EFFECT OF PRE - WETTED TECHNIQUE ON SOIL TEMPERATURE, MOISTURE CONTENT, ORGANIC CARBON AND GREENHOUSE GAS EMISSIONS IN NIGER STATE, NIGERIA

BY

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MTech/SNAS/2013/4216

WEST AFRICAN SCIENCE SERVICE CENTER ON
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FEDERAL UNIVERSITY OF TECHNOLOGY,
MINNA

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THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY (MTECH) IN CLIMATE CHANGE AND ADAPTED LAND USE

OCTOBER, 2015

DECLARATION

I hereby declare that this thesis titled: "Effect of Pre - Wetted Technique on Soil Temperature, Moisture Content, Organic Carbon and Greenhouse Gas Emissions in Niger State, Nigeria" is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

KOGLO, YAWOVI SENA ……………………………………
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FEDERAL UNIVERSITY OF TECHNOLOGY,
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CERTIFICATION

This thesis titled "Effect of Pre - Wetted Technique on Soil Temperature, Moisture Content, Organic Carbon and Greenhouse Gas Emissions in Niger State, Nigeria", carried out by KOGLO, Yawovi Séna (MTech/SNAS/2013/4216) meets the regulation governing the Award of Degree of Master of Technology in WASCAL (Climate Change and Adapted Land Use) of the Federal University of Technology Minna, and is approved for its contribution to scientific knowledge and literary presentation.

Dr. (Mrs) A. Abdulkadir ……………………

Supervisor Signature & Date

Dr. A. A. Okhimamhe …………………….

Director, WASCAL, FUT-Minna Signature & Date

Prof. M. G. M. Kolo ……………………

Dean, Postgraduate School Signature & Date

DEDICATION

This work is dedicated to my father (Koglo K. A. Simon), mother (Awuve Akuvi), two brothers (Koglo Komi Eric and Koglo Kossi Joseph), the whole Koglo family and my beloved Assogba A. D. Honorine and her family.

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ABSTRACT

Poor agricultural practices, depletion of croplands productivity and carbon pools have continued to exacerbate indirect greenhouse gas (GHGs) emissions subsequently aggravating malnutrition and food security issues in Nigeria. For this purpose, an experiment was conducted at Edozhigi, in Niger State on integrated formulations of rice straw and urea at different rates respectively: 2, 3 and 4 t/ha and 25, 50 and 75 kg/ha with one check plot (C) (without straw and urea). Pre-wetted technique of the integrated formulations was adopted under Randomized Complete Block Design with (04) replications of ten (10) plots. The effect of treatments on the following variables; Soil Temperature (ST, ^{o}C), Moisture Content (SMC, %), GHGs emissions (kg/ha), Soil Organic Carbon Density (SOCD, t/ha), Soil Organic Carbon Density Gain per Month (SOCDG/month, kg/ha) and SOCD versus ST and SMC under each treatment were determined in order to identify the best treatments. Data collected were analysed using GenStat 16.2 and CCAFS-MOT 1.0 for SOC balance. Matlab 11.0 and Excel 2013 were also used for data plotting and regression graphs. Significance and Duncan's Multiple Range Test were performed at 95% confidence level. Results indicated significant difference of treatments on each parameters evaluated. ST reduction; SMC, SOCD and SOCDG increase is a function of the quantity of straw and urea incorporated (Fpr.<0.001). Moreover, the study revealed strong decrease of SOCD with ST (r= -0.801) and increase with SMC (r= 0.851), and three best treatments (T2, T4 and T5) were identified. Their responses (TR, %) to each variable were; Soil Temperature (ST, oC) reduction was up to 20 %, Soil Moisture Content (SMC, %) increased about 41%. Similarly, Soil Organic Carbon Density (SOCD, t/ha) and Soil Organic Carbon Density Gain per Month (SOCDG/month, kg/ha) have increased respectively to 40.3% and 43 %. Potential carbon sequestration was about 44.4 % for the improved practices identified with 0 % methane emission and scanty nitrous oxide emission up to 31.3 %. These results gave strong evidence concerning the use of pre-wetted technique as panacea to both mitigate climate change and enhance croplands productivity and resilience to these changes in Edozhigi.

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ABBREVIATIONS AND ACRONYMS

CH_4	Methane
CO_2-e	Carbon Dioxide Equivalent
C.V.	Coefficient of Variation
FUT-Minna	Federal University of Technology, Minna, Niger State
GHGs	Greenhouse Gas
IMP	Improved Management Practices
Kg	kilogramme
mol	molecule
N_2O	Nitrous oxide
NCRI	National Cereal Research Institute
SALMP	Sustainable Agricultural Land Management Practices
SOC	Soil Organic Carbon
SOCD	Soil Organic Carbon Density
SOCDG	Soil Organic Carbon Density Gain
SOM	Soil Organic Matter
SSA	Sub Sahara Africa
t	tonne
UNFCCC	United Nations Framework Convention on Climate Change
WASCAL	West African Science service on Climate Change and Adapted Land Use

CHAPTER ONE

1.0 INTRODUCTION

The impact of climate change and global warming are worldwide, and an increasing number of evidences in recent years have clearly established the fact that anthropogenic climate change is a reality. According to studies conducted by Intergovernmental Panel on Climate Change (IPCC, 2013); Stockmann, Adams, Crawford, Field, Henakaarchchi and Jenkins (2013); World Bank (2012), developing countries are more exposed to experience the negative impacts of climate change owing to their fragile economic sectors and the reliance of many livelihoods on climate-sensitive sectors. An increase of human activities exacerbates the release of greenhouse gases such as carbon dioxide, methane, nitrous in the atmosphere. According to the fifth report of IPCC (2013), human activities such as poor agricultural practices, deforestation, fossil burning, and poor land management practices are the main drivers of global warming since the mid-20th century.

Lal (2009) posited that carbon dioxide is the main greenhouse gas released in the atmosphere since the past twenty years. IPCC (2007) in its fourth assessment quoted that CO_2 concentration from agricultural practices in the atmosphere has increased from 280 μmol/mol before industrial revolution to 379 μmol/mol in 2005, and it would be increasing by a rate of 1.9 μmol/mol per year. Consequently, agriculture is considered as the main source of CO_2 released in the atmosphere as well as soil health degradation (Lal, 2003; Oelbermann, Voroney and Gordon 2004; Wang, Zhang, Song, Lui and Ren, 2010). Thus, world agricultural soils are historitically considered as a major source of atmospheric enrichment of carbon dioxide.

Though, certain uncertainties dwelled in the statistics, about 80% of the global emissions presently came from land use change and poor croplands management practices (IPCC, 2001; Lal, 2003; World Bank, 2009). Globally, croplands have the capacity to store 248 Pg of carbon in the top 3 metre of soil, but this proportion is seriously disturbed by land use practices which exacerbate the loss of SOC (Soil Organic Carbon) (Stockmann *et al.*, 2013). Nonetheless, agriculture can play an imminent role in removing carbon dioxide from the atmosphere through soil conservation practices commonly named Improved Management Practices (IMPs) techniques. This is to enhance soil organic matter storage with minimum soil disturbance through management of farming systems (Fuentes, Govaerts, Leon, Hidalgo, Dendooven, Sayre and Etchevers, 2009; Lal, 2005; Liu,Yufang, Shenjaio, Shiqing, and Fang, 2011). Accordingly, implementation of judicious mulching tillage combined with fertilizers applications, cover crops, hedgegrow intercropping (alley farming), less or no tillage and other Sustainable Agricultural Land Management Practices (SALMP) are options that can help to maintain, control, monitor and enhance croplands resilience to temperature increase, humidity and soil carbon losses (Jarecki and Lal, 2006).

From the aforementioned, IMPs (Improved Management practices) are paramount to mitigate and adapt to climate change through sequestration of terrestrial carbon. Besides, they can help to augment soil agricultural values, veritable way to avoid and lessen food insecurity problems, considered as crucial imprint of climate change on rainfed agricultural systems in developing countries. Therefore, it is crucial to develop IMPs to maintain soil moisture, reduce soil temperature consequently enhance soil organic carbon and improve crop productivity.

1.1 Background of the Study

Climate change is viewed as the change of climate parameters (rainfall, temperature) over a long period of years due to greenhouse gases (GHGs) mainly, carbon dioxide (CO_2), nitrous (N_2O) and methane (CH_4). Their quantity are rising in the atmosphere owing to anthropogenic activities since the advent of industrial era (Wallington, Jayaraman, Ole and Ellie, 2004; Muñoz, Paulino, Monreal and Zagal, 2010; Intergovernmental Panel on Climate Change: IPCC, 2013). Amongst the three GHGs aforementioned, CO_2 represents the most important almost 60% of the total GHGs emitted.

These emissions are generated mainly from poor agricultural practices (mechanical tillage, soil burning, monocropping) due to the fact that soils are the major reservoirs of carbon (75%) (Lal, 2003). In the light of this, improved management practices on agriculture lands are regarded as panacea to mitigate these changes through sequestration of these molecules in soils which are considered as the major pool of sequestration (Jarecki *et al.,* 2006; Jordan, Zavala and Gil, 2010). However, the effectiveness of this sequestration depends on certain physico-chemical conditions of soils, but also on the type of management used (Cambridge Conservation Initiative, 2011; Gruber, Mohring and Claupein, 2011). Numerous studies have underlined utmost relationships between soil temperature, moisture on soil organic carbon and greenhouse gases emissions from soils (Wang *et al.*, 2013; Wang *et al.*, 2010; Zhu, Yang and Chen, 2012). Accordingly, adequate soils management are the sole way to enhance resilience of agricultural lands to temperature increase, moisture depletion and labile carbon losses for sustainable farming under climate change and variability threats.

1.2 Problem Statement

Nigeria in general and Edozhigi in particular, is considered as one of the major pole of rice production and consumption in West Africa, and similarly to other Africans' countries and villages, one of the most vulnerable to climate change owing to poverty, dominance of rainfed agriculture and poor soil management practices (Obioha, 2008; Fasona and Omojola, 2005; World Bank, 2012). Akinro, Opeyemi and Ologunagba (2008) reported that, Edozhigi rice growers encountered a veritable problem in the management of rice straw and they are constrained to burn these residues, that is, increase emission of greenhouse gases in the atmosphere. Moreover, agricultural lands in that area are experiencing an increase in temperature, decrease in soil moisture renders crops sensitive to heat accordingly, crops failure (Akinro *et al.*, 2008; Abioha, 2008; Ojeniyi, Odedina and Akinola, 2009). Whereas, these straw can be used as biological fertilizers in combination with urea in order to enhance soil resilience under climate negative effects on croplands but also as co-benefit to yield agriculture productivity in degraded zones (Christopher and Lal, 2007; Jordan *et al.*,2010).

Moreover, no study has been conducted in Edozhigi over short period concerning pre-wetted rice straw and urea utilization as alternative to soil organic carbon sequestration through soil moisture and temperature regulations under short-term experimental trial (Nigeria Environmental Study/Action Tool: NEST, 2011; Building Nigeria's Response to Climate Change**:** BNRCC, 2007; Gwary, 2008; Ojeniyi *et al.*, 2009). These vacuums underscore the relevance of this study, through which best improved management practices, available, accessible and less cost effect will be input and proposed to smallholders for both croplands resilience and economic livelihood improvement under climate change in Edozhigi community.

1.3 Justification of the Study

Increasing in atmospheric CO_2 is a dual consequence of poor management of crop residues and agricultural land practices (IPCC, 2013; Lal, 2009). Therefore, enhance carbon depletion from the atmosphere, necessitates a fairly changes in land use management practices for both enhancing soils carbon pool mainly labile organic carbon, and reinforce soils net productivity through regulation of soil temperature and moisture content (Liu *et al.*, 2011; Lal, 2005). Moreover, crop residues burning are also considered as a chief contributor of GHGs emissions in the atmosphere. Accordingly, to find an appropriate methods which can enable farmers to incorporate these residues in land use practices will be a great benefit to meet the expectations of the UNFCCC (Jordan, 2010; Gruber, 2011; Krishna, Arun, Kuntal, Kali, Prabir and Manoranjan, 2004).

Therefore, in the light of this, it is quite paramount to promote improved management practices (IMPs) based on the use of crops residues and local assets and accessible chemicals used by the smallholders of Edozhigi, Gbako Local Government as alternative to climate change impacts and mitigation strategies. Moreover, short term experimental trials on IMPs and soil organic carbon and soil physical properties (humidity and temperature) are still unknown and unclear (Ma, 2009; Munoz, 2010). These weaknesses underscore the reason for this research which tried to find out the short time effects of rice straw and urea application on soil labile organic carbon density, possible gain; soil temperature regulation and soil moisture conservation as primary factors influencing SOC mineralisation. Besides, the study tried to identify the linear relationship between the IMPs and soil quality parameters, also to identify the best combination that can enhance Edozhigi croplands resilience to global warming.

1.4 Scope

This study focuses on the use of rice straw and urea application as integrated formulations on cropland resilience to climate change. It was an experimental trial in randomized complete block design with four replications. Rice straw and urea were used at three differently proportions respectively: 2, 3, 4 t/ha and 25, 50, 75 kg/ha. Major parameters, viz: soil organic carbon density (SOCD, t/ha), soil organic carbon density gain per month (SOCDG, kg/ha), moisture content (SMC, %), temperature (ST, ^{0}C), SOCD versus SMC and ST, and greenhouse gas emissions (GHGs, kg/ha) level of each treatment were measured after three months in order to appreciate and identify the best treatment in terms of mitigation and adaptation of croplands under climate change threats. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) were measured with Climate Change Adaptation Food Security Mitigation Option Tool (CCAFS-MOT) developed by the International Centre for Tropical Agriculture (CIAT) (Feliciano, Nayak, Vetter and Hiller, 2015).

1.5 Limitation of the Study

This study was limited by the time frame. It is relevant to seek the implication of the practices on crop yields before taking any final decision because farmer’s main target is crop yield. Moreover, greenhouse gas emissions must also be assessed in addition to improve practices for an effective choice of sustainable agricultural management practices before it is carried to rural communities.

1.6 Aim and Objectives of the Study

The overarching goal of this present research was to assess improved management practices on croplands resilience to climate change using rice straw and nitrogen applications on soil temperature and moisture regulation and soil organic carbon storage over a short period of time. The objectives include:

i. Evaluate the variation of soil temperature, moisture and greenhouse gas (CO_2, CH_4 and N_2O) emissions under each treatment;
ii. Compute the dose and gain per month of unstable SOC for each treatment;
iii. Determine the relationships between soil moisture and unstable SOC dose; temperature and unstable SOC dose;
iv. Identify the best treatment in terms of high SOC storage, soil temperature and moisture regulation with scanty emissions of greenhouse gas.

1.7 Research Questions

To achieve each objective aforementioned, our study tried to answer the following questions:

i. What is the implication of each treatment on soil temperature, moisture regulation and greenhouse gas (CO_2, CH_4 and N_2O) emissions?
ii. What is the storage rate of unstable SOC for each treatment?
iii. What is the relationships between soil moisture, temperature and unstable SOC dose?
iv. What is the best treatment in terms of soil temperature, moisture regulation, unstable SOC storage and scanty greenhouse gas emissions of within three months?

1.8 Study Area

This study was conducted at Edozhigi, Gbako Local Government Area of Niger State, Nigeria. This is located between Longitude 5^o46^1 to $6^o\,03^1$E and Latitude 8^o25^1 to $9^o\,13^1$N at 12 kilometre northwards Bida town. Estimated population is about 150,640 habitants and more than 70% of the villagers are totally involved in rainfed agriculture as main revenue source (Nigeria Environmental Study/Action Tool: NEST, 2011) (Figure 1.1).

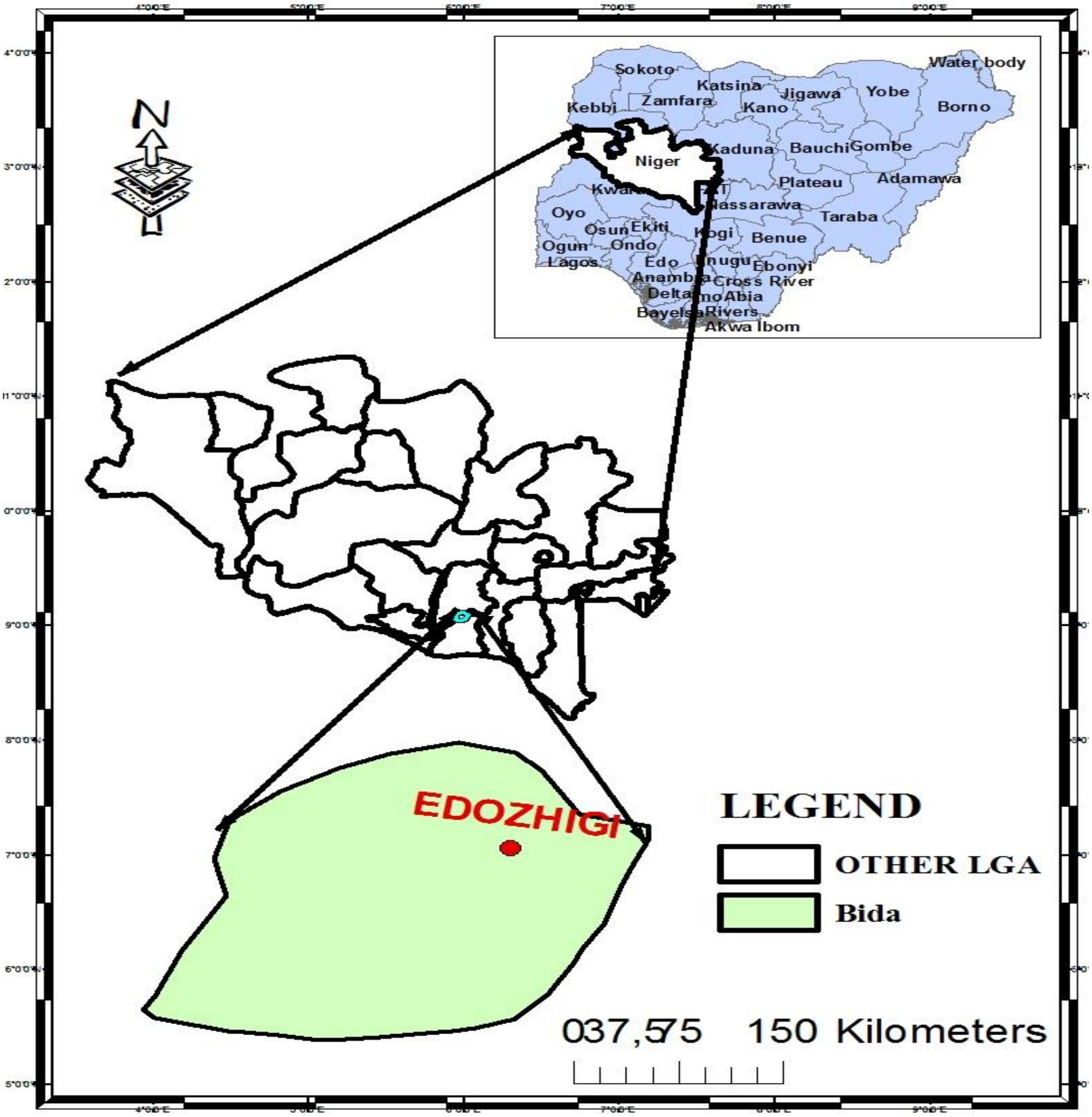


Figure 1. 1 Study Area

1.8.1 Climate of the Area

Niger State experiences a distinct dry season and a wet season. Annual rainfall in the State varies from an average of 1,100 mm in the northern part to about 1,600 mm in the southern part. The rainy season lasts for an average of 150 days in the Northern parts and about 210 days in the southern parts of the State. The mean maximum temperature is recorded between March and June, the average temperature is 34 ^{o}C, while the mean minimum is recorded usually between December and January (Ojeniyi *et al.*, 2009).

1.8.2 Soil, Vegetation and Water Bodies

Three major soil types characterize the State. These include ferruginous tropical soils, hydromorphic soils and ferruginous tropical soil. The most predominant soil types are the ferruginous tropical soils and are basically derived from the Basement Complex Rocks, as well as from old sedimentary rocks. Such ferruginous tropical soils are ideal for the cultivation of guinea corn, maize, millet and groundnut. Hydromorphic or waterlogged soils are largely found in the extensive flood plain of the Niger River (Gwary, 2008). This constitutes the major soil type of the study area, these are poorly drained and are generally grayish or sometimes whitish in color due to the high content of silt. Lastly, ferruginous tropical soils which developed on sandstone formations are characteristically red in color and enriched with a clay sub soil which are found within the Niger trough.

The Guinea Savannah vegetation covers the entire landscape of the state. This type of vegetation is characterized by woodlands and tall grasses interspersed with tall dense species. In addition, within the Niger trough and flood plains, taller tree and a few oil palm tree occur. The State’s major rivers are: Niger, Kaduna, Gbako, Eko, Gurara, Ebba, Ega, Mariga, and their tributaries (Building Nigeria’s Response to Climate Change: BNRCC, 2007; Gwary, 2008).

1.8.3 Study Population and Economic Activities

The total land area of the state is about 74, 244 sq.km out of which 80% is suitable for agriculture. This makes the state the largest in the country in terms of landmass. According to the 2006 census, the State's population is about 3,950,249 with 51.5% males and 48.5% being females; the population density is about 33 per sq km. It should be noted, however, that this low population density conceals local variations, particularly in some of the largest local government areas such as Wushishi, Borgu, Mariga and Shiroro where population density is below the state average. As a result of such low density of population, large expanses of land exist which are currently undeveloped or uncultivated. Niger State has an annual growth rate of about 3. 4% (Niger State Bureau of Statistics, 2012).

The state has about 26 identifiable native ethnic groups and languages. The predominant ones are the Nupe, Hausa, and Gbagyi. However, Baruba, Dibo, Dukkawa, Fulani, Gade, Ganagana, Ingwai, Kadara, Koko, Kambari, Kamuku, and Pangu, as other ethnic groups also exist. Islam and Christianity are the major religions in the State. Administratively, the state comprises of twenty-five (25) Local Government Areas (LGAs) grouped into three (3) agricultural zones which coincide with the senatorial divisions of the state. The LGAs are grouped as follows: Zone I (made up of Agaie, Bida, Edati, Gbako, Mokwa, Katcha, Lapai and Lavun LGAs), Zone II (made up of Bosso, Chanchaga, Gurara, Munya, Paikoro, Rafi, Shiroro, Suleja and Tafa LGAs) and Zone III (made up of Agwara, Borgu, Kontagora, Magama, Mariga, Mashegu, Rijau and Wushishi LGAs). Finally, it serves as market centre for mainly rice followed by sorghum, yams, millet, groundnuts and cotton. (Nigeria Environmental Study/Action Tool, 2001)

CHAPTER TWO

2.0 LITERATURE REVIEW

This section focuses on the concept and review of related studies on soil organic carbon (SOC), viz: definition, forms, assessment, factors affecting soil SOC and long-term combined effect of rice straw and urea on SOC, soil temperature and moisture content.

2.1 Conceptual Framework

2.1.1 Soil Organic Carbon (SOC)

Soil organic carbon is the main constituent of soil organic matter which is formed from natural, biological, chemical and physical processes from above ground and/or below ground sources (Chan *et al*., 2010). It had been considered for long time both by farmers and scientists as the major indicator of soil health for sustainable agriculture. Higher carbon content enables soils to make more water and nutrients available to support plants growth; enhances and increases plants and soils resilience to pests and diseases (Cambridge Conservation Initiative, 2011; Krull, Baldock, Skjemstad, 2003). The amount and quality of SOC emanate both from the decomposition of macro-organisms and micro-organisms (Wolters, 2000). The major SOC comes from the decomposition of plant litters while microbial and animal constitute the secondary source of SOC in the soil (Wolters, 2000; Krull, Baldock and Skjemstad, 2003; Wang, Baldock, Dalai and Moody, 2004; Nielson, 2011). Simply put, the proportion of Soil Organic Carbon (SOC) depends on the amount and the quality of biomass added to this soil. These organic matter come mostly from farming activities. Otherwise, crops residues, rest of plants are the one involved in the process of humification and mineralisation through microbiologic activities.

It is quite clear from those quotations aforementioned that, terrestrial organic carbon constitutes the main sink of carbon. In absolute terms, terrestrial organic carbon stocks are much larger than carbon sequestered in biomass and oceans (Lal, 2009; Nielsen *et al.*, 2011). Soils are generally capable of holding more carbon than vegetation and account for 81% of terrestrial stock at the global level (Lal, 2011; Word bank, 2012). In the light of this, better understanding of soil carbon, mainly organic carbon, and the improvement of the assessment models, is quite crucial in climate change mitigation strategies.

2.1.2 Forms and Assessment of Soil Carbon

Soil carbon is very dynamic, and the process of formation varies in function of the type of carbon (Cambridge Conservation Initiative, 2011; Chan *et al.*, 2010). Meanwhile, according to several studies, soil is the reservoir of two major pools of carbon namely: Soil Inorganic Carbon (SIC) coming from geologic or soil parental materials as carbonates. It is not strongly affected by land management and therefore not as relevant to climate mitigation (Walcott, Bruce and Sims, 2009; Lal, 2011). On the other hand, Soil Organic Carbon (SOC) derived from organic matter such as plant and animal materials at various stage of decomposition. The storage of SOC in the soil depends on both abiotic and biotic factors such as temperature, soil moisture and soil texture which influence SOC stabilization and destabilization processes (Lal, 2009; Oelbermann, Voroney and Gordon, 2004). SOC pool at 1m to 2m depth in tropical regions is lowest compared to other regions, and the highest SOC concentrations were observed in the upper soils layer (Jackson, Schenk, Jobbagy, Canadell, Collelo and Dickinson, 2000). Thereby any disturbance in the relocation of SOC through soil management is quite significant to alter the global carbon. Depth distribution of SOC is not equal over different types of soils (boreal, temperate, tropical and subtropical) (World Bank, 2012; Bationo and Buerkert, 2001). Most of soils stored the maximum amounts of SOC between 1 and 2 m depth (Jackson *et al.*, 2000). By convention, SOC has been graded into three main pools: labile, slow and stable carbon. Unstable carbon emanates from the decomposition of organic matter and microbial biomass while, the slow and recalcitrant carbon are respectively the sub-products of humus and charcoal (Lal, 2011).

Unstable (labile) soil organic carbon is the most exposed and sensible to poor land management practices for agricultural activities, and constitutes the most concerned by improved land management practices in order to mitigate its releases in the atmosphere and to render soil healthy for sustainable agriculture. Meanwhile, assessment of soil carbon over large areas is quite onerous and crucial. According to World Bank study in 2012, certain key parameters are significant in determining or measuring soil carbon. Soil carbon content, soil depth and bulk density aid to assess soil carbon. Depth and bulk density together aid to estimate soil mass per unit area whereas, soil carbon aids in determining what proportion of the mass is carbon. Meanwhile, three major methods are usually used namely: Biomass Average Estimation (BAE), Forest Inventory (volume of carbon stock, tree diameter) and the use of Ground Truth Tool (GTT). Optical radar sensors to map the different carbon sites and several models (RothC, CENTURY, CO_2FIX, DNDC, PROCOMAP) to assess the above-ground biomass are recently used as more sophisticated tools in assessing soil carbon (Cambridge Conservation Initiative, 2011; World bank, 2012). However, in soil survey analysis to determine soil organic carbon, the core sample method developed by Morisada, Ono and Kanomata (2004) is commonly used for soil sampling on the terrain before the laboratory analysis. Concerning the laboratory analysis, several methods are used to analyse SOC levels in soil. All of them differed slightly, and the choice of measurement depends on the objective of the study, soils health status and the economic level of the researcher. Dry combustion, Wet chemical oxidation and Loss on ignition (LOI) are more accurate methods used for laboratory measurement in determining soil organic carbon. Firstly, dry combustion method is considered as the most precise and accurate procedure today but its high cost constitutes the major limitation to many laboratories (Konen, Jacobs, Burras, Talaga and Masson 2002) especially of developing countries. Moreover this method demands highly technical and experienced manpower, sophisticated equipments and laboratory facilities. Secondly, wet chemical oxidation (Walkley and Black, 1934). It is relatively simple, rapid and easy to perform (Schumacher, 2002) but has significant uncertainties regarding oxidation of constituents other than SOC, and the proportion of total SOC that is oxidized (Konen *et al.*, 2002). It measures, on average, about 80% of SOC, and the coefficient of correction (1.25) is applied before having the total soil organic carbon. Meanwhile, various modifications of this method are made to overcome these uncertainties and variability in estimation (Wang, Zhang, Song, Lui, and Ren, 2010). Finally, since decades, Loss on ignition (LOI) technique is also viewed as the most reliable. Meanwhile, the procedure is not universal (Schumacher, 2002; Hoogsteen, Lantinga, Bakker, Groot and Tittonell, 2015), and it is accurate and cost effective to determine SOC and SOM (Schulte and Hopkins, 1996).

2.1.3 Importance of Soil Organic Carbon

Soil organic carbon is one of factors which affects greenhouse gases emissions in the atmosphere mainly carbon dioxide (CO_2). Because, every tonne of carbon lost from agricultural practices is a tonne of carbon emitted into the atmosphere. And for every tonne of carbon in the soil is equivalent to 3.67 tonne of CO_2 (Lal, 2011). Simply put, 1 tonne of carbon losses from soil owing to poor land management generates 3.67 tonne of carbon dioxide in the atmosphere. Therefore, adoption of improved land management practices in order to enhance soil carbon pools, mainly labile carbon is quite useful and crucial for mitigation and adaptation strategies. Simply put, it is considered as the important regulators of CO_2 in the atmosphere (Walcott, Bruce and Sims, 2009; Lal, 2011). Moreover, apart from its influences on GHGs releasing in the atmosphere, it is also considered as a key indicator of soil quality and agronomic suitability because of its benefit role on soil physical, biological and chemical properties and serves as repository source of plant nutrients (Table 2.1).

Table 2. 1 Soil Organic Carbon Effects on Soil Fertility

SOIL FERTILITY	EFFECTS OF SOIL ORGANIC CARBON (SOC)	C POOLS
Nutrients available	Release of N, P, K and others macro and micro Elements	Labile, slow
Enhance texture And structure	Soil holds more water and it is facile to till and cultivate	Labile, slow
Enhance soil micro And macrofaunes	Humus percentage is high	Labile
Control of toxins	Elimination of pesticide and toxins residues	Slow and

Source: Adapted from: Chan, Oates, Lui, Li, Prangnell, Poile and Conyers (2010)

As aforementioned in the Table 2.1, it is quite clear that the three pools of SOC have an imminent roles to play in maintaining soil health hence, it is relevant to adopt land management systems that can yield the amounts of SOC. However, the quantity and quality of SOC depends on various factors such as: land use techniques (tillage practices, crop residue management) and climatic (temperature and humidity) (Wolters, 2000; Krull, Baldock and Skjemstad, 2003; Jarecki and Lal, 2006).

2.2 Literature Review

2.2.1 Factors Affecting Soil Organic Carbon

The quality of SOC depends both of abiotic and biotic factors. Therefore well management and control of these factors will be of great benefit to enhance soil organic carbon pools. Soil practices and soil characteristics are more considered as key factors that enable and influence soil ability in storing soil organic carbon.

2.2.1.1 Soil and Management Practices

Soil types and Land use management have a significant role to play in soil organic maintenance. Numerous studies have demonstrated the peculiar influence of soil texture on SOC sequestration**.** The rate of storage in clayey soils is quite different in sandy soils and loamy soils (Lal, 2011; Bationo, Kihara, Vanlauwe, Waswa and Kimetu, 2005). Moreover, the stabilization and the variations of soil organic compounds is tightly related to the soil content in clay and silt (Bationo and Buerket, 2001). Bationo and Buerket (2001) have conducted a soil survey study in West Africa, and arrived at the conclusion that, there is a positive linear relationship between soil organic compounds under different land use systems and soils content in clay and silt. Moreover, Six, Conant, Paul and Paustian (2002) have emphasised the closely association in carbon content with clay and silt content. Study revealed that, silt and clay enhances soil particles aggregations, that is, physically protects SOC by controlling microbial activities.

Apart from soil texture, soil depth also has an important negative effect on soil organic carbon. In other word, the increase in depth entails the depletion in SOC. Indeed, Chan *et al.* (2010) have experimented long-term experimental trial in China in order to seek the correlation between soil depth and soil organic carbon through conservation tillage. This study led to the conclusion that, the difference of carbon stored on the upper and bottom soil was significantly different. Besides, organic matter mineralisation is lower on the lower layer of the soil compared to the upper layer. In contrast, there are uncertainties in the direct relationship between soil depth and SOC. According to the literature, the depth distribution of SOC depends on the management practices which, have an exponential forces to enhance microbial activities in the deep layers of the soil (Chan *et al.*, 2010; Bationo *et al.*, 2005). Following this perspective, Bationo *et al.* (2005) have demonstrated the positive correlation of improved management practices and SOC depth distribution. Study had shown that soil organic carbon is both affected by soil depth and management practices. By assessing different land management practices in West Africa and their probable effects on soil carbon, arrived at the conclusion that the intensity of the management on soil disturbance could affect SOC depth distribution. From these previous comments, it is quite clear that, soil organic carbon storage depends on the management practices due to their ability to increase soil organic matter and enable micro-organisms activities. It is likely that, integrated formulations of organic and inorganic fertilizers in order to improve soil fertility can help to maintain and increase soil organic carbon. Several studies have posited both positive and negative relationships in nitrogen fertilizer application.

It is obviously demonstrated the positive correlation between nitrogen fertilizer and soil organic carbon storage, but the rate of sequestration varies with application levels of nitrogen fertilizer (Lu, Wang, Han, Ouyang, Duan and Zheng, 2010; Lu, Zhou, Luo, Yang, Fang, Chen and Li, 2011; World Bank, 2012). However, the level of SOC increases under nitrogen fertilization only when crop residues are returned to the soil (Lal, 2005; Lu *et al.*, 2011). In contrast, according to Christopher and Lal (2007), Nitrogen addition has either a limit or benefit effect on SOC. Campbell, Selles, LaFond and Zentner (2001) have related this statement to the fact that SOC is linearly related to the amount of crop residues returned to the soil and crop residues were directly related to nitrogen addition. Another concern of nitrogen fertilization is its implication in Nitrous oxide emissions however, there is a great uncertainty between N_2O emissions either for no and conventional tillage (Grandy, Loecke, Parr and Robertson, 2006).

Studies reported that, nitrogen application has an influence on both No Tillage (NT) and Conservation Tillage (CT) N_2O emissions (Grandy, Loecke, Parr and Robertson, 2006; Wanger *et al.*, 2007). While, Lemake, Izaurrable, Nyborg and Solberg (1999) have observed lower N_2O under NT compared to CT. Other studies also have confirmed the fact that, N_2O fluxes can be higher from CT compared to NT under mulching tillage or nitrogen application (Mutegi, Munkholm, Petersen, Hansen and Petersen, 2010). Meanwhile, soil physical factors are also chief contributor to GHGs emissions.

2.2.1.2 Soil Physical Properties (Temperature, Moisture)

Several soil factors are the main contributor to terrestrial GHGs emissions in the atmosphere. Jarecki and Lal (2006) study highlighted that, carbon dioxide fluxes are positively correlated with both soil and air temperature, and negatively correlated with soil moisture content. Potter, Velazquez-Garcia, Scopel and Torbert (2007) explored interactions with residue management practices in maize fields at six different sites under different temperature regimes across Mexico and discovered that, an increase in soil temperature exacerbated the rate of carbon mineralisation, leading to a decrease in the soil organic carbon pools. It is likely in future that, soil organic carbon amounts will vary with soil temperature Kirschbaum (1994). Study reveals that, 1°C increase in temperature could ultimately lead to a loss of over ten percent (10%) of soil organic carbon. In a regions of the world with annual mean temperature of 5^{o}C whereas, the same temperature increase would lead to a loss of only three percent (3%) of soil organic carbon at 30^{o}C. Indeed, soil ability to decompose soil organic matter under colder temperatures is slow while, it increases rapidly under higher temperatures. Otherwise, under hot conditions, decomposition rates are so pronounced that all organic carbon is decomposed, despite high plant productivity. Moreover, Wang, Zhou, Xu, Ruan and Wang (2013) have conducted a similar study in China, in order to better understand temperature sensitivity on soil organic carbon mineralisation through incubation method. Results revealed that the rates of temperature sensitivity of SOC mineralisation on surface soils (0-10cm) in the four sites surveyed are positively correlated with an increase of incubation temperature during the entire incubation.

Wang, Li, Lü, Sun and Wu (2010) have conducted a close study on peat soil by using incubation method with variation of temperature during 40 day. The incubation experiments was carried out under well control temperature (5℃ , 10℃, 15℃ and 20℃), and the soil carbon mineralization was determined using alkali traps in order to absorb CO_2 emitted by the peat samples. It resorts from this study an increase of total carbon mineralization from 24.87 mg/g to 113.92 mg/g, but with significant mineralization in the upper peat layer than the lower peat. From these analyses, it is quite obvious to remark that temperature is a subset of one of the important environmental factors that affects the accumulation and decomposition of soil organic carbon.

2.2.2 Crop Residues and Nitrogen Application

In general, crop residues are considered as rest of plants left in the field after crops have been harvested and threshed. Estimation (10^6 Mg/yr) of crop residues from rice field in the tropics and the world was up to 604 in 2001 while, the amount of crop residues produced in the world was up to 3758x10^6 Mg/yr (World Bank, 2012; Lal, 2011; Liu *et al.*, 2011) . However, management of residues, mainly rice straw management became a major challenge of rice growers due to its high silica content, that is, poor feed for the animals (Krishna, Arun, Kuntal, Kali, Prabir and Manoranjan, 2004; Lal, 2005). At time considered as waste, they are now involved in soil health improvement and in soil improved management practices to mitigate and adapt to climate change instead of burning or using it to feed animals. Burning for residues can generate as much as 13 tonnes of carbon dioxide per hectare, thus indirectly depriving soils organic matter whereas, non-burning on just 2 million hectare would reduce the huge flux of yearly CO_2 emissions by 17 million of tonnes (Lal, 2005; Liu, 2011; Ma, Ma, Xu and Yang, 2009).

Simply put, it has been demonstrated that, the ability of soils to sequester SOC under crop residue management in temperate and arid tropical regions is about respectively 250 to 1000 kg/ha/yr and 50 to 250 kg/ha/yr (Krishna *et al.*, 2004; Lal, 2005; Singh, Singh and Timsina, 2005). Therefore, removal of crop residues for other purposes such as burning will render croplands poor and exacerbate atmospheric CO_2. Reason why, there is a need to convert and improve their use in soil management practices, sole durable and reliable method to both mitigate and increase agronomy productivity and profitability.

Numerous positive impacts of crop residue return include soil erosion reduction, temperature reduction, moisture conservation and organic carbon enhancement (Zhu, Yang, and Chen, 2012; Zhou, Li, Jin and Song, 2009; Kar, 2003). According to several authors, crop residues apply in form of mulch reduce the flux of incoming solar energy into the soil, as a result soil temperature is minimized under mulched plots rather than no mulched plots (Kar, 2003; Jordan, Zavala and Gil, 2010).

2.2.2.1 Effect on Soil Carbon Sequestration

Crop residues and nitrogen application have a dual effects on soil organic carbon (SOC). They can enhance or deplete SOC content however, the degree of negativity is marginalised when judicious and adequate managements are adopted (Lal, 2009; Lu *et al.*, 2010). Numerous researches have posited that, crop residues can yield SOC up to 250 to 1000 kg/ha/yr and 50 to 250 kg/ha/yr respectively under temperate and arid tropical regions. Moreover, they intervene in moderating GHGs fluxes if evenly incorporated (Krishna *et al.*, 2004; Lal, 2005; Singh *et al.*, 2005). Jacinthe, Lal and Kimble (2002) have conducted long-term experiment using wheat straw and urea at different proportions on Luvisol, Ohio State, USA. The idea behind was to find out how urea and wheat straw utilization as soil amendment can aid to halt carbon losses from Ohio State agricultural lands Two ways completely randomised block has been used as experiment unit. Three fractions of urea and wheat straw have been applied.

Results of the study revealed that, incorporation of mulch and urea in soil increase both SOC concentration and enhance soil ability to sequester SOC by reducing carbon dioxide emission from soil. In addition, study has shown that application of wheat residues with Urea fertilization increased humification of biomass and enhance SOC sequestration rate.

Blanco-Canqui and Lal (2007) have undertaken 10 years experiment trial using wheat residues in order to find out their positive effects on soils structure improvement and carbon sequestration on no-till soil. Experiments were conducted on field. Results have shown that application of mulch on cultivated soil increases soil organic concentration, but also enhances soil agricultural values.

Ma, Xu and Yagi (2009) and Muetgi *et al.* (2010) have ascertained that, crop residues incorporation and adequate nitrogen application can increase methane emission and decrease nitrous oxide respectively by 3.9 - 10.5 and 78% , but augment plants biomass by then soil carbon content. After five years experiment trials, they arrived at the conclusion that, nitrogen enhances biomass mineralisation, but also contributes to scanty emission of GHGs mainly N_2O. Varughese (2011) has conducted similar study over twenty two years (22) experiment trial by using different proportions of rice straw, viz: 0, 8 and 16 kg added annually on each plot of 2 m^2 in order to assess, the effect of mulching and tillage on greenhouse gas emissions. Research outcomes have shown that, the average diurnal fluxes of CO_2 were lower under No-tillage (NT) than Conventional tillage (CT). N_2O emissions were also higher under CT due to plowing and NT was more a sink for CH_4 while CT was more a source of emissions. Moreover, organic carbon was higher in NT than CT treatment.

Zhu *et al.* (2012) have experimented four land use practices over a long period of time in wheat-maize double cropping in China. The four treatments considered were organic manure (OM), manure with chemical (MF), straw return (SR) and reduced or no tillage (RNT) over a respective period of 48, 26, 22 and 18 years. On average, the IMPs of OM, MF, SR and RNT have enhanced SOC density by 260, 328, 278 and 134 kg/ha/yr respectively, and the gain of SOC for each treatment was 34.7%, 36.1%, 22.0% and 12% respectively. In fact positive effects of straw management on soil properties and soil organic carbon measurement is a dual function of biotic and abiotic (climate and time). Green, Cavegelli, Dao and Flanagan (2005) assessed the role of farming systems especially crop residues maintaining after harvesting on soil carbon, nitrogen and phosphorus enrichment. Through long-term experiment trials (5 years) under organic and conventional cropping systems, results revealed that crops litter maintaining during post-harvest period has a huge benefit on soil health improvement. Otherwise, organic plots carbon, nitrogen and phosphorus sequestration were highly significant at 5% than unmulched plots.

Zoratelli, Alves, Urquiage, Torres, dos Santos, Boddey and Six (2005) have also experimented two farming systems techniques in two oxisols in Ohio State. The rational behind this study was to assess the impact of mulching tillage, crop rotation on soil carbon sequestration. Study has been conducted using two ways factorials block design over long period. Outcomes from this trial have clearly established the fact that, mulching tillage enhances soil protection and aggregates soil carbon than crop rotation. Rotated plots carbon were less compared to mulched plots. This study is further confirmed by Lopez-Frando and Pardo (2009) and Gruber, Mohring and Claupein (2011) under different environment respectively semi-arid environment and temperate (Germany). Sheng-wei Nie, Huang, Zhang, Guo, Zhang and Bao (2012) have experimented Long-term combined fertilization experiment (1991- 2008) in the Huang-Huai-Hai Plain (China) under maize (*Zea mays* L.) and wheat (*Triticum aestivium*) rotation system in winter in order, to estimate the dynamics of grain yields, soil organic carbon and total nitrogen. On the whole, four (04) treatments have been used, viz: no fertilization as control (CK), inorganic fertilization (N, NK, NP, PK and NPK), combination NPK and 150% of organic manure (1.5 MNPK) and NPK and straw combination (SNPK). Results showed that except N and PK, almost all the treatments have increased the trend of soil organic carbon and total nitrogen contents over eighteen (18) years. Furthermore, the balance-fertilization NKP only and with organic fertilizers led to high wheat and corn grain yields. Correlation analyses have also indicated strong positive relationship grain yields and organic carbon, total nitrogen and other soil properties. Moreover, application of organic fertilizer in combination with inorganic fertilizers greatly improved soil organic and nitrogen concentrations over the years of the experiment. Otherwise, mixed application of organic and inorganic fertilizers constitutes a sole way to maintain and enhance soil organic carbon reservoir and sequestration, that is, guarantee food security for all.

Li-Hua , He-Ma and Shi-Wei (2012) analysed the distribution of soil organic carbon (SOC), labile organic carbon (LOC), and available nitrogen, as well as, the corresponding relationships between carbon and nitrogen on meadows soil with varying degrees of degradation (normal, slight and severe) in Dangxiong, Tibet. The increasing severity of meadow degradation corresponded with decreasing SOC, LOC and available nitrogen. The SOC distributions in the 0 to 10 cm soil layer of the slightly degraded and severely degraded meadows were lower than that of the normal meadow by 13.2 to 27.5% and 39.5 to 78.6%, respectively. The LOC distribution in the two areas decreased by 11.1 to 50.9% and by 31.2 to 77.2%. The corresponding available nitrogen decreased by 25.6 to 38.2% and 48.8 to 68.0%, whereas the SOC decreased by 6.0 to 29.7% and 53.2 to 73.2%. The degradation of soil carbon and nitrogen occurred first in the 0 to 10 cm layer. In the 0 to 10 cm and the 10 to 20 cm layers, the relationship between soil available nitrogen and LOC was more significant than that between soil available nitrogen and SOC.

Grassland degradation caused a decrease in the ratio of soil LOC to available nitrogen. The average proportions of LOC and available nitrogen in the normal, slightly degraded, and severely degraded meadows were 24, 19, and 17. These values showed that the nitrogen loss caused by grassland degradation is faster than LOC loss. Otherwise, during degradation, organic carbon was more stable than soil available nitrogen. Raun, Johnson, Phillips and Westerman (2005) assessed long-term (23 years) effect of nitrogen (N) fertilization wheat cultivation. At N greater than 90 kg/ha, surface soil organic carbon was the same or slightly greater as the control plot where, no nitrogen was incorporated. Nitrogen increased at the high rates at all plots. However, at two locations, total soil N decreased at low N rates. In general, the ratio carbon upon nitrogen, increased at the low rates of applied N and then decreased to levels below that found in check plots.

Paul, Rasmussen, Allmaras, Rohde and Roager (1998) have assessed crop residues influences on soil carbon and total nitrogen in a wheat fallow system on degraded Pacific Northwest semiarid soils over eleven (11) years. Seven crops residue treatments were initiated in 1931 to measure long-term residue management effects on soil organic matter in a wheat-fallow cropping system on Pacific Northwest semiarid soils. Soil organic carbon (C) and total nitrogen (N) were measured at approximately 11 years interval to determine residue effects on the rate of change in soil OM content. Only the addition of 22.4 metric tons of manure/ha to straw residue before incorporation prevented a decline in soil N and C. The addition of 45 or 90 kg fertilizer N or of 2.2 metric tonnes of pea vines/ha to straw residue before incorporation reduced N and C loss when compared to straw only incorporation. Burning of straw in the fall following wheat harvest accelerated the loss of N but not C. Burning of straw in the spring just prior to tillage had no effect on N or C loss. Changes in N and C were primarily confined to the top 20 cm of soil. Soil

C/N ratios in 1976 differed between treatments proportional to the rate of N loss; they were highest in burn or straw only treatments and lowest in the manure treatment. In all treatments, changes in soil N were best described by a linear function of time; slope within the linear function depended upon residue treatment. This linear function of time over a 45-year period following approximately 50 years of previous cultivation suggests that 100 or more years may be required before N levels become stationary. Residual effects confirm that the new stationary level will depend on past crop residue management practices. Changes in soil C correlated highly with the amount of organic C supplied by each treatment, regardless of the different kinds of residue applied. Thus, changes in soil organic matter levels were controlled primarily by the amount of organic C supplied in crop residue. Regression equations indicate that approximately 5 metric tons of mature crop residue ha−1 year−1 are needed to maintain soil organic matter.

Russell, Laird, Parkin and Mallarino (2005) assessed the impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern Mollisols. Split-plot design was used under conventional tillage, during the period 1990 to 2002 in association with four rates of N fertilization (0-270 kg/ha) and four cropping systems, viz: continuous corn (CC) (*Zea mays* L.); corn-soybean (*Glycine max* L.) (CS); corn-corn-oat-alfaalfa (oat, Avena sativa L.; alfalfa, Medicago sativa L.) (CCOA), and corn-oat-alfalfa-alfalfa (COAA). As results, cropping systems that contained alfalfa had the highest soil organic carbon (SOC) stocks compared to CS plots which had the lowest SOC stocks. SOC concentration had increased significantly (1990-2002) in only two plots: CC and COAA systems. N fertilization had also increased SOC stocks only in the CC system at one site at the end of the experiment.

Witt, Cassman, Olk, Biker, Liboon and Samson (2000) experimented crop rotation and residue management effects on carbon sequestration, nitrogen cycling and productivity of irrigated rice systems during two years (1994-1995). Completely randomized design was used during dry season (DS) and wet season (WS) in maize-rice (M-R) rotation and maize only cropping system. As a result, soil carbon, nitrogen and grain yields were highly significant under crop residue management plots compared to check plots (control). This result documents the capacity of continuous sequestration of carbon and nitrogen on covered plots with crop residues either during the dry season or wet season. In 1991, Bhat, Beri and Sidhu had conducted long-term (7 years) recycling study of crop residues on soil productivity using completely randomized design on field. The bottom line of the experimentation was to determine how recycled crop residues can help to overcome soil carbon and fertility depletion in Indian.

After seven years of trial monitoring, they discovered that soil carbon content and fertility have been improved significantly compared to the control plots which were not significant. Following this perspective, Beri, Sidhu, Bahl and Bhat (1995) have conducted similar study over thirteen years in order to find out the implication of crop residues management on carbon, nitrogen and phosphorus transformation and on crop yield. Their results were consistent with Bhat *et al*. (1991) outcomes. Otherwise, study has revealed that, adequate management of residues can enhance soil carbon content up to 50% compared to the initial dose of carbon contained under unmulched plots. In addition, as co-benefit it helps to augment crop yield, canopy, that is, enhance soil organic matter coverage compared to uncovered croplands.

2.2.2.2 Effect on Soil Temperature

Crop residues applied as mulch have a huge capacity to reduce and intercept the flux of incoming solar energy into the soil, and as a result, maximum soil temperature is less under mulched lands than uncovered agricultural lands (Campel, Selles, LaFond and Zentner, 2001; Chan *et al.*, 2010; Pervaiz, Iqbal, Shahzad and UI-Hassan, 2009). Varughese (2011) posited that, mulching application significantly reduced the diurnal amplitude of soils temperature. Soils maximum temperature under mulched plots where 4 - 6^{o}C compared to unmulched plots which have been recorded the highest temperature. Soil temperature control under covered lands, was also reported by many authors. For instance, Liu *et al.* (2011) have conducted two years field experiment at the Changwu agro-ecosystem research station to evaluate the effects of mulch and irrigation practices on temperature and moisture in the upper layers of the soil and on spring maize productivity in Loess Plateau of China. Four treatments, viz: film mulching (FM), supplementary irrigation (SI), straw mulching (SM) and control (rainfed: RF) were used. Over the whole season, the seasonal diurnal and nocturne soil temperature were lowest under straw mulching plots compared to the uncovered and irrigated plots.

Kar and Kumar (2007) also had carried similar study in Indian by using irrigation and mulch treatments. The aim of this long-term experiment was to appreciate soil moisture content of each treatment and tuber yield potato improvement. Results are in concordance with the previous studies. Study revealed that, temperature reduces under mulched plots compared to unmulched plots. Indeed, the ability of litters and crop residues on soil moisture conservation is significant when they are evenly incorporated to soil. Additionally, it is likely due to their low thermal conductivity and their high degree of reflectivity (albedo). Property which enables them to reduce the amplitude and the magnitude of the solar radiation, that is, soil temperature under warmer conditions. Horton, Bristow, Kluitenberg and Sauer (1996) have undertaken control chamber and field experiment by using crop residues essentially rice straw in order to understand their effects on surface radiation and energy balance. Results confirmed that, crop residues have the ability to reflect short wavelength radiation therefore limit and deplete solar radiation actions on soil. After this long-term experiments using different straw proportions and one control, study revealed that, unmulched plots soils temperature were positively correlated with solar radiation. However, it were negatively correlated under mulched plots. Under mulched plots, temperature decreases was positively correlated with the mass and proportion of soil coverage.

Cinzia, Christian, Giardina, Randal, Kolk and Carl (2008) also, studied Temperature and vegetation effects on soil organic carbon quality along a forested mean annual temperature gradient in North America. Results indicated that, soil organic carbon (SOC) quality is both influenced by biological and climate factors. SOC was predicted under mean annual temperature (MAT) and forest type. Results showed that, SOC quality and quantity is higher under tree species used whereas, it decreased with increasing MAT.

Straw mulching systems enhance soil water conservation and deplete soil temperature because of their non-disturbance and their action in increasing residues accumulation at the soil surface (Zhang, Lovdahi, Grip, Tong, Yang and Wang 2009). From these assertions and referring to the reviewed literature, it is quite clear to ascertain on the fact that, in general mulching moderates soil temperature and conserves soil moisture.

2.2.2.3 Effect on Soil Moisture Content

Soil moisture content is also identified as an additional benefit contribution of crop residue amendments. Mousavi, Moazzeni, Mostazadeh and Yazdani (2012) have conducted short-term experiment in Iran in order to overcome soil cracks under intermittent irrigation agriculture system. The experiment was performed with split-split plots based on a complete randomized blocks design. Treatments included four soil textures and seven rates of rice straw (0, 2, 3, 4, 5, 6 and 7% by weight). Results revealed a positive effect of rice straw on soil water content. Though the level of soil water content is function of soil texture, the effect of rice straw on soil water was significant. The highest and lowest amounts were 44.7% and 35.0% were measured respectively from 7 and 0% rates of rice straw treatments.

Mulumba and Lal (2008) have experimented mulching effects on selected soil physical properties over long-term field plots (1989-2000). Treatments included five mulch applications (0, 2, 4, 8 and 16 Mg/ha/year) without crop cultivation. Results demonstrated that mulch rates significantly increased available water by 18 - 35%. The highest moisture content was obtained with 8 Mg/ha/year. In addition, results revealed also that soil moisture content is function of the degree soil coverage. Simply put, they have posited that, soil moisture content under mulch increases owing to soil greater porosity and lower evaporation. This study was consistent with Varughese (2011) who, had also found out that, over the year, soil moisture content increases highly under mulched than unmulched soils. Mulching helps in reducing rain drop intensity, that is, enhances soils ability to reduce surface run-off by increasing water infiltration rate.

Liu *et al.* (2011) have conducted two-year field experiment at the Changwu agro-ecosystem research station to evaluate the effects of mulch and irrigation practices on temperature and moisture in the upper layers of the soil and on spring maize productivity in Plateau China. Four treatments, viz: film mulching (FM), supplementary irrigation (SI), straw mulching (SM) and control (rainfed: RF) were used. Over the whole season, the average topsoil water content was highly significant at 5% under straw mulching (SM) than supplementary irrigation (SI), film mulching (FM) and rainfed (RF) which constitutes the control of the experiment.

Wang, Jia and Liang (2014) have conducted two-year field experiment from 2008-2010 in order to appreciate the real effects of straw incorporation on soil moisture, evapotranspiration, and rainfall-use efficiency of maize under dryland farming in the Weibei Highlands of China. The rational underlined this study was to limit maize productivity failure on dryland farming. Completely randomized design was used. Four treatments were used: low straw (LS), medium straw (MS) and high straw (HS) at different proportions respectively 4.5, 9.0 and 13.5 tonnes/hectare and control (chemical fertilizer: CF). The study revealed that, straw incorporation on soil surface moisture content during the filling stage of maize was the highest compare to the control which water content was non-significant. Finally, Wang, Liu, Dang and Sainju (2013) have also undertaken long-term experiment using nitrogen only at different rates in the Loess Plateau of China. It aimed to find out the positive effect of nitrogen on wheat yield and soil water storage on dryland. Five nitrogen rates (0, 45, 90, 135, and 180 kg/N/ha) have been used from 2005 to 2010. This study revealed that, nitrogen fertilization can increase soil water storage from 19 to 22 % on the dryland.

2.3 Inferences

The reviewed articles indicates the dual benefits of direct application over long-term of mulch and nitrogen on soil property improvement. They enhance soil ecological environment and significantly increase soil water content (Varughese, 2011; Mousavi *et al.*, 2012). Especially, it is quite obvious that, straw ability in reducing water evaporation from soil surface layer is due to its capability to form a barrier between the soil surface and the atmosphere and thus reducing the vapor pressure gradient at the soil atmosphere interface system (Campel *et al.*, 2001; Chan *et al.*, 2010; Liu *et al.*, 2011). However, it is clearly cut that the effective positive effects expected from each study were obtained after a long-term experiment. Besides none short-term technique was not experimented, and single treatment and single factor (variable) was mostly considered (Jarecki and Lal, 2006; Blanco-Canqui and Lal, 2007; Ma *et al.*, 2009; Muetgi *et al.*, 2010). Moreover, practices effects on greenhouse gas (GHG) emissions, dose and monthly SOC input, cause effects of soil temperature and moisture on SOC as well as the identification of best treatment in terms of good SOC storage capacity, soil temperature and moisture regulation with scanty emission of GHGs were overlooked. Hence, there is need to identify best management practices for enhance climate change adaptation and mitigation particular, on rainfed agriculture in the study area. This new approach must have positive effects in short time, reduce soil temperature, enhance soil water storage, play an important role in enhancing soil carbon reservoir and reduce carbon, methane and nitrous oxide losses from agricultural lands. These lacuna underscore our aim to undertake this short-term experiment using new approach. We propose the use of wet straw and pre-application of minimum fertilizer (improved technique) before it incorporation on the field in order to:

- Reduce straw decomposition time. Make it short therefore facilitate short experiment trial on residues management with chemical application;
- Limit direct GHGs emissions on-farm during decomposition of the straw and chemical nutrient due to their direct incorporation. In fact, in this method urea is mineralized under tilts and straw decomposition has started before their incorporation. Therefore, only scanty emission can be observed;
- Enhance unstable soil organic carbon in short time with minimum effort from the farmers once applied on the farm;
- Limit water demand, necessary to embark the decomposition process. Soil moisture can be reinforced through the wetted combined technique. Accordingly, soil moisture can be enhanced and conserved during short droughts and little or no rain periods.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

The overarching goal of this present research was to find out the significance of rice straw and nitrogen applications on soil temperature, moisture regulation, soil organic carbon storage over a short period of time and evaluate CO_2, CH_4 and N_2O emissions from each treatment using CCAFS-MOT model. Therefore, this chapter focuses on the materials used for the experiment, experiment design, parameters (variables) collected and methods used. Techniques for data collection and analysis as well as software used are also included in this section.

3.1 Materials

To attain each objective addressed by the research, certain requisites were used for different purposes, viz: trial installation (rice straw + urea, hoes and machete, decametre and ropes), management (hoes and machetes, plastic bucket) and data collection (GPS, soil core sampler, soil auger) as enumerated in the Table 3.1.

Table 3. 1 List of Experiment Requisites

No	Material	Purpose
1	Rice straw+ Urea	Factors of the trial
2	Digital thermocouple probe	soil temperature sampling
4	Soil core sampler	Soil bulk density and soil moisture content
5	Soil auger	carbon concentration and soil particle
6	mannual scale	weighting rice straw and Urea
7	hoes and machetes	trial installation and maintenance
8	GPS	coordinate of the experiment sites
9	Digital camera	for photography
10	decametre and ropes	for trial designing
11	stakes and nets	trial fencing
12	plastic buckets	soils composite
13	Polyethylene bags	collect of soil samples
14	Pencils, pens, trial sheets	data recording

Source: Author’s, 2015

3.2 Methods

This sub-section emphasises on the experimental design, integrated formulations (treatments) used, data set collected, and softwares used for data analysis and interpretation.

3.2.1 List of Treatments

This experiment was conducted with integrated formulation (treatments) of rice straw and urea at different rates respectively 2, 3 and 4 t/ha and 25, 50 and 75 kg/ha; with a control (C) without straw and urea application (check plot). Nine treatments were generated from the formulation. 0S+0F stands for 0 tonne of straw (S) and 0 kilogramme of fertilizer (F) ; 3S + 50F stands for 3t of straw and 50 kg of Fertilizer as graded in Table 3.2. Each treatment on the field was watered at equal amount of water (1.5 litres) at fifteen days interval through manual spray using plastic buckets.

Table 3. 2 List of Experiment Treatments

No	Treatment (xt/haS+ykg/haF)	Treatment code
1	0S+0F	C
2	3S+50F	T1
3	4S+50F	T2
4	2S+75F	T3
5	4S+75F	T4
6	4S+25F	T5
7	2S+25F	T6
8	2S+50F	T7
9	3S+75F	T8
10	3S+25F	T9

S: Rice straw; F: Fertilizer (Urea), C: Control, XS+YF(X=quantity of straw in t/ha; Y=quantity of urea in kg/ha)

Source: Author’s, 2015

3.2.2 Improved Technique: Straw Preparation and Treatment Management

As aforementioned in the inferences, straw and mineral fertilizers are just applied directly on the field without any preliminary treatments. Accordingly, mineralisation of residues into soil organic carbon takes a lot of time. Thus, in our suggested new approach, we propose the use of wet straw and pre-application of minimum fertilizer (improved technique) before it incorporation on the field.

With this approach (pre-wetted straw and urea fertilization), both incorporation of straw and urea on each corresponding plot was not direct. The straw of each treatment was wetted first with equal and minimum volume of water (1.5 litre) and then covered with small empty tilts of 50 kg during seven (07) days at ambient temperature condition. After seven days, lump quantity of urea was broadcasted based on the rate of each treatment (Table 3.2) and each treatment was covered again with the same tilts for the same period of seven Days before Plotting (DBP). On the fifteen Day of Plotting (DOP: 15-03-2015), each pre-wetted treatment was now incorporated on each plot using hoes. In addition, hoes were used to mix-up soil surface with the incorporated application on each plot for each replication without soil disturbance. Thereafter, an additional quantity of water (1.5litre/plot) was added after each fifteen Days after Plotting (DAP). Trial was monitored, managed and different data were collected over a period of three months from 15th March to 15th June 2015.

3.2.3 Experimental Design: Randomized Complete Block Design

The experiment was a Randomized Complete Block Design, and ten (10) integrated formulations (treatments) were used with four (04) replications. Each replication, was made of ten (10) plots giving a total number of forty (40) plots. Each plot measured

2mx2m. Experiment design occupies 406 m^2 as total surface but 160 m^2 as useful surface excluding borders, space between plots and alley between blocks. Space within plots and between replications was respectively 1m and 2m. Our experimental layout is shown in Figure 3.1. Treatments were disposed randomly in each block, and each treatment was replicated once within each block including the control (check plot).

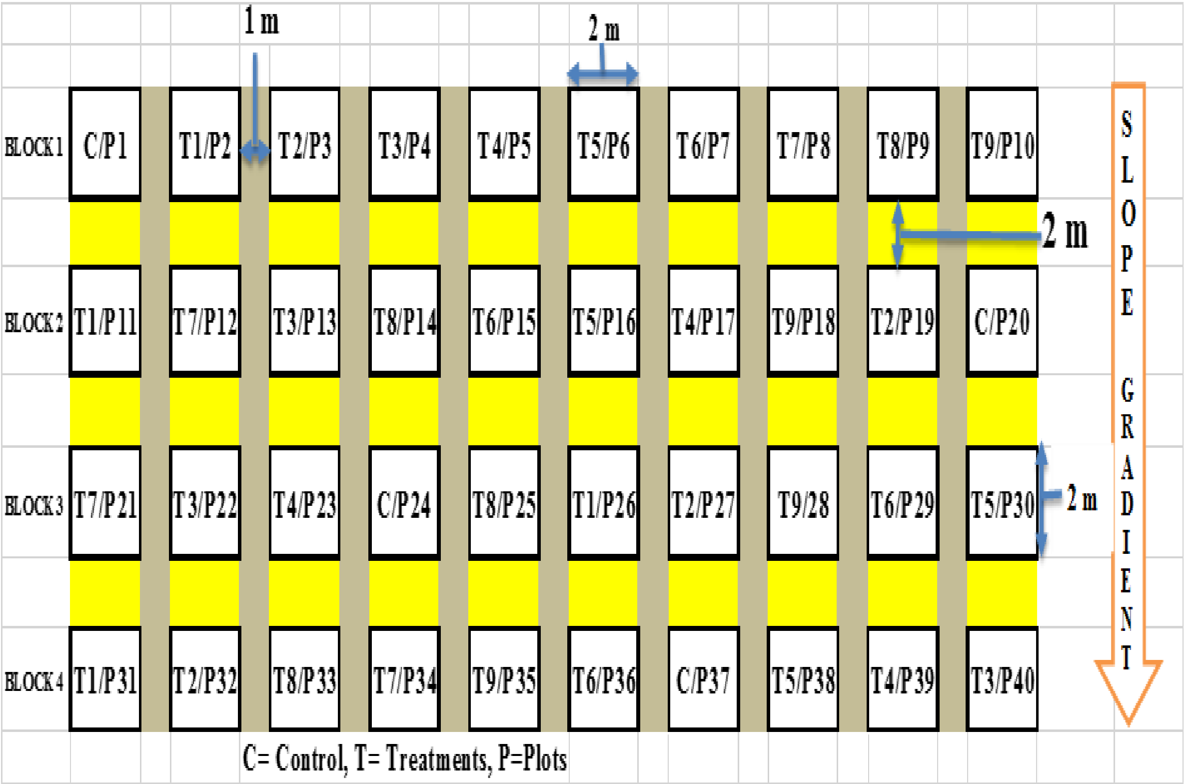


Figure 3. 1 Experiment Layout

3.2.4 Evaluation of Soil Temperature, Moisture and Greenhouse Gas (CO_2, CH_4 and N_2O) Emissions

This sub-section indicates how soil temperature was collected, moisture content was determined, greenhouse gas emissions was estimated from each treatment and how treatments response to each measured variable (Soil Temperature, Moisture and Greenhouse Gas emissions (CO2, CH_4 and N_2O) was determined.

3.2.4.1 Soil Temperature

A composite diurnal soil temperature was collected from each plot at 0 to 5cm and 5 to 15cm depth at fifteen days interval by using digital thermocouple probe. The spike stem of the thermometer was pressed into the soil at different depths of measurement during each diurnal temperature data collection. The average soil temperature was computed at the end of three months in order to see the mean monthly temperature under each treatment and its implication on soil organic carbon stored after three months.

3.2.4.2 Soil Moisture Content

Soil samples were collected within three months at different depths from 0 to 5cm and 5 to 15cm using soil sampler. Samples were weighed and oven-dried for 48 hours at 105 degree Celsius and were weighted again. Soil water after the three months was computed using gravimetric method based on the following formula (Mousavi *et al*., 2012):

$$\boldsymbol{\theta}(\%) = \frac{\mathbf{M_w - M_d}}{\mathbf{M_d - M_c}} \times \mathbf{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(3.1)}$$

Where $\theta(\%)$, M_w, M_d and M_c are respectively soil water content (%), mass of wet soil sample (g), mass of dry soil sample with the container (g) and weight of the container (g). The average soil moisture was computed at the end of three months in order to see the ability of each treatment to conserve soil moisture and its implication on soil organic carbon storage after three months.

3.2.4.3 Greenhouse Gas (CO_2, CH_4 and N_2O) Emission

GHGs were determined using CCAFS-MOT model developed by CIAT, University of Aberdeen and Vermont’s (Feliciano *et al.*, 2015). Therefore, model input data such as: region (country, climate type and soil type) and treatments information (experiment duration, land management, quantity of straw and urea input for each treatment) were used to run the model. Soil type information which included: soil texture, organic C (%), nitrogen content N (%), soil pH and bulk density (g/cm^3) were determined through laboratory analysis of the sampled soil of the study area before trial installation. Soil core sampler was used to sample the soil from 0 – 15 cm.

3.2.5 Computation of the Dose (Density) and Gain per Month of Unstable SOC

Wet chemical oxidation method was adopted to determine SOC concentration (%) which was used to compute the density (dose) and gain per month of soil organic carbon. Composite soil of each treatment was sampled for determining SOC concentration after three months.

- **Determination of Bulk Density (BD)**

Soil samples were collected from all plots from 0 to 5cm and 5 to 15cm depths in order to determine the bulk density. Samples were collected by using a core sampler of 5.5cm diameter and 4 cm long cores from 0-5cm and 6 cm long cores from 5-15cm.The dry bulk density was computed for each plot by using the oven dried method. The dry weight of soil was obtained by oven drying it at 105^{0}C for 48 hours until the constant weight obtained. The dry bulk density was computed using the following equation (Lal, 2009).

$$\mathbf{BD}\left({}^{\mathbf{g}}/_{\mathbf{cm^3}}\right) = \frac{\mathbf{M_s}}{\mathbf{V_t}} \quad \text{……….. (3.2)}$$

Where BD stands for dry bulk density; M_s for mass of oven dried soil at 105^{0}C and V_t the volume of each core (total volume of soil of each core).

- **Density of SOC (SOCD in t/ha)**

Knowing the dry bulk density, the density (dose) of soil organic carbon under each treatment was determined by using the following formula (Lal, 2009; Chan *et al.*, 2010):

$$\mathbf{SOCD}\left({}^{\mathbf{t}}/_{\mathbf{ha}}\right) = \mathbf{C_{soc}} \times \mathbf{BD} \times \mathbf{H} \quad \text{............ (3.3)}$$

Where SOCD, C_{SOC}, BD and H are respectively the soil organic carbon density (t/ha), concentration of soil organic carbon (%), dry bulk density (g/cm^3) and soil thickness (cm).

- **Gain of Soil Organic Carbon per Month**

Knowing the density of soil organic carbon of each treatment, the gain (ΔD) of each treatment in organic carbon in the soil per month was determined using the modified Osenberg, Samelle, Cooper and Holt (1999) formula defines as:

$$\boldsymbol{\Delta}\mathbf{D}\left(\frac{{}^{\mathbf{t}}/_{\mathbf{ha}}}{\mathbf{month}}\right) = \frac{\mathbf{SOCD_f} - (\mathbf{SOCD_{cf}} - \mathbf{SOCD_{ci}})}{\mathbf{time}} \quad \text{............ (3.4)}$$

Where $\mathrm{SOCD_f}$, $\mathrm{SOCD_{cf}}$, $\mathrm{SOCD_{ci}}$ are respectively the density of soil organic carbon of last month for each treatment and last and first month of the check plot. Composite soils were sampled at the two depths during the trial installation after soil preparation for determining SOCDci.

3.2.6 Determination of the Relationships between Soil Moisture and SOC Dose, and Soil Temperature and SOC Dose

Mean soil moisture, SOC dose and soil temperature values were used to determine the cause effect (correlation and regression). Regression method was used to appreciate how SOC dose varies with soil temperature and moisture under the pre-wetted technique.

3.2.7 Identification of the best Treatments

Identification of best treatments was based on the mean value of SOC dose, soil temperature and soil moisture computed, and greenhouse gas emission rate gave by CCAFS-MOT model. Treatments were ranked based on the amount of carbon concentration to determine best treatments in terms of significant SOC storage, low soil temperature, high moisture content with tiny emissions of GHGs. Treatments responses in percentage (TR, %) on soil temperature, moisture, soil organic carbon dose, SOC dose per month and greenhouse gas emissions, were determined with the following formula (Lal, 2005):

$$\mathbf{TR_{vi} = \frac{V_{vi}}{\sum_{n=10}^{n} T} \times 100} \quad \text{............... } \mathbf{(3.5)}$$

Where, TR_{vi} stands for treatment response to variable i (%), V_{vi} for variable value of treatment i (%, ^{0}C, kg/ha or t/ha) and $\sum_{n=10}^{n} T$ for total value of treatment for the variable i (%, ^{0}C, kg/ha or t/ha).

3.3 Data Analysis

- **List of Software Used for Data Analysis**

Table 3. 3 List of Software Used for Data Analysis

No	Software	Purpose
1	Genstat 16.2	ANOVA, test of significance and discrimination of the variables means
2	Excel 2013 and MATLAB 11.0	display correlation and regression graphs of the variables
3	CCAFS-MOT 1.0	Greenhouse gas emissions estimation

Source: Author’s, 2015

The ANOVA and test of significance difference of each treatment on soil temperature, moisture, unstable SOC storage and dose was determined through GenStat 16.2. while, climate change adaptation food security mitigation option tool (CCAFS-MOT) developed by International Centre for Tropical Agriculture (CIAT) and its partners (University of Aberdeen and Vermont's) was used to estimate greenhouse gas (CO_2, CH_4 and N_2O) emissions (kg/ha) from each treatment. To attain objectives three and four, Excel and MATLAB 11.0 software, were used to display the correlation and degree of relationship between soil temperature, moisture and labile soil organic carbon. The coefficient of correlation r (Table 3.4) was used to appreciate the degree of association between soil organic carbon dose (SOCD) versus soil temperature (ST) and soil organic carbon dose versus moisture content (SMC).

Table 3. 4 Indication of Pearson's Coefficient of Correlation (r)

r	Indication
0	No linear relationship between the two variables
+1.0	strong positive linear relationship, as X increases in value Y also increases and vice versa
-1.0	Strong inverse linear relationship, as X increases in value, Y decreases and vice versa.

Source: Author's, 2015

Coefficient of determination (R^2) was computed for the determination of the certainty percentage between variables aforementioned (SOCD, ST and SMC). Statistical discrimination of the means of each treatment was done through DUNCAN'**S** Multiple Range Test (DMRT) at $p = 0.05$ (95% confidence level) in order to identify the best treatment in response to mitigation and adaptation strategies.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter emphasizes on main results obtained which tally with the research objectives. These results are obtained through terrain data analyses, and the outputs are organized in tables and graphs in order to facilitate results interpretations and discussions. Significance difference test of treatments effects on soil temperature, moisture, dose of SOC and monthly gain of SOC is done at 5% level of error (95% confidence) using GenStat 16.2. Finally, best techniques in response to the main goal of this research are also identified.

4.1 Implication of Improved Practice on Soil Temperature, Moisture and Greenhouse Gas (CO_2, CH_4 and N_2O)

This sub-section emphasizes on the results, analyses and interpretations of treatments effects on soil temperature, moisture and greenhouse gas emissions.

4.1.1 Soil Temperature

The descriptive statistic summary (Table 4.1) gives a range of soil temperature (ST) variation under each treatment during the three months from 0 to 15 cm. The mean temperature from 0 - 5 cm, ranged between 2.43 and 6.23^0C with maximum and minimum temperature recorded respectively under the control C (6.5^0C) and treatment T5 (1.9 ^{0}C).

Table 4. 1 Statistical Summary of Soil Temperature (^{0}C)

Soil Temperature (^{0}C) from Each Treatment									
Depth (cm)		**0 - 5**				**5 - 15**			
Treatment	**Code**	**Mean**	**Max**	**Min**	**Stdev.**	**Mean**	**Max**	**Min**	**Stdev.**
0S+0F	C	6.23	6.5	5.9	0.32	6.58	7	6	0.51
3S+50F	T1	4.3	5	4	0.47	4.58	4.8	4.4	0.17
4S+50F	T2	3.07	4.2	2.5	0.80	3.33	4.4	2.4	0.85
2S+75F	T3	4.85	5.5	3.9	0.71	5.00	5.5	4.2	0.57
4S+75F	T4	2.73	3.6	2.1	0.62	2.85	3.7	2.1	0.66
4S+25F	T5	2.43	3.5	1.9	0.73	2.68	3.6	2	0.70
2S+25F	T6	4.98	5	4.9	0.05	5.10	5.2	5	0.08
2S+50F	T7	5.05	5.2	4.9	0.12	5.13	5.5	5	0.25
3S+75F	T8	4.27	4.8	3.8	0.46	4.43	4.8	4	0.35
3S+25F	T9	4.3	5.1	3.8	0.57	4.43	4.8	4	0.35

S: rice straw (t/ha); F: urea (kg/ha); C: control; T: treatment; Max: maximum; Min: minimum; Stdev: standard deviation from the mean.

Source: Author’s field data analysis, 2015

Whereas from 5-15 cm, the Table 4.1 indicates a maximum temperature of 7 ^{0}C under the check plot (control C) with a minimum of 2 ^{0}C under T5. The mean value ranged between 2.68 – 6.58 ^{0}C. The standard deviation also showed a large dispersion between the improved technique treatments in terms of soil temperature regulation. It ranged between 0.05 to 0.80 (^{0}C) and 0.08 to 0.85 (^{0}C) respectively from 0 - 5 and 5 - 15 cm, simply put, the mean value indicates an increase of soil temperature with soil depth under each treatment. Though, soil temperature variation is known, it is better to have deep insights concerning the exact contribution of each treatment in terms of significance on soil temperature reduction. Therefore, Analysis of Variance (Table 4.2) was used to test the significance difference. A precision of 15 percent at the 95 percent confidence level was chosen as criterion for reliability of each integrated formulation (treatment) on soil temperature variation at various depths.

Results (Table 4.2) indicated high significant difference (Fpr.<0.001) of soil temperature variation from 0 - 5cm and 5 - 15cm under each treatment and the control. The least significant error bar (Figure 4.1) reveals in contrast no significance in terms of soil temperature variation per depth under each treatment. High temperature was recorded under the control plot (6.225 - 6.58 ^{0}C), followed by treatments T1, T3, T6, T7 and T8 (4.275 – 5.13 ^{0}C) and finally treatments with low temperature which embodied T2, T4 and T5 (2.475 – 3.33 ^{0}C).

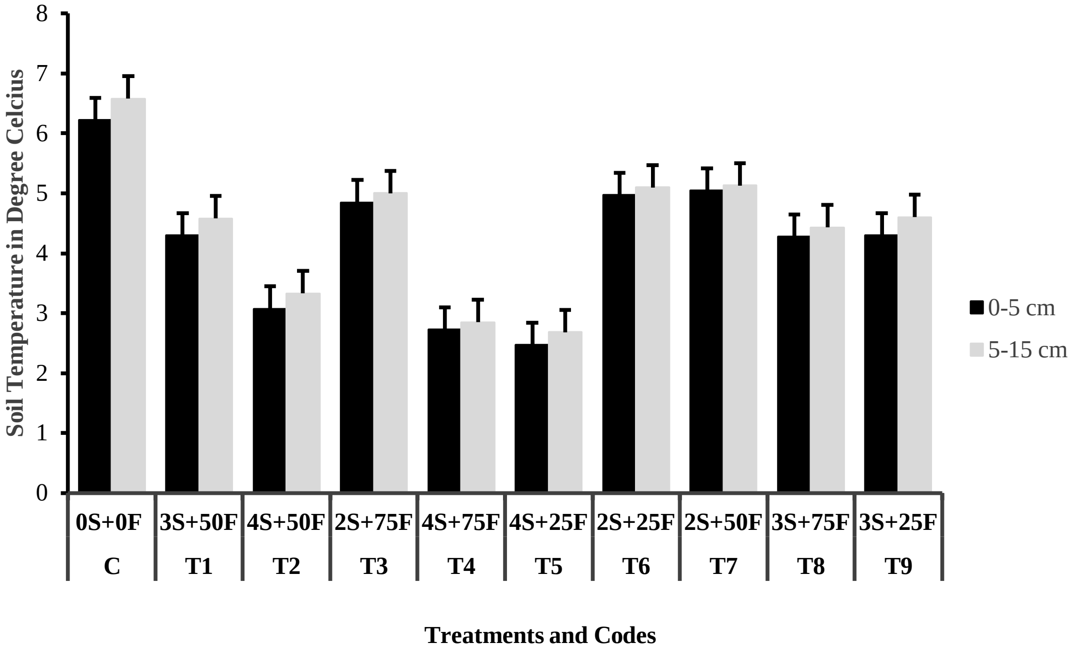


Figure 4. 1 Mean Variation of Soil Temperature (^{0}C)

Similarly speaking, analysis of variance (Table 4.2) indicates high significance difference of tested pre-wetted techniques. T2, T4 and T5 have the same level of influence on soil temperature reduction at various depth. Similarly, T1, T3, T6, T7, T8 and T9 effects on soil temperature is not significantly different. In contrast, results revealed differences between treatments and the control in terms of temperature reduction.

Table 4. 2 Effect of Straw Mulch and Urea Formulation on Soil Temperature

			Depth (cm)	
			0 - 5 cm	5 - 15 cm
Treatment			Temperature Mean Significant Value (^{0}C)	
	T2	4S+50F	3.08 a	3.33 a
	T4	4S+75F	2.73 a	2.85 a
Straw + Urea	T5	4S+25F	2.48 a	2.68 a
	T1	3S+50F	4.3 b	4.58 b
	T3	2S+75F	4.85 b	5 b
	T6	2S+25F	4.98 b	5.1 b
	T7	2S+50F	5.05 b	5.13 b
	T8	3S+75F	4.28 b	4.43 b
	T9	3S+25F	4.3 b	4.6 b
	C	0S+0F	6.23 c	6.58 c
	C.V. (%)		9.0	6.1
	lsd		0.60	0.71
	Mean (^{0}C)		4.2 (± 0.4)	4.4 (±0.4)

S: rice straw (t/ha); F: urea (kg/ha); CV: coefficient of variation; lsd: least significant difference. Number with same letter are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT at 5%).

Source: Author’s field data analysis, 2015

It is likely that, T2, T4 and T5 ability to reduce incoming solar radiation therefore, deplete soil temperature under high ambient temperature is significantly different when compared to T1, T3, T6, T7, T8 and T9. However, both of them proffered better response of temperature reduction compared to the control due to the addition of mulch. Conclusions drawn from the analysis lead to the fact that, the level of significance observed under each treatment was a function of the rate of straw incorporated, and likely due to the amount of urea applied. Indeed, Crop residues applied as mulch have a huge capacity to reduce and intercept the flux of incoming solar energy into the soil, and as a result, maximum soil temperature is less under mulched lands than uncovered agricultural lands (Campel *et al.*, 2001; Chan *et al.*, 2010). Similarly, Pervaiz *et al.* (2009) and Varughese (2011) discovered that, mulching application significantly reduced the diurnal amplitude of soils temperature. Additionally, high reflectivity of solar radiation therefore low temperature under high proportion of straw plots compared to low rates of straw or check plots was also reported by Liu *et al*. (2011) and Horton *et al*. (1996). Based on the results (Table 4. 2), T5 (2.475 – 2.68 ^{0}C), T4 (2.725 – 2.85 ^{0}C) and T2 (3.073 – 3.33 ^{0}C) were identified as pre-wetted techniques treatments that can help to lessen croplands temperature under global warming in the study area. These outcomes are in accordance with previous studies undertaken over long-term by direct combined application of straw and urea (Campel *et al.*, 2001; Chan *et al.*, 2010). Similarly, Liu *et al.* (2011), also reported after two years of direct straw mulching experiment that, seasonal diurnal and nocturne soil temperature were lowest under high rates straw mulching plots compared to the uncovered plots. Straw mulching combined with chemical fertilizers temperature regulation compared to unmulching plots was also highlighted by Kar and Kumar (2007) over long-term experiment. Results indicated that, treatments temperature regulation was due to their low thermal conductivity and their high degree of reflectivity (albedo) and as such reduce the amplitude and the magnitude of the solar radiation, that is, soil temperature under warmer conditions.

From these analyses, it is likely that, crop residues have the ability to reflect short wavelength radiation thereby, limit and deplete solar radiation actions on soil. Because, unmulched plots soil temperature positively correlated with solar radiation. Whereas, under mulched plots, temperature decreases positively correlated with the mass and proportion of soil coverage but not of urea quantity broadcasted. Likewise, Zhang *et al.*, (2009) ascertained the combine straw mulching and catch cropping effects on soil temperature depletion due to their non-disturbance and their action in increasing residues accumulation at the soil surface. From these assertions and referring to the reviewed literature, it is quite clear to ascertain on the fact that in general, mulching moderates soil temperature.

Accordingly, it is likely to avoid soil moisture losses under mulched plots. Therefore, this approach can be used to enhance soil water necessary for plants growth under little or no rain conditions in regions likely to experience droughts events and where water for agricultural activities is scarce as Edozhigi.

4.1.2 Soil Moisture

Statistical analysis (Table 4.3) reveals a range of Soil Moisture Content (SMC) variation under each treatment during the three months of data collection from 0 to 15 cm. The mean SMC from 0 - 5 cm, ranged from 3.80 to 15.02 % with maximum and minimum of SMC recorded respectively under the treatment T4 (18.32 %) and control C (3.40 %).

Table 4. 3 Statistical Summary of Soil Moisture Content (%)

		Soil Moisture Content (%) under each Treatment							
Depth (cm)		**0- 5**				**5-15**			
Treatment	**Code**	**Mean**	**Max**	**Min**	**Stdev.**	**Mean**	**Max**	**Min**	**Stdev.**
0S+0F	**C**	3.80	4.25	3.40	0.36	3.40	3.50	3.20	0.14
3S+50F	**T1**	9.25	10.99	7.03	1.96	9.06	10.65	7.10	1.79
4S+50F	**T2**	13.69	16.88	12.05	2.18	13.15	15.58	12.20	1.63
2S+75F	**T3**	9.60	12.63	8.14	2.04	8.80	11.78	6.98	2.10
4S+75F	**T4**	15.02	18.32	11.48	3.08	14.49	17.77	10.58	3.17
4S+25F	**T5**	13.09	16.40	10.39	2.92	12.62	16.01	10.00	2.95
2S+25F	**T6**	10.81	12.44	8.08	1.92	10.06	11.55	7.78	1.67
2S+50F	**T7**	9.47	10.46	7.38	1.41	9.12	10.45	7.00	1.53
3S+75F	**T8**	8.09	10.65	4.98	2.90	7.72	10.59	4.60	2.88
3S+25F	**T9**	9.99	13.39	6.74	2.78	9.27	12.98	4.64	3.51

S: rice straw (t/ha); F: urea (kg/ha); C: control; T: treatment; Max: maximum; Min: minimum; Stdev: standard deviation from the mean.

Source: Author’s field data analysis, 2015

Whereas from 5-15 cm, the mean value of SMC ranged from 3.40 – 14.49 % with a maximum of 17.77 % and minimum of 3.20 % respectively under T4 and check plot (control C). The standard deviation also showed a large dispersion between the improved technique treatments in terms of soil moisture storage. It ranged from 0.36 to 3.08 % and 0.14 to 3.17 % respectively between 0 – 5cm and 5 - 15cm. Though, SMC variation is known, it is better to have clear understanding concerning the exact contribution of each treatment in terms of significance difference on SMC. Therefore, ANOVA Table 4. 4 was used to test the significance difference of each treatment on soil moisture storage at various depth. Results of the integrated formulation (Straw + Urea) (Table 4. 4) give high significant difference (Fpr.<0.001) in terms of treatments contribution to soil moisture storage. The level of response to soil moisture content (SMC) varies from one treatment to another at different depth. Meanwhile, the least significant error bar (Figure 4.2) reveals no significance of soil depth on SMC. Otherwise, SMC was function of residue input. The lowest SMC was recorded under the check plots, 3.8 % and 3.4 % respectively from 0 – 5 cm and 5- 15 cm. The highest moisture content of 15.0 and 14.5 % at both respectively 5 and 15cm were observed under T4 (Table 4. 4).

Table 4. 4 Effect of Treatments on Soil Moisture Content (%)

			Depth (cm)	
			0 - 5 cm	5 - 15 cm
Treatment			Soil Moisture Content Mean Significant Value (%)	
Straw + Urea	T4	4S+75F	15.0 a	14.5 a
	T2	4S+50F	13.7 b	13.1 b
	T5	4S+25F	13.1 c	12.6 c
	T6	2S+25F	10.8 d	10.1d
	T9	3S+25F	9.9 e	9.3 e
	T3	2S+75F	9.6 e	8.8 e
	T7	2S+50F	9.5 e	9.1 e
	T1	3S+50F	9.3 f	9.1 e
	T8	3S+75F	8.1 f	7.7 f
	C	0S+0F	3.8 g	3.4 g
	C.V. (%)		5.7	6.4
	lsd		3.4	3.5
	Mean (%)		10.3 (±1)	9.8 (±1)

S: rice straw (t/ha); F: urea (kg/ha); CV: coefficient of variation; lsd: least significant difference. Number with same letter are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT at 5%).

Source: Author's experiment data analysis, 2015

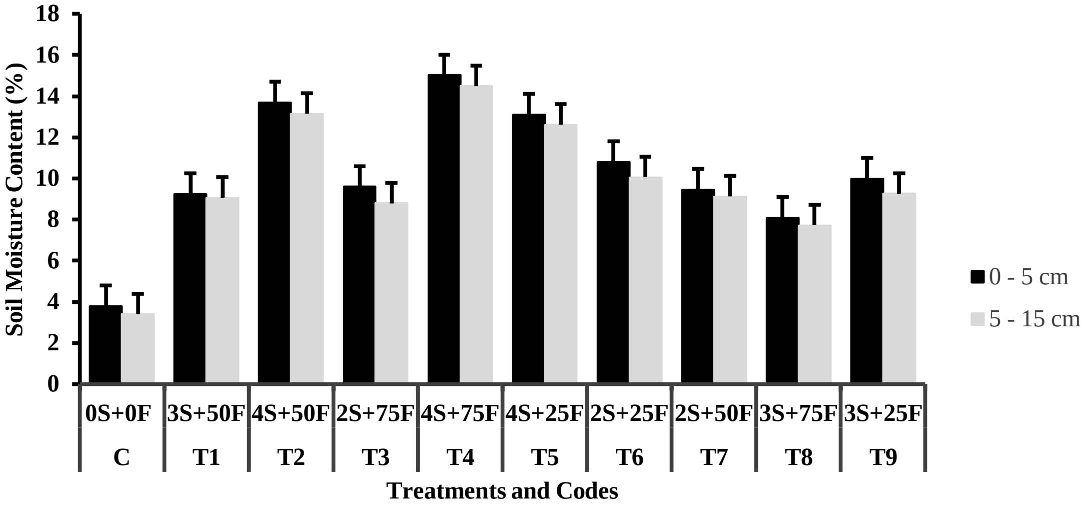


Figure 4. 2 Mean Variation of Soil Moisture Content (%)

Treatments T2 (13.7 – 13.1 %) and T5 (13.1 – 12.6 %) have recorded high amount of moisture content when compared to the rest of the tested treatments with the pre-wetted method. Finally, SMC of the rest of the treatments ranged between 9.3 – 10.8 % from 0 – 5 cm and 7.7 – 10.1% from 5 – 15 cm as aforementioned in Table 4.4. Additionally, Table 4. 4 indicates at various depth that, treatment T4 is highly significant in terms of moisture storage compared to treatment T2. Similarly, T2 effect on soil moisture storage is higher when compared to T5 which also gives higher soil moisture content than T6. Moreover, T9, T3 and T7 have same moisture content level but significantly different from T1 and T8 with same level of significance. However, treatments tested have given different significant moisture content compared to the control plot. These results indicates the probability of very significant increase in soil moisture content with increase in quantity of straw residues incorporated in combination with minimum quantity of urea added. In addition, study outcomes indicate the importance on the quantity of straw incorporated and urea applied. It is likely that, moisture content will increase with an increase in quantity of pre-wetted straw and urea integrated formulation.

Positive effects of straw residues on SMC were also reported by Mulumba and Lal (2008), Mousavi *et al.* (2012), and Kar and Kumar (2007) after long-term experiments. Indeed, Mulumba and Lal (2008) have experimented mulching effects on selected soil physical properties over long-term field plots (1989-2000). Treatments included five mulch applications (0, 2, 4, 8 and 16 Mg/ha/year) without crop cultivation. Results demonstrated that mulch rates significantly increased available water by 18-35%. This study was consistent with Gupta and Acharya (1993), Varughese (2011) and Wang *et al.* (2014) who, had also found out that, over the years, soil moisture content increases highly under mulched than unmulched soils.

Moreover, results from this short-term experiment using the pre-wetted technique are consistent with Liu *et al.* (2011) who reported after two years straw mulching experiment that, seasonal diurnal and nocturne SMC were highest under straw mulching plots compared to the check plots. An additional effect is that, mulching reduces water losses (evapotranspiration) due to its barrier between the soil surface and atmosphere. Accordingly, depletes the vapor pressure gradient at the soil surface interface (Gupta and Archarya, 1993). Based on the mentioned results, we could identify T4 (15.0 - 14.5 %), T2 (13.7– 13.1 %) and T5 (13.1 – 12.6 %) as pre-wetted technique treatments that could help to enhance croplands soil moisture content under global warming in the study area. However, there is need to now to check on their GHGs emissions and carbon sequestration levels.

4.1.3 Greenhouse Gas (CO_2. CH_4 and N_2O) Emissions

Climate Change Adaptation Food Security Mitigation Option Tool (CCAFS-MOT) model analysis (Table 4.5) indicates significant variation in terms of greenhouse gas (GHG) emissions from field under each treatment and the Soil Organic Carbon (SOC) balance significance as results of the pre-wetted technique. For the SOC balance, negative values stand for sequestration whereas, positive values indicate emission from the pre-wetted integrated formulations.

The standard deviation for SOC balance (Stdev = 324.6 kg/ha) in Table 4.5 indicates large dispersion of carbon added to the soil by each treatment when compared to the control plot where no addition of carbon is recorded (0 kg/ha). Methane emission is zero for all treatments including the control but insignificant emission of nitrous oxide can be observed from 0.1 – 0.2 kg/ha with non-significant dispersion (Stdev. = 0.05 kg/ha).

Table 4. 5 CCAFS-MOT Estimated GHGs from Field and SOC Balance

			GHGs Emissions from Field (Kg/ha)	
Treatment	Code	SOC Balance (Kg/ha)	CH_4 (Kg/ha)	N_2O (kg/ha)
0S+0F	C	0	0	0.1
3S+50F	T1	-778.1	0	0.2
4S+50F	T2	-1037.5	0	0.2
2S+75F	T3	-518.8	0	0.2
4S+75F	T4	-1037.5	0	0.2
4S+25F	T5	-1037.5	0	0.1
2S+25F	T6	-518.8	0	0.1
2S+50F	T7	-518.8	0	0.2
3S+75F	T8	-778.1	0	0.2
3S+25F	T9	-778.1	0	0.1
Mean (kg/ha)		-700.32 (±102.7)	0	0.16 (±0.02)
Stdev.(kg/ha)		324.6	0	0.05
C.V. (%)		-0.46	0	0.32

S: rice straw (t/ha); F: urea (kg/ha); C: control; T: treatment; SOC: Soil Organic Carbon Balance (negative values: sinks or sequestration and positive values: emissions or release); CH_4: methane; N_2O: Nitrous oxide; GHGs: greenhouse gases; Stdev: standard deviation from the mean.

Source: Author's experiment data, 2015

The risk of avoiding emission or enhancing carbon sequestration was higher under T2, T4 and T5 with a carbon balance up to -1037.5 kg/ha; followed by T1, T8 and T9 (-778.1 kg/ha) and finally T3, T6 and T5 (-518.8 kg/ha). These results draw our attention to the fact that soil organic carbon pool enhancement is likely a function of the amount of residues incorporated into the soil. It is likely that, the high carbon stock obtained under T2, T4 and T5 is due to the quantity of straw residues incorporated into the soil (Christopher and Lal, 2007; Chan *et al.*, 2010).

Accordingly, from the aforementioned results, treatments T2, T4, and T5 could be promoted in order to increase soil carbon pools knowing that, for every tonne of carbon sequestered in the soil is a tonne of carbon removed from the atmosphere, and every tonne of carbon in the soil is equivalent to 3.67 tonne of CO_2 (Walcott, Bruce and Sims, 2009; Lal, 2011). In contrast, no carbon addition was observed with the control (0 kg/ha). Similarly, Alluvione, Halvorson and Del Gosso (2009); Reicosky and Archer (2007) have also quoted lower emissions of CO_2 under mulching plots compared to unmulching plots. Indeed, carbon dioxide fluxes under straw mulching or crop residues are due to slow decomposition of crop residues placed on the surface of the soil compared to residues incorporated under conventional tillage (Curtin, Wang, Selles, McConkey and Campbell, 2000). Moreover, high carbon sequestration under T2, T4 and T5 can be correlated to their likely high soil moisture content. Otherwise, there is a negative correlation between CO_2 fluxes and soil moisture content. This negative relationship was also highlighted by Curtin *et al.* (2000) and Varughese (2011).

In contrast, no methane (CH_4) emissions were observed both from the treatment and the control. Those outcomes are in accordance with previous studies done which had stated that there is no correlation between CH_4 fluxes and soil moisture, but sometimes these fluxes are negatively correlated with soil temperature (Varughese, 2011; Rochette, 2008). In fact scanty information exist concerning methane emissions from agricultural practices either for mulching tillage or conventional tillage. Meanwhile, Ussiri, Lal and Jarecki (2009); Venterea, Burger and Spokas (2005) have clarified the fact that, lower CH_4 fluxes under mulching plots compared to bare plots are likely due to significant CH_4 oxidation under straw mulching practices. Therefore, negative fluxes that are sometimes observed.

Concerning the nitrous oxide (N_2O) fluxes, tiny fluxes (0.1 – 0.2 kg/ha) were recorded from both treatments and control plots. This study has confirmed the scare information and the misunderstanding in terms of N_2O emissions under combined application of straw mulching and fertilizers (Grandy, Loecke, Parr and Robertson, 2006). Some argued for negative correlation whereas some stated higher emission under mulching and fertilizer uses (Grandy *et al.*, 2006; Rochette, 2008; Gregorich, Rochette, St-Georges, McKim and Chan, 2008). According to Ma *et al.* (2009), straw application can decrease nitrous oxide (N_2O) emission by 1 – 7 % compared to bare soils. In contrast, Snyder (2009) and Mutegi *et al.* (2010) quoted that, the amount of N_2O emitted is a function of type of fertilizer used, method of broadcasting, soil moisture content, soil temperature and amount of oxygen available in the study area.

4.2 Density and Gain of Unstable Soil Organic Carbon (SOC)

4.2.1 Density of SOC (SOCD) (t/ha)

Soil Organic Carbon Density (SOCD, t/ha) was determined using the soil carbon content (%), bulk density (g/ cm^3) and the depth (cm) of the soil. Summary of the general results (Table 4.6) reveals significant variation of SOCD between treatments from 0 – 15cm. Maximum and minimum values obtained ranged from 9.52 – 20.18 t/ha and 5.05 – 15.99 t/ha between 0 – 5cm against 19.36 – 44.98 t/ha and 9.97 – 32.40 t/ha between 5 – 15cm. The standard deviation (Stdev) also showed a large dispersion of SOCD between treatments from one depth to another. Stdev from 0 – 5cm ranges from 1.5 – 5.42 t/ha for 2.90 – 10.12 t/ha between 5 – 15cm.

Table 4. 6 Statistical Summary of Soil Organic Carbon Density (t/ha)

Soil Organic Carbon Density (t/ha) under each Treatment									
Depth (cm)			**0 - 5**				**5 - 15**		
Treatment	**Code**	**Mean**	**Max**	**Min**	**Stdev.**	**Mean**	**Max**	**Min**	**Stdev.**
0S+0F	**C**	7.66	9.52	6.38	1.50	14.58	19.36	10.78	3.56
3S+50F	**T1**	9.50	11.41	7.87	1.47	20.08	25.02	16.52	3.58
4S+50F	**T2**	14.61	22.05	9.12	5.42	30.90	44.20	19.59	10.12
2S+75F	**T3**	11.08	12.24	9.47	1.26	22.60	25.14	19.78	2.90
4S+75F	**T4**	18.42	20.18	15.99	2.06	38.35	44.98	32.40	5.41
4S+25F	**T5**	11.70	17.40	8.29	3.95	23.90	37.38	16.10	9.31
2S+25F	**T6**	10.01	12.32	8.96	1.58	20.07	24.92	17.70	3.28
2S+50F	**T7**	8.46	10.53	5.05	2.39	17.58	21.70	9.97	5.24
3S+75F	**T8**	10.10	12.20	8.64	1.58	20.70	24.96	17.66	3.15
3S+25F	**T9**	10.40	14.09	7.80	2.64	21.58	29.17	16.28	5.43

S: rice straw (t/ha); F: urea (kg/ha); C: control; T: treatment; Max: maximum; Min: minimum; Stdev: standard deviation from the mean.

Source: Author’s experiment data analysis, 2015

Accordingly, significance difference of each pre-wetted technique can now be discussed further in order to give more insights about the relevance of each integrated formulation of the pre-wetted technique on SOCD. In that respect, Table 4. 7 as well as Figure 4.3 were analysed and discussed.

Concerning treatments responses to SOCD, statistical output (Table 4.7) gives strong positive effects of each treatment on soil organic carbon improvement. The F statistic is less than 1% (Fpr.<0.001). In addition error bars (Figure 4.3) have given significant difference between organic stock between 0 - 5 and 5 - 15 cm.

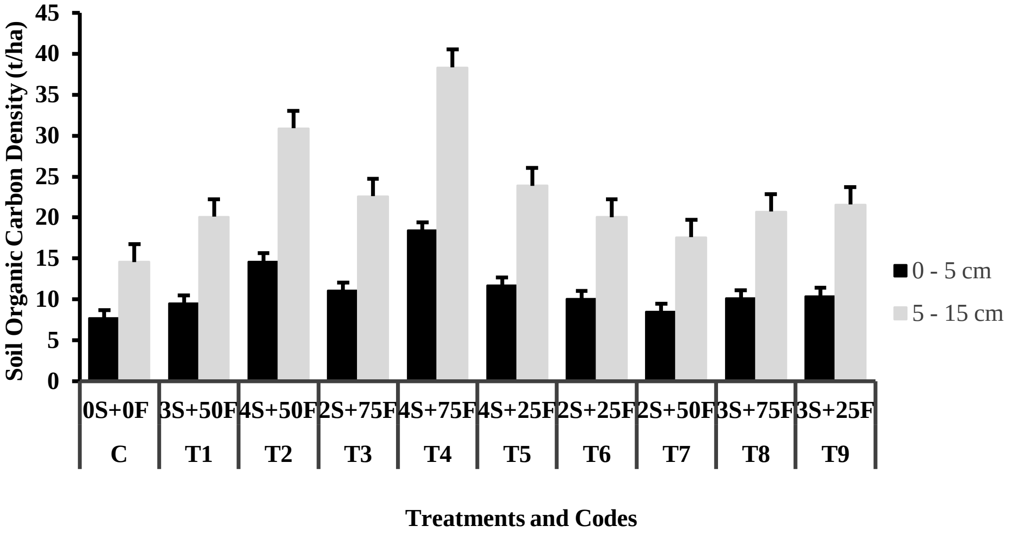


Figure 4. 3 Mean Variation of Soil Organic Carbon Density

This significance difference can be explained based on the fact that, soil depth and bulk density were taken into account during SOCD computation. Therefore, the higher the depth, the higher its carbon density (t/ha) compared to soil organic carbon concentration (%) which decreases with depth. This is because SOCD is function of the soil thickness whereas the concentration depends on the organic matter and microorganism activities. This assertion is in accord with those reported by Bationo, Kihara, Vanlauwe, Waswa and Kimetu (2005) and Chan *et al.* (2010). Meanwhile, treatments significance difference (Table 4.7) on SOCD (t/ha) can be graded into five (05) classes from 0 – 15 cm notably: very high density T4 (18.4 – 38.4), high density T2 (14.6 – 30.9), medium T5 (11.7 – 23.9), low density which embodies T1, T3, T6, T7, T8 and T9 with values ranged from 8.5 – 22.6 and poor carbon stock under control C (7.7 – 14.6).

Table 4. 7 Effect of Treatments on Soil Organic Carbon Density (t/ha)

Treatment			Depth (cm) 0 - 5 cm	Depth (cm) 5 – 15 cm
			Soil Organic Carbon Density (t/ha) Mean Significant Value	
	T4	4S+75F	18.4 a	38.4 a
	T2	4S+50F	14.6 b	30.9 b
	T5	4S+25F	11.7 c	23.9 c
	T1	3S+50F	9.5 d	20.1 d
Straw + Urea	T3	2S+75F	11.1 d	22.6 d
	T6	2S+25F	10.0 d	20.1 d
	T7	2S+50F	8.5 d	17.6 d
	T8	3S+75F	10.1 d	20.7 d
	T9	3S+25F	10.4 d	21.6 d
	C	0S+0F	7.7 e	14.6 e
C.V. (%)			14.7	14.8
Lsd			3.3	7.1
Mean (t/ha)			11.2 (±0.9)	23.1 (± 2.2)

S: rice straw (t/ha); F: urea (kg/ha); CV: coefficient of variation; lsd: least significant difference. Number with same letter are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT at 5%)

Source: Author's trial data analysis, 2015

It is obvious from the aforesaid discussion that, best responses on SOCD were observed under treatment with high mass of straw. Therefore, amount of straw has a role to play in terms of carbon content. Meanwhile, urea proportion under straw can also be observed due to the fact that, it enhances the micro-organism compounds and humification processes under the straw mulch. Combined effects of straw and nitrogen over long-term experiment was also reported by Jacinthe *et al.* (2002); Ma *et al.* (2009) and Muetgi *et al.* (2010). In addition, our findings using the integrated formulations (pre-wetted technique) method confirmed strongly, previous studies conducted over long-term. Green *et al.* (2005), through long-term agricultural farming system with maintenance of crop residues after harvesting observed that, organic plots carbon, nitrogen and phosphorus sequestration were highly significant at 5% than unmulched plots.

Moreover, Zoratelli *et al.* (2005) have assessed the effect of mulching tillage on SOC sequestration. Results confirmed that, mulching tillage enhances soil protection, aggregates soil carbon and increases soil carbon pool. Further, Lopez-Frando and Pardo (2009) and Gruber, Mohring and Claupein (2011) got similar result respectively under semi-arid and temperate environment. Similarly, Sheng-wei *et al.* (2012) have experimented Long-term combined fertilization experiment (1991- 2008) in the Huang-Huai-Hai Plain (China) under maize (Zea *mays* L.) and wheat (*Tritium aestivium*). Trial outcomes have highlighted the fact that, application of organic fertilizer in combination with inorganic fertilizers greatly improved soil organic and nitrogen concentrations over the years of the experiment. Besides, mixed application of organic and inorganic fertilizers constitutes a sole way to maintain and enhance soil organic carbon reservoir and sequestration, that is, guaranty food security for all.

4.2.2 Gain of SOC (SOCG) (t/ha/month)

Soil carbon gain per month (Table 4.8) was computed by subtracting the carbon dose from each treatment to carbon dose from the control at the beginning and after three months then, we have divided by the time of the experiment in order to have the significance per month from each integrated formulation (treatments). Results in Table 4.8 reveal small dispersion between treatments in terms of carbon gained per month. Generally, amount stored per month differs from one treatment to another however the quantity was not too high between treatments from 0– 15cm.

Table 4. 8 Statistical Summary of Soil Organic Carbon Gain per Month

		Gain per Month of Organic Carbon (t/ha/month) under each Treatment							
Depth (cm)			**0 - 5**				**5 - 15**		
Treatment	**Code**	**Mean**	**Max**	**Min**	**Stdev.**	**Mean**	**Max**	**Min**	**Stdev.**
0S+0F	**C**	0.05	0.08	0.01	0.03	0.09	0.11	0.05	0.03
3S+50F	**T1**	0.09	0.11	0.07	0.02	0.18	0.23	0.14	0.04
4S+50F	**T2**	0.15	0.23	0.09	0.06	0.30	0.45	0.17	0.11
2S+75F	**T3**	0.11	0.12	0.09	0.01	0.21	0.23	0.17	0.03
4S+75F	**T4**	0.19	0.21	0.16	0.02	0.38	0.45	0.31	0.06
4S+25F	**T5**	0.12	0.18	0.08	0.04	0.22	0.37	0.13	0.10
2S+25F	**T6**	0.10	0.12	0.09	0.02	0.18	0.23	0.15	0.04
2S+50F	**T7**	0.08	0.10	0.04	0.03	0.15	0.20	0.07	0.06
3S+75F	**T8**	0.10	0.12	0.08	0.02	0.18	0.23	0.15	0.04
3S+25F	**T9**	0.10	0.14	0.07	0.03	0.19	0.28	0.14	0.06

S: rice straw (t/ha); F: urea (kg/ha); C: control; T: treatment; Max: maximum; Min: minimum; Stdev: standard deviation from the mean.

Source: Author’s field data analysis, 2015

Mean monthly storage (t/ha/monthly) varies from 0.05 – 0.15 with maximum and minimum range between 0.08 – 0.23 and 0.01 – 0.16 respectively with standard deviation between 0.01 – 0.06 at 5 cm. At 15 cm, mean of SOCDG ranges between 0.09 – 0.38 with maximum and minimum ranging from 0.11 – 0.45 and 0.05 - 0.31 respectively. Standard deviation is between 0.03 – 0.11 at 15 cm. Treatments (Table 4.9) demonstrated very significant effects on soil organic carbon gain (SOCDG, kg/ha/month) from 0 – 15cm. The level of significance is highly less than 1% (Fpr.<0.001). Moreover, the error bars (Figure 4.4) indicate a large variation of SOCDG (kg/ha/month) between 0 – 5cm and 5 – 15cm. Treatments evaluated indicate better contribution in terms of monthly carbon pool compared to the check plot which, has the lowest (0.052 – 0.085) monthly carbon pool after the three months experiment.

Table 4. 9 Effect of Treatments on Soil Carbon Gain

Treatment			Depth (cm) 0 - 5 cm	5 – 15 cm
			SOCG (t/ha/month)	Mean Significant Value
Straw + Urea	T4	4S+75F	0.2 a	0.4 a
	T2	4S+50F	0.15 b	0.3 b
	T1	3S+50F	0.1 c	0.2 c
	T3	2S+75F	0.1 c	0.2 c
	T5	4S+25F	0.1 c	0.2 c
	T6	2S+25F	0.1 c	0.2 c
	T7	2S+50F	0.1 c	0.2 c
	T8	3S+75F	0.1 c	0.2 c
	T9	3S+25F	0.1 c	0.2 c
	C	0S+0F	0.05 d	0.09 d
	C.V. (%)		19.0	20.3
	lsd		0.04	0.07
	Mean (t/ha/month)		0.1 (± 0.01)	0.2 (±0.03)

S: rice straw (t/ha); F: urea (kg/ha); CV: coefficient of variation; lsd: least significant difference. Number with same letter are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT at 5%)

Source: Author’s experiment data analysis, 2015

In general (Table 4.9), treatments net addition in carbon (t/ha) per month vary from 0.05 – 0.2 between 0 – 5 cm and 0.09 – 0. 4 between 5 – 15 cm. Based on the depth variation between 0 – 5 cm, highest significance difference on SOCDG (t/ha/month) was obtained with T4 followed by T2 then, T1, T3, T5, T6, T7, T8 and T9 which have the same level of significance on carbon input but significant when compared to the control effect on carbon gain per month. This is due to the level of decomposition and mineralisation of straw residues under each treatment which depend on the quantity of straw and urea applied. Similarly, between 5 – 15cm, the highest input in carbon was obtained with T4 (0.4) followed by T2 (0.3) and a batch of treatments T1, T3, T5, T6, T7, T8 and T9 with same significance on carbon input but significantly different from the control C in terms of soil carbon gained per month.

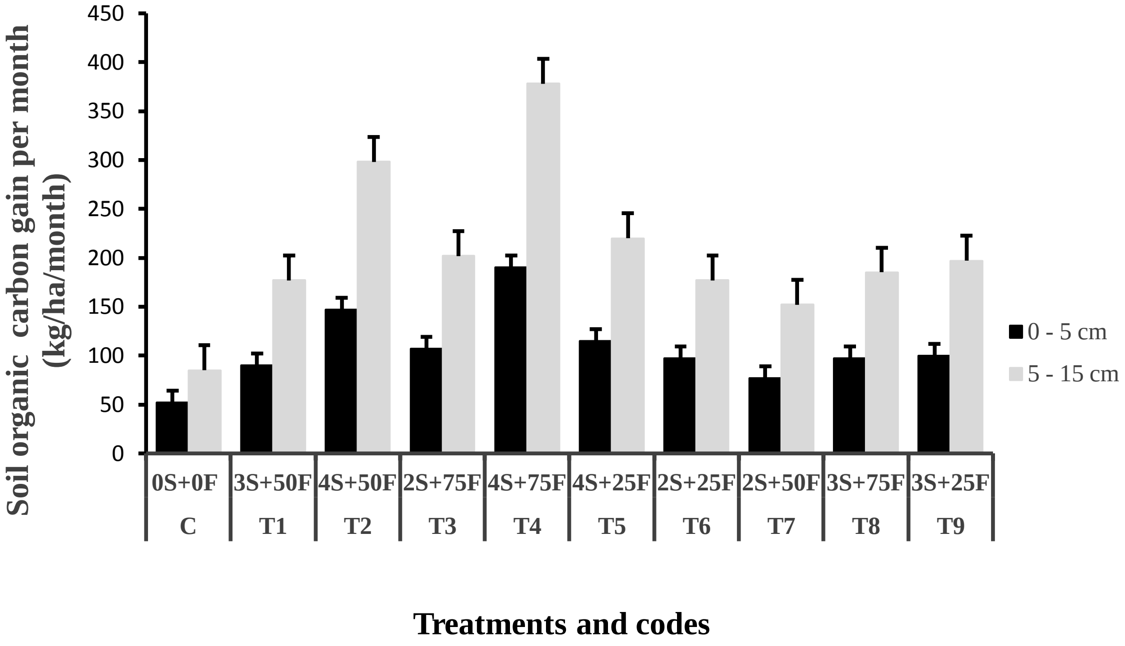


Figure 4. 4 Mean Variation of Soil Organic Carbon Gain

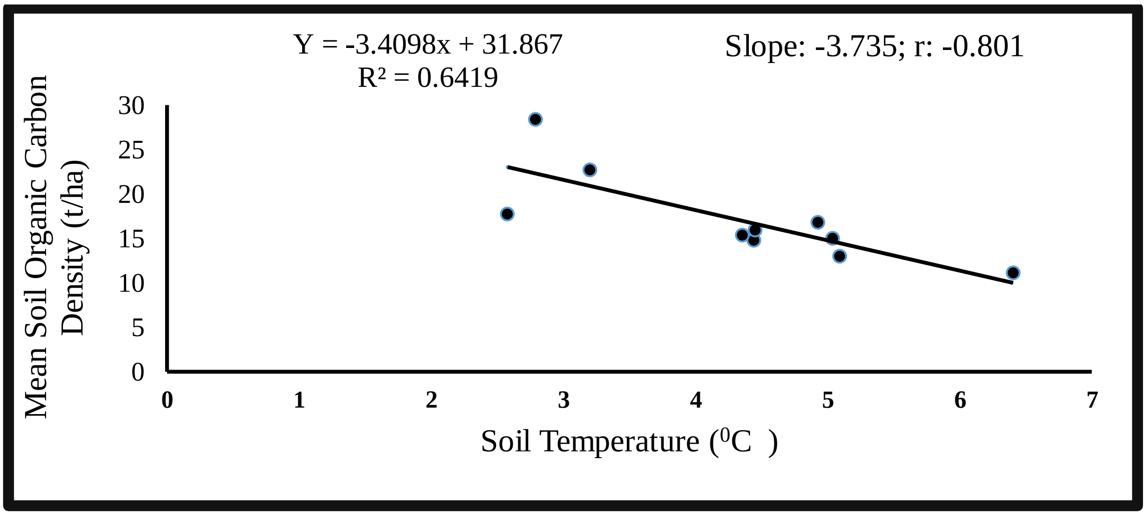
Results from this short-term experiment, coincide with Zhu *et al.* (2012) on the effects of time on improved management practices carbon sequestration. In fact, carbon input from crop residues duration is synonymous with the time to which soil carbon steady state is reached. In addition, this sequestration is not finite but will get to saturation point after certain periods (Watson, Noble, Bolin, Ravindranath, Verado and Dokken, 2000; West and Six, 2007). Reason why it is paramount to identify the practice that can enhance carbon pool within a short period of time in order to know the finite limit of soil in carbon sequestration for implementation of adaptation and mitigation policies.

4.3 Relationships Between SOC, Soil Moisture and Temperature

This sub-section focuses on the real relationship between soil temperature, moisture and soil organic carbon. Besides, variation of soil organic carbon with soil temperature and moisture will be discussed respectively.

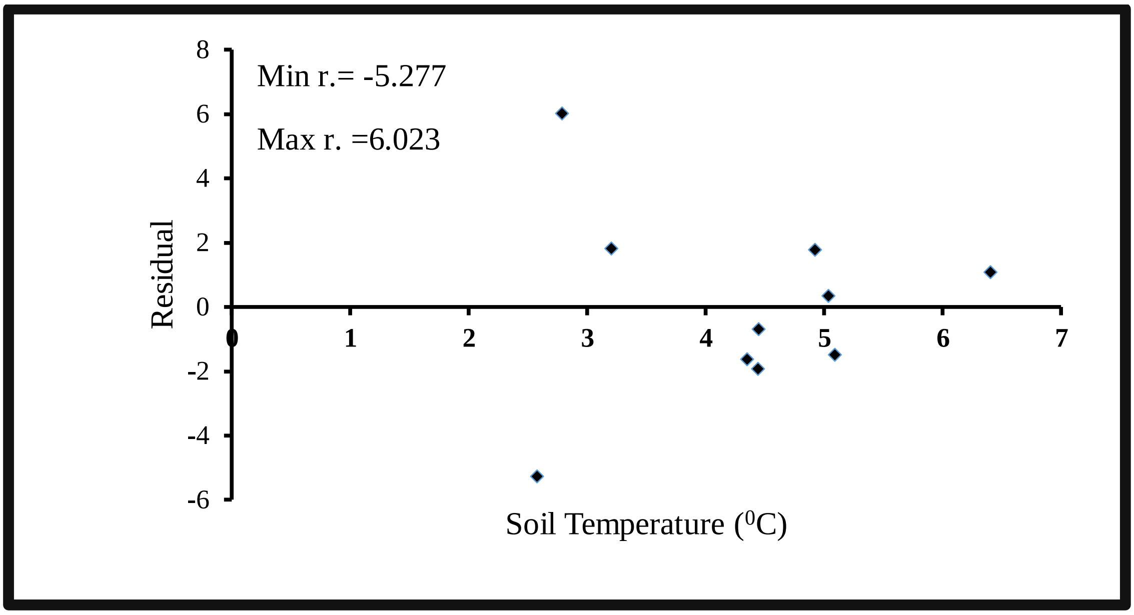
4.3.1 Relationship Between SOC and Soil Temperature

Mean soil organic carbon density (t/ha) and soil temperature was computed from 0 - 15 cm in order to determine the correlation of the mean value. As indicated in Figure 4.5, we observed a strong negative (r=-0.801) correlation between organic carbon input and soil temperature increase. Coefficient of determination R^2, indicates that soil organic carbon releases (emission of carbon) due to soil temperature increase accounts for 64% whereas other factors account 36%. Simply put, the Figure 4.5 explains that, as the soil temperature increases, the amount of organic carbon also decreases, hence high emission of carbon can occur. Because residues decomposition is accelerated due to heat. By computing the residual error which is the difference between the observed carbon emission and the predicted emission due to future soil temperature increase, we obtained a non - regular pattern (Figure 4.6) ranged from -5.277 to 6.023 t/ha which attests tiny disparity between the real and the predicted carbon emission.



Y: line of best fit equation; R^2: coefficient of determination and r: Pearson's coefficient of correlation.

Figure 4. 5 Mean Variation of SOCD (t/ha) versus Soil Temperature (^{0}C)



Min r.: minimum of the residual (Yobserved- Ypredicted) and Max r.: maximum residual.

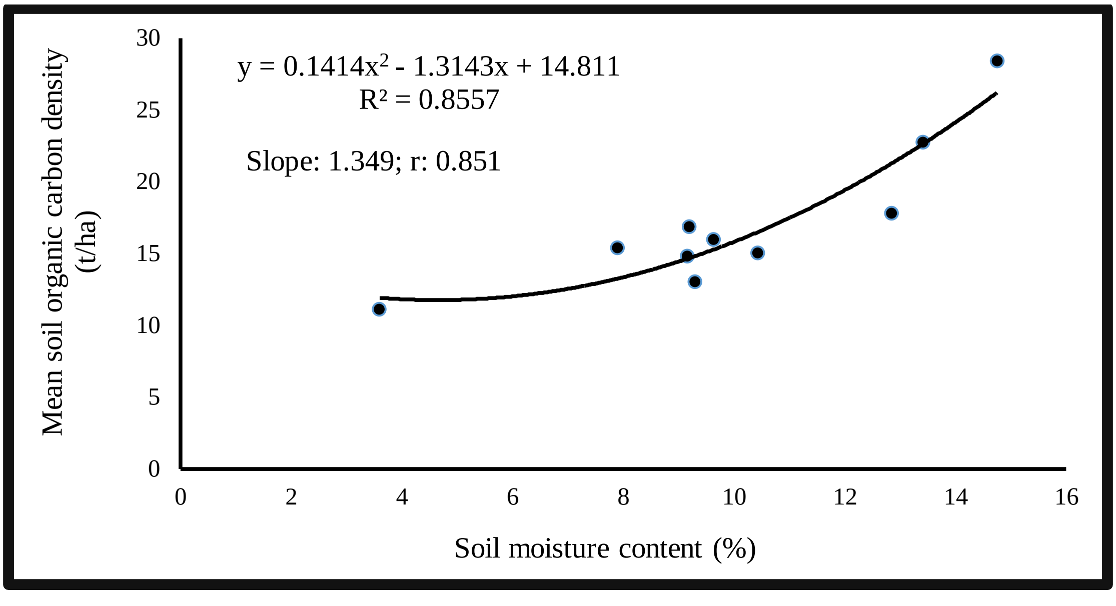
Figure 4. 6 Residual Plot of Mean Variation of SOCD (t/ha) versus ST (^{0}C)

Therefore, existing negative correlation between carbon input and soil temperature stated by Wang *et al.* (2010) is confirmed by our study using the pre-wetted technique over short-term experiment. Jarecki *et al.* (2006) have highlighted from their study that, carbon dioxide fluxes are positively correlated with both soil and air temperature. In fact, an increase in soil temperature exacerbates the rate of carbon mineralisation, leading to a decrease in the soil organic carbon pools (Potter *et al.*, 2007).

Furthermore, Kirschbaum (1994) posited that the future trend in amounts of soil organic carbon will depend on the relative temperature sensitivities of net primary productivity and soil organic matter decomposition rate. It is likely that, 1^{0}C increase in temperature could ultimately lead to a loss of over ten percent (10%) of soil organic carbon. This study supports the conclusion of previous studies which indicated that soil organic carbon contents may decrease significantly with global warming and thereby provide a positive feed-back in the global carbon cycle. Therefore, identification of best practices that can reduce both soil respiration soil temperature constitutes a panacea to halt global warming.

4.3.2 Relationship Between SOC and Soil Moisture

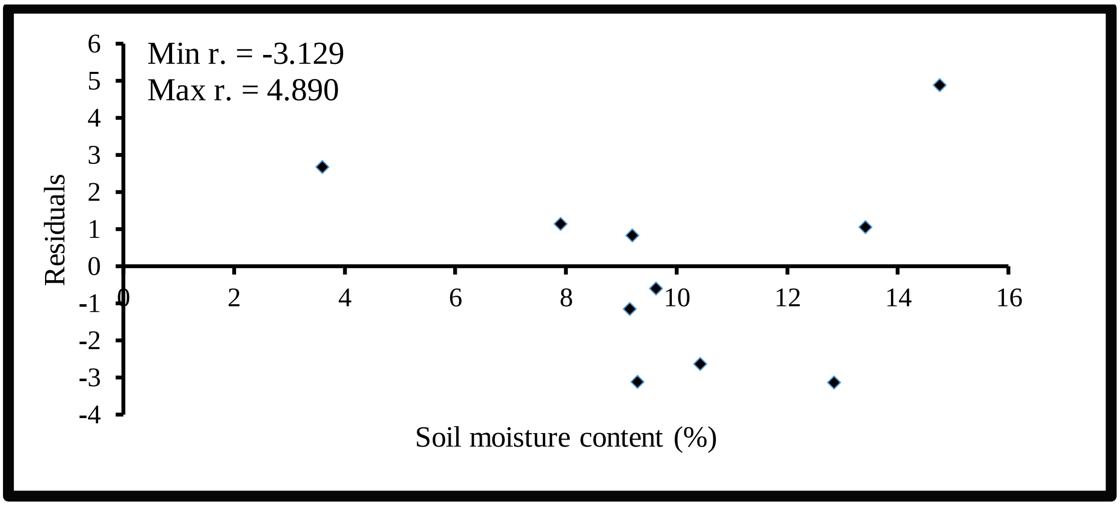
Likewise, soil organic carbon density and soil moisture content mean were computed in order to determine the relationship between variations of one parameter on another. Results on figure 4.7 reveal strong positive (r = 0.851) effects of soil moisture increase on soil carbon input. Simply put, the higher the soil moisture storage, the higher the ability of humification and microorganism's population therefore, an increase of carbon sink. Moreover, the risk of error and the level of uncertainties for this relationship are very low when referred to the coefficient of determination (R^2) which accounts for 85% of confidence level. Meaning that, the risk of increasing carbon emission through agricultural practices that can enhance soil moisture content is 15% compared to the benefit to enhance carbon sequestration which accounts for 85%.



Y: line of best fit equation; R^2: coefficient of determination and r: Pearson's coefficient of correlation

Figure 4. 7 Mean Polynomial Variation of SOCD (t/ha) versus SMC (%)

These results are confirmed by the residual plot (Figure 4.8) with a residual carbon ranged from – 3.129 to 4.890 t/ha. Results are in accordance with those reported by Jarecki *et al.* (2006) and Wang *et al.* (2010) on the fact that, carbon dioxide fluxes are negatively correlated with soil moisture content. Howard (1993) by evaluating carbon dioxide evolution under three moisture content rates found a quadratic negative correlation between carbon dioxide emissions and soil moisture content. Rawls, Pachepsky, Ritchiea, Sobeckic and Bloodworth (2003) also demonstrated that soil carbon content is also function of soil moisture content.



Min r.: minimum of the residual (Yobserved- Ypredicted) and Max r.: maximum residual

Figure 4. 8 Residual Plot of Mean Variation of SOCD (t/ha) versus SMC (%)

Meanwhile, organic matter input and soil texture also played an important major role. Accordingly, identification of best improved techniques that can enhance both organic matter and soil moisture content will be a significant contribution to enhance soil carbon pool. Relationship between soil moisture and the amount of crop residues input was also reported by Liu *et al.* (2011), Varughese (2011), Wang *et al.* (2013) and Wang *et al.* (2014).

4.4 Identification of best Improved Practices

This study aims to identify at the end of the three months experiment using the pre-wetted technique (improved technique), best treatments with significant effect in reducing soil temperature (ST, ^{0}C); enhancing soil moisture content (SMC, %), soil organic carbon density (SOCD, t/ha), soil organic carbon density gain per month (SOCDG, kg/ha/month) with scanty emission of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

In respect to the summary Table (Table 4.10), soil temperature (^{0}C) ranges between 2.8 – 6.4 with highest under check plot (6.4), soil moisture between 3.6 – 14.8 % with lowest moisture content with the control (3.6 %).

Table 4. 10 Summary Table of Treatments versus Measured Variables

		Measured Variables						
Treatment	Code	ST (^{0}C)	SMC (%)	SOCD (t/ha)	SOCDG/month (kg/ha)	SOC B. (kg/ha)	CH_4 (kg/ha)	N_2O (kg/ha)
T4	4S+75F	2.8	14.8	28.4	284	-1037.5	0	0.2
T2	4S+50F	3.2	13.4	22.8	222.5	-1037.5	0	0.2
T5	4S+25F	2.6	12.9	17.8	167.5	-1037.5	0	0.1
T3	2S+75F	4.9	9.2	16.8	154.5	-518.8	0	0.2
T9	3S+25F	4.6	9.6	16	148.5	-778.1	0	0.1
T8	3S+75F	4.4	7.9	15.4	141	-778.1	0	0.2
T6	2S+25F	5	10.4	15	137	-518.8	0	0.1
T1	3S+50F	4.4	9.2	14.8	133.5	-778.1	0	0.2
T7	2S+50F	5.1	9.3	13	114.5	-518.8	0	0.2
C	0S+0F	6.4	3.6	11.1	68.5	0	0	0.1

ST: Soil Temperature; SMC: Soil Moisture Content; SOCD: Soil Organic Carbon Density; SOCDG: Soil Organic Carbon Gain per Month; SOC B.: Soil Organic Carbon Balance (carbon stock changes. Negative value=sink or sequestration and Positive value=emissions); CH_4: Methane and N_2O: Nitrous oxide.

Source: Author’s field data compilation, 2015

In terms of carbon content (Table 4.10), soil organic carbon density is lower under the control plot (11.1 t/ha) but ranges between 11.1 – 28.4 t/ha. On the other hand, maximum gain per month (kg/ha) was obtained under T4 (284) whereas minimum gain was recorded on the control plot (68.5). Finally, in terms of greenhouse emissions and soil carbon balance, we observed high potential carbon sequestration under treatment T2, T4 and T5 up to 1037.5 kg/ha whereas, neither carbon sequestration nor emission was observed with the control C (0 kg/ha). No methane emission was observed from the analysis for all treatments and the control used. However, nitrous oxide emission was scanty and ranges between 0.1 – 0.2 kg/ha. Therefore, best improved practices can be identified from the summary table.

Results from the pre-wetted technique were promising and more valuable in terms of time scale response compare to the existing method used. Three best treatments (T2, T4 and T5) were identified (Table 4.11), Treatments response (TR, %) for each variable was computed. Soil Temperature (ST, ^{0}C) reduction was up to (20 %).

Table 4. 11 Pre-wetted Practices Identified

Treatment	Code	Measured Variables						
		ST (^{0}C)	SMC (%)	SOCD (t/ha)	SOCDG/month (kg/ha)	SOC B. (kg/ha)	CH_4 (kg/ha)	N_2O (kg/ha)
T4	4S+75F	2.8	14.8	28.4	284	-1037.5	0	0.2
T2	4S+50F	3.2	13.4	22.8	222.5	-1037.5	0	0.2
T5	4S+25F	2.6	12.9	17.8	167.5	-1037.5	0	0.1
Treatments Response (TR, %)		20	41	40.3	43	44.4	0	31.3

ST: Soil Temperature; SMC: Soil Moisture Content; SOCD: Soil Organic Carbon Density; SOCDG: Soil Organic Carbon Gain per Month; SOC B.: Soil Organic Carbon Balance (carbon stock changes. Negative value=sink or sequestration); CH_4: Methane and N_2O: Nitrous oxide.

Source: Author’s experiment analysis summary, 2015

In the meantime, Soil Moisture Content (SMC, %), Soil Organic Carbon Density (SOCD, t/ha) and Soil Organic Carbon Density Gain per Month (SOCDG/month, kg/ha) have increased respectively up to 41%, 40.3% and 43%. Potential carbon sequestration was about 44.4 % for the improved practices identified with 0 % methane emission and scanty nitrous oxide emission up to 31.3 %. In addition, Table 4.10 indicates T2, T4 and T5 as satisfactory best treatments that have given significant responses to our different research questions when compared to the rest of the treatment used and the farmers practice (control). Their ST ranged from 2.6 – 3.2 ^{0}C, SMC (12.9 – 14.8 %), SOCD (17.8 – 28.4 t/ha), SOCDG/month (167.5 – 284 kg/ha). Methane (CH_4) emission was zero (0 kg/ha) and nitrous oxide (N_2O) very scanty (0.1 – 0.2 kg/ha). In contrast they have witnessed very high SOC sequestration potential (1037.5 kg/ha) when compared to the rest of the treatments. Based on the results, treatments T2, T4 and T5 can be identified as best improved practices in terms of croplands temperature reduction, moisture improvement and soil organic carbon enhancement with insignificant GHGs emissions. Therefore, they can be disseminated as best pre-wetted techniques that can aid to enhance cropland resilience to climate change and subsequently mitigate climate in Edozhigi, Niger State, Nigeria.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

Our study aims to identify pre-wetted techniques that reduce soil temperature, enhance both soil moisture content, soil organic carbon with scanty GHGs emissions. In addition, we have also determined the interplay between pre-wetted techniques soil organic carbon variation with both soil temperature and moisture. Therefore, this chapter emphases on the relevant findings of our research. It gives also the conclusion and useful recommendations for an effective implementation the best practices chosen for our study area in response to climate change issues.

5.1 Summary

Findings from this study proffered more understanding and significant relevance of short-term experiment on long-term monocropping croplands using pre-wetted straw and minimum urea application technique (improved technique). Moreover, results from this study were in accordance with the aforementioned objectives and research questions. It is obvious that, compared to the existing long-term experiment method, there is significant difference in terms of soil temperature reduction over short- term when compared to the existing method usually used. Treatments T5 (2.6 ^{0}C), T4 (2.8 ^{0}C) and T2 (3.2 ^{0}C) have given lowest temperature compared to the control C (6.4 ^{0}C). In addition, soil moisture content over the short period was also significantly different. Compared to the control C (3.6 %), high moisture content were recorded under treatments T5, T2 and T4 respectively 12.9, 13.4 and 14.8 %. Besides, in accordance with long-term experiment, soil organic carbon density were significantly different under each treatment during this short period. High carbon input were observed with T4 (28.4 t/ha), T2 (22.8 t/ha) and T5 (17.8 t/ha) with lowest amount under the check plot (11.1 t/ha).

Moreover, carbon gained per month was also confirmed by our study with high significant amount under the tested treatments for the pre-wetted technique. Simply put, soil organic carbon gain per month (kg/ha/month) was lowest under the control C (68.5) when compared to treatments T4, T2 and T5 which accounted respectively 284, 222.5 and 167.5 kg/ha/month. Additionally, pre-wetted technique confirms the cause effect between soil organic carbon and soil temperature and moisture. Besides, soil organic carbon under the pre-wetted technique decreases with increase of soil temperature whereas, the study reveals a polynomial positive relationship between soil organic carbon and soil moisture content. Finally, high carbon storage were also observed under T4, T2 and T5. All pre-wetted techniques used had indicated zero methane emission. However, Nitrous oxide was tiny (0.1 – 0.2 kg/ha) under the control plot and treatments T4. T2 and T5.

5.2 Conclusion

Our study brings strong evidence on the fact that, pre-wetted technique (improved technique) is a potential method that can halt climate change and enhance agricultural land productivity. In fact, it has a huge possibility to reduce croplands soil temperature and enhance soil moisture content over short time period. Furthermore, its ability to increase soil carbon pool and monthly soil carbon addition is also confirmed. Therefore, pre-wetted technique has a great potential to the attainment of sustainable agricultural land management practice. Practice, that can help to enhance croplands resilience to climate change and boost sustainable rainfed agriculture productivities in Edozhigi, Gbako Local Government and Sub - Sahara Africa in general. In the light of the aforementioned, some useful recommendations can be addressed for an effective dissemination, implementation and use of the pre-wetted technique in the study area.

5.3 Recommendations

From the aforementioned results given by our short term study, some useful recommendations can be addressed therein for the effective use of our new method.

- The positive results from this study are promising and justify the need for its immediate implementation, recommendation and adoption as adequate sustainable agricultural land management projects under climate change events;
- Pre-wetted straw mulching in combination with minimum chemical fertilizer must be assessed under different crops cultivated in the study area in order to appreciate the level of yield improvement of the technique compared to the farmers practices;
- Agricultural field extension staff must be introduced and trained on the basic and principles of pre-wetted technique for large scale extension in rural communities likely to suffer from climate effects therefore, facilitate local and national adaptation and mitigation action strategy implementation;
- We suggest a second test in order to check the stability of the chosen treatments (T2, T4 and T5) and confirmation of our results.

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APPENDIXES

Appendix A: ANOVA Tables

a) TEMPERATURE

Variate: Temp_0_5cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCKS stratum	3	4.2910	1.4303	8.33	
BLOCKS.*Units* stratum					
SXU	9	49.1300	5.4589	31.81	<.001
Residual	27	4.6340	0.1716		
Total	39	58.0550			

Variate: Temp_5_15_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCKS stratum	3	2.1970	0.7323	3.10	
BLOCKS.*Units* stratum					
SXU	9	50.8200	5.6467	23.90	<.001
Residual	27	6.3780	0.2362		
Total	39	59.3950			

b) MOISTURE

Variate: Moist_0_5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCKS stratum	3	10.187	3.396	0.62	
BLOCKS.*Units* stratum					
SXU	9	365.554	40.617	7.41	<.001
Residual	27	147.914	5.478		
Total	39	523.655			

Variate: Moist_5_15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCKS stratum	3	11.854	3.951	0.70	
BLOCKS.*Units* stratum					
SXU	9	355.014	39.446	6.99	<.001
Residual	27	152.332	5.642		
Total	39	519.200			

c) DOSE OF SOC

Variate: Dsoc_0_5_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCKS stratum	3	80.749	26.916	5.27	
BLOCKS.*Units* stratum					
SXU	9	360.573	40.064	7.84	<.001
Residual	27	137.987	5.111		
Total	39	579.310			

Variate: Dsoc_5_15_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCKS stratum	3	349.81	116.60	4.92	
BLOCKS.*Units* stratum					
SXU	9	1694.86	188.32	7.95	<.001
Residual	27	639.35	23.68		
Total	39	2684.01			

d) GAIN OF SOC

Variate: Gain_SOC_0_5_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCKS stratum	3	0.0125700	0.0041900	7.08	
BLOCKS.*Units* stratum					
SXU	9	0.0518000	0.0057556	9.72	<.001
Residual	27	0.0159800	0.0005919		
Total	39	0.0803500			

Variate: Gain_SOC_5_15_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCKS stratum	3	0.053268	0.017756	7.02	
BLOCKS.*Units* stratum					
SXU	9	0.230472	0.025608	10.13	<.001
Residual	27	0.068257	0.002528		
Total	39	0.351998			

Appendix B: Experiment pictures

a) **Land grading and levelling**

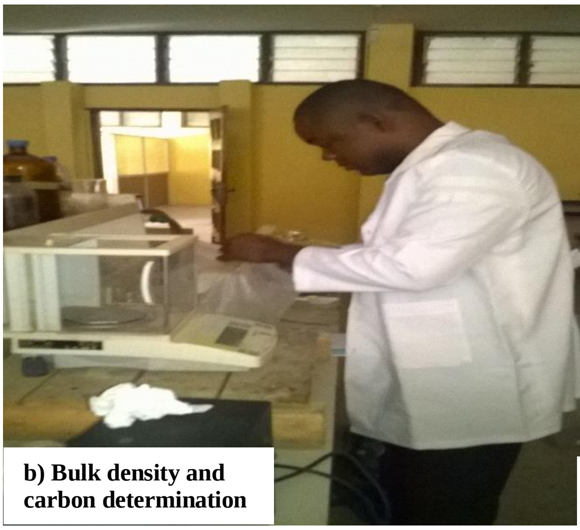
b) Plots and blocks measurements

c) Combined straw and urea incorporation

d) Trial fencing

Appendix C: Laboratory pictures

a) **Dry soil samples on Lab table**



b) Bulk density and carbon determination

c) Oven dry chamber

d) Hot chamber : straw nitrogen determination

e) Blinder : straw dry mass determination

f) Straw Phosphorus and Potasium determination