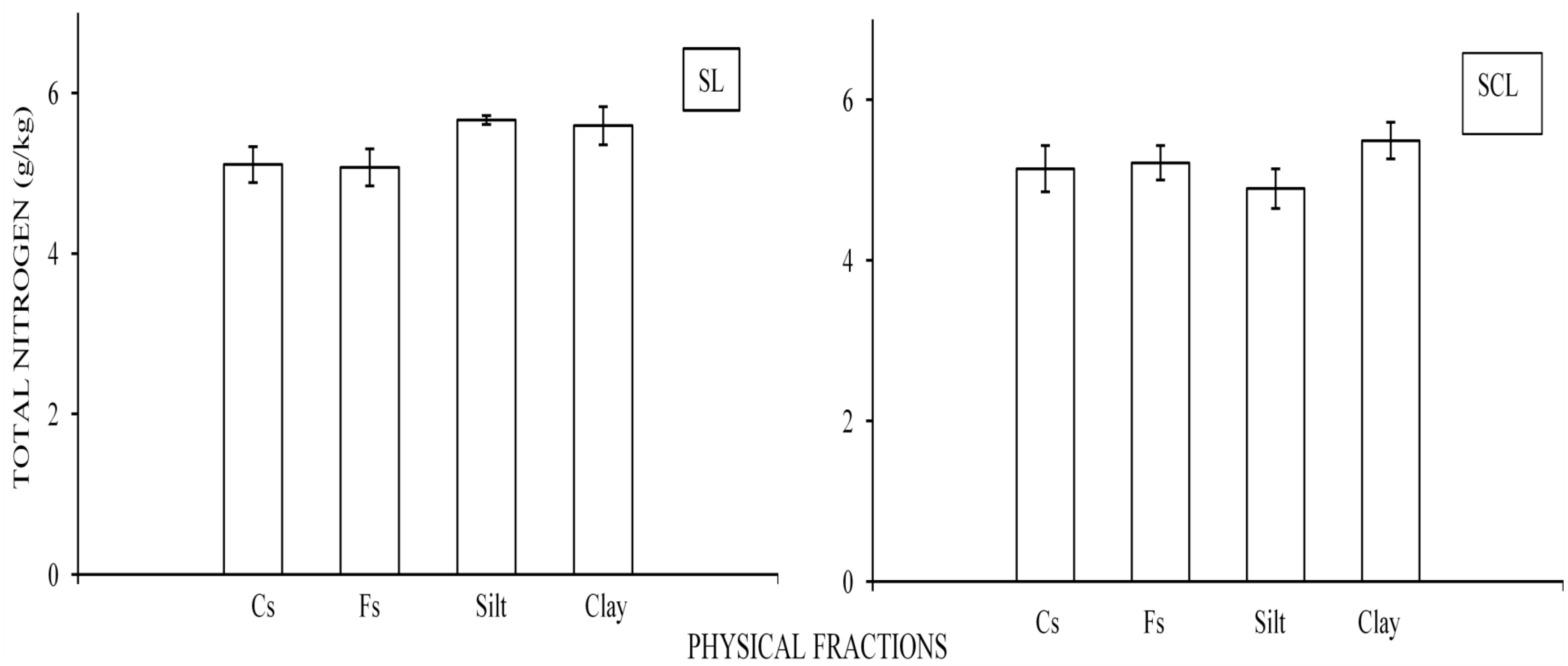


SL = Sandy loam, SCL = Sandy clay loam, Cs = Coarse sand, Fs = Fine sand. Bars indicate standard error. Scales on Y-axis vary.

Figure 12. Total carbon in different physical fractions of the soils with contrasting texture.

Other authors had reported varying views on the relationship between clay and carbon content in soils. Percival et al., (2000) in their study of New Zealand soils reported a poor relationship ($r^2 < 0.05$) between clay and carbon content. McLauchlan (2006) observed a slight relationship between SOC and texture. Six et al., (2000) opined that clay has a slight effect on SOC accumulation rate. These results imply that the relationship between clay and SOC is not universal and caution must be exercised in making assertions based on this relationship. It is suggested that other factors like mineralogy might have contributory effect on texture – SOC relationship.

The total nitrogen content in the physical fractions of the soils is shown in Figure 13. There was no consistent trend in the distribution of nitrogen across the physical fractions of the soils in both SL and SCL textural classes. The total nitrogen was highest (5.7 g/kg) in the silt fraction of the SL soils and the highest in the SCL soils (5.5 g/kg) was observed in the clay fraction. For SL soils the total nitrogen was 5.1 g/kg in the Cs fraction, 5.1 g/kg in the Fs fraction, 5.7 g/kg in the silt fraction and 5.6 g/kg in the clay fraction. The total nitrogen for the SCL soils was 5.1 g/kg in the Cs fraction, 5.2 g/kg in the Fs fraction, 4.9 g/kg in the silt fraction and 5.5 g/kg in the clay fraction.



SL = Sand loam, SCL = Sandy clay loam, Cs = Coarse sand, Fs = Fine sand. Bars indicate standard error.

Figure 13. Total nitrogen in the physical fractions of the soils with contrasting texture.

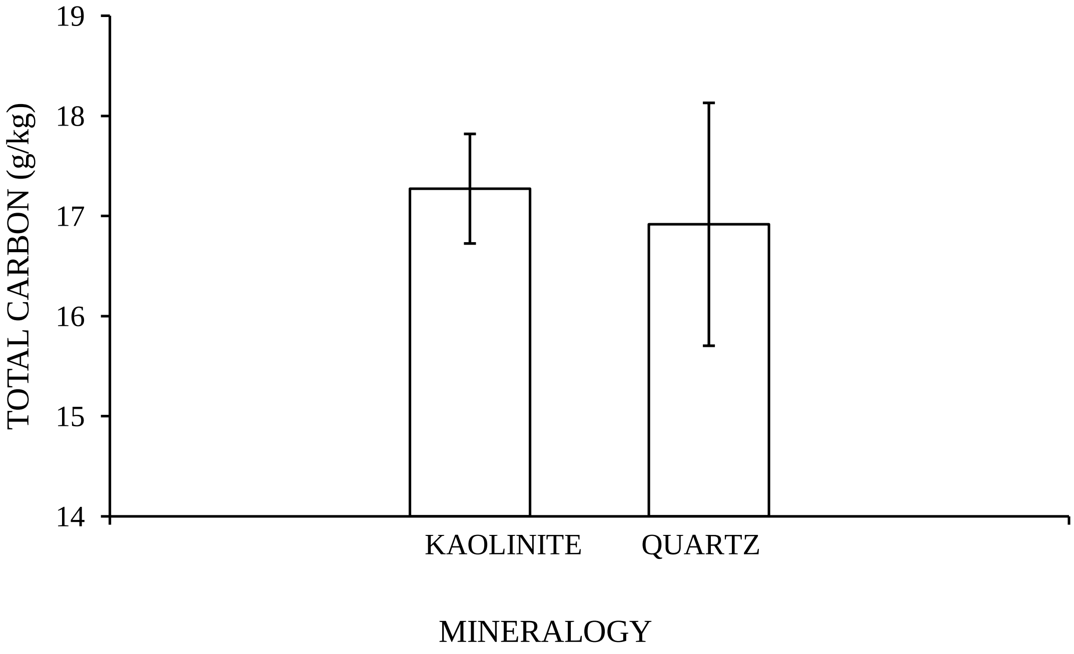
The highest total nitrogen (5.7 g/kg) of the two textural classes (SL and SCL) considered was observed in the silt fraction of the SL soils. Higher values of total nitrogen were observed in the silt and clay fractions in SL soils compared to SCL soils. This result implies that nitrogen accumulation in these soils was influenced more by SL than SCL texture. Clay fraction influenced the total nitrogen content of these soils more than other physical fractions. Studying chromic luvisols in semi-arid northern Tanzania, Solomon et al., (2000) observed similar relationship between nitrogen and clay fraction. The authors asserted that there was nitrogen enrichment in the association of SOM with clay. This association the authors further stated was characterised by a strong attachment with the mineral phase. This result implies that nitrogen content expressed by these soils is a result of the combined effect of all physical farctions. Management practices aimed at improving the nitrogen content of the soils should take into cognisance the textural composition of the soils without much empharses on the physical fractions.

4.3.3 Implication of mineralogy on carbon and nitrogen in soil physical fractions

The total carbon and nitrogen content of the soils as influenced by mineralogy is shown in Figures 14 to 19. The total carbon in the soils dominated with kaolinite (Figure 14) was 17.3 g/kg and the total carbon in quartz dominated soils was 16.9 g/kg. The results showed that kaolinite influenced the total carbon in these soils more than quartz. This result could be attributed to the surface charges of the kaolinite crystals. Schulten and Leinweber (2000) observed an attraction between kaolinite platelets and SOC. Trakoonyingcharoen et al., (2012) reported the effect of the size of kaolinite on cooperation bonding with SOC.

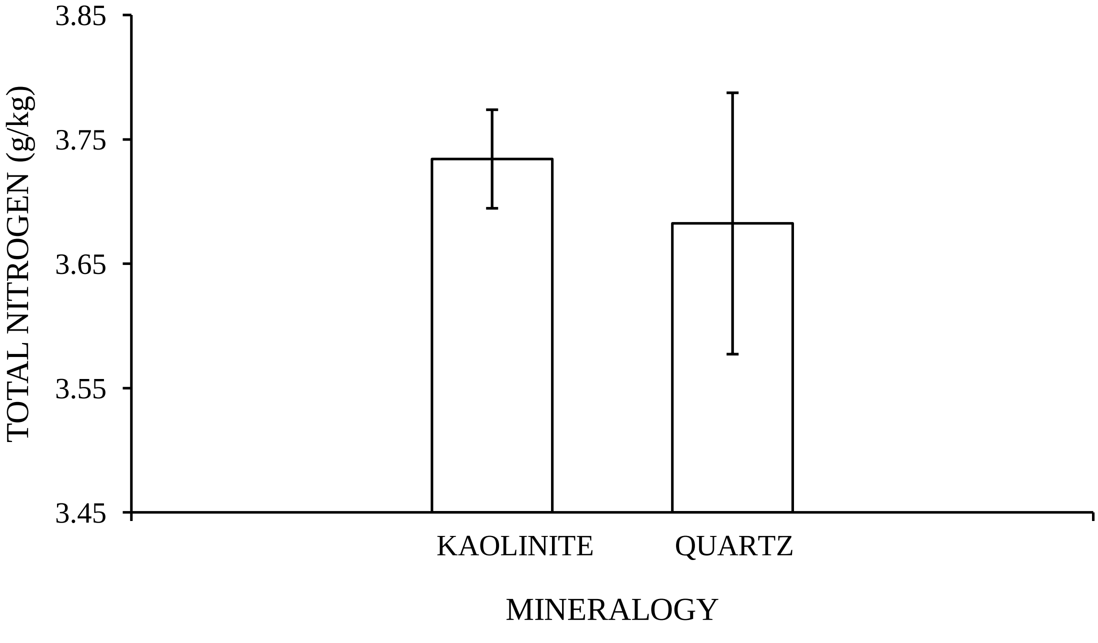
The total nitrogen in the soils with contrasting mineralogy (Figure 15) showed that the total nitrogen in the soils dominated with kaolinite was 3.7 g/kg and the total nitrogen in the soils dominated with quartz was 3.7 g/kg. The margin between the effects of kaolin and quartz minerals for these soils was small but significantly different (p >5%). The implication of this result is that the mineralogy of these soils only influence carbon mineralisation differently. Therefore management measures considering kaolinite and quartz will vary in terms of carbon and nitrogen accumulation. Similar conclusion was reached by Cote et al., (2000) and Castellano et al., (2013) who observed that the total amount of nitrogen an ecosystem can retain is a function of the SOM properties of the ecosystem.

The total carbon in the physical fractions of kaolinite and quartz dominated soils is shown in Figures 16 and 17. The total carbon in the clay fraction was higher than the total carbon in other fractions for both kaolinite and quartz dominated soils. The total carbon in the Fs and silt fractions were consistent for both kaolinite and quartz dominated soils. The total carbon in kaolinite dominated soils (Figure 16) was 13.5 g/kg in the Cs fraction, 14.2 g/kg in the Fs fraction, 15.3 g/kg in the silt fraction and 20.6 g/kg in the clay fraction. For quartz dominated soils (Figure 17) the total carbon was 14.9 g/kg in the Cs fraction, 12 g/kg in the Fs fraction, 12.4 g/kg in the silt fraction and 17.1 g/kg in the clay fraction. The total carbon expressed in both kaolinite and quartz dominated soils is higher in the clay fraction. For these soils it could be said that the clay fraction influenced the carbon content irrespective of mineralogy.



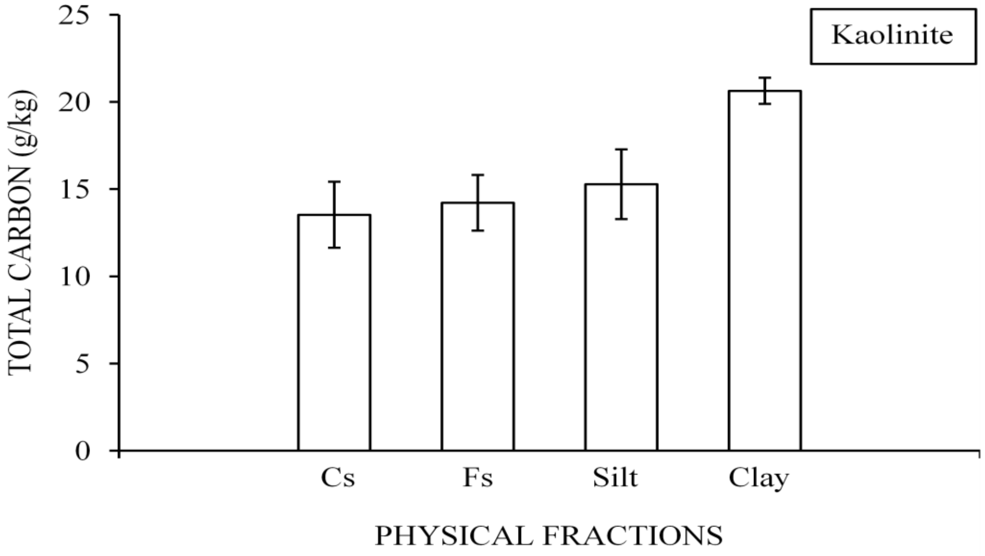
Bars indicate standard error.

Figure 14. Total carbon in the soils with contrasting mineralogy.



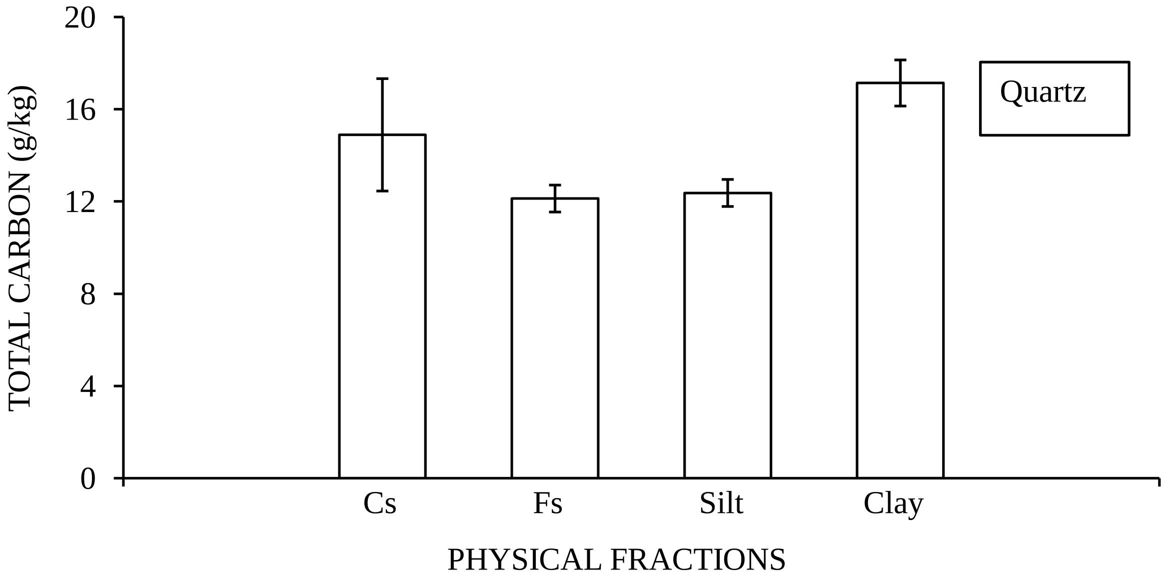
Bars indicate standard error.

Figure 15. Total nitrogen in the soils with contrasting mineralogy.



Cs = Coarse sand, Fs = Fine sand. Bars indicate standard error

Figure 16. Total carbon in the physical fractions of the soils dominant in kaolinite.

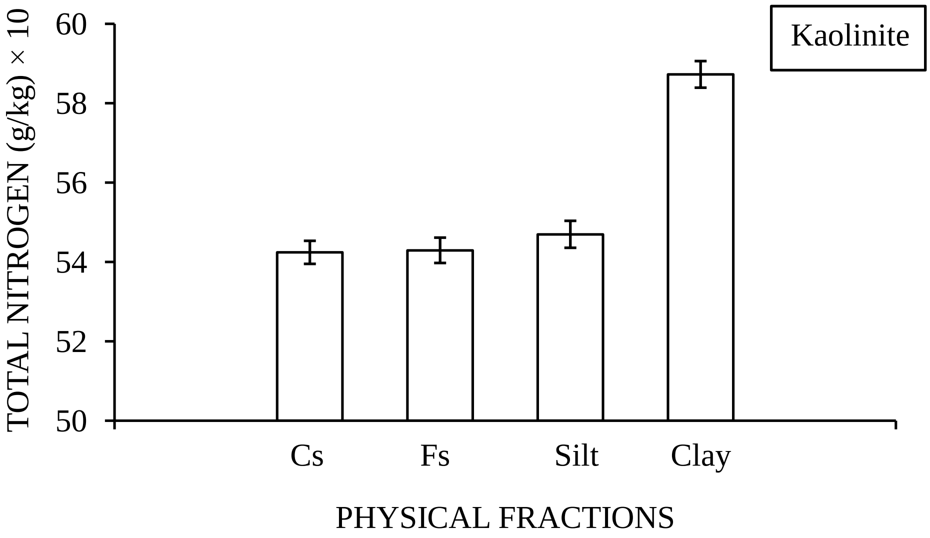


Cs = Coarse sand, Fs = Fine sand. Bars indicate standard error.

Figure 17. Total carbon in the physical fractions of the soils dominated with quartz.

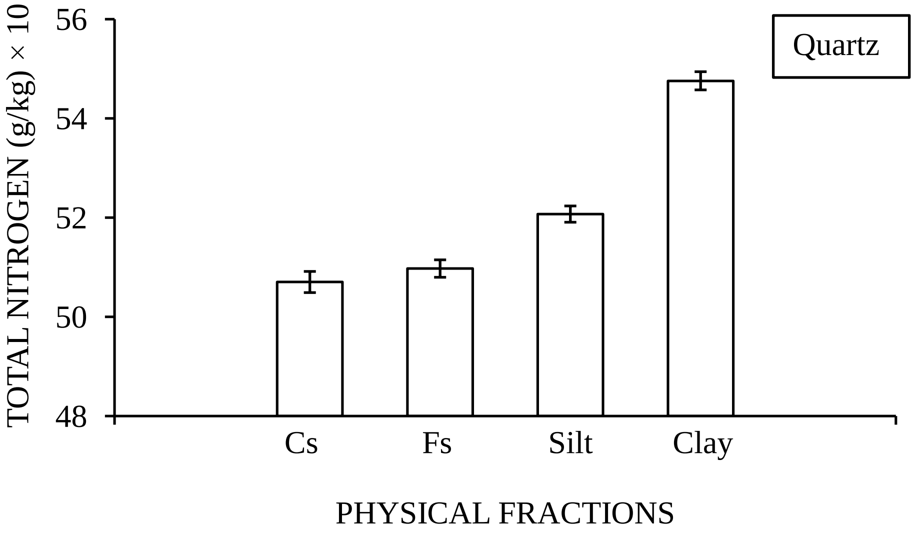
The total nitrogen in the physical fractions (Figure 18) showed that the physical fractions of soils dominated with kaolinite did not influence the total nitrogen in the soil. The effect of kaolinite on the nitrogen content of these soils was expressed more in the clay fraction. The total nitrogen was 5.4 g/kg in the Cs fraction, 5.4 g/kg in the Fs fractions, 5.4 g/kg in the silt fraction and 5.8 g/kg in the clay fraction. For quartz dominated soil (Figure 19) the total nitrogen was 5.1 g/kg in the Cs fraction, 5.1 g/kg in the Fs fraction, 5.2 g/kg in the silt fraction and 5.5 g/kg in the clay fraction. This result is an indication of the effect of texture on nitrogen mineralization in these soils. The nitrogen mineralization in these soils was not a function of any individual physical fraction.

This result showed that the nitrogen content was lower in the Cs and Fs fractions compared to the silt and clay fractions. Similar result was obtained by Bimüller et al., (2014) who observed a lag in nitrogen mineralization in the sand fraction of a German soil classified as Rendzic Leptosol. The lag was due to the larger C/N ratio in the sand fraction compared to other fractions (Aber, 2001) and a labile carbon-rich organic matter pool in the sand fraction (Weintraub & Schimel, 2003) which must first be exhausted before microbes become carbon-starved and start mineralizing nitrogen (Bimüller et al., 2014).



Cs = Coarse sand, Fs = Fine sand. Bars indicate standard error.

Figure 18. Total nitrogen in the physical fractions of the soils dominated with kaolinite.



Cs = Coarse sand, Fs = Fine sand. Bars indicate standard error

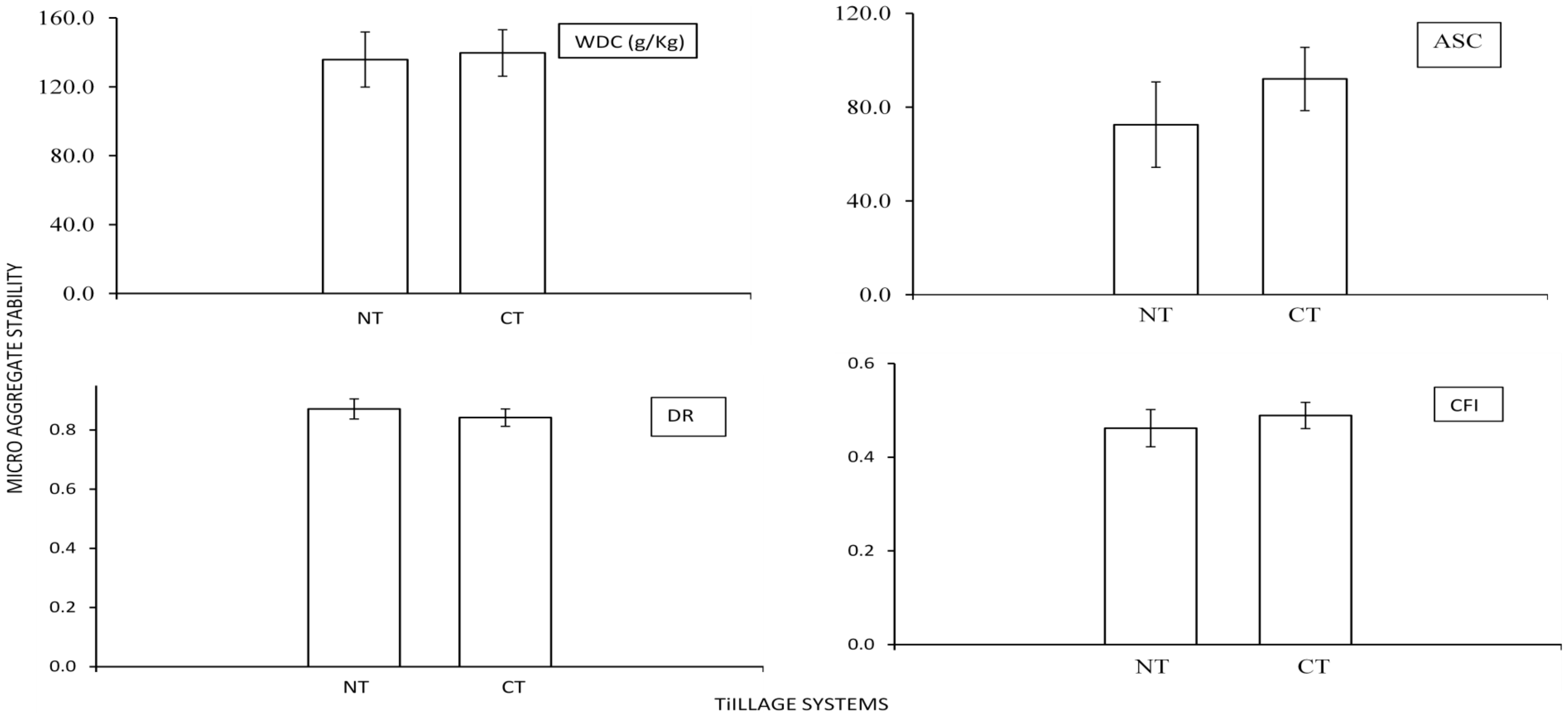
Figure 19. Total nitrogen in the physical fractions of the soils dominated with quartz.

4.4 Implication of tillage, texture, and mineralogy on aggregate stability

4.4.1 Implication of tillage on aggregate stability

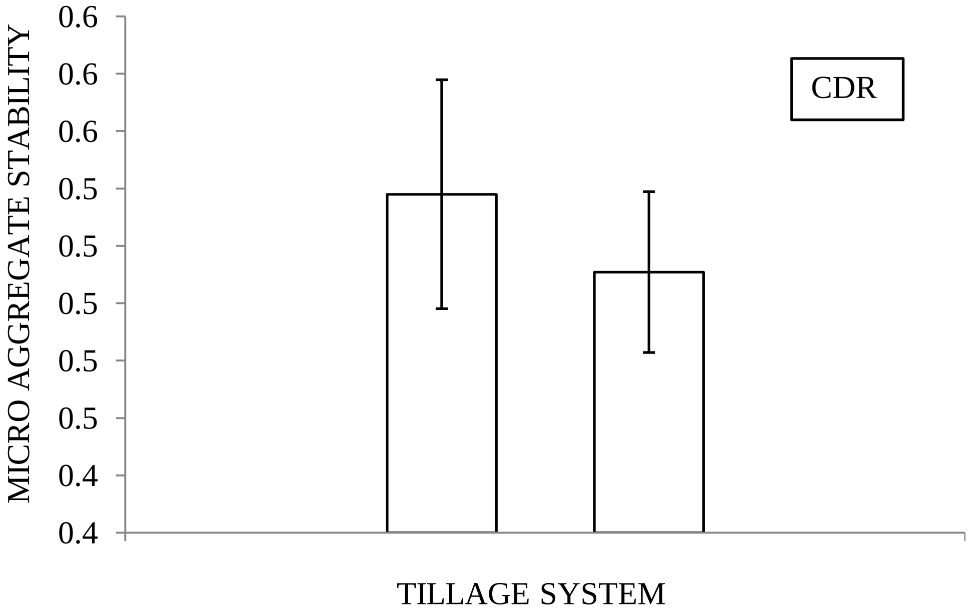
The response of the soils under different tillage management to micro aggregate stability indices is shown in Figures 20 and 21. The WDC for soils under NT was 135.8 g/kg and the value for soils under CT was 139.7 g/kg. The value of ASC for soils under NT was 72.5 and the value for soils under CT was 92.0. The DR for soils under NT was 0.9 and the value for soils under CT was 0.8. The value of CFI for soils under NT was 0.5 and the value for soils under CT was 0.5. The value of CDR (Figure 21) for soils under NT was 0.5 and the value for soils under CT was 0.5.

These results showed that the soils under different tillage management were responsive to WDC, ASC, DR micro aggregate stability indices. While CFI, CDR indices did not show any difference in values between CT and NT soils. Generally the micro aggregate stability of these soils was weak irrespective of tillage system. Igwe and Udegbunam (2008) regarded the values of 0.50 to 0.80 for DR of an Ultisol in southeastern Nigeria as high and implied weak structure. While the values of 0.20 to 0.85 for CFI were regarded as low and implied weak structure. Other researchers (Six et al., 2000; Amezketa et al., 2003; Ogban et al., 2013) reported that soil disaggregation was predominantly attributed to slaking forces irrespective of tillage system. Further studies on slaking and related conditions in these soils will be helpful in management planning.



WDC = Water Dispersible Clay, ASC = Aggregated Silt and Clay, DR = Dispersion Ratio. CFI = Clay Flocculation Index. Bars indicate standard error. Scales on Y-axis vary

Figure 20. Micro aggregate stability of the soils under contrasting tillage systems.



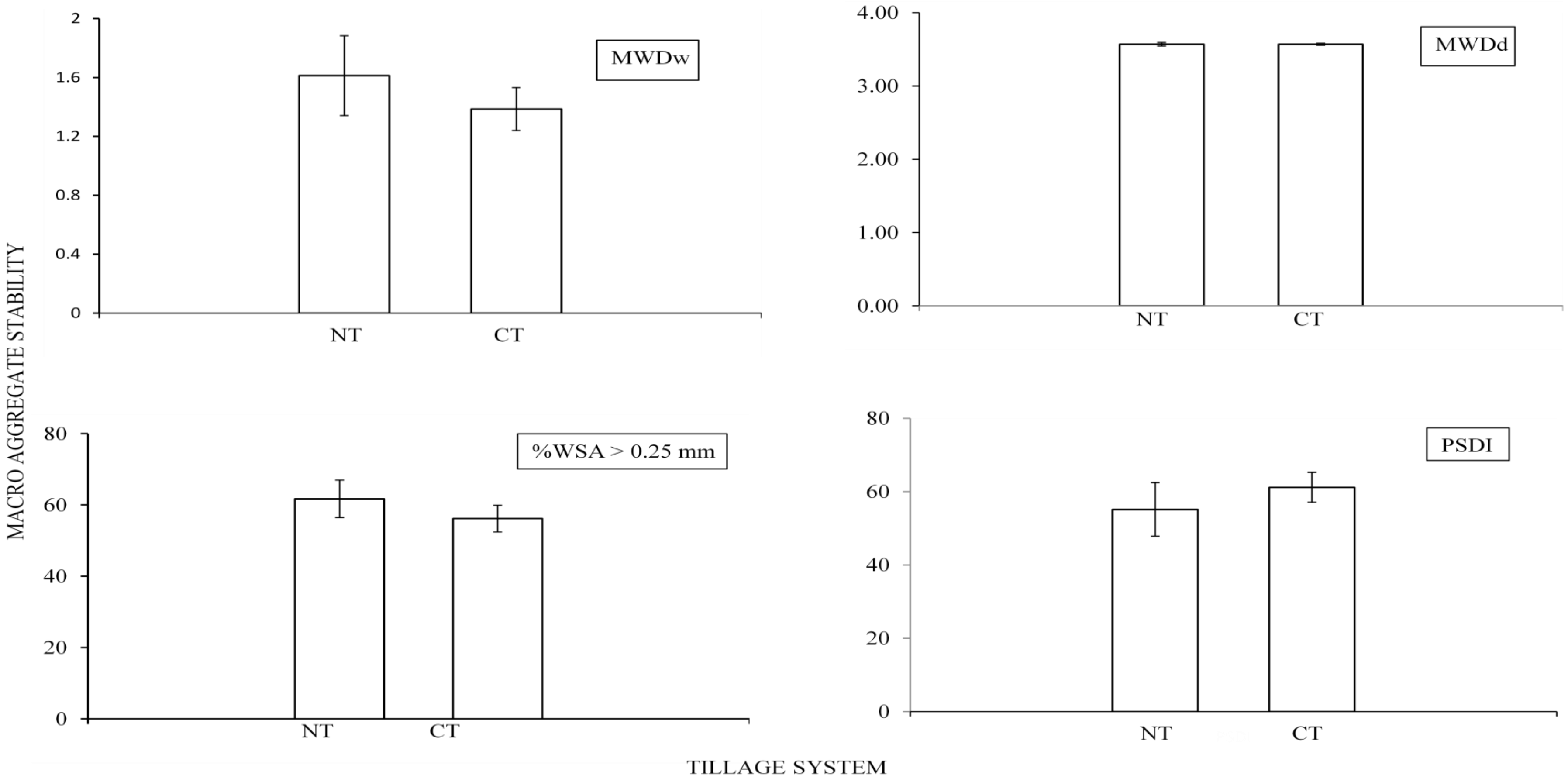
CDR = Clay dispersion ratio, NT = No tillage, CT = Conventional tillage. Bars indicate standard error

Figure 21. Micro aggregate stability of the soils under contrasting tillage systems using CDR.

The response of the soils to macro aggregate stability indices is shown in Figures 22, 23 and 24. For soils under NT, the MWDw (Figure 22) was 1.6 mm and the value for soils under CT was 1.4 mm. The MWDd was 4.0 mm for soils under NT and 4.0 mm for soils under CT. The WSA > 0.25 mm was 61.7 % for soils under NT and 56.2 % for soils under CT. The PSDI was 55.2 % for soils under NT and 61.15 % for soils under CT. The state of aggregation for the soils under contrasting tillage systems is shown in Figure 23. The SA for soils under NT was 43.2 % and the value for soils under CT was 37.89 %.

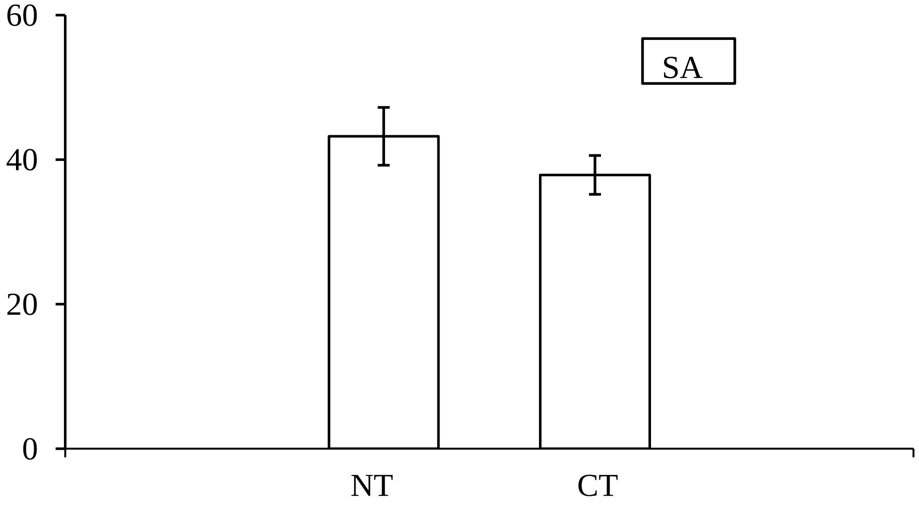
The WSA of different aggregate size classes is shown in Figure 24. The SA was 43.2 % for soils under NT and 37.89 % for soils under CT. The WSA of different aggregate size classes is shown in Figure 24. The WSA for 1 to 2 mm aggregate size class was 0.27 % for soils under CT and 0.22 % for soils under NT. For the 0.5 to 1 mm aggregate size class the WSA was 0.19 % for soils under CT and 0.15 % for soils under NT. For the 0.25 to 0.5 mm aggregate size class, WSA was 0.15 % for soils under CT and 0.15 % for soils under NT. For the < 0.25 mm aggregate size class the WSA was 0.08 % for soils under CT and 0.07 % for soils under NT.

These results indicate that tillage influenced the response of the soil to these indices. The WSA > 0.25 mm, SA, and MWDw indices were sensitive to detect differences in macro aggregate stability among tillage system in these soils. The MWDd index was not sensitive to detect differences in macro aggregate stability among tillage system in these soils. The indices showed a decrease in macro aggregate stability with tillage. These results are consistent with the reports of Zhangliu et al., 2015; and Jatta et al., 2015 who reported decrease in macro aggregate stability with CT. The implication of these results is that reports on macro aggregate stability can be misleading with some indices.



MWDw = Mean weight diameter (mm, wet sieving), MWDd = Mean weight diameter (mm, dry sieving), WSA = Water stable aggregates, PSDI = Potential structural deformation (%). Bars indicate standard error. Scale on Y-axis vary

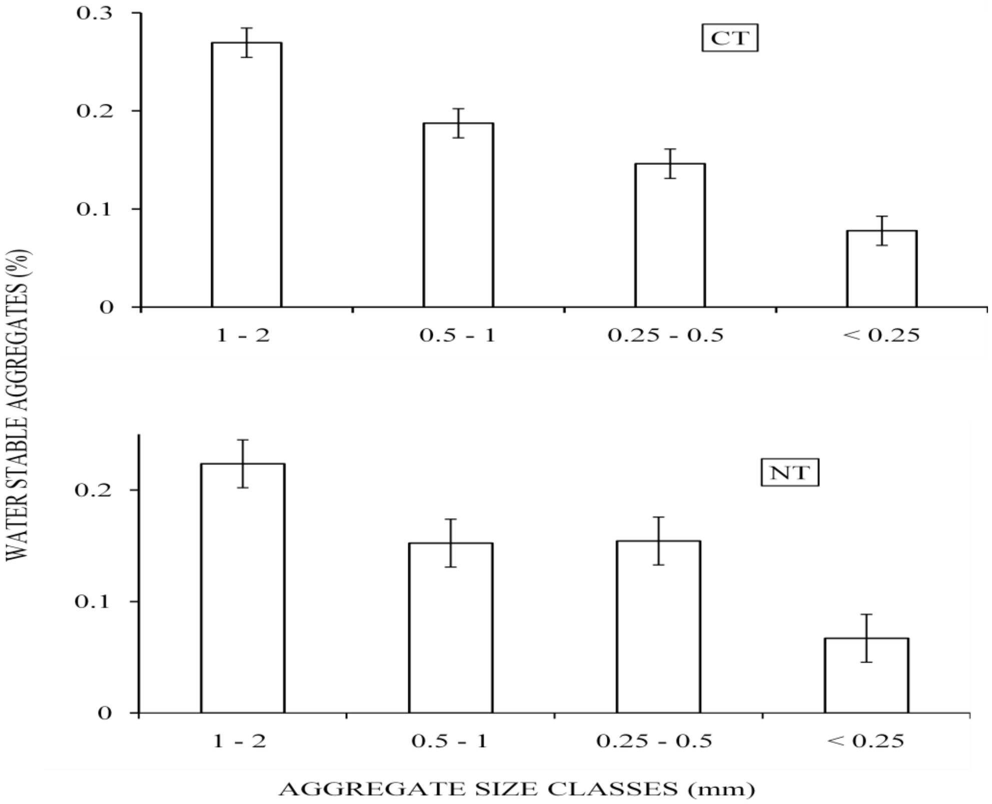
Figure 22. Macro aggregate stability of the soils under contrasting tillage system.



SA = State of aggregation, NT = No Tillage, CT = Conventional Tillage.

Bars indicate standard error

Figure 23. State of aggregation of the soils under contrasting tillage systems.



CT = Conventional Tillage, NT = No Tillage. Bars indicate standard error.

Figure 24. Water stable aggregates of different aggregate size classes.

The PSDI showed that dry soils under CT had higher susceptibility to disintegrate upon contact with water compared to soils under NT. The implication of this result is that PSDI was sensitive in these soils. This result suggests that the negative impact of CT on these soils in dry condition is expressed upon contact with water. Therefore introduction of water to these soils after dry conditions using irrigation or rainfall must consider this fact. Further studies on moisture properties of these soils will enhance management approach that will better suit the water needs of these soils. María, et al., (2015) and Deborah et al., (2015) had reported that CT enhanced the disruption of soil aggregates.

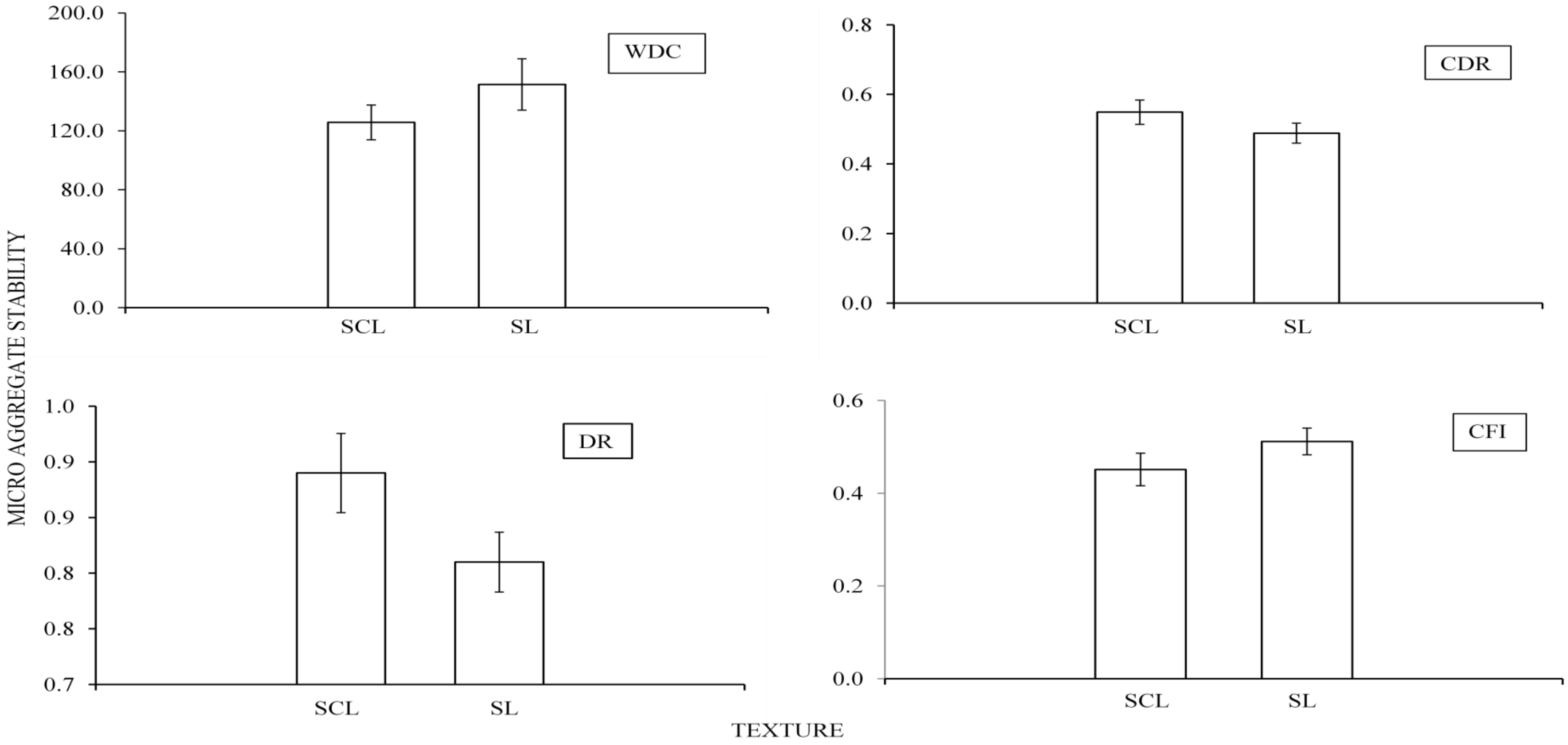
The WSA index was sensitive within different aggregate size classes. There was decrease in WSA with decrease in aggregate size class for soils under CT. For soils under NT the WSA values for the 0.5 to 1 mm and 0.25 to 0.5 mm classes were close. The implication of this result is that stability of these soils at different aggregate size classes can be assessed using the WSA index. While soils under CT showed a distinction in WSA values in different aggregate size classes, soils under NT did not show much variation in WSA values. This result showed a close level of aggregate stability among aggregate size classes for these soils under NT. Similar findings were reported by Gajić et al., (2013) who observed a decrease in WSA along aggregate size classes when natural grassland was converted to arable soils.

4.4.2 Implication of soil texture on aggregate stability indices

The response of different micro aggregate stability indices to these soils under different texture is shown in Figure 25 for WDC, CDR, DR, and CFI indices while for ASC index is shown in Figure 26. The WDC was 125.7 g/kg for SCL soils and 151.4 g/kg for SL soils. The CDR was 0.5 for SCL soils and 0.5 for SL soils. The DR was 0.9 for SCL soils and 0.8 for SL soils. The CFI was 0.5 for SCL soils and 0.5 for SL soils. The ASC (Figure 26) was 56.2 g/kg for SCL soils and 115 g/kg for SL soils. These results indicate that the WDC, DR and ASC indices were more sensitive in dictating differences between SCL and SL soils compared to CDR and CFI indices. Caution has to be applied when using indices in determining micro aggregate stability for these soils under different texture.

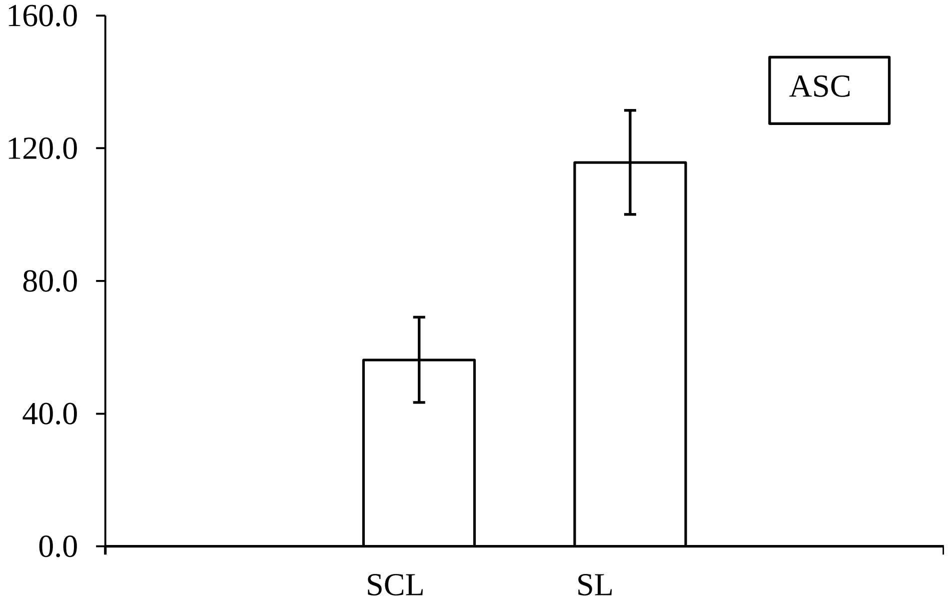
The macro aggregate stability of the soils under different texture is shown in Figure 27 (MWDw, MWDd, WSA > 0.25 mm, PSDI), Figure 28 (ASC) and Figure 29 (WSA aggregate size classes). The MWDw was 1.5 mm for SCL soils and 1.4 mm for SL soils. The MWDd was 3.6 mm for SCL soils and 3.6 mm for SL soils. The WSA > 0.25 mm was 53.0 % for SCL soils and 62.5 % for SL soils. The PSDI was 59.2 % for SCL soils and 59.7 % for SL soils. The SA was 33.6 % for SCL soil and 45.2 % for SL soils.

The indices MWDw, MWDd, SA, and WSA > 0.25 MM were sensitive to detect differences in stability of the soils with different texture in these ecotopes while PSDI was not. These results indicate that texture did not influence dry aggregate stability of these soils and that only water stable aggregates were detectable using indices. These results are important for consideration since rainfall in these areas is low and mosture availability is limiting. Determination of dry aggregate stability for these soils should consider several indices for better assessment in management decisions.



WDC = Water dispersible clay (g/kg), CDR = Clay dispersion ratio, DR = Dispersion ratio, CFI = Clay flocculation index, SCL = Sandy clay loam, SL = Sandy loam. Bars indicate standard error, scales on Y-axis vary.

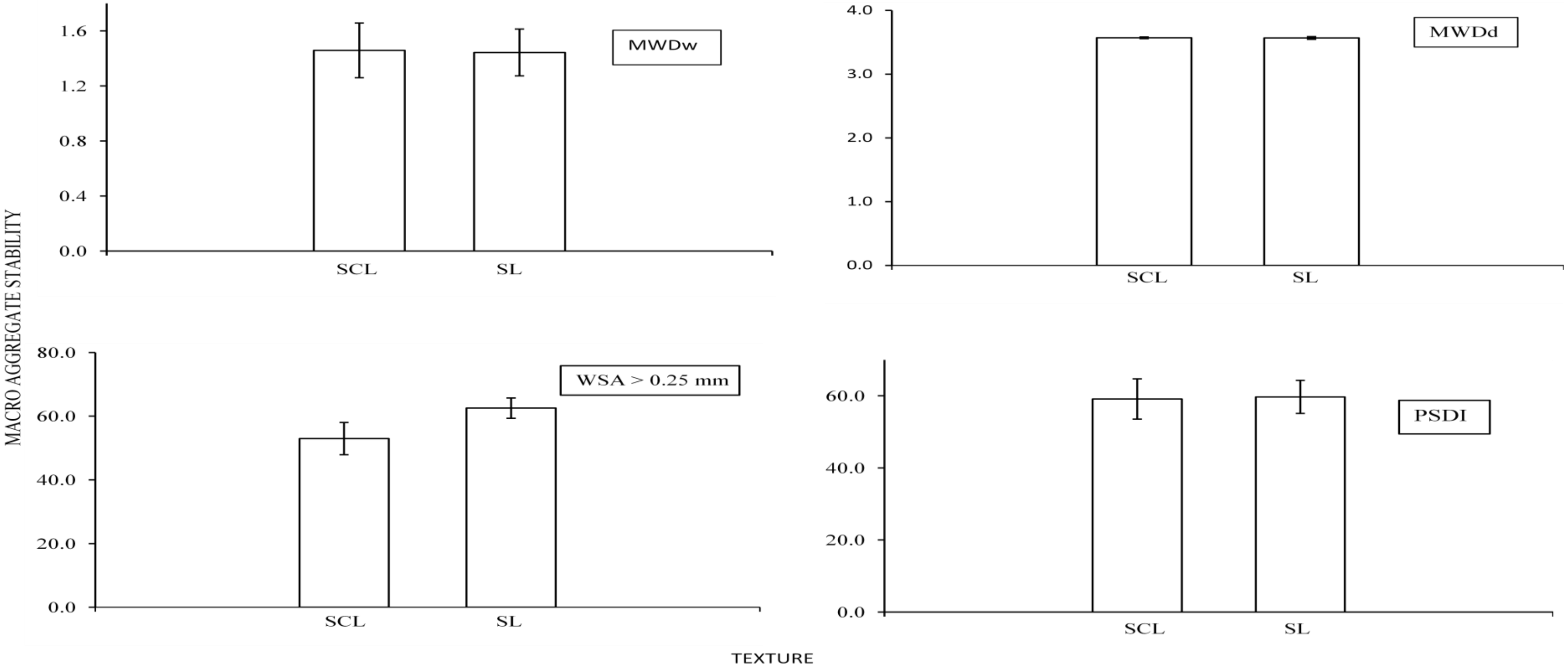
Figure 25. Micro aggregate stability of the soils with contrasting texture.



ASC = Aggregated silt and clay, SCL = Sandy clay loam, SL = Sandy loam.

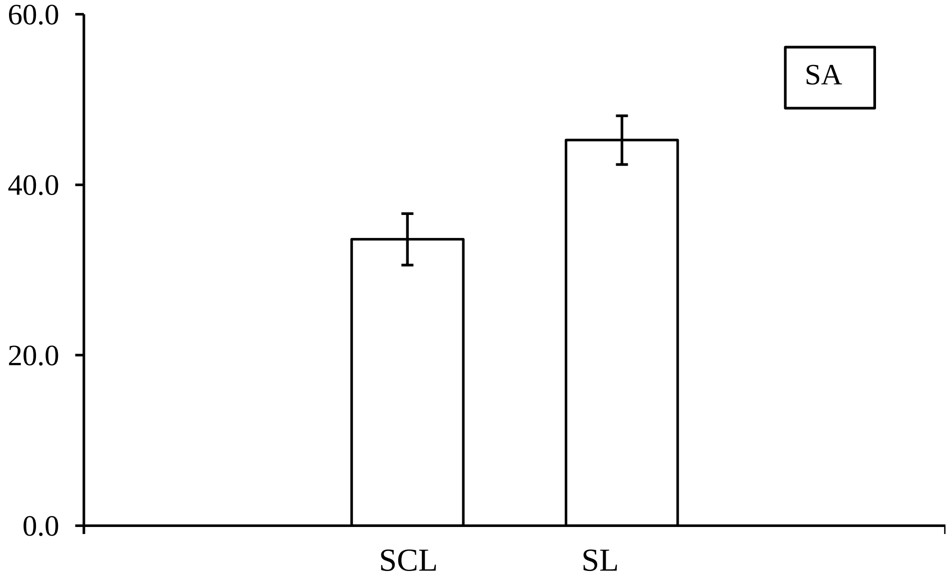
Bars indicate standard error.

Figure 26. Micro aggregate stability of the soils with contrasting texture using ASC index.



MWDw = Mean weight diameter (wet sieving) (mm), MWDd = Mean weight diameter (dry sieving) (mm), WSA = Water stable aggregate (%), PSDI = Potential structural deformation index (%). Bars indicate standard error. Scales in Y-axis vary.

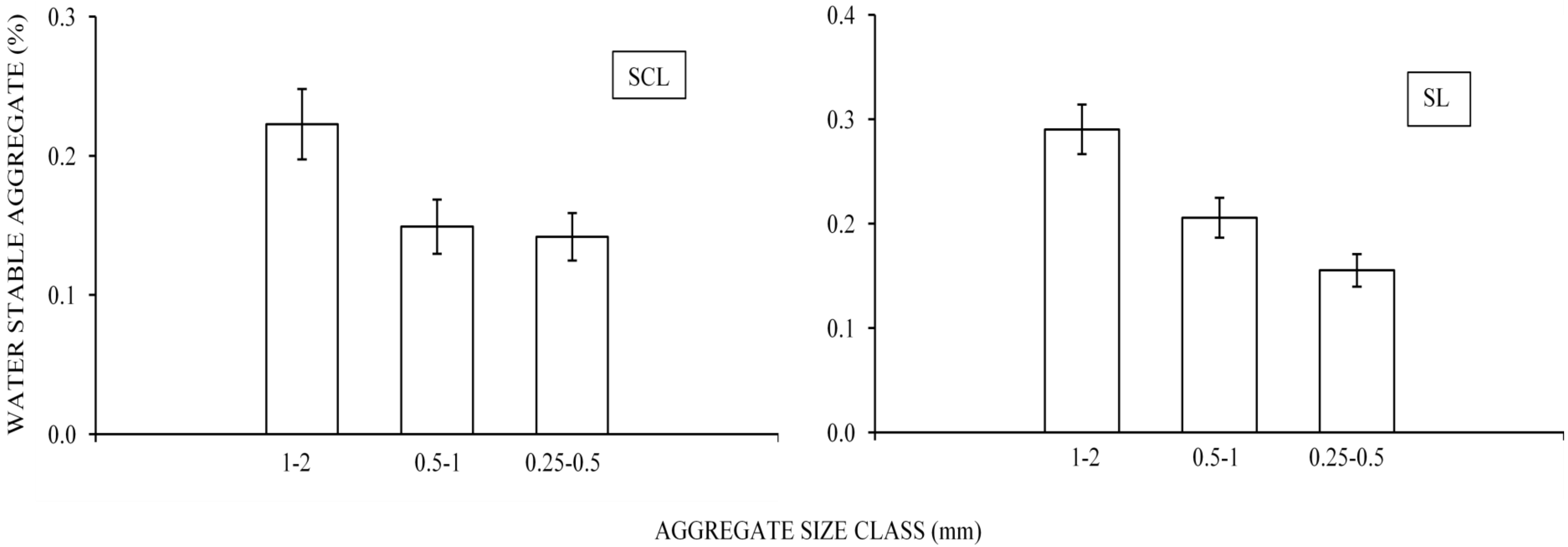
Figure 27. Macro aggregate stability of the soils with contrasting texture.



SA = State of aggregation (%), SCL = Sandy clay loam, SL = Sandy loam. Bars indicate standard error

Figure 28. Macro aggregate stability of the soils with contrasting texture.

The WSA decreased with aggregate size class (Figure 29) for both SCL and SL textured soils. The WSA index was sensitive to detect stability of different aggregate size classes in SCL and SL soils. For 1 to 2 mm aggregate size class in SCL soils the WSA was 0.2 % and for SL soils WSA was 0.3 %. The WSA for 0.5 to 1 mm aggregate size class was 0.1 % for SCL soils and 0.2 % for SL soils. The WSA for SCL soils in the 0.25 to 0.5 mm aggregate size class was 0.1 % and the value for SL soils was 0.2 %. These results showed that macro aggregate stability in both SCL and SL soils can be detected with indices in these ecotopes. WSA index is sensitive at different aggregate size ranges. The implication is that management strategies to enhance structural stability can be better implemented with early detection of structural weakness at individual aggregate size ranges.



SCL = Sandy clay loam, SL = Sandy loam. Bars indicate standard error

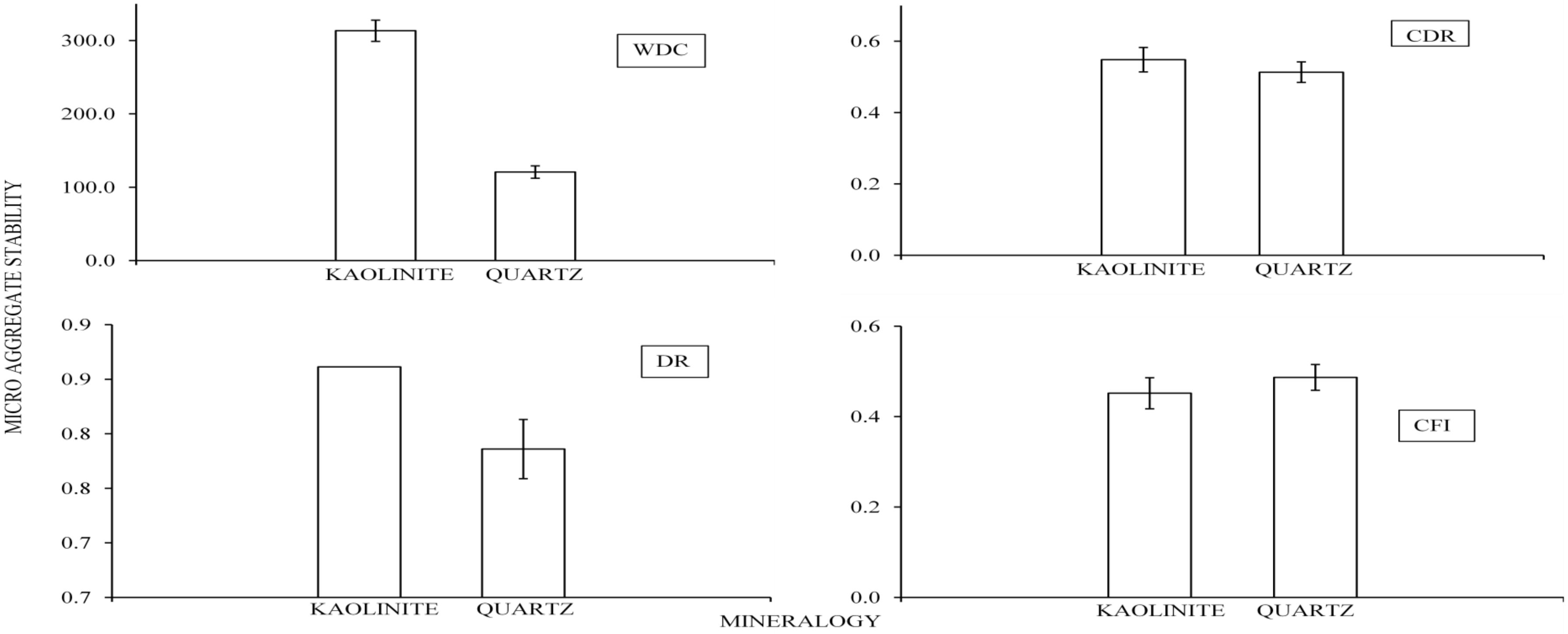
Figure 29. Water stable aggregates in different aggregate size classes and texture.

4.4.3. Implication of mineralogy on aggregate stability indices.

The responses of these soils with contrasting mineralogy to aggregate stability indices are shown in Figures 30 and 31. For micro aggregate stability indices (Figure 30), the WDC was 313.3 g/kg for kaolinitic soils and 120.7 g/kg for quartz dominated soils. The CDR was 0.5 for kaolinitic soils and 0.5 quartz dominated soils. The DR was 0.9 for kaolinitic soils and 0.8 for quartz dominated soils. The CFI for kaolinitic soils and quartz soils was 0.5. The ASC (Figure 31) was 110.0 g/kg for kaolinitic soils and 101.7 g/kg for quartz soils.

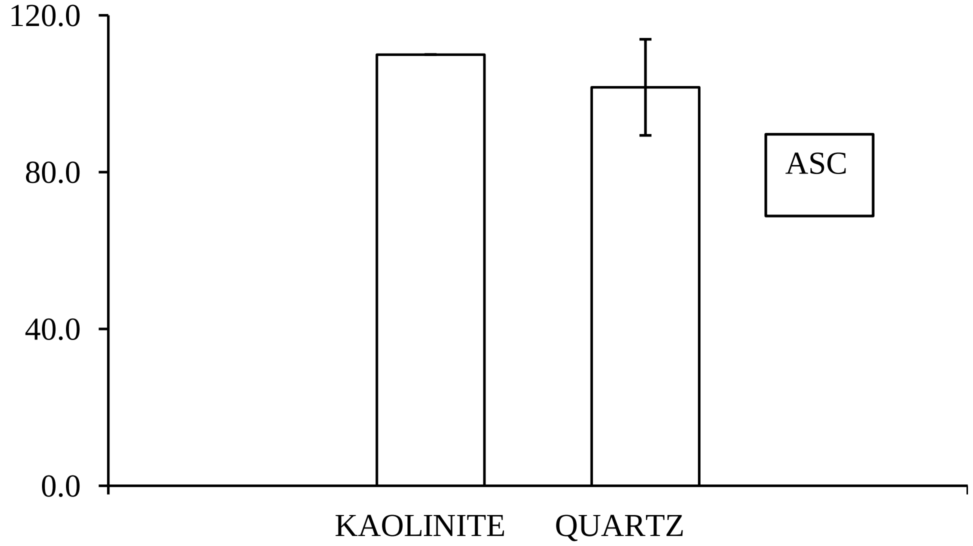
These results showed that DR and WDC indices were more sensitive in detecting differences in micro aggregate stability between soils dominated with kaolinite and quartz. The influence of Kaolinite and quartz on micro aggregate stability were expressed by DR and WDC

Macro aggregate stability of the soils using several indices is shown in Figures 32 and 33. The WSA > 0.25 mm was 57.3 % for quartz dominated soils and 68.4 % for kaolinitic soils. The MWDw was 1.6 mm for quartz dominated soils and 0.8 mm for kaolinitic soils. The MWDd was 3.6 mm for quartz dominated soils and 3.4 mm for kaolinitic soils. The PSDI was 56.3 for quartz dominated soils and 76.0 for kaolinitic soils (Figure 32). The macro aggregate stability of the soils with contrasting mineralogy using SA index the (Figure 33) showed sensitivity. This result however has to be accepted with caution because factors reported to influence aggregate stability in kaolinitic soils vary from moisture regime (Shrestha et al., 2007), electrostatic charges between platelets (Schulten and Leinweber, 2000), organic matter and/or oxides (Amrakh et al., 2012) to cristal size (Trakoonyingcharoen et al., 2012).



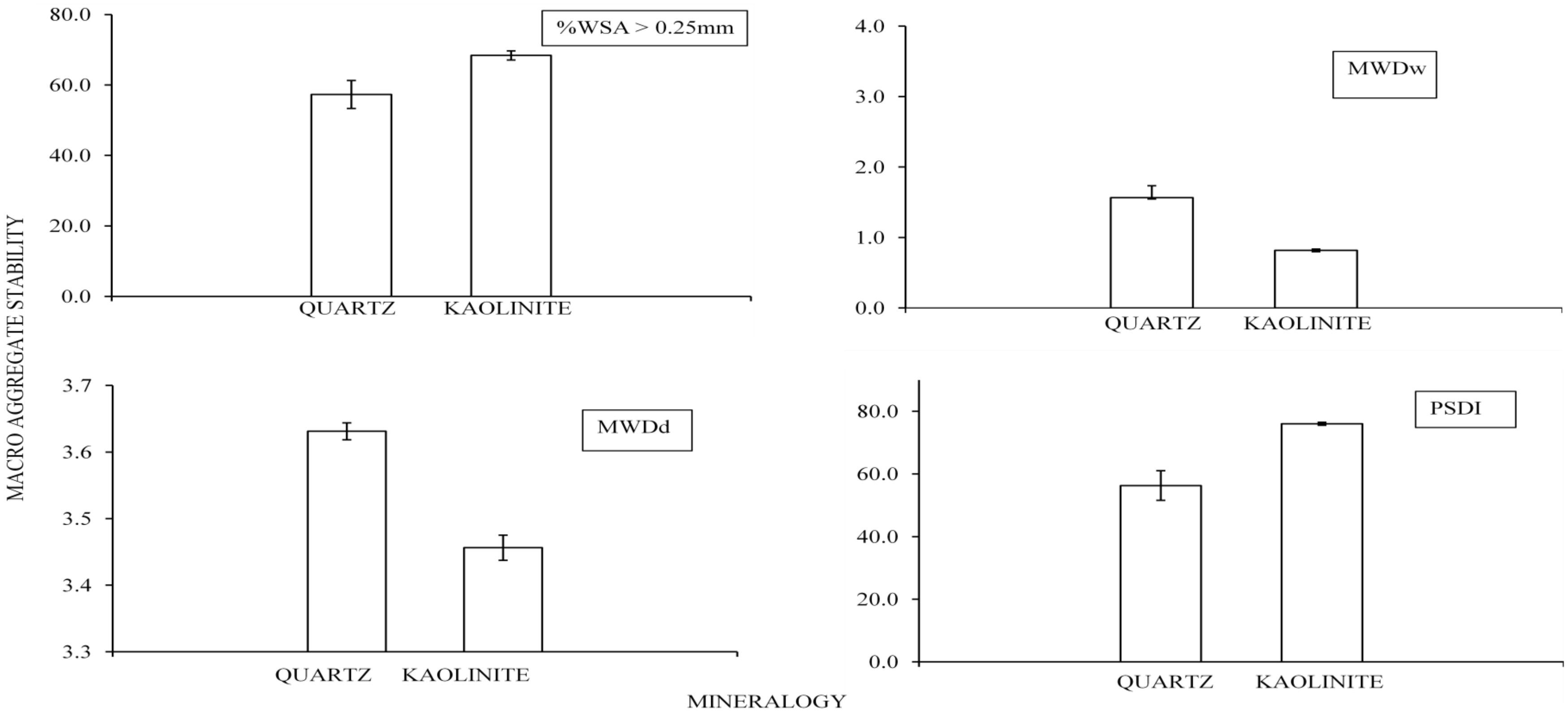
WDC = Water Dispersible Clay, CDR = Clay dispersion ratio and Clay, DR = Dispersion Ratio, CFI = Clay Flocculation Index. Bars indicate standard error. Scales on Y-axis vary

Figure 30. Micro aggregate stability of the soils with contrasting mineralogy



ASC = Aggregated silt and clay. Bars indicate standard error

Figure 31. Micro aggregate stability of the soils with contrasting mineralogy using ASC index.



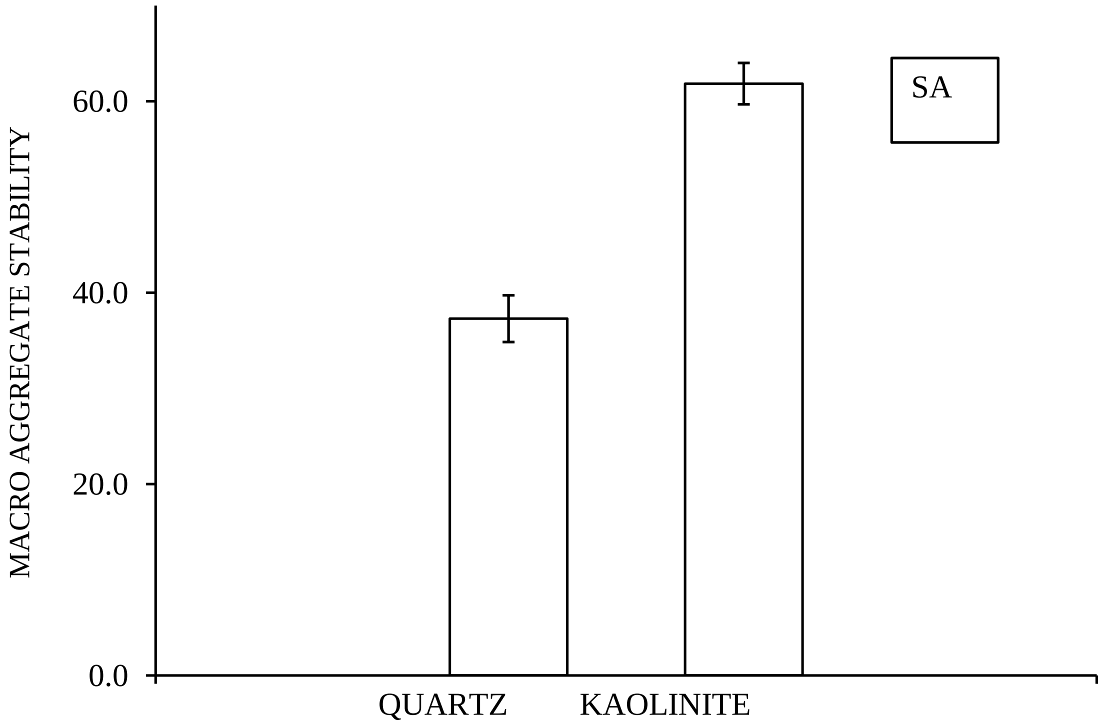
WSA = Water stable aggregates (%), MWDw = Mean weight diameter (wet sieving) (mm), MWDd = Mean weight diameter (dry sieving) (mm), PSDI = Potential structural deformation index (%). Bars indicate standard error. Scales on Y-axis vary.

Figure 32. Macro aggregate stability of the soils with contrasting mineralogy.

The WSA > 0.25 mm, MWDw, MWDd, PSDI and SA indices were sensitive to detect difference in aggregate stability of these soils under different mineralogy. Quartz dominated soils had higher values of MWDw and MWDd than kaolinitic soils. The values of WSA > 0.25 mm and PSDI indices were similar with mineralogy, but these results have opposite implications. This can be explained by the report of Shrestha et al., (2007) who observed that the stability of kaolinitic soils was also determined by the moisture regime of the soils. The MWDw and MWDd indices were more sensitive to interpret the stability of the macro aggregates of soils in these ecotopes with contrasting mineralogy.

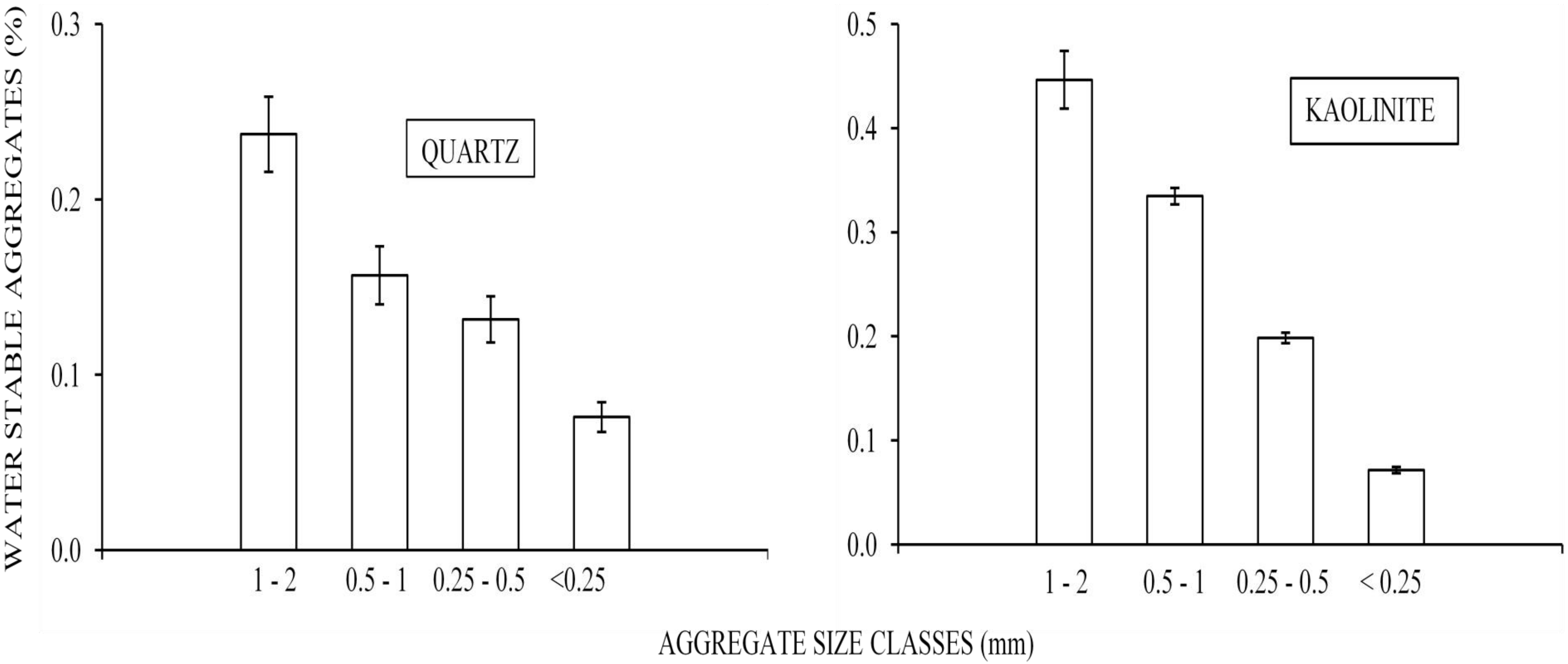
The macro aggregate stability of the soils within different aggregate size classes is shown in Figure 34. Aggregates within different size classes were expressed for both quartz and kaolinitic soils. The WSA for 1 to 2 mm size class was 0.2 % in quartz dominated soils and 0.4 % for kaolinite dominated soils. For the 0.5 to 1 mm size class WSA was 0.2 % in quartz dominated soils and 0.3 % for kaolinite soils. The WSA for the 0.25 to 0.5 mm size class was 0.1 % for quartz dominated soils and 0.2 % for kaolinite soils. The WSA for the < 0.25 mm size class was 0.1 % in quartz dominated soils and 0.1 % for kaolinite soils.

The WSA for all aggregate size class was higher in kaolinite soils compared to corresponding aggregate sizes in quartz soils. This result was due to the response of kaoline mineral crystals to moisture which had been reported to influence aggregate stability (Shrestha et al., 2007). For these ecotopes, soils dominated with kaolinite were more stable at both micro and macro aggregate levels than quartz dominated soils.



SA = State of aggregation (%). Bars indicate standard error

Figure 33. Macro aggregate stabilty of the soils with contrasting mineralogy using SA index.



Bars indicate standard error. Note: scales in Y-axis vary

Figure 34. Water stable aggregates in different aggregate size classes.

CONCLUSION

Tillage, texture and mineralogy influenced the result of the sieving operation using Iris FTLVH – 0200 digital electromagnetic sieve shaker (Filtra Vibración SL Spain). Sieving efficiency attained for these soils varied with tillage and mineralogy. The aggregate size composition and distribution in soils of these ecotopes are a function of mineralogy rather than tillage.

Tillage influenced Nitrogen in the physical fractions of these soils. Changes in nitrogen content due to tillage were expressed more in the silt fraction of the soils. Soils in these ecotopes showed tendency for slow nitrogen accumulation. Texture influenced the accumulation of carbon and nitrogen in these soils. Clay fraction was prominent in determining the amount of carbon and nitrogen in these soils.

Tillage influenced the sensitivity of different aggregate stability indices in these soils. The indices WSA > 0.25 mm, SA, and MWDw were sensitive to detect differences in macro aggregate stability among tillage system in these soils. Micro aggregate stability indices were generally not sensitive in detecting expected differences among tillage systems in these soils. The micro aggregate stability indices DR and ASC were more sensitive in soils of different texture. The macro aggregate stability indices MWDw, MWDd and PSDI were not sensitive to detect difference in stability with texture. The SA and WSA > 0.25 mm indices were sensitive to detect differences in the stability of the soils with texture. The micro aggregate stability indices DR and WDC were sensitive in soils of different mineralogy.

For these soils it could be said that the clay fraction influenced the carbon content irrespective of mineralogy. The soils responded to different indices differently under different conditions of tillage, texture and mineralogy. Therefore caution must be exercised in adopting any index; it is however suggested to use the response of more than one index for any given conclusion. Further research on site specific measures to improve soil nitrogen retention in these soils is suggested to forestall nitrogen emission. Also proper delineation of these ecotopes according to carbon response to tillage, texture and mineralogy for enhanced carbon sequestration measures is recommended

REFERENCES

Aber, J.D. & Melillo, J.M., 2001. *Terrestrial Ecosystems*. San Diego: Academic Press Harcourt.

Adesodun, J.K., Mbagwu, J.S. & Oti, N., 2004. Distribution of carbohydrate pools within water stable aggregates of an Ultisol in Southeastern Nigeria. *International Agrophysics*, 18, pp.103-09.

Alam, M.K. & Salahin, N., 2013. Changes in Soil Physical Properties and Crop Productivity as Influenced by Different Tillage Depths and Cropping Patterns. *Bangladesh Journal of Agricultural Research*, 38, pp.289-99.

Ali, E., Ekwue, E.I., Bridge, J. & Birch., R., 2013. A three – stack mechanical sieve shaker for determining aggregate size distribution of soils. *The West Indian Journal of Engineering*, 35, pp.36-44.

Allwood, J., 2006. Beyond Conservation Agriculture: A science program on the transition from promise to practice. In Brussaard, L. & Hebinck, P., eds. *Contribution to the conservation agriculture research program development workshop.* Workshop held at Pretoria South Africa, 2006. Eastern Cape Province Department of Agriculture.

Alvarez, M.F., Osterrieth, M.L. & del Rio, J.L., 2012. Changes on aggregates morphology and roughness induced by different uses of typical Argiudolls, Buenos Aires province, Argentina. *Soil & Tillage Research*, 119, pp.38–49.

Alvarez, R. & Steinbach, H.S., 2009. A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yield in the Argentine Pampas. *Soil & Tillage Research*, 104, pp.1–15.

Amezketa, E., Aragues, R., Carranza, R. & Urgel, B., 2003. Macro- and Micro-aggregate staility of soils determined by a combination of wet-sieving and laser-ray diffraction. *Spanish Journal of Agriculture*, 1, pp.83-94.

Amrakh, I.M., Guy, J.L. & Fariz, D.M., 2012. Runoff and Erosion as Affected by Soil Spatial Variation and Temporal Conditions. *Journal of Institute Science & Technology*, 2, pp.105-12.

Antonio, J, 2014. *What is soil structure?* [Online] Available at: http://gsoil.wordpress.com/2013/08/19/what-is-soil-structure/ [Accessed 14 July 2014].

Asma, H; Shahzada, S I; Rattan, L; David, B; Muhammad, A; Safdar, A; Shiguo, J. 2015. Tillage effect on partial budget analysis of cropping intensification under dryland farming in Punjab, Pakistan. *Archives of Agronomy and Soil Science*, pp.http://dx.doi.org/10.1080/03650340.2015.1043527.

Ayoubi, S., Khormali, F., Sahrawat, K.L. & Rodrigues de Lima, A.C., 2011. Assessing Impacts of land use change on Soil Quality Indicators in a Loessial Soil in Golestan Province. *Iran Journal of Agricutural Science Technology*, 13, pp.727-42.

Balashov, E. & Bazzoffi, P., 2003. Aggregate water stability of sandy and clayey loam soils differently compacted with and without wheat plants. *International Agrophysics*, 17, pp.151-55.

Ball, B.C., Batey, T. & Munkholm, L.J., 2007. Field assessment of soil structural quality – a development of the Peerlkamp test. *Soil Use and Management*, 23, pp.329–37.

Barbera, V; Poma, I.; Gristina, L.; Novara, A.; Egli, M. 2012. Long-term cropping systems and tillage management effects on soil organic carbon stock and steady state level of C sequestration rates in a semiarid environment. *Land Degradation & Development*, 23, pp.82–91.

Barja, M.D., 2008. *Principles of Geochemical Engineering*. 2nd ed. The University of Texas at el Paso.

Barthès, B. & Roose, E., 2002. Aggregate stability as an indicator of soil susceptibility to runoff and erosion; validation at several levels. *Catena*, 47, pp.133–49.

Bast, A; Wilcke, W; Graf, F; Lüscher, P; Gärtner, H. 2015. A simplified and rapid technique to determine an aggregate stability coefficient in coarse grained soils. *Catena*, 127, pp.170-76.

Bayer, C., Martin-Neto, L., Mielniczuk, J. & Ceretta, C.A., 2000a. Effect of no-till cropping systems on soil organic matter in a sandy clay loam Acrisol from Southern Brazil monitored by electron spin resonance and nuclear magnetic resonance. *Soil & Tillage Research*, 53, pp.95-104.

Ben-Hur, M. & Wakindiki, I.C., 2004. Soil mineralogy and slope effects on infiltration, interrill erosion, and slope factor. *Water Resources Research*, 40, p.W03303.

Bimüller, C; Mueller, W C; von Lützow, M; Kreyling, O; Kolbl, A; Huag, S; Schloter, M; Kogel-Knabner, I. 2014. Decoupled carbon and nitrogen mineralization in soil particle size fractions of a forest topsoil. *Soil Biology and Biochemistry*, 78, pp.263-73.

Blanco-Canqui, H; Lal, R; Post, W M; Izaurralde, R C; Shipitalo, M. J. 2007. Blanco-Canqui, H., R. Lal, W. M. Post, R. C.Izaurralde, and M. J. Shipitalol. *Soil Tiilage & Research*, 92, pp.144-55.

Borůvka, L., Valla, M., Donátová, H. & Němeček, K., 2002. Vulnerability of soil aggregates in relation to soil properties. *Rostlinná Výoba*, 48, pp.329-34.

Bronick, C.J. & Lal, R., 2005. Soil structure and management: A Review. *Geodema*, 124, pp.3-22.

Cañasveras, J.C., Barrón, V., del Campillo, M.C. & Gomez, J.A., 2010. Estimation of aggregate stability indices in Mediterranean soils by diffuse reflectance spectroscopy. *Geoderma*, 158, pp.78-84.

Castellano, M.J., Kaye, J.P., Lin, H. & Schmidt, J.P., 2012. Linking Carbon Saturation Concepts to Nitrogen Saturation and Retention. *Ecosystems*, 15, pp.175-87.

Castellano, M.J., Lewis, D.B. & Kaye, J.P., 2013. Response of soil nitrogen retention to the interactive effects of soil texture, hydrology, and organic matter. *Journal of Geophysical Research: Biogeosciences*, 118 , pp.280–90.

Chen-Yang, X., Zheng-Hong, Y. & Hang, L., 2015. The coupling effects of electric field and clay mineralogy on clay aggregate stability. *Journal of Soil Sediments*, 15, pp.1159–68.

Christensen, B.T., 2001. Physical fractionation of soil and structural and functional complexity in organic matter turnover. *European Journal of Soil Science*, 52, pp.345–53.

Cimélio, B; João, M; Elvio, G; Ladislau, M; Aurélio, P. 2006. Tillage Effects on Particulate and Mineral-Associated Organic Matter in Two Tropical Brazilian Soils. *Communications in Soil Science and Plant Analysis*, 37, pp.389–400.

Ćirić, V., Manojlović, M., Nešić, L. & Belić, M., 2012. Soil dry aggregate size distribution: effects of soil type and land use. *Journal of Soil Science and Plant Nutrition*, 12, pp.689-703.

Cordula, V; Katja, H; Franz, B; Irina, T; Stephan, H; Michael, S; Ingrid, K. 2015. Cordula Vogel, KClay mineral composition modifies decomposition and sequestration of organic carbon and nitrogen in fine soil fractions. *Biology and Fertility of Soils*, 51, pp.427–42.

Cote, L; Brown, S; Pare, D; Fyles, J; Bauhus, J. 2000. Dynamics of carbon and nitrogen mineralization in relation to stand type, stand age and soil texture in the boreal mixedwood. *Soil Biology & Biochemistry*, 32, pp.1079–90.

Das, B.M., 2002. *Principles of Geotechnical Engineering*. 5th ed. Califonia: Pacific Grove.

Dawit, S; Fritzasche, F; Tekalign, M; Lehmann, J; Zech, W. 2002. Soil organic matter composition in the sub-humid Ethiopian highlands as influenced by deforestation and agricultural management. *Soil Science Society of America Journal*, 66, pp.68-82.

Deborah, L; Friedhelm, T; Daniel, G; Rainer, G J; Bernard, L. 2015. Temporal variations of the distribution of water-stable aggregates, microbial biomass and ergosterol in temperate grassland soils with different cultivation histories. *Geoderma*, 241-242, pp.221-29.

Dexter, A., 2002. Soil structure: the key to soil function. In M. Pagliai & R. Jones, eds. *Advances in Geoecology. Sustainable land management- environmental protection. A soil physical approach.* 35th ed. Verlag Reiskirchen Germany: IUSS Catena. pp.57-69.

Diaz-Zorita, M., Grove, J.H. & Perfect, E., 2007. Sieving Duration and Sieve Loading Impact on Dry Soil Fragmant Size Distributions. *Soil & Tillage Research,* 94, pp.15-20.

Diaz-Zorita, M., Perfect, E. & Grove, J.H., 2002. Disruptive Methods for Assesing Soil Structure. A Review. *Soil & Tillage Research*, 64, pp.3-22.

Ding, G. et al., 2005. Effect of cover crop management on soil organic matter. *Geoderma* , 130, pp.229–239.

Eccles, C. & Ekwue, E.I., 2008. A mechanical shaker for sieving dry soil samples. *West Indian Journal of Engineering,* 30, pp.13-23.

Eden, M., Schjønning, P., Moldrup, P. & De Jonge, L.W., 2011. Compaction and rotovation effects on soil pore characteristics of a loamy sand soil with contrasting organic matter content. *Soil Use and Management.*, 27, pp.340–49.

Erika, F M P; David, V B de C; Fabiano, de C B; Lucia, H C dos A; Marcos, G P. 2015. Tillage systems effects on soil carbon stock and physical fractions of soil organic matter. *Agricultural Systems,* 132, pp.35-39.

Eusterhues, K., Rumpel, C., Kleber, M. & Kogel-Knabner, I., 2004. Stabilisation of soil organic matter by interactions with minerals as revealed by mineral dissolution and oxidative degradation. *Organic Geochemistry*, 34, pp.1591-600.

Fairbanks, D. H.K.; Thompson, M. W.; Vink, D. E.; Newby, T. S.; Van den Berg, H. M.; Everad, D. A 2000. D.H.K. FairbaThe South African land-cover characteristics database: a synopsis of the landscape. *South African Journal of Science*, 96, pp.69–82.

Fanqiao, M; Rattan, L; Xing, K; Guangwei, D; Wenliang, W 2014. Soil organic carbon dynamicswithin density and particle-size fractions of Aquic Cambisols under different land use in northern China. *Geoderma Regional* , 1, pp.1-9.

FAO, 2010. *Land Degradation Assessment in Drylands (LADA). Assessing the status causes and impact of land degradation*. FAO.

Fernández-Ugalde, O; Virto, I; Bescansa, P; Imaz, M J; Enrique, A; Karlen, D L. 2009. No-tillage improvement of soil physical quality in calcareous, degradation prone semi arid soils. *Geoderma*, 106, pp.29-35.

Ferro, N. Dal; Sartori, L.; Simonetti, G.; Berti, A.; Morari, F. 2014. Soil macro- and microstructure as affected by different tillage systems and their effects on maize root growth. *Soil and Tillage Research*, 140, pp.55–65.

Fox, R.C. & Rowntree, K.M., 2001. Redistribution, Restitution and Reform: Prospect of the Land in the Eastern cape Province, South Africa. In A.J. Canacher, ed. *Land Degradation in Mediterranian Environments of the World*. 1st ed. Dodrecht: Springer-Science+Business Media. pp.167-86.

Francisco, J.M., Christopher, H.L. & Christian, R.M., 2008. Effects of Soil Texture, Carbon Input Rates, and Litter Quality on Free Organic Matter and Nitrogen Mineralization in Chilean Rain Forest and Agricultural Soils. *Communications in Soil Science and Plant Analysis*, 39, pp.187–201.

Francisco, M., Claudia, H., Carlos, M. & Jorge, E., 2011. Land use Impact on Physical-based soil organic matter fractions on three hillside Ferrasols in Mexico. *Chilean Journal of Agricultural Research*, 71, pp.283-92.

Gajić, B; Tapanarova, A; Tomić, Z; Kresović, B; Vujović, D; Pejić, B. 2013. Land use effects on aggregation and erodibility of Luvisols on undulating slopes. *Australian Journal of Crop Science*, 7, pp.1198-204.

Gale, W.J., Cambardella, C.A. & Bailey, T.B., 2000. Root-derived carbon and the formation and stabilization of aggregates. *Soil Science Society of America Journal*, 64, pp.201–07.

Garcia-Franco, N., Albaladejo, J., Almagro, M. & Martínez-Mena, M., 2015. Beneficial effects of reduced tillage and green manure on soil aggregation and stabilization of organic carbon in a Mediterranean agroecosystem. *Soil & Tillage Research*, 153, pp.66–75.

Garland, G.G., Hoffman, M.T. & Todd, S., 2000. Soil degradation. In T.S.N.Z.a.T.S. Hoffman MT, ed. *A National Review of Land Degradation in South Africa.* Pretoria, South Africa: South African National Biodiversity Institute. pp.69-107.

Garry, P., 2007. *Soil.* [Online] Available at: http://www.enviropaedia.com/topic/default.php?topic_id=217 [Accessed 30 June 2014].

Gopi, A. & Krishna, G.B., 2015. Impact of pulp and paper mill effluents and solid wastes on soil mineralogical and physicochemical properties. *Environmental Monitoring Assessment*, 187, pp.DOI 10.1007/s10661-015-4330-z.

Green, V.S., Cavigelli, M.A., Dao, T.H. & Flanagan, D.C., 2005. Soil physical properties and aggregate-associated C, N and P distributions in organic and conventional cropping systems. *Soil Science*, 170, pp.822–31.

Gregorich, E.G., Beare, M.H., McKim, U.F. & Skjemstad, J.O., 2006. Chemical and biological characteristics of physically uncomplexed organic matter. *Soil Science Society of American Journal*, 70, pp.975-85.

Han, K.-H., Ha, S.-G. & Jang, B.-C., 2010. Aggregate Stability and Soil Carbon Storage as Affected by Different Land Use Practices. In *Int. Workshop on Evaluation and Sustainable Management of Soil Carbon Sequestration in Asian countries*. Bogor, Indonesia, 2010.

Herath, H.M., Marta, C. & Mike, H., 2013. Effect of biochar on soil physical properties in two contrasting soils: an Alfisol and an Andisol. *Geoderma*, 209-210, pp.188-97.

Hoffman, M.T. & Ashwell, A., 2001. *Nature Divided: Land Degradation in South Africa*. Cape Town: Cape Town University Press.

Hoffman, M.T. & Todd, S., 2000. National review of land degradation in South Africa: the influence of biophysical and socio-economic factors. *Journal of Southern African studies*, 26, pp.743–58.

Hoffman, M.T., Todd, S., Ntoshona, Z. & Turner, S., 1999. *Land Degradation in South Africa*. CapeTown: National Botanical Institute.

Igwe, C.A. & Nwokocha, D., 2006. Soil organic fractions and micro-aggregation in an ultisol under cultivated and secondary forest in south-eastern Nigeria. *Australian Journal of Soil Research*, 44, pp.627-35.

Igwe, C.A. & Stahr, K., 2004. Water stable aggregate of flooded inceptisols from south-eastern Nigeria in relation to mineralogy and chemical properties. *Australian Journal of soil Research*, 42, pp.171-79.

Igwe, C.A. & Udegbunam, O.N., 2008. Soil properties influencing water-dispersible clay and silt in an Ultisol in southern Nigeria. *International Agrophysics,* 22, pp.319-25.

Igwe, C.A., Zarei, M. & Stahr, K., 2006. Clay dispersion of hardsetting inceptisols in Southeastern Nigeria as influenced by soil compaction. *Communications in Soil Science and Plant analysis*, 37, pp.751-66.

Igwe, C.A., Zarei, M. & Stahr, K., 2013. Stability of aggregates of some weathered soils in south-eastern Nigeria in relation to their geochemical properties. *Journal of Earth System Science*, 122(5), pp.1283–94.

Ingram, J.S.I. & Fernandes, E.C.M., 2001. Managing carbon sequestration in soils: concepts and terminology. *Agriculture Ecosystem Environment*, 87, pp.111–17.

Isavi, S. & Mahmoudi, A., 2013. Design, fabrication and evaluation of a mechanical transducer for real time measurement of tilth aggregate sizes. *Agricultural Engineering International CGR Journal*, 15, pp.130-37.

Jatta, S., Kristiina, R., Laura, A. & Johan, S., 2015. Impact of no-till and reduced tillage on aggregation and aggregate-associated carbon in Northern European agroecosystems. *Soil & Tillage Research*, 150, pp.107–13.

Jorge, R., Juan, J.M. & Marina, N., 2013. Influence of sieving time on the efficiency and accuracy of grain-size analysis of beach and dune sands. *Sedimentology*, 60, pp.1884-496.

José, F.C., Beutler, A.N. & Menezes de Souza, Z., 2004. Physical Attributes of Kaolinitic and Oxidic Oxisols Resulting from Different Usage Systems. *Brazilian Archives of Biology and Technology*, 47, pp.725-32.

Krull, E.S., Baldock, J.A. & Skjemstad, J.O., 2003. Importance of mechanisms and processes of the stabilisation of soil organic matter for modelling carbon turnover. *Functional Plant Biology*, 30, pp.207–22.

Krull, E.S., Skjemstad, J.O. & Baldock, J.A., 2004. *Functions of Soil Organic Matter and the Effetcs on Soil Properties*. GRDC Australia Project No CSO 00029. CSIRO Land & Water.

Lado, M., Ben-hur, M. & Shainberg, I., 2007. Clay mineralogy, ionic composition, and pH Effects on hydraulic properties of depo¬sitional seals. *Soil Science Society of America Journal*, 71, pp.314–21.

Lazarovitch, N., Ben-Gal, A., Šimůnek, J. & Shani, U., 2007. Uniqueness of soil hydraulic parameters determined by a combined Wooding inverse approach. *Soil Science Society of America Journal*, 71, pp.860–65.

Leifeld, J. & Kögel-Knabner, I., 2005. Soil organic matter fractions as early indicators for carbon stock changes under different land-use? *Geoderma*, 124, pp.143-55.

Liebig, M.A., Tanaka, D.L. & Wienhold, B.J., 2004. Tillage and cropping effects on soil quality indicators in the northern Great Plains. *Soil & Tillage Research*, 78, pp.131-41.

Lieskovský, J. & Kenderessy, P., 2012. Modelling the effect of vegetation cover and different tillage practices on soil erosion in vineyards: a case study in Vráble (Slovakia) using watem/ sedem. *Land Degradation & Development.*, 25, pp.288–96.

Maharaj, A. & Paige-Green, P., 2013. The SCS Double Hydrometer Test in dispersive soil identification. CSIR Built Environment, Pretoria, South Africa. In *Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering*. Paris, 2013.

Maki, A. & Rota., W., 2014. Evidence of aggregate hierarchy at micro- to submicron scales in a Allophonic andisol. *Geoderma*, 216, pp.62-74.

Mandiringana, O. T.; Mnkeni, P. N. S.; Mkile, Z.; van Averbeke, W.; Van Ranst, E.; Verplancke, H. 2005. Mineralogy and Fertility Status of Selected Soils of the Eastern Cape Province, South Africa. *Communications in Soil Science and Plant Analysis*, 36, pp.2431–46.

Marco, Nocita; Lammert, Kooistra; Martin, Bachmann; Andreas, Müller; Mike, Powell; Silvia, Wee. 2011. Predictions of soil surface and topsoil organic carbon content through the use of laboratory and field spectroscopy in the Albany Thicket Biome of Eastern Cape Province of South Africa. *Geoderma*, 167–168, pp.295–302.

María, B.V., Joseph, L. & Emerson, D.N., 2015. Corn residue, tillage, and nitrogen rate effects on soil properties. *Soil & Tillage Research*, 151, pp.61-66.

Martínez, F S J; Ortega, F J M; Monreal, F J C; Kravchenko, A N; Wang, W. 2015. Soil aggregate geometry: Measurements and morphology. *Geoderma*, 237-238, pp.36-48.

Mbagwu, J.S., 2003. *Aggregate stability and soil degradation in the tropics*. Treasty Italy: College on Soil Physics The Abdus Salam International Center for Theoretical Physics.

McLauchlan, K.K., 2006. Effect of soil texture on soil carbon and nitrogen dynamic after cessation of agriculture. *Geoderma*, 136, pp.289-99.

Mikha, M.M. & Rice, C.W., 2004. Tillage and manure effects on soil aggregate-associated carbon and nitrogen. *Soil Science Society of America Journal*, 68, pp.809-16.

Mills, A.J. & Fey, M.V., 2004. Frequent fires intensify soil crusting physico-chemical feedback in the pedoderm of long-term burn experiments in South Africa. *Geoderma*, 121, pp.45–64.

Miwa, A M; Yukio, T; Hiroshi, W; Yoshinori, W; Atsushi, Y; Nobuhiro, K. 2014. Changes in water stable aggregate and soil carbon accummulation in a no-till with a weed mulch management site after conversion from conventional management practices. *Geoderma*, 221-222, pp.50-60.

Mohammad, S.A., Junfang, C., Sharon, M.O. & Nicholas, M.H., 2015. Evaluation of soil structural quality using VIS–NIR spectra. *Soil & Tillage Research.*, 146: Part A, pp.108–17.

Moraes, Sá J. C.; Séguy, L.; Tivet, F; Lal, R.; Bouzinac, S.; Borszowskei, P. B; Briedis, C.; Dos Santos, J. B.; da Cruz, Martman D.; Bertoloni, C. G.; Rosa, J.; Friedrich, T. 2013. Carbon depletion by ploughing and its restoration by no-till cropping systems in oxisols of subtropical agro-ecosystems in Brazil. *Land Degradation & Development*, 26, pp.531-43.

Munkholm, L.J. & Schjonning, P., 2004. Structural vulnerability of a sandy loam exposed to intensive tillage and traffic in wet conditions. *Soil & Tillage Research.*, 79, pp.79-85.

Murungu, F., 2012. Conservation Agriculture for small holder farmers in the Eastern Cape Province of South Africa: Recent developments and future prospects. *African Journal of Agriculture Research*, 7, pp.5278-84.

Nahia, G; González-Arias, A; Merino, A; Martínez de, A; Martínez de Arano, I. 2009. Soil organic matter in soil physical fractions in adjacent semi-natural and cultivated stands in temperate Atlantic forests. *Soil Biology and Biochemistry*, 41, pp.1674-83.

Nahia, G., Marta, C.A., Ekhi, M. & Inazio, M., 2011. Physical protection of soil organic matter following mechanized forest operations in Pinus radiata D. Don Plantations. *Soil Biology and Biochemistry*, 43, pp.141-49.

Naoki, M., Gaku, I., Keisuke, K. & Naohiro, M., 2015. Simple method for measuring soil sand content by nylon mesh Sieving. *Soil Science and Plant Nutrition*, pp.1-5.

Nciizah, A.D. & Wakindiki, I.I.C., 2012. Particulate organic matter, soil texture and mineralogy relations in some Eastern Cape ecotopes in South Africa. *South African Journal of Plant and Soil*, 29, pp.39–46.

Nciizah, A.D. & Wakindiki, I.I.C., 2014. Rainfall pattern effects on crusting, infiltration and erodibility in some South African soils with various texture and mineralogy. *Water SA*, 40(1), pp.57-64.

Nimmo, J.R. & Perkins, K.S., 2002. Aggregate stability and size distribution. In J.H. Dane & G.C. Top, eds. *Methods of soil analysis part 4 Physical methods*. Madison Wisconsin: Soil Science Society of America. pp.317-28.

Nweke, I.A. & Nnabude., P.C., 2014. Aggregate size distribution and stability of aggregate fraction of fallow and cultivated soils. *Journal of Experimental Biology and Agricultural Sciences*, 1, pp.514-20.

Ogban, P I; Obi, J C; Sam, I J; Domingo, M U; Deezim, P; Okoror, P. 2013. Effect of land use on soil structural stability in Akwa Ibom State, Southeastern Nigeria. *Nigerian Journal of Soil & Environmental Research*, 11, pp.9 - 16.

Okalebo, J.R., Kenneth, W.G. & Paul, L.W., 2002. *Laboratory methods of soil and plant analysis: A working manual*. 2nd ed. Nairobi Kenya: SACRED Africa.

Ondřej, J; Radka, K; Adam, K; Iva, S; Ondřej, D; Aleš, K. 2015. Soil aggregate stability within morphologically diverse areas. *Catena*, 127, pp.287–99.

Paradelo, R., van Oort, F. & Chenu, C., 2013. Water-dispersible clay in bare fallow soils after 80 years of fertilizer addition. *Geoderma*, 200-201, pp.40-44.

Percival, H.J., Parfitt, R.L. & Scott, N.A., 2000. Factors controlling soil carbon levels in New Zealand grasslands: is clay content important? *Soil Science Society American Journal*, 64(5), pp.1623–30.

Pinheiro, E.F.M., Pereira, M.G. & Anjos, L.H.C., 2004. Aggregate distribution and soil organic matter under different tillage systems for vegetable crops in a Red Latosol from Brazil. *Soil & Tillage Research* , 77, pp.79–84.

Plante, A F; Conant, R T; Stewart, C E; Paustian, K; Six, J. 2006. Impact of soil texture on the distribution of soil organic matter in physical and chemical fractions. *Soil Science Society American Journal*, 70, pp.287–96.

Rabbi, S M F; Wilson, B R; Lockwoood, P V; Daniel, H; Young, I M. 2015. Aggregate hierarchy and carbon mineralization in two Oxisols of New South Wales, Australia. *Soil & Tillage Research*, 146, pp.193–203.

Ramasamy, V; Sundarrajan, M; Suresh, G; Paramas, K; Meenakshisundaram, V. 2014. Role of light and heavy minerals on natural radioactivity level of high background radiation area, Kerala, India. *Applied Radiation and Isotopes*, 85, pp.1–10.

Sainju, U.M., 2006. Carbon and nitrogen pools in soil aggregates separated by dry and wet sieving. *Soil Science*, 171, pp.937-49.

Sakin, E., 2012. Relationships between of carbon, nitrogen stocks and texture of the Harran plain soils in Southeastern Turkey. *Bulgarian Journal of Agricultural Science*, 18, pp.626-34.

Sánchez-Marañón, M., Soriano, M., Delgado, G. & Delgado, R., 2002. Soil quality in Mediterranean Mountain environments effects of land use change. *Soil Science Society of American Journal*, 66, pp.948-58.

SAS, 2013. 978-1-61290-664-5 *JMP® 11 Discovering JMP*. NC, USA: Cary SAS Institute Inc.

Schaefer, C.E.R., 2001. Brazilian latosols and their B horizon microstructure as long-term biotic constructs. *Australian Journal of Soil Research*, 39, pp.909–926.

Schaefer, C.E.G.R., Gilkes, R.J. & Fernandes, R.B.A., 2004. EDS/SEM study on microaggregates of Brazilian Latosols, in relation to P adsorption and clay fraction attributes. *Geoderma*, 123, pp.69–81.

Schulten, H.R. & Leinweber, P., 2000. New insights into organic-mineral particles: Composition, properties and models of molecular structure. *Biology and Fertility of Soils*, 30, pp.399–432.

Selen, D.S., Gunay, E. & Mustafa, B., 2015. Comparison of Aggregate Stability Measurement Methods for Clay-Rich Soils in Asartepe Catchment of Turkey. *Land Degradation and Development*, pp.DOI: 10.1002/ldr.2383.

Shadrack, B D; Zhong-Du, C; Lal, R; Zhang, H; Fu, C. 2014. Changes in soil organic carbon and nitrogen as affected by tillage and residue management under wheat–maize cropping system in the North China Plain. *Soil & Tillage Research*, 144, pp.110-18.

Shangyu, M; Zhenwen, Y; Yu, S; Zhiqiang, G; Lanping, L; Pengfei, C; Zengjiang, G. 2015. Soil water use, grain yield and water use efficiency of winter wheat in a long-term study of tillage practices and supplemental irrigation on the North China Plain.. *Agricultural Water Management*, 150, pp.9-17.

Shepherd, M.A., Harrison, R. & Webb, J., 2002. Managing soil organic matter – implications for soil structure on organic farms. *Soil Use and Management*, 18, pp.284–92.

Shrestha, B M; Singh, B R; Sitaula, B K; Lal, R; Bajracharya, R M. 2007. Soil aggregate- and particleassociated organic carbon under different land uses in Nepal. *Soil Science Society American Journal*, 71, pp.1194–203.

Singh, M.J. & Khera, K.L., 2008. Soil erodibility indices under different land uses in lower Shiwaliks. *Tropical Ecology*, 49(2), pp.113-19.

Six, J., Bossuyt, H., Degryze, S. & Denef, K., 2004. A history of research onthe link between(micro)aggregates, soil biota, and soil organic matter dynamics.. *Soil & Tillage Research* , 79, pp.7-31.

Six, J., Conant, R.T., Paul, E.A. & Pustian, K., 2002. Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant and Soil*, 241, pp.155-176.

Six, J., Elliott, E.T. & Paustian, K., 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biology & Biochemistry*, 32, pp.2099-103.

Soil Classification Working Group, 1991. *Soil Classification: A Taxonomic System for South Africa. Memoirs on the Agricultural Natural Resources of South Africa No. 15.*. Pretoria: Soil Classification Working Group.

Solomon, D., Lehmann, J. & Zech, W., 2000. Land use effects on soil organic matter properties of chromic luvisols in semi-arid northern Tanzania: carbon, nitrogen, lignin and carbohydrates. *Agriculture, Ecosystems and Environment* , 78, pp.203–13.

Spohn, M. & Giam, L., 2010. Water-stable aggregates, glomalin-related soil protein, and carbohydrates in a chronosequence of sandy hydromorphic soils. *Soil Biol Biochem*, 42, pp.1505–11.

Stacy, M.Z., Gevan, D.B., Emerson, D.N. & Maria, B.V., 2015. Crop Rotation and Tillage Effects on Soil Physical and Chemical Properties in Illinois. *Agronomy Journal*, 107, pp.971–78.

Stewart, C E; Plante, A F; Paustian, K; Conant, R T; Six, J. 2008. Soil carbon saturation: linking concept and measurable carbon pools. *Soil Science Society of America Journal*, 72, pp.379–92.

Sundermeier, A P; Islam, K R; Raut, Y; Reeder, R C; Dick, W A. 2011. Not-ill impacts of soil biophysical carbon sequestration. *Soil Science Society of American Journal*, 75, pp.1779-88.

Takahiro, I; Masaaki, A; Masakazu, K; Nobuhiro, K; Hiroyuki, O. 2015. Soil nematode community structure affected by tillage systems and cover crop managements in organic soybean production. *Applied Soil Ecology*, 86, pp.137–47.

Tisdall, J.M. & Oades, J.M., 2012. Organic matter and water-stable aggregates in soils. *European Journal of Soil Science, Landmark papers No. 1*, 63, pp.1–21.

Todd, A.O., Cynthia, A.C., Lisa, A.S. & Randall, K.K., 2015. Factors influencing soil aggregation and particulate organic matter responses to bioenergy crops across a topographic gradient. *Geoderma*, 255–256, pp.1–11.

Trakoonyingcharoen, T., Robert, J.G. & Kumut, S., 2012. Factors Contributing to the Clay Dispersion and Aggregate Stability of Thai Oxisols. *Walailak Journal of Science & Technology*, 9, pp.19-30.

Van Breemen, N. & Buurman, P., 2002. *Soil Formation 404 p.* Dordrecht: Kluwer Publishers.

Veronika, J; Radka, K; Antonín, N; Marcela, M; Anna, Ž. 2013. Temporal variability of structure and hydraulic properties of topsoil of three soil types. *Geoderma*, 204-205, pp.43–58.

Wakindiki, I.C. & Ben-Hur, M., 2002. Soil mineralogy and texture effects on crust micromorphology, infiltration, and erosion. *Soil Science Society of America Journal*, 66, pp.897–905.

Wattel-Koekkoek, E.J. & Buurman, P., 2004. Mean residence time of kaolinite and smectite-bound organic matter in Mozambiquan soils. *Soil Science Society America Journal*, 68, pp.154-61.

Weintraub, M.N. & Schimel, J.P., 2003. Interactions between carbon and nitrogen mineralization and soil organic matter chemistry in arctic tundra soils. *Ecosystems*, 6, pp.129-43.

Weiqiang, L; Xiaojing, L; Hailong, Q; Jialing, S; Deyu, D. 2004. *Two phase tillage: A quick method for crop production in saline soils*. Agrifood Research Report. No. 68: 66-72.

Wessels, K.J., Prince, S.D., Frost, P.E. & van Zyl, D., 2004. Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series. *Remote Sensing of Environment.*, 91, pp.47–67.

Williams, N.D. & Petticrew, E.L., 2009. Aggregate stability in organically and conventionally farmed soils. *Soil Use and Management*, 25, pp.284–92.

Zabala, M.S., Conconi, M.S., Alconada, M. & Torres, S.R.M., 2007. The Rietveld method applied to the quantitative mineralogical analysis of some soil samples from Argentina. *Revista Ciencia del Suelo*, 25, pp.65–73.

Zhang, S.; Li, Q.; Lu, Y.; Zhang, X.; Liang, W. 2013. Contributions of soil biota to C sequestration varied with aggregate fractions under different tillage systems. *Soil Biology and Biochemistry*, 62, pp.147–56.

Zhangliu, D., Tusheng, R., Chunsheng, H. & Qingzhong, Z., 2015. Transition from intensive tillage to no-till enhances carbon sequestration in microaggregates of surface soil in the North China Plain. *Soil & Tillage Research*, 146, pp.26–31.

Zhang, S; Li, Q; Zhang, X; Wei, K; Chen, L; Liang, W. 2012. Effects of conservation tillage on soil aggregation and aggregate binding agents in black soil of Northeast China. *Soil & Tillage Research*, 124, pp.196-202.