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ENHANCED SOIL CARBON SEQUESTRATION FOR IMPROVED FINGER-MILLET [*ELEUSINE CORACANA* (L.) GAERTN.] PRODUCTION IN TESO FARMING SYSTEM IN EASTERN UGANDA

BY

EKWANGU JOSEPH

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DECEMBER, 2020

DECLARATION

I, Ekwangu Joseph, declare that this proposal is my original work, except for literature acknowledged and has not been presented to Uganda Martyrs University or any other degree awarding institution before.

Signature.. **Date**.18th/11/2020..

Ekwangu Joseph

APPROVAL

This Proposal has been submitted for examination with our approval as supervisors

Associate Professor Tumwebaze Susan Balaba

Department of Forestry, Bio-Diversity and Tourism

School of Forestry, Environmental and Geographical Sciences,

College of Agricultural and Environmental Sciences,

Makerere University, Kampala.

Signature...STumwebaze.................. **Date**...03/12/2020.....................

Associate Professor Twaha Basamba Ali

Department of Agricultural Production,

School of Agricultural Sciences,

College of Agricultural and Environmental Sciences,

Makerere University, Kampala.

Signature.............................. **Date: 3rd December 2020**

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LIST OF ABBREVIATIONS AND ACRONYMS

CIMMIT	International Maize and Wheat Improvement Centre
SOC	Soil Organic Carbon
NUE	Nutrient Use Efficiency
FAO	Food and Agricultural Organization
F.Y.M	Farm Yard Manure
GDP	Gross Domestic Product
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
NARO	National Agricultural Research Organization
NaSARRI	National Semi-Arid Resources Research Institute
TVC	Technology Verification Centre
UBOS	Uganda Bureau of Statistics

ABSTRACT

Land degradation and Low soil fertility has been attributed to be the major cause of poor yields among small holder farmers in sub Saharan Africa. The problem is further increased by the failure of the soils to respond to fertilizer application due low very low soil carbon in the soil especially the highly weathered ferralsol soils which occupy the largest portion of sub Saharan Africa.

Studies conducted in sub Saharan Africa indicate low fertilizer response especially in cereals grown in ferralsol soils with soil carbon levels below the critical level of 1.2%, similar problem has been reported in Uganda. A study is therefore proposed to be conducted to determine the effect of legume integration on soil organic carbon levels in the soil and finger-millet productivity in Teso farming system. Specifically the study will determine the spatial distribution of soil organic carbon, Nitrogen, Phosphorus and Potassium levels in the finger millet growing areas of Eastern Uganda; determine the effect of finger millet legume integration options on soil organic carbon in Eastern Uganda; to determine the effect of legume integration on finger millet productivity and nutrient use efficiency and to determine the effect of legume integration on nutrient composition of the three varieties of finger millet flours grown in Eastern Uganda.

A field experiment will be conducted at National Semi-arid Resources Research Institute (NaSARRI) in Serere district eastern Uganda. The Center is located at 02002'north $33^0 39'$east of the equator. The experiment will be conducted during the short and long rains of 2020 and 2021 and the study will be laid down in a randomized complete block design in a three by two by two factorial treatment structure. The three factors will be legume varieties (groundnuts, green gram and cowpeas), two finger millet varieties (SEREMI 2, NARO MIL3) and two cropping systems (Intercropping and Crop rotation). Finger millet will be intercropped with legumes in a 1 by 1 arrangement (one row of legume followed by one row finger millet) and also rotated with the three legumes (Groundnuts, green gram and cowpeas). The study will therefore, be replicated three times and the experiment will be planted in the poor, moderately fertile and fertile fields and fertility levels used for blocking. Crop growth data, soil data and yield data will also be entered in Microsoft Excel spreadsheet. Simple correlation (between Days to flowering and maturity, grain yield and maturity time; nutrient use efficiency and finger millet varieties, SOC and finger millet grain yield), multivariate regression (legume integration options and yield, legume treatment and SOC, fertilizer rates and tiller number, days to 50% flowering, Days to maturity and finger number) and analysis of variance (ANOVA) to determine nutrient use efficiency, tillering ability, days to 50% flowing days to maturity, finger number, head size and grain yield will conducted using GenStat 14th Edition statistical software will be conducted. The means will be separated by LSD at 5% level of significance.

CHAPTER ONE

INTRODUCTION

1.0 General Introduction

This chapter presents background (historical and theoretical background), statement of the problem, objectives of the study, hypotheses, scope of the study, significance of the study, Justification of the study, definition of key terms as seen below;

1.1 Background of the Study

1.1.1 Historical and Contextual Background

Finger-millet (*Eleusinecoracana* (L.) is a major food crop of the semi-arid tropics of Asia and Africa and fits well in dry land farming systems (Goron and Raizada, 2015). The crop was domesticated in the highlands of Ethiopia and Uganda approximately 5000 years ago, and today it is ranked fourth globally in importance, after sorghum, pearl millet, and foxtail millet (Das, 2013). It is cultivated in more than 25 countries, mainly in Africa and Asia(Chandrasekara and Shahidi, 2010). Finger-millet is a major staple crop in Uganda and is rated second to maize (*Zea mays* L.) in importance among the cereals (UBOS, 2016).

According to the National Agricultural Research Organization, finger-millet is a high priority food commodity research crop, ranking second only after bananas (Owere, Tongoona, Derera, & Wanyera, 2014a). The crop is grown on an estimated annual area of 249,987 ha which provides grain harvests of up to 276,928 metric tonnes, production of the crop is largely in the northern, eastern and western regions of the country(UBOS, 2010)

Besides its importance as a staple food crop, finger millet contributes greatly to the incomes of rural households, particularly women in Uganda. It is brewed into local beer for sale or is sold directly as grain in local markets where there is ready demand(UBOS, 2010). Furthermore, finger millet plays a major role in providing for the dietary needs of the rural people who constitute more than 80% of the Ugandan population. It is a major preventative food against malnutrition, owing to its high content of essential amino acids namely, tryptophan, cystine, methionine, and total aromatic amino acids (phenylamine and trysone) from the recently released varieties by national agricultural research organization (NARO) 2017. In addition finger millet has high amount of iron which is one of the most deficient nutrient for children under five in Uganda (Tumwine et al., 2018). Increasing production and productivity of finger millet in Uganda and eastern Uganda in particular would help in addressing the problem of iron deficiency in children below five years among rural households especially if they are fed on finger millet porage. Also finger millet is a fairly resilient crop; it is drought tolerant and its grain has good storage qualities without significant damage by storage pests. Finger millet, therefore, offers great food security opportunities for the small holder farmers in the semi-arid regions (Gupta et al., 2017).

Despite the great value associated with this crop by the population, its productivity (yield per unit area) has remained low in Uganda. Production figures consistently show an increase in area under finger millet production, but paralleled by a decline in land productivity (as low as 600 kg ha^{-1})(UBOS, 2016). Several causes have been advanced to explain this decline and the major ones are thought to be low soil fertility, poor agronomic practices, poor quality varieties and weed proliferation (Ebanyat, 2009; Kidoido et al., 2002; Owere et al., 2014a). Low soil fertility is associated with low Soil Organic Carbon(SOC) which is a key indicator of soil quality and productivity in the semi-arid tropics of sub-Saharan Africa (Tittonell and Giller, 2013). Soil Organic Carbon (SOC) refers only to the carbon component of organic compounds (FAO, 2017). Soil organic matter (SOM) is difficult to measure directly, so laboratories tend to measure and report SOC. Soil organic carbon therefore, is a measureable component of soil organic matter. Organic matter makes up just 2–10% of most soil's mass and has an important role in the physical, chemical and biological function of agricultural soils. Organic matter contributes to nutrient retention and turnover, soil structure, moisture retention and availability, degradation of pollutants, carbon sequestration and soil resilience (Government of Western Australia, 2019). In fact most soils in the semi-arid tropics has been reported to have SOC below the thresh hold (critical value) of less than 1.2 % (Musinguzi et al., 2016a). Yet SOC has been reported to influence soil quality, NPK amounts in the soil and nitrogen use efficiency in cereal production (Musinguzi et al., 2016b). In addition, the quality of finger millet grain has been found to be influenced by environment, agronomic practices, the genetics of the crop, SOC and soil fertility(Gupta, N., Gaur, & Kumar, 2012).Interventions that increase biomass in the soil such as legume integration in cereal production, a combination of organic and in organic fertilizers have been used to manage

SOC levels and soil fertility in the semi-arid tropical areas of Sub Saharan Africa (ICRISAT, 2013). However, the quantity of SOC added by different legumes, organic and in organic fertilizers over time remains scanty. Therefore, there is need to provide practical and context based solution to address the problem of low soil organic carbon which in turn contributes to increased soil fertility and consequently increased finger millet yields for the benefit of the small holder farmer.

1.1.2 Theoretical and Philosophical Background

Theoretical Background

A number of studies have attempted to explore critical Soil Organic Carbon (SOC) concentrations to attain desirable soil characteristics, production potentials and a good functional ecology. These studies have indicated 2% SOC as the critical concentration for structural stability, water holding capacity, cation exchange capacity, soil aggregate stability and < 1.2% for optimal yield response to N fertilizer (Musinguzi et al., 2016). In the past decades these studies were based on the classic ecological theory that states that SOC is a function of recalcitrance properties of the soil and stabilization process leading to the formation of complex organic compounds. These compounds are made of dead plants and other organic materials degraded by soil micro-organisms into organic compounds such as large humic substances that are highly resistant to further decomposition (Tan, 2014). This theory was challenged by the ecological equilibrium theory (Caruso et al., 2018)., that states that 'persistence of SOC is an equilibrium point where SOC losses resulting from continuous decomposition and SOC gains due to SOC protection are balanced' and stated as $dc/dt= G(c_{soil})-L(c_{soil})$

Where; dc/dtis SOC persistence or accumulation, $G(c_{soil})$ is SOC gains and $L(c_{soil})$ is SOC losses. As a result of these theories, more than thirty models have been developed to study soil organic matter dynamics in the soil and in the past one decade, Roth C model (Coleman and Jenkinson, 1996) and Century model have commonly been used (Parton et al., 2010). Studies conducted by (Smith et al., 1997) compared nine models and found out that Roth c, CANDY, DNDC, CENTURY, DAISY and NC soil models did not differ significantly from each other while SOMM, ITE and Verberne did not differ significantly from each other but significantly showed larger model errors. It is upon this background that this study will apply the Roth c model principles which consider the parameters of interest in this study. The Roth c model states that Soil Organic Carbon (SOC) is a function of soil type (Amount of clay content in the soil express in %), average monthly rainfall, average monthly temperature (^{O}C), soil cover/cropping system, monthly input of farm yard manure(FYM) or compost, the decomposition of the incoming plant material and depth of soil sampled.

Philosophical Background

The study is grounded on the positivism philosophy. Positivism is the view that the only authentic knowledge is scientific knowledge, and that such knowledge can only come from positive affirmation of theories through strict scientific methods (techniques for investigating phenomena based on gathering observable, empirical and measurable evidence, subject to specific principles of reasoning). The doctrine was developed in the mid-19th Century by the French sociologist and philosopher ("Comte, Auguste (1798 - 1857) - Credo Reference," n.d.).

The term "positive" in the epistemological sense indicates a "value-free" or objective approach to the study of humanity that shares much in common with methods employed in the natural sciences, as contrasted with "normative", which is indicative of how things should or ought to be.

Comte saw the scientific method as replacing Metaphysics in the history of thought and Philosophy of Science. His law of three stages (Universal Rule) sees society as undergoing three progressive phases in its quest for the truth; the theological (where everything is referenced to God, and the divine will subsume human rights); the metaphysical (the post-enlightenment humanist period, where the universal rights of humanity are most important); and the positive (the final scientific stage, where individual rights are more important than the rule of any one person). Comte believed that Metaphysics and theology should be replaced by a hierarchy of sciences, from mathematics at the base to sociology at the top.

There are five main principles behind Positivism:

- The logic of inquiry is the same across all sciences (both social and natural).
- The goal of inquiry is to explain and predict, and thereby to discover necessary and sufficient conditions for any phenomenon.
- Research should be empirically observable with human senses, and should use inductive logic to develop statements that can be tested.
- Science is not the same as common sense, and researchers must be careful not to let common sense bias their research.
- Science should be judged by logic, and should be as value-free as possible. The ultimate goal of science is to produce knowledge, regardless of politics, morals and values.

Positivism is therefore, a way of thinking/an epistemology that seeks explanation of events for the discovery of underlying laws so that any future event of that type can be predicted and the implication controlled. On the basis of these predictions, it becomes possible to manipulate a particular set of variables, control events so that desirable goals are achieved and undesirable consequences eliminate (Benson, 1989).

Epistemology is the investigation of the nature of knowledge itself. Its study focuses on our means for acquiring knowledge and how we can differentiate between truth and falsehood. Modern epistemology generally involves a debate between rationalism and empiricism. Rationalists believe that knowledge is acquired through the use of reason, while empiricists assert that knowledge is gained through experiences (Alston, 1989; Cline et al., 2019).

1.2 Statement of the Problem

The soils in the Teso farming system in the semi-arid regions of Uganda are majorly ferralsols characterized by low soil organic carbon (SOC), a key indicator of soil fertility and soil health (Musinguzi et al., 2016b). In addition, the soils are deficient in N and P which are the main nutrients required for finger millet growth and grain development (Ebanyat, 2009; Musinguzi et al., 2016). The low soil carbon is attributed to continuous cultivated due to reduction in house hold land size and poor agronomic practices such as bush burning. Consequently, Finger millet yields have been reported to be declining (UBOS, 2016). For instance, yield trends over a ten-year period showed a growing gap between on-farm (400-

800 kg ha^{-1}) and on-station productivity (2,500 kg ha^{-1}(UBOS, 2016). This is majorly attributed to low SOC resulting to low soil fertility (especially low N-less than 0.1% and P-less than 7 mgkg^{-1} soil) and weed proliferation, (Kidoido et al., 2002; Opole, Prasad, & Staggenborg, 2013; Owere, Tongoona, Derera, & Wanyera, 2014b). And according to Musinguzi et al., (2016b), a critical SOC level below 1.2% does not favor grain yield even with application of NPK fertilizer. Yet most soils in eastern Uganda have very low SOC (<1.2%) implying that application of NPK fertilizers will not greatly influence grain yield. Therefore, application of integrated soil and N management practices (ISFM) such as finger millet legume inter cropping, finger millet legume rotation and fertilizer application could lead to achieving critical SOC required to boost productivity on Ferralsol soils. In addition to timely weed control and, pest and disease management. Information on the effect of integration of legumes with good agronomic practices to enhance SOC and finger millet yields in ferralsol soils is scanty. This is because of the limited research on finger millet, thus has been considered an 'orphan crop'. Therefore this study seeks to determine the effect of legume integration on soil organic carbon and finger-millet productivity in Teso farming system in Eastern Uganda.

1.3 Objectives of the Study

1.3.1 Major Objective

The overall objective of this study is to contribute to increased finger millet productivity in Teso farming system in eastern Uganda through finger millet legume integration.

3.1.2 Specific Objectives

The specific objectives are:

1. To determine the spatial distribution of soil organic carbon, Nitrogen and Phosphorus levels in the finger millet growing areas of Eastern Uganda
2. To assess the effect of finger millet legume integration options on soil organic carbon, nitrogen and phosphorus levels in Eastern Uganda
3. To examine the effect of legume integration on finger millet productivity and nitrogen phosphorus and potassium nutrients use efficiency
4. To determine the effect of legume integration on nutrient composition of the three varieties of finger millet flours grown in Eastern Uganda

1.4 Hypotheses

H_{01}: There is no difference in the distribution of soil organic carbon, Nitrogen and Phosphorus in the finger millet growing areas of Eastern Uganda varies in space

H_{02}: Soil carbon sequestration, nitrogen and phosphorus levels are not affected by legume integration options

H_{03}: Legume integration options has no effect on finger millet productivity in Eastern Uganda

H_{04}: Nutrient use efficiency of different finger millet varieties is not affected by legume type used in the intercrop or rotation

H_{05}: Legume integration options has no effect nutrient composition of the three finger millet varieties grown in Eastern Uganda

1.5 Scope of the Study

This looks at the conceptual, Geographical and time scope of the study.

1.5.1 Conceptual Scope

Generally, the concern of the study is to contribute to increased productivity of finger millet in Teso eastern Uganda and this can be aided by increasing Organic matter levels through legume integration and fertilizer application in finger millet production. Specifically, the study will focus on determining the effect of finger millet legume integration on soil fertility and finger millet yields.

1.5.2 Geographical Scope

The study will be conducted in Amuria, 40 kilo meters (km) north of Soroti town and Kumi district 60 km east of Soroti town. These areas have been chosen because the soils are largely ferralsols characterized by low soil organic carbon and therefore low soil fertility (Patrick et al., 2013a; UBOS, 2016) and are major finger millet growing areas in Teso.

1.5.3 Time Scope

The study will be conducted between 2019 and 2020. This is the period when funds for research will be provided by the sponsor of this study

1.6 Significance of the Study

It is hoped that the study findings and recommendations will be an addition to the body of knowledge in the academia. To the policy makers especially Ministry of Agriculture Animal Industry and Fisheries (MAAIF), the findings will guide on policy formulation on training of agricultural extension staff and farmers, development of dissemination and training materials on how to increase soil organic carbon, soil fertility and finger millet productivity. To farmers, if the technologies are adopted finger millet productivity will be improved. This will contribute to food and nutrition security, incomes and wellbeing of small holder farmers in eastern Uganda. This will contribute to the attainment of sustainable development goal (SDG) 1 (ending all forms of poverty) and 2 (eradication of malnutrition).

1.7 Justification of the Study

Finger millet is an important cereal with outstanding attributes as a subsistence food crop. In Africa and South Asia, finger millet is a staple food grain upon which millions depend. Additionally, finger millet straw also makes good animal fodder, containing up to 60% total digestible nutrients (Goron and Raizada, 2015). Finger millet grain is rich in calcium, iron, methionine, and tryptophan(Gupta et al., 2017) forming an integral part of the diet of the rural populations in developing tropical countries where calcium deficiency and anemia are widespread (Babu et al., 2013). Besides its importance as a staple food crop in the region, finger millet contributes greatly to the incomes of rural households, particularly to women's income (Wanyera, 2007). It is sold directly as grain in local markets where there is a high demand for the crop, and is also brewed into local beer for sale. Moreover it is a fairly resilient crop, it is drought tolerant, and its grain has an extended shelf life of several years without significant damage by storage pests (Kidoido et al., 2002). As a country millet contributes to about 23.7% of the country's GDP (UBOS, 2010).

1.8 Definition of key terms

1.8.1 Soil Organic Carbon (SOC)

Soil Organic Carbon is a measurable component of soil organic matter and soil organic matter is a component of soil consisting of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms and substances synthesized by soil organisms.

1.8.2 Soil carbon sequestration

This is a process in which Carbon dioxide is removed from the atmosphere and stored in the soil carbon pool. The process is primarily mediated by plants through photosynthesis with carbon stored inform of SOC (Jackson, 2017). Soil carbon pool is a system that has the capacity to release or store carbon. The Marrakesh accords recognizes five main carbon pools or reservoirs in forests: Above ground biomass, below ground biomass, dead wood, litter and organic matter

1.8.3 Climate

Weather conditions prevailing in an area observed over a long period of time is climate and weather is a state of the atmosphere described in terms of hot or cold (temperature), wet or dry (humidity), calm or stormy and clear or cloudy.

1.8.4 Topography

It is the arrangement of natural and artificial physical features of an area for example hills, mountains, valleys, forests etc.

1.8.5 Soil texture

The relative composition of sand, clay and silt particles in a given soil

1.8.6 Land use

Land use is the purpose to which the land cover is committed

1.8.7 Fertilizer

Natural or synthetic chemical based substance added to the soil to enhance its fertility

1.8.8 Inorganic fertilizer

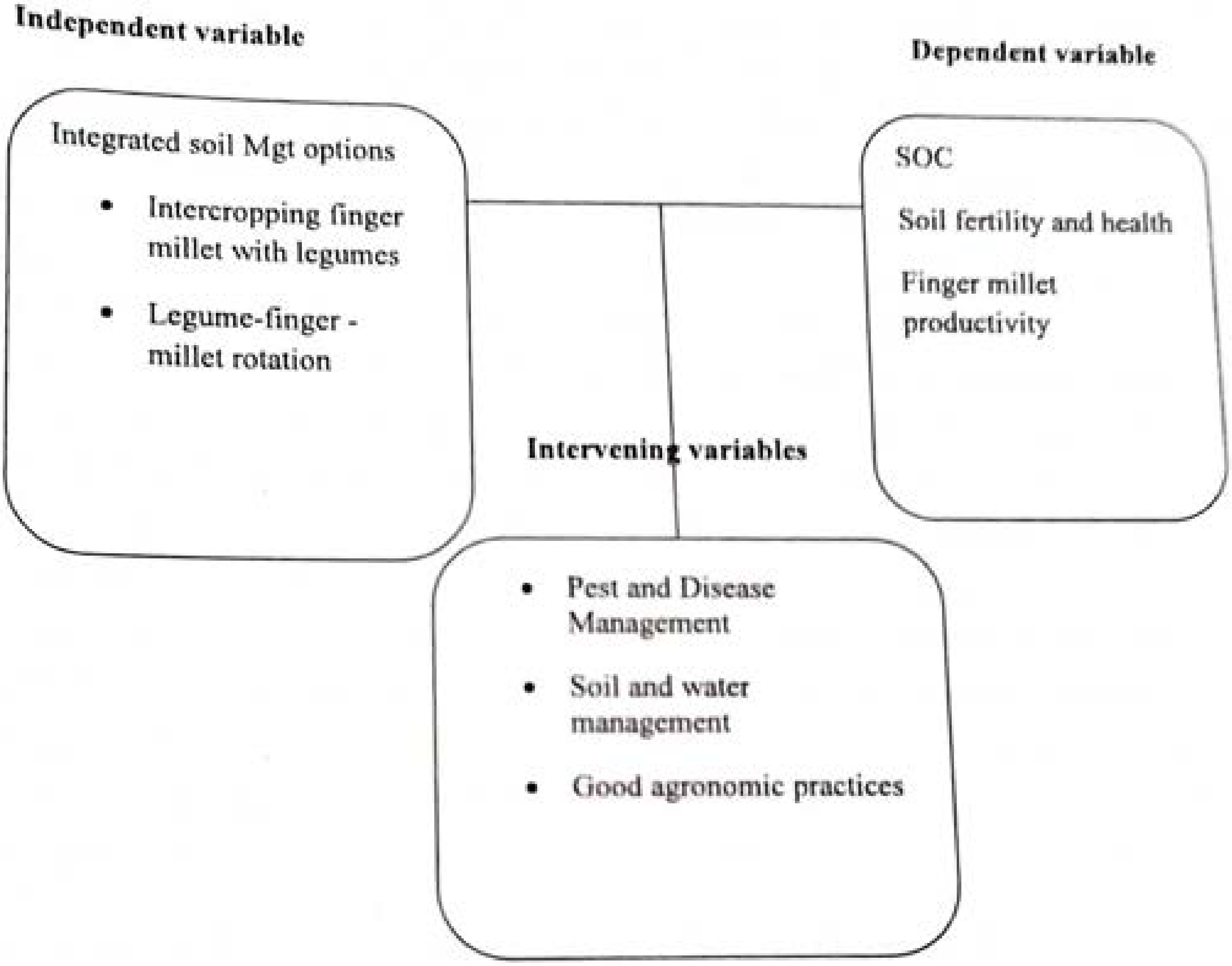
This is artificially manufactured/ chemical fertilizers

1.8.9 Organic fertilizer

It is a plant fertilizer that is derived from organic sources such as organic compost, cow manure, Goat/sheep droppings etc. Organic fertilizer contains only plant or animal based materials that are either a bi-product or end product of natural processes such as manure, leaves or compost.

1.9 Conceptual Framework

This is a scheme of concepts (variables) which a researcher will operationalize in the study in order to achieve set objectives. The framework is normally presented graphically (diagrammatically) as shown below.



Explanation of the Conceptual Framework

The conceptual frame work above shows the relationship between integrated soil management options and improved finger millet productivity. The integrated soil management options that are anticipated to improve finger millet productivity include; a combination of organic and inorganic fertilizers, intercropping and legume, finger-millet rotation. Pest and disease management, soil erosion control, soil water management and environmental management would enhance the above independent variables in improving finger millet yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Status of soil organic carbon (SOC) stocks in sub Saharan Africa

Soil Organic Carbon is the main indicator of soil fertility in the tropics and is also the main cause of soil fertility heterogeneity due to its variation across tropics (Patrick et al., 2013b; Tittonell and Giller, 2013). Soil organic carbon plays a major role in improving soil quality through the soil aggregate stabilization, reduced effect of soil erosion ,improvement in cation exchange capacity water holding capacity, biological functioning and availability of macro and micro nutrients (Carter et al., 2004). Studies conducted by Patrick et al. (2013b); Tittonell and Giller(2013) and (Musinguzi et al., 2016b), in tropical sub-Saharan Africa reported high SOC to be associated with high soil fertility and yield. However, high yield was not reported with soils low in SOC (Ebanyat, 2009). Most soils with low SOC are associated to highly weathered tropical soils especially ferralsols characterized by high levels of sequioxides, kaolinitic clays and inherently low in nutrient retention capacity (Bruun et al., 2010; Steiner et al., 2007). Because of the low levels of SOC, yield response to mineral N fertilizer application was reported insignificant (Ebanyat, 2009). Thus Musinguzi et al. (2014) explored to determine the critical SOC concentration for optimal yield response to mineral N fertilizers, this was observed at SOC > 1.2%. However, the rate at which different soil management practices/options attain the critical SOC concentration is unknown. Therefore, this study will seek to determine the effect of fertilizer application and finger millet legume integration on soil organic carbon and finger-millet productivity in Teso farming system.

2.2 Finger millet legume integration and its effect on soil organic carbon and finger millet yield

Legume integration is one of major components of integrated soil fertility management in sub Saharan Africa (Giller, 2001). In drier areas, common beans are often replaced by cowpea or groundnut. Farmers commonly intercrop to secure food production by averting risk, and to maximize utilization of land and labor. When crops are complimentary in terms of growth pattern, aboveground canopy, rooting system, and their water and nutrient demand, intercropping effectively enables a more efficient utilization of available resources (sunlight, moisture and soil nutrients), and can result in relatively higher yields than when crops are grown separately, as pure stands (Willey, 1979). Different legumes fix nitrogen at varying rates and also generate varying biomass. These biomass contributes to SOC stocks and enhances cereal grain yield (Myaka et al., 2006).

Studies conducted in west Africa particularly Nigeria, on the practice of rotating *Mucunapruriens* with maize(ICRISAT, 2013) and soil fertility management in *maize* production in Nigeria (Kamara et al., 2014) reported grain yield increase between 25-50% and improvement of SOC and soil fertility. In Kenya, Ngosong et al.(2015) reported grain yield increase between 21-24% when maize was intercropped with *Mucunapruriens*. However, limited studies have been conducted on legume integration and fertilizer application to enhance soil in finger millet production in the semi-arid region of Sub Saharan Africa.

2.3 Soil organic carbon as influenced by organic and inorganic fertilizer input in the soil

2.3.1 Soil organic carbon as influenced by organic fertilizer input in the soil

Terrestrial eco-system especially soil is an important sink for carbon (Musinguzi et al., 2016b). And long term application of organic fertilizers sequestered carbon between 1.5 – 2.0 times higher than balanced inorganic fertilizer under rice wheat cropping system (Gupta Choudhury et al., 2018). This study was conducted under long-term rice-wheat cropping system along with its productivity in gypsum-amended partially reclaimed sodic soils of semi-arid sub-tropical Indian climate. Similarly Hs and Bs (2016) reported an increase in soil organic carbon when farm yard manure (FYM) was applied to the soil over a long period of time. Similar observations were made by (Yang et al., 2016), they reported manure application to have significantly to have led to accumulation of carbon and nitrogen in the soil leading to improved soil physical properties. Also biomass carbon was reported to have significantly increased when organic fertilizer was applied in barley, wheat, beans, maize, cotton and rice (Wang et al., 2016).The above studies were limited to rice- wheat; maize, beans, barley, cotton and rice cropping system with very limited information on SOC sequestration studies under finger millet fertilizer application yet finger millet is a very important cereal in semi-arid tropical regions of Sub Saharan Africa.

2.3.2.2 Soil Organic Carbon stocks as influenced by inorganic fertilizer application

Application of inorganic fertilizer to the soil especially Phosphorus (P) has been reported to increase organic carbon (OC) and Nitrogen (N) stocks in soil with > 2mm aggregates (Hao et al., 2017). On the contrary, Su et al., (2006) reported carbon and nitrogen accumulation in a newly cultivated farm land to be influenced by a combination of organic and inorganic fertilizer application. Application of nitrogenous fertilizers to cereals has been reported to increase plant biomass (Fayisa et al., 2016). The biomass when returned to the soil plays a big role in adding SOC to the soil through the decomposition and mineralization processes the organic residues undergo (Wang et al., 2016).

2.4 Nutrient use efficiency of different finger millet varieties

2.4.1 Nitrogen, Phosphorous and Potassium status in Uganda

Considerable proportions of soils in Uganda are highly weathered with low nutrient reserves and therefore, have limited capacity to supply P, K, Ca, Mg, and S to meet the crop requirements for growth (Gupta, Gaur, & Kumar, 2014; Nkonya, 2004). Some soils in Uganda are acidic leading to high Aluminum toxicity, and this is a common phenomenon in Ferralsols and Acrisols soils. These soils constitute more than 70% of Uganda's soils on which most of the crop production is done (Nkonya, 2004). In the semi-arid regions of eastern Uganda, the common soil types are Plinthisols, light textured Ferralsols and vertical. These soils are low in P and N levels due to high level of weathering and nutrient mining leading to depletion rate of 41 Kg N, 4 Kg P and 31Kg K per hectare per annum (Bekunda et al., 2005). In summary it should therefore, be noted that the N and P levels in most soil types in Uganda is below the finger millet N and P requirement and there is need to address this if finger millet yield per hectare is to be increased.

2.4.2 Finger millet N and P requirements

Finger millet is known to be one of the most efficient crops in utilizing nitrogen in the soil hence indicating high nitrogen use efficiency (NUE) (Gupta et al., 2014). The mechanisms by which finger it achieves this has not been understood, however studies conducted by Kumar et al., (2016), suggests that finger millet has a unique mechanism through which the small amounts of nitrogen in the soil is maximally utilized by the crop. This mechanism is associated to the genetic influence of a wide range of finger millet varieties to nitrogen utilization within the crop (Gupta et al., 2014) . To maximize this benefit, this benefit there is need to increase the quantity of soil organic carbon (SOC) to and above the critical levels (Musinguzi et al., 2016b). On the other hand, studies on finger millet P requirements show different P rates. However, the rates range from 25 – 69kg per hectare depending on the agro-ecological zone and specifically soil types. For instance, (Anbessa Fayisa, (2016a) recommended 69kg P for sandy loam and sandy clay soil soils while Ebanyat, (2009) recommended 52 Kg P for degraded sandy loam soils in eastern Uganda. However these recommendations were based on sole cropping and not other cropping systems like finger millet legume integration and intercropping. In addition studies on the effect of a combination of inorganic & organic fertilizers and cropping systems on finger millet yields and soil organic carbon are limited.

2.4.3 The effect of nitrogen and phosphorus on finger millet growth and yield

Nitrogen is the main component of the protoplasm which is responsible for various metabolic processes such as photosynthesis (Razaq et al., 2017), cell division and elongation (Ali, 2010). These metabolic processes are responsible for accumulation of dry matter, plant height increase and tillering (Ayub et al., 2009). This therefore means that nitrogen plays a big role in influencing yield and yield components of finger millet. Areas with low nitrogen levels have been reported to have poor yield of finger millet and this is attributed to the critical roles of nitrogen in growth and development of crops (Opole et al., 2013).

On the other hand, Phosphorus (P) is a major plant nutrient responsible for initiation and growth of plant roots responsible for the uptake of nutrients and moisture from the soil (Ayub et al., 2009). Optimal P levels in the soil inhibit formation of excess roots leading to reduction in the loss of carbon from the rooting system and energy production efficiency (Wafula et al., 2016). This study did not investigate the effect of combination of different sources of P on sustaining P release but only looked at inorganic source of P which often does not sustain long term and continuous supply of P (Opiyo, 2004). Furthermore, increase in the spikes' length and number per head in wheat have been attributed to application of P fertilizer, however, information on the direct effect of P fertilizer application on finger millet is limited but additive and synergistic interactions between P and N has been reported. Soils with deficient P have low response and uptake of N (Opiyo, 2004) . This therefore, means that interactive effect of P and N plays an indirect and direct role in influencing finger millet yields respectively. Prasad (2014), observed that response of finger millet to nitrogen (N) application was poor or even negative in the soils deficient of P leading to low recovery efficiency. Therefore, there is need to identify and exploit the positive interactions key in increasing finger millet returns (yield, quality and nutrient use efficiency) from applied N and

P (Milkha and Sukhdev, 2005). This will be one of the most important interactions of practical significance.

2.4.4 Finger millet nutrient use efficiency

Majority of old finger millet varieties (released earlier than 2017) are known to be efficient crops in utilizing nitrogen in the soil hence indicating high nitrogen use efficiency (NUE) (Gupta et al., 2014). The mechanism by which finger millet achieves this has not been understood. A study by Kumar et al.(2016), suggests that finger millet has a unique mechanism through which the small amounts of nitrogen in the soil is maximally utilized by the crop as a nutrient. This mechanism is associated to the genetic influence of a wide range of finger millet varieties to nitrogen utilization within the crop (Gupta et al., 2014) . In addition NUE has been associated with the amount of initial SOC in the soil, if the SOC is >1.2% then the NUE of maize could be generally high compared to when the soil organic carbon (SOC) is < 1.2 % (Musinguzi et al., 2014). Studies comparing nutrient use efficiency of finger millet and carbon levels in the soil are scanty. There is therefore need to determining how Soil carbon levels influence nutrient use efficiency of finger millet varieties cultivated in the semi-arid region of eastern Uganda.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter discusses the materials of the study, experimental sites, experimental design, soil sampling and manure characterization and data collection procedures.

3.2 Materials of the study

3.2.1 Objective one

Global positioning system tool (GPS) for taking position (location) of a given parameter of study, soil auger for obtaining soil samples and paper/polythene bags for storing soil

3.2.2 Objective two, three and four

One finger-millet variety commonly grown by farmers and one Striga tolerant varieties (SEREMI 2, NARO MIL 3) and three most grown legumes (groundnuts-Serenut 11, cowpea-SECOW 2 and green gram NARO GRAM 1), Meter rule for measuring plant height and digital weighing scale for measuring grain yield (kg).

3.3 Study sites

3.3.1 Objective 1 (spatial distribution of soil organic carbon, Nitrogen, Phosphorus and Potassium levels in the finger millet growing areas of Eastern Uganda)

The study will be conducted in the districts of Amuria, Kumi and Serere. These three districts are the major finger millet producing Districts in Teso farming systems eastern Uganda. These districts also experience unreliable weather patterns, regular flooding, prolonged dry spells and low soil fertility (UBOS 2017).

3.3.2 Objective two, three and four

Field experiments will be conducted in Amuria, Kumi and Serere districts. These districts experience high incidences of unreliable weather patterns, low soil fertility and prolonged dry spells in the region. The experimental fields will be purposively selected and fields with ferralsol soil will be considered. Field trials will be planted for three consecutive seasons; second rains of 2020 (2020B), first rains of 2021 (2021A) and second rains of 2021 (2021B).

On-station experiment will be conducted at National Semi-arid Resources Research Institute (NaSARRI) located in the central part of eastern Uganda in Serere district.

National Semi-arid Resources Research Institute is located 28 Km south of Soroti town with a mean annual rainfall that ranges from 800 to 1200 mm and distributed in a bimodal pattern. The first rains are from March to June and the second rains from August to October or November. A dry spell stretches from November to March. Monthly temperature ranges from 15^0C to 36^0C, with an annual mean of 25^0C (Yost and Eswaran, 1990). The soils are predominantly sandy loam and sandy clay loam (Ebanyat, 2009). While on farm experiment will be conducted in the three districts of Amuria, Kumi and Serere.

3.4 Experimental design

The study will mainly employ quantitative and qualitative methods of inquiry with field experiments conducted in three districts in eastern Uganda where finger millet is highly grown with high rates of low soil fertility. For objective one, a soil survey will be conducted and for objective two three and four, a 3 by 2 by 2 factorial treatment structure laid down in a randomized complete block design (RCBD), replicated three times.

3.4.1 Objective one

The study will be a soil survey to be conducted in Serere Kumi and Amuria districts purposively selected from the nine districts in Teso. These three districts is where finger millet is majorly grown in Teso (UBOS, 2016). Three major finger millet growing sub counties will be purposively sampled from each district based on finger millet production information from UBOS. Three parishes from each selected sub county will also be randomly selected. In addition, two villages will be randomly selected from each selected parish. Finally, two finger millet growing households from each village will be randomly selected and soil sampled from a poor, moderate and fertile field per farmer house hold for determination of organic carbon. The poor, moderate and fertile fields will be selected based on Farmers' Field Experience model (Musinguzi el al., 2013), where fertility rating is based of farmers experiences on weed type growing in the field, slope position, years of cultivation and cropping history.

Sample size determination and sampling techniques

It is not possible for the researcher to study the whole target population due to time and resource constraints; therefore, a representative population will be selected (sample). This is in line with (Ghosh and Rao, 1994) who stated that the sample size is of great importance in the study of the population.

The Sample size will be determined using the equation as described by Yamane (1967)

$$n = \frac{N}{1 + N(e)^2}$$

Where n is sample population; N is the total population and e is the degree of precision (confidence level)

According to UBOS (2018), there 86911 hectares of cultivated land in the 36 districts of eastern Uganda. This translates to 2414 hectares of cultivated land per district on average. Therefore, in the three districts purposively sampled, the average cultivated land size will be three districts (3) times 2414 hectares. Giving a total of 7242 hectares, therefore, $n = \frac{N}{1 + N(e)^2} =$

$$\frac{7242}{1 + 7242\,(0.05)^2} = 379$$

The total number of field sampled will be 379 (Two fields per category per selected village, making a total 126 fields per field category). Geographical Positioning System coordinates will be recorded for each sampling point. Diagonal sampling technique will be used and from each field 21 sub samples will be taken. A composite sample will be obtained from each five sub samples per field.

3.4.2 Objective two, three and four

3.4.2.1 On-station experiment

The study will be conducted in Randomized Complete Block Design (RCBD) with a 3x2x2 factorial treatment structure. The three factors are three legumes (groundnuts, green gram and cowpeas), two finger millet varieties (SEREMI 2, and NARO MIL3) and two cropping systems (Intercropping and Crop rotation). Finger millet will be intercropped with legumes in a 1 by 1 arrangement (one row of legume followed by one row finger millet) and also rotated with the three legumes (Groundnuts, green gram and cowpeas). There will be blanket application of nitrogen and phosphorus fertilizers at a rate of 18 and 17 kg N and P per hectare respectively (fertilizer micro dose, Ekwangu et al., 2020). Phosphorus will be applied at planting along the furrows covered and finger millet seeds planted on top of the covered fertilizer along the furrows and also covered. While N will be applied between rows as side dress at vegetative growth stage (45 days after sowing) and the P and N sources will be Di-ammonium phosphate (DAP) and Urea respectively. Application of urea will be by drilling a hole in between the two rows of plants applying fertilizer and covering it. The study will therefore, be a 3x2x2 factorial experiment laid down in a randomized complete block design (RCBD) and replicated three times.

3.4.2.2 On-farm experiment

Two farmer households will be purposively selected from the sampled villages from each of the three districts (Amuria, Kumi and Serere) to host the experiment. The selection process of the farmers is well elaborated in objective one. The farmers are selected purposively to enable the researcher select fields with ferralsol soils for the establishment of the experiment. A total of six farmers will be selected to host the experiment.

The study will also be a 3x2x2 factorial experiment. The three factors are three legumes (groundnuts, green gram and cowpeas), two finger millet varieties (SEREMI 2, and NARO MIL3) and two cropping systems (Intercropping and Crop rotation). Finger millet will be intercropped with legumes in a 1 by 1 arrangement (one row of legume followed by one row finger millet), also rotated with the three legumes (Groundnuts, green gram and cowpeas) and laid down in a randomized complete block design (RCBD), in a split-split plot treatment structure replicated three times.

3.4.3 Determination of Nutrient Composition of Different Flour Obtained from Three Finger-millet Varieties

Moisture, Crude protein, Crude fat, Ash content, Carbohydrate content and Energy content

Moisture content of flours will be determined by oven drying method (AOAC International, 1995) Method 934.1; Crude protein will be determined by the micro Kjeldahl method (AOAC International, 1995) Method 992.23; Crude fat content will be determined using the Soxhlet extraction method (AOAC International, 1995) Method 920.29; Ash content will be determined using (AOAC International, 1995) Method 923.03;Carbohydrate content will be determined by subtracting the sum of weights of protein, lipid, ash, and moisture from the total wet matter basis (FAO, 2003); Energy content will be determined by multiplying the mean values of crude protein, crude fat and total carbohydrate by Atwater factors of 16.736 kJ, 37.656 kJ and 16.736 kJ respectively. Results will be expressed as kilojoules per 100 g sample (FAO, 2003).

Phosphorus, iron and Zinc

The amount of iron and zinc in the flour of different finger millet varieties will be determined using Atomic Absorption Spectrometer as described by Association of Official Analytical Chemist (AOAC), 1995 method 999.11, while Phosphorus will be determined using AOAC 1995 method 995.11 (Cunniff, 1996).

3.4.4 Treatment Structure for objective two, three and four

Table 1: Treatment structure for Rep 1

SEREMI II		NARO MILL 3	
Intercrop	Rotation	Intercrop	Rotation
5	8	4	10
3	9	5	8
4	10	7	9
6	8	2	10
2	10	1	9
1	9	3	8
7	7	6	7

The above structure will be replicated three times

Note: 1= Intercrop of millet with cowpea; 2= Intercrop of millet with groundnuts; 3= Intercrop of millet with green gram; 4= Sole crop of Green gram; 5= Sole crop of cowpea, 6=Sole crop of groundnuts; 7=Sole crop of finger millet; 8= Rotation of finger millet with groundnuts; 9= Rotation of finger millet with green gram; 10= Rotation of finger millet with cowpea.

3.5 Data collection Procedures and Instruments

3.5.1 Data collection procedures

3.5.2 Objective one

Five samples of soil will be taken from each sampled (poor, moderate and good field) field at a depth of 0-30 cm and composite sample obtained by quarter sampling. Geographical Positioning System coordinate recorded per field. The composite soil sample obtained from each field will be taken for oven drying at 65°C for 48 hours to obtain the average moisture content. Air-dried composite samples will be ground and sieved through 2 mm sieve and later subjected to physico-chemical analysis at Makerere soil laboratory using spectral and standard wet chemistry analysis procedures (Shepherd and Walsh, 2002). Organic N will be determined by the Kjeldahl procedure (Bremner and Mulvaney, 1982) and Soil Organic carbon (SOC) by using dichromate oxidation (Walkley and Black, 1934). Available P will be determined using Bray 1 method. The above soil analysis methods will be applied as described by Okalebo et al. (2002). Also data will be recorded on cropping history for the past five years and present vegetation cover type.

3.5.3 Objective two three and four

Prior to experimentation and after harvesting of the experimental crops, soil samples will be taken from three spots of each experimental plot (3.3 m by 3.3 m) randomly selected and soil sampled at a depth of 0-30 cm. A composite sample will be obtained from the sampled soil by quarter sampling for determination of SOC, N and P as described by Okalebo et al., (2002). In addition data will be collected on monthly rainfall(mm) amounts, monthly temperature (^{O}C), soil type, stand count, days to 50% flowering, pod numbers, pod length, pod damage by pests, disease incidence, plant height, finger number, 1000 seed weight, land area under intercrop, land area under sole crop and grain yield.

The annual rate of SOC sequestration (Se t ha^{-1}) in each treatment will be determined as the difference between the contents of SOC in the final season and the initial season (Kong et al. 2005; Zhang et al. 2012). Positive and negative changes in SOC values will be interpreted as gains and losses of SOC, respectively, in each treatment.

$$Se = [(SOC_{final} \times SBD_{final}) - (SOC_{initial} \times SBD_{initial}) \times d/n]$$

Where 'final' and 'initial' are the contents in the final season and the initial season for each experiment, respectively; n is the duration of the experiment in years; SBD (g cm^{-3}) is the soil bulk density measured at the initial and final years of experiment; and d is the depth of the soil horizon. A value of 20 cm will be used for d in the calculation.

3.5.3.1 Rainfall (mm)

Average monthly rainfall at the station (NaSARRI) will be recorded. The rainfall is important in determining the changes in SOC in the soil as a result of decomposition.

3.5.3.2 Daily Temperature (^{0}C)

Daily temperature recordings will be taken using a temperature meter installed at NaSARRI and later average monthly temperature computed. The temperature is important in determining SOC added to the soil. This will be an automated temperature meter recording temperature at half hour basis and generating mean daily temperature

3.5.3.3 Stand count

Stand count will be assessed ten days after sowing (DAS); in *situ* observation per plot is conducted and percentage germination score per treatment is determined.

3.5.3.4 Tiller number no.

Tillering will be assessed at 50 days after sowing (DAS); in *situ* sampling will be done by randomly selecting ten plants from the six middle rows of each plot leaving out two border rows from each side of the plot. The number of tillers per sampled plants will be counted and recorded (Rebetzkeaf et al., 2012).

3.5.3.5 Growth vigor

Growth vigor will be determined at 60 DAS. Ten (10) plants will be randomly selected from the six middle rows of each plot; the growth vigor of each plant sampled will be recorded by scoring using a scale of 0-4 as described by (Hatier et al., 2014). Where O= Plant is dead/ did not germinate= poor; 1= plant has no tiller= low; 2= Plant has less than two tillers= Moderate; 3 = Plant has 2-3 tillers= vigorous; 4= plant has above three tillers= Very vigorous. Average value for plant vigor per plot will be computed and used for data analysis? Determined and recorded for further analysis.

3.5.3.6 Days to 50% flowering

Days to 50% flowering will be determined at the initiation of flowing stage. One by one meter (1x1 m) condrant was randomly thrown at each plot of the experiment and number of plants that carry at least one flower will be counted. If they plants are less than 50% the process is repeated each coming day until the 50% plants with at least one flower is obtained and that date will be recorded. Days to 50% flowering will be recorded for further analysis.

3.5.3.7 Plant height (cm)

Plant height for finger millet will be measured at harvesting (75 days after sowing). Ten plants will be randomly selected from the four middle rows out of 10 rows per plot. Plant height will be taken from the stem base up to the finger millet head by use of a meter rule. Average plant height per treatment will then be recorded for further analysis.

3.5.3.8 Pod number and number of seeds per pod

Ten plants will be randomly selected from the four middle rows of each plot/ treatment leaving out three border rows from each side. Pod number per plant will be counted. Average pod number and number of seeds per pod per treatment will also be recorded. The recording is done at pod filling stage and at physiological maturity.

3.5.3.9 Pod length (cm)

Pod length will be recorded at physiological maturity when the pods harden and become firm. Ten plants will be randomly selected from the four middle rows of each plot leaving out three border rows from each side. Pod length will be taken from the point of attachment of the pod to the stem base to the tip of the pod. Average pod length per treatment will also be recorded.

3.5.3.10 Pod damage (%)

This will be observed and recorded at pod filling and physiological maturity stages. Ten plants will be randomly selected from the four middle rows of each plot leaving out three border rows from each side. Observations are made on them to assess for any pest damage on the pods for each sampled plant. The average number of pods damaged for each treatment will be determined.

3.5.3.11 Leaf number

Ten plants will be randomly selected from the four middle rows of each plot leaving out three border rows from each side. Leaves from each sampled plant will be counted and the average leave number for each treatment will be determined.

3.5.3.12 Finger number

Ten plants will be randomly selected from the four middle rows of each plot leaving out three border rows from each side. Fingers from each sampled plant will be counted and the average leave number per plant for each treatment will be determined.

3.5.3.13 Disease incidence (%)

This will be observed and recorded at vegetative, pod filling and physiological maturity stages. Ten plants will be randomly selected from the four middle rows of each plot leaving out three border rows from each side. Observations are made on them to assess for any disease attack. Disease severity will be scored using a scale as described by Saari & Prescott (1975).

3.5.3.14 Soil organic carbon and nutrients

From each treatment/plot, soil cores will be collected for SOC and nutrient determination. Five soil sub-samples will be taken from each experimental site at 0-30 cm depth using a soil auger. It will be thoroughly mixed and by quarter sampling composite samples will be obtained. Simple random soil sampling with diagonal sampling technique will be used. Composite samples will be taken for oven drying at 65°C for 48 hours to obtain the average moisture content. Air-dried composite soil (<2 mm) samples will be subjected to physico-chemical analysis at Makerere soil laboratory.

3.5.3.15 Grain yield (kg/ha)

Harvesting of finger millet heads will be done manually by hand cutting using local knives at 75 days after sowing. Six middle rows per plot will be harvested leaving two border rows from each side. The area where the six rows of finger millet will be harvested is measured and recorded for determination of grain yield per unit area. The harvested finger millet heads are sun dried to a proximately 12 % moisture content and there after threshed, hurled and grain weight recorded in kilograms per unit area of the plot from which it will be harvested.

3.5.16 Agronomic efficiency

Data on N and P in the plant tissue will also be collected by destructive sampling where one corner of each plot will be randomly sampled by placing 1 mx 1 m quadrant and 10 % of the plants within the quadrant sample at physiological maturity. The plant samples obtained from each field will be taken for oven drying at 65°C for 48 hours. Air-dried samples will be ground and sieved through 2 mm sieve and later subjected to physico-chemical analysis at Makerere soil and plant analytical laboratory using spectral and standard wet chemistry analysis procedures (Shepherd and Walsh, 2002). Organic N will be determined by the Kjeldahl procedure (Bremner and Mulvaney, 1982) and available P using Bray 1 method.

Therefore, agronomic efficiency of nutrients supplied to degraded fields by legume integration options will be computed from the following equations:

$AE = (GYT - GYC) / RN$………………………………………………………… (Equation 1)

Where:

AE is agronomic efficiency (kg kg^{-1}); GYT = grain yield of treatment (kg ha^{-1}) and GYC is grain yield of control treatment (kg ha^{-1}) and RN is the quantity of N supplied by legume integration option (kg ha^{-1}) as adapted from (Witt et al., 1999). The quantity of N supplied by legume is determined by subtracting N from the soil at the onset of the experimentation from total available N (N in the plant tissue + N at harvesting).

3.5.17 Determination of Moisture content, Nitrogen, Fat, Carbohydrates, Phosphorus Iron and Zinc in Finger millet flour (procedure)

Moisture Content

Moisture content of flours obtained from different finger millet varieties will be determined by oven drying method (AOAC International, 1995) Method 934.1. About 2 g of the samples will be oven dried at 105^0 C for 3.5 hours then cooled in a desiccator and weighed. The moisture content of the sample will be expressed as a percentage of the initial weight of the sample using the following formula:

$$\%\ \text{Moisture content} = \frac{\text{Weight of wet sampe} - \text{Weight of dry sample}}{\text{Weight of wet sample}} \times 100$$

Crude Protein

Crude protein will be determined by the micro Kjeldahl method (AOAC International, 1995) Method 992.23. A sample of 0.3 g of each of the flours will digested in a heating block (Model DK series 20 digester unit, 115 V / 50 - 60 Hz, manufactured by VELP Scientifica Srl, Milano Italy) at 370-400^0 C for about 60-90 minutes or until the contents became clear. In 0.2 ml of the digested sample, 5ml of a previously prepared N1 mixture will be added and allowed to stand for about 15 minutes before 5 ml of N2 is added. The mixture will be allowed to stand for one hour during which it develops a blue color whose absorbance was read off a spectrophotometer (Spectronic 21D AKIU®, Milton Roy, Germany) at 650 nm. The %N in the sample will be calculated using the formula:

$$\% \text{ Nitrogen} = \frac{(a - b) \times v \times 100}{1000 \times w \times al \times 1000}$$

Where

a = Concentration of N in the solution

b = Concentration of N in the blank

v = Total volume at the end of analysis procedure

w = Weight of the dried sample and

al = Aliquot of the solution taken.

The crude protein will then be determined by multiplying the % nitrogen by a factor (6.25).

Crude Fat

Crude fat content will be determined using the Soxhlet extraction method (AOAC International, 1995) Method 920.29. Samples of 2 g will be weighed into a thimble and oil extracted using petroleum ether (40-60^{0}C) for 8 hrs. The extract will be oven-dried at 105 ^{0}C for about 30 minutes, cooled in desiccators, and weighed. The oil content will be as determined using the following formula:

$$\% \text{ Crude fat} = \frac{\text{Weight of fat}}{\text{Weight of sample}} \times 100$$

Ash content

Ash content will be determined using (AOAC International, 1995) Method 923.03. Samples of 2 g will be burnt at 500 – 6000C for 6 hours in a muffle furnace (Carbolite 530 2 AU, Bamford, Sheffield, England) to constant weight. The samples will be cooled in desiccators and weighed. Ash content will be determined using the following formula:

$$\% \text{ Ash} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100$$

Carbohydrate content

Carbohydrate content will be determined by subtracting the sum of weights of protein, lipid, ash, and moisture from the total wet matter basis (FAO, 2003).

$$\% \text{ Carbohydra tes} = 100 - (\% \text{ fat} + \% \text{ moisture} + \% \text{ ash} + \% \text{ proteins})$$

Energy content

Energy content will be determined by multiplying the mean values of crude protein, crude fat and total carbohydrate by Atwater factors of 16.736 kJ, 37.656 kJ and 16.736 kJ respectively. Results will be expressed as kilojoules per 100 g sample (FAO, 2003).

Phosphorus, iron and Zinc

The amount of iron and zinc in the flour of different finger millet varieties will be determined using Atomic Absorption Spectrometer as described by Association of Official Analytical Chemist (AOAC), 1995 method 999.11, while Phosphorus will be determined using AOAC 1995 method 995.11 (Cunniff, 1996).

3.6. Data collection Instruments

3.6.1 Data sheet

A data sheet is a research instrument that contains variables (data) to be measured at different cycles of experimentation.

3.6.2 Rain gauge

A rain gauge is an instrument for measuring the amount of precipitation

3.6.3 Temperature meter

This is equipment for measuring temperature

3.6.4 Global Positioning system receiver (GPS receiver)

GPS receiver is a tool used to capture x and y coordinates showing location of a given point, line or polygon. A GPS receiver works when there is a satellite and master station (ground station).

3.7 Data Quality Control Methods

3.7.1Validity

3.7.1.1 Data Sheet

The researcher will engage the supervisor to verify if the measurements to the conducted in the field are in line with the objectives of the study.

3.7.1.2 Global Positioning System (GPS) Receiver

The researcher will engage the supervisor to determine whether the GPS receiver to be used for capturing data(x and y) coordinates is the right one to be used.

3.7.1.3 Rain gauge

The rain gauge will be verified by an expert in the metrology department at National Semi Arid Resources Research Institute (NASARRI) where the studies will be conducted

3.7.1.4 Temperature meter

The instrument will be procured with a protocol that can easily be followed; the supervisor will also verify the instrument.

3.7.2 Reliability

3.7.2.1 Data Sheet

The data sheet will be pretested to determine whether it could be used to collect the required data. Five plants in a plot will be randomly selected and measurement was conducted to gage the understanding of the research assistants on data collection.

3.7.2.2 Global Positioning System (GPS) Receiver

The researcher will pre-test the GPS receiver by collecting x and y coordinates of ten points and polygons and maps generated using geographical information system (GIS) before going to the field. Also the research assistants will be trained on how to collect data using GPS before going to the field.

3.7.2.3 Rain gauge

The rain gauge will pre tested by an expert in the metrology department of National Semi Arid Resources Research Institute (NaSARRI) where the studies will be conducted in the presence of the researcher and research assistants. Also installation of these rain gauges will be done by the expert.

3.7.2.4 Temperature meter

Also the temperature meter will be pre tested by the researcher and research assistants and installation will be done with the help of the expert at NaSARRI.

3.8 Data Management and Processing

Data will be entered into Microsoft excel spread sheet, cleaned and sorted using application tool in the Microsoft excel sheet called the pivot tables. After sorting and cleaning, data will be stored in Microsoft excel spread sheet folders awaiting analysis

3.9 Data Analysis

3.9.1 Objective one

Soil data will be captured in GIS software (ARC GIS) from excel and SOC, NPK and pH distribution map generated using GIS software. Descriptive statistical analysis will be conducted to determine the means of N, P, K, and pH, SOC, Mg, Fe and CEC of the sampled soil in the three districts of Amuria, Kumi and Serere. Analysis of variance (ANOVA) will be conducted on N, P, K, and pH, SOC, Mg, Fe and CEC using GenStat 14th Edition statistical software. The means will be separated by LSD at 5% level of significance

3.9.2 Objective two

Soil data (N, P, K, and pH, SOC, Mg, Fe and CEC) entered in Microsoft Excel spreadsheet and will be exported to Minitab version 17. Linear correlation between Groundnuts finger millet inter crop and SOC, cowpea finger millet inter crop and SOC, green gram finger millet inter crop and SOC, green gram finger millet rotation and SOC, cowpea finger millet rotation and SOC, groundnuts finger millet rotation and SOC; SOC and pH, SOC and N SOC and P, SOC and K, SOC and Mg, SOC and Fe and SOC and CEC will be conducted to determine the type (Positive, negative or no correlation) and strength of correlation. Multivariate regression will be used to build a model which best predicts SOC as influenced by legume integration options using backward selection, stepwise selection and forward selection. The criteria to select the best model that explains the major variables causing variation in SOC levels and growth parameters will be based on R, R^2 CP and variance inflation factor (VIF).

3.9.3 Objective three

Crop growth data (Growth vigor, plant height, tiller number, Days to 50% flowering and maturity time) , soil data (N, P, K, and pH, SOC, Mg, Fe and CEC) and grain yield entered in Microsoft Excel spreadsheet will be exported to Minitab version 17. Linear correlation between Groundnuts finger millet inter crop and vigor, plant height, days to 50% flowering, maturity time, grain yield and agronomic efficiency; cowpea finger millet inter crop and vigor, plant height, days to 50% flowering, maturity time, grain yield and agronomic efficiency; Green gram finger millet inter crop and vigor, plant height, days to 50% flowering, maturity time, grain yield and agronomic efficiency; Green gram finger millet rotation and vigor, plant height, days to 50% flowering, maturity time, grain yield; Cowpea finger millet rotation and vigor, plant height, days to 50% flowering, maturity time, grain yield; groundnuts finger millet rotation and vigor, plant height, days to 50% flowering, maturity time, grain yield; SOC and crop vigor; SOC and plant height; SOC and Days to 50% flowering; SOC and maturity; SOC and finger millet grain yield will be conducted to determine the type (Positive, negative or no correlation) and strength of correlation. Multivariate regression will be used to build a model which best predicts finger millet yield and finger millet nutrient use efficiency as influenced by legume integration options using backward selection, stepwise selection and forward selection. The criteria to select the best model that explains the major variables causing variation in finger millet grain yield and agronomic nutrient efficiency will still be based on R, R^2 CP and variance inflation factor (VIF).

3.9.4 Objective four (Proximate analyses of finger millet flour obtained from three varieties used in the experiment)

Data from proximate analysis of finger millet flour will be entered into excel spreadsheet and later exported to Genstat 14th edition. Descriptive analysis will conducted to generate means for the variables (moisture content, crude protein, crude fat, ash content, carbohydrate and energy). Two-way ANOVA will be conducted to determine the differences between the means of the variables. The mean of each variable will be separated using Fishers least significant difference (LSD) test at 5%.

3.10 Presentation of results

The results in all the four objectives will be presented in graphs, Geographical Information System (GIS) maps, scatter plots and tables.

3.11 Ethical Considerations

The research will seek approval of the study from the Uganda Martyrs University research and ethics committee and also from Uganda council of science and technology.

The researcher will also employ the principle of voluntary participation where the farmer household is given the opportunity to voluntarily provide land for experiments and also conduct field management with the researcher. The researcher will also employ the principle of informed consent where consent is sought from farmer household to take part in the study by explaining comprehensively what the study is about.

Confidentiality; the researcher will not release any information about the hosting farmer without seeking permission from him.

When reporting the research findings, the name of the farmer will not be declared, the farmers name will be replaced with codes for purpose of their security.

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APPENDICES

Appendix One: Work plan

Activity	Oct 2018 - July 2019	Aug – Dec 2019	Jan – Mar 2020	Apr – July 2020	Aug – Dec 2020	Jan – Mar 2021	Apr	May	June - July	Aug- Sep.	Nov
Attend lectures	x										
Proposal development	x										
Proposal defense											
Setting up of first set of experiments and data collection	x										
Setting up of second set of experiments and data collection		x									
Setting up of third set of experiments and data collection				x							
Data analysis					x						
Thesis writing					x	x					
Thesis review with supervisors							x	x			
Activities continued	Oct	Aug –	Jan –	Apr –	Aug –	Jan –	Apr	May	June -	Aug-	Nov

Appendix Two: Budget

Season one					
Activity Description	**Unit**	**Unit cost**	**quantity**	**Total cost**	**Notes**
First ploughing	acre	100,000	3	300,000	1.5 per experiment
Second ploughing	acre	100,000	3	300,000	
Hand leveling	acre	50,000	3	150,000	
Planting	acre	110,000	3	330,000	
Weeding	acre	120,000	3	360,000	
Harvesting	acre	100,000	3	300,000	
Threshing, bagging and weighing	acre	200,000	3	600,000	
Traveling and accommodation during data collection	night	200,000	16	3,200,000	Four nights per trip and four trips per season
Allowance for two research assistants	month	100,000	4* 2 persons	800,000	
Sample analysis in Nairobi				18,000,000	
Sub Total				**24,340,000**	

Season two					
Activity Description	**Unit**	**Unit cost**	**quantity**	**Total cost**	**Notes**
First ploughing	acre	100,000	3	300,000	1.5 per experiment
Second ploughing	acre	100,000	3	300,000	
Hand leveling	acre	50,000	3	150,000	
Planting	acre	110,000	3	330,000	
Weeding	acre	120,000	3	360,000	
Harvesting	acre	100,000	3	300,000	
Threshing, bagging and weighing	acre	200,000	3	600,000	
Traveling and accommodation during data collection	night	200,000	16	3,200,000	Four nights per trip and four trips per season
Allowance for two research assistants	month	100,000	4* 2 persons	800,000	
Sample analysis in Nairobi				18,000,000	
Sub Total				**24,340,000**	
Season three					

Activity Description	Unit	Unit cost	quantity	Total cost	Notes
First ploughing	acre	100,000	3	300,000	*1.5 per experiment*
Second ploughing	acre	100,000	3	300,000	
Hand leveling	acre	50,000	3	150,000	
Planting	acre	110,000	3	330,000	
Weeding	acre	120,000	3	360,000	
Harvesting	acre	100,000	3	300,000	
Threshing, bagging and weighing	acre	200,000	3	600,000	
Traveling and accommodation during data collection	night	200,000	16	3,200,000	Four nights per trip and four trips per season
Allowance for two research assistants	month	100,000	4* 2 persons	800,000	
Sample analysis in Nairobi				18,000,000	
Sub Total				**24,340,000**	
Grand Total				**73,020,000/=**	