UNIVERSITY OF CAPE COAST

MAPPING SOIL QUALITY AT BAIFIKROM SMALL-SCALE IRRIGATION SCHEME IN THE CENTRAL REGION OF GHANA

VINCENT YAW, OPPONG SARKODIE

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BY

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Thesis submitted to the Soil Science Department of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Land Use and Environmental Science

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this University or elsewhere.

Candidate's Signature:.. Date:..........................

Name: Vincent Yaw, Oppong Sarkodie.

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:................................... Date:........................

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ABSTRACT

Continuous irrigation has been observed to degrade soil quality, through leaching of soluble and colloidal materials, development of saline conditions and breakdown of soil structure. Evaluating the quality of soils give information on the current soil condition as has resulted from previous soil management practices such as continuous application of fertilizer, and direct future management practices to sustain the soil ecology. Soil physical parameters (aggregate stability); Chemical parameters (pH, electrical conductivity, total nitrogen, extractable P, exchangeable K) and Biological parameters (organic carbon and microbial respiration) were selected to represent three soil indicators: soil degradation, nutrient cycling and crop productivity, respectively. These indicators were set to estimate soil quality. A raster interpolation for all the parameters and a reclassification of these raster maps was constructed in ArcGIS using all parameter maps to produce soil quality index (SQI). The highest SQI class ranged from 4.9 to 15.9 and the lowest class ranged from 0 to 1.5. Of the 11 plots, five had medium SQI while four had low SQI. Medium soil quality supports vegetable production; however, there is the need to improve pH and organic carbon content of the soils.

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DEDICATION

To my sisters Doreen Cobbinah and Erica Oppong Pima

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA: Analysis of Variance

AS: Aggregate Stability

DR: Dispersion Ratio

EC: Electrical Conductivity

EO: Expert Opinion

FAO: Food and Agriculture Organisation

GIA: Ghana Irrigation Authority

GIDA: Ghana Irrigation Development Authority

GIS: Geological Information System

GPS: Global Positioning System

JHS: Junior High School

LSD: Least Significant Difference

MDS: Minimum Data Set

MSA: Measure of Sampling Adequacy

M-SQR: Muencheberg Soil Quality Rating

OC: Organic Carbon

PCA: Principal Component Analysis

RR: Respiration Rate

SEM: Standard Error Mean

SL: Significance Level

SPSS: Statistical Package for Social Sciences

SQ: Soil Quality

SQI: Soil Quality Index

CHAPTER ONE

INTRODUCTION

Soil management practices such as intensive tillage, excessive nutrient, and pesticide applications accounts for the moderate to severe degradation of soils around the world (Franzlubbers & Haney, 2006). Soil quality as a concept encompasses the integrated relations and functions for biological, chemical and physical soil properties and processes important for sustaining agricultural systems. An assessment of the quality of existing soil resources provides opportunity to monitor the sustainability of agricultural systems, and this is important for efficient planning (Franzlubbers & Haney, 2006; Sağlam, Dengiz, & Saygın, 2015). Information on soil quality assessment guides stakeholders to better approach soil management (Dutta, Sharma, Sharma, Sharma, & Sankhyan, 2015).

Background to the Study

The soil is the most basic component of human life and is important in the production of the vast majority of food, animal feed, fibre, and bioenergy. Problems relating to soil fertility and productivity necessitate that much attention be given to soil quality assessment (Karlen, Andrews, & Doran, 2001). Soil quality assessment provides information on the state and conditions of soils. This information provided by the assessment of soil quality is important for shaping land use policy decisions. Assessment of soil quality is specific to land use function (Senthilkumar, Basso, Kravchenko, & Robertson, 2009). Dick, Lawrence, & Islam, (2015) noted that soil nutrition is sustainable when the biological, chemical and physical properties of soil are in ecological equilibrium, and this is possible within the context of soil quality.

Severe drought stress and high temperatures precipitate low crop yields in the tropics. This drought stress and high temperature impacts are controlled by the supply of moisture to crops via irrigation. When irrigation is applied at early growth stages of the crop, where moisture is required for physiological development, there is a potential increase of 23% to 25% in yields, however, the timing and method of irrigation are important for irrigation efficiency (Lal, 2009). Continuous irrigation has been observed to degrade soil quality, through leaching of soluble and colloidal materials, development of saline conditions and breakdown of soil structure (Adejumobi, Ojediran, & Olabiyi, 2014; Lal, 2009).

The Baifikrom small scale irrigation scheme has supported vegetable production since 2004 (GIDA, 2018). Evaluating the quality of soils of the site would give information on the current soil condition as has resulted from previous soil management practices such as continuous application of fertilizer, and direct future management practices to sustain the soil ecology. Adeyolanu et al. (2016) defined soil quality as the capacity of soil to function sustainably without degrading the environment, animal and human health. The evaluation of soils in Baifikrom encompassed management and inherent parameters that influence the quality of soils.

Statement of the Problem

Due to rising population increase, agricultural lands are continuously cropped because of the scarcity of land in Ghana (Okae-Anti & Ogoe, 2006), however, there is little information available concerning the effect of continuous irrigation and prolonged vegetable cultivation on the quality of soils of the Baifikrom soils. To ensure that management of soils within the Baifikrom irrigation schemes promotes sustainable production of vegetables, within balanced soil ecology, it is important to assess changes in the quality of the soil to inform remedial measures.

Indexing is a method of simplifying evaluation as a process; it makes evaluation easier to be conducted for monitoring purposes. Evaluating soil quality with the indexing method enhances monitoring of soil quality (Vasiliniucing, 2014). Extensive research have been conducted on the quality of soils in the temperate regions, however, limited soil quality research have been done on tropical soils (Chaudhury, Mandal, Sharma, Ghosh, & Mandal, 2005), this makes the evaluation of soil quality in the tropics relevant for the management of tropical soils. Again, monitoring has been conducted to compare the impacts of different land use types and their management practices on soil quality, mostly using the minimum data set approach (Adeyolanu, Ogunkunle, & Tejada Moral, 2016; Mukherjee & Lal, 2014; Rezaei, Gilkes, & Andrews, 2006; Sağlam et al., 2015; Salvati & Colantoni, 2013; Senthilkumar et al., 2009; Singh, Bordoloi, Kumar, Hazarika, & Parmar, 2014; Vasiliniucing, 2014), however, irrigated soil quality monitoring remains limited, especially in Ghana.

Objective of Study

The general objective of this study was to estimate soil quality index for soils of Baifikrom Small Scale Irrigation Scheme.

Specific objectives

Specifically, the objectives of this study were to:

1. Estimate quality index for soils of the Baifikrom irrigation scheme.
2. Map the spatial variability of soil quality in the irrigation scheme.

Significance of the Study

Soil Quality Index of long-term land use and management is relevant for sustainable soil development. This information will be useful for the development of mechanisms to manage the soil/crop/irrigation system. Soil quality index enables planners and decision makers to take land use decisions and craft policy (Tesfahunegn, 2014). The outcomes of this study will provide information on the quality of Baifikrom irrigation scheme soils. This study seeks to reduce the dearth of knowledge of soil quality in the area of irrigation for sustainable food, feed, and fibre production.

Organisation of the Study

The work is presented in five chapters. Chapter One, the Introduction, presents the background to the study, problem statement, objective and significance of the study. In the second chapter, a review of relevant literature was presented. Chapter Three presents the methods used for the research. In

Chapter Four, results obtained from the research and its discussion was presented. Chapter Five, in the last chapter, summarized the study, indicating the conclusions and recommendations drawn from the study.

CHAPTER TWO

LITERATURE REVIEW

Overview

Increasing world population growth has increased the demand for food, feed, and fibre. This has imposed intense pressure on available land resources (Diyer, Namrani, & Elkadiri, 2013). According to Diyer et al. , economies of many countries including Ghana, who depend mostly on their land resources have suffered due to degradation and poor land management practices. To ensure that soil resources continuously support human activities such as agriculture and remain sustainable, there is the need to keep other functions of soil in ecological balance (Diyer et al., 2013).

The world over, especially in areas where agriculture is dependent on rainfall, irrigation has and will continue to play an important role in meeting the increasing demands for food, feed, and fibre. The FAO has noted that, depending on whether in the temperate or tropical region, and the type of crop, crops produced under irrigation gives yields that are 2.3 times higher than yields of crops that depend solely on rainfall (Dowgert, 2010). Dowgert further observed that irrigation extenuates the risk associated with rainfall in agricultural production, thus, farmers are able to consistently produce more food, feed and fibre and on less land. This is important for adequately meeting the growing food, feed and fibre needs of the increasing world population as there is an unfavourable competition for different land use against agriculture (Dowgert, 2010). Irrigation practices, however, is observed to have negatively impacted 20% of irrigated soils by different levels of developed saline conditions (Adejumobi et al., 2014). Sprinkle irrigation amongst the methods of irrigation is noted to alleviate this problem of saline conditions in soils. This is achieved by the downward washing of potential accumulated salt away from the root region where saline conditions may occur (Brady, 1996a).

According to Murray & Grant (2007), irrigation allows amounts of water that may be higher than amounts that would go through soil from rainfall conditions to pass through the soil profile. This higher amount of water has the potential for leaching soluble and colloidal materials downward within the soil, break down the soil structure and raise the local water table. These potential degradation caused by the higher amounts of water running through the soil are dependent on the intensity of irrigation (Murray & Grant, 2007). Irrigation, as is known to increase agronomic production, degrades the quality of soil and pollute surface and ground water sources when the efficiency of water and fertilisers in such systems are low (Lal, 2009). The improvement of soil quality requires the restoration of degraded soils, and this could be achieved by physical, chemical and biological improvement of soil such as enhancement of the soil's structure, balancing and increasing its nutrient reserves and taking steps to improve the activities and diversity of soil organisms respectively (Lal, 2009).

Agricultural modernisation such as utilising irrigation potential, new improved technologies and agronomic practices among others are in response to increasing production of food to satisfy the increasing population (Namara et al., 2010). However, the type of irrigation method may cause negative impacts such as saline soil conditions, waterlogging and reduction in irrigation water quality (Dougherty, Hall, & Wallingford, 1995). The authors further noted that these impacts may be cumulative after several years of irrigation system operation.

The soils of Baifikrom Small-Scale Irrigation scheme have been cultivated since the inception of the scheme in 2004 (GIDA, 2018), with no monitoring or major intervention at sustaining the quality of its soils. With the fragile nature of tropical soils, it is prudent to assess their quality periodically (Adeyolanu et al., 2016). There is a direct relationship between agricultural production and the quality of soils within which the production is done (Torbert, Krueger, & Kurtener, 2008), For this reason, Torbert et. al. noted that degradation or improvement of soil has a direct influence on agricultural productivity and therefore, prudent to maintain irrigation soil quality for sustainable food, feed, and fibre production as well as protect irrigation schemes.

To conserve soils in Ghana, Namara et al. (2010) observed that, a Land Improvement and Preservation Unit was established within the then Department of Agriculture in the early 1950s. This Land Improvement and Preservation Unit has evolved into the Ghana Irrigation Development Authority (GIDA), with a shift in its mandate to survey potential sites for irrigation development and developing irrigation facilities, managing and maintaining existing schemes and disseminating irrigation farming technologies among farmers. According to Namara et al. (2010), the focus of Ghana's irrigated agriculture is the production of rice and vegetables. However, challenges within the rice industry have shifted farmer's attention to vegetable production which seems more profitable. The reliance on rain contributes to a generally low productivity of developed farm lands in Ghana, especially in the Northern regions (Mekonnen & Hoekstra, 2011). To ensure management of irrigation schemes that will promote sustainable production of vegetables and rice, in a soil with the balanced ecological system, it is important for the development of mechanisms to measure changes in soil quality (Torbert et al., 2008).

Importance of Soil for Food Production

Soils are indispensable in the production of food as food availability is largely dependent on soils. This is true because the soil is the source of essential nutrients, water, oxygen and provides support for crop roots, buffering them from drastic temperature fluctuations where necessary (FAO, 2015). There are diverse organisms inhibiting soil systems. These organisms (plant roots, bacteria, fungi, protozoa and invertebrate) through their activities contribute to sustaining and maintaining soil productivity (Black & Okwakol, 1997). The continuous cultivation of soils leads to their depletion. However, soil quality assessment and monitoring ensure planning of soil management towards sustainable food productivity (Franzlubbers & Haney, 2006; Sağlam et al., 2015).

Soil Quality: Historical Overview and Evolution

According to Brady (1996b), human's assessment of soil with which they work, play and live on has existed from the beginning of time. In this assessment, words such as ‘‘good’’, ‘‘bad’’ and ‘‘worn-out’’, ‘‘productive’’ or ‘‘unproductive’’ are used for classifying soils. With the awareness of the degrading state of soils and efforts to better understand and manage soils, soil scientists have adopted the concept of Soil Quality which is concerned with the soil's ability or fitness to better carry out its expected function (Brady, 1996b).

This concept of soil quality surfaced within the second half of the 20th-century with interpretations, definitions and understanding originating from specific viewpoint and motivations, with influence from such factors as land use traditions, social environments, scientific schools, languages among others (Tóth, Stolbovoy, & Montanarella, 2007). Soil quality, as a concept can be hypothesised as a three-legged stool, serving as the function and balance, which requires integration of three foremost components. These components are the soil as a medium to promote sustainable biological productivity of plants and animals; as a buffer to ensure environmental quality (assimilates and degrades environmentally hazardous compounds); as well as a factor to enhance the health of plants and animals including human (Brady, 1996b; Karlen et al., 1997).

There is an attempt to balance the multiple uses of soils with the soil quality concept. This attempt is seen from its environmental quality goals in the use of soils for agricultural productivity, remediation of wastes, forest, and rangeland, recreation as well as urban developments (Brady, 1996b; Karlen et al., 1997).

Defining Soil Quality

Amidst the diverse definitions and conceptual understanding of the concept of soil quality, one widely accepted definition given by the Food and Agriculture Organisation (FAO) in 1976 was "a complex attribute of soil, which acts in a distinct manner in its influence on the suitability of soil for a specific kind of use". Though this was widely accepted, there was no common agreement on the meaning of soil quality. This diversity was an indication of the fact that, soil quality definition and understanding cannot be same for diverse land uses, however, this concept may represent the sum of perceptions on a higher level of aggregation (Tóth et al., 2007).

In a review of different definitions of soil quality, each reflecting a different conceptual understanding based on land use and values of soils, Franzlubbers & Haney (2006) observed different definitions of the concept in respect of ascending years. Soil quality was defined by Mohler & Johnson, (2009) as ‘‘the potential utility of soils in landscapes resulting from the natural combination of soil chemical, physical, and biological attributes’’. However, Parr, Papendick, Hornick, & Meyer, (1992) also defined soil quality as ‘‘the capability of soil to produce safe and nutritious crops in a sustained manner over the long-term, and to enhance human and animal health, without impairing the natural resource base or harming the environment’’. In the same review, Doran & Parkin (1994) defined the concept as ‘‘the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health’’. The definition of soil quality was given as ‘‘the capacity of soil to function’’ by Karlen et al., (1997) and by Schjønning, Elmholt, & Christensen (2003) as ‘‘how well soil does what we want it to do’’. These definitions relate to soil quality to the specific use of soils (Franzlubbers & Haney, 2006).

According to Brady (1996b), soil quality based on the three components is defined as the soil’s capacity to function within, and sometimes outside, its ecosystem boundaries to sustain biological productivity and diversity, maintain environmental quality, and promote plant and animal health. In the context of farmlands being used for the sustainable feeding of mankind, soil quality was defined by Vigier , Gregorich, Kroetsch, & King (2003) as "…the soil's fitness to support crop growth without becoming degraded or otherwise harming the environment''. Soil quality is a complex concept and constitutes the many services human enjoy from the soil, as well as, the numerous ways in which soil impacts terrestrial ecosystems (Franzlubbers & Haney, 2006). Soil quality is the capacity of the soil to function in a sustainable way without causing any havoc to the environment, animal and human health (Adeyolanu et al., 2016).

These definitions have all been given considering the use of soils, emphasising also the ecosystem protection and sustainability of quality of the soil. Defining this concept in relation to the composition of soil, its use, ecosystem protection and sustainability, soil quality may be seen as the capacity of the soil to function as expected of it by a human in a balanced and sustainable ecological system.

Assessment of Soil Quality

There have been many attempts in past years at evaluating soil quality (Mueller, Schindler, AxelBehrendt, & Eulenstein, 2007). These attempts have focused on management induced factors that influence soil quality, reflected by favourable soil structure. Aside management influence is also inherent genetic makeup and age of the soil, these inherent parameters, such as plant available water, ought to be considered in soil quality evaluation (Mueller et al., 2007).

According to Karlen et al. (1997), there exist the potential of land use diversity and soil in its nature is also dynamic. Karlen et al. noted that this diversity and dynamism in the nature of soil cause a difference in quality for a particular soil function and the assessment of soil quality is, therefore, recommended to be relational and not absolute. Identifying appropriate criteria and methods for evaluating soil quality with respect to various soil functions will be an evolving process (Karlen et al., 1997).

Karlen et al. (1997) in a developed conceptual framework for soil quality evaluation, identified five levels of assessing soil quality. These levels referred to as multi-scales for soil quality evaluation are point scale evaluation processes mechanisms, plot or treatment response, field/forest evaluations, farm and watershed and Regional/National/International evaluations. Point scale evaluation is done basically at a sub-disciplinary level. This sub-discipline could be the biological, chemical or physical aspect of soil. The function of soil for this level of evaluation is defined according to the soil's physical, chemical, or biological properties and processes.

An example of such definition for a physical sub-discipline evaluation was given as how well a specific soil retains and transmits water to crops. Soil evaluation for such a sub-discipline in a point-scale level requires the measurement of physical properties such as soil structure, pore space size, and distribution, aggregate stability, saturated hydraulic conductivity, particle bonding or retention mechanisms. To achieve an overall assessment of soil quality, it is imperative to integrate all the disciplines investigated into full potential values for the specific soil function. Soil quality information from the point scale evaluation can be transferred only to soils of similar biological, chemical and physical conditions.

The plot scale level is also conducted with a focus on soil disciplines, however, a cross-disciplinary interaction makes the evaluation more useful for identifying the function of soil within a larger system. At this level of soil quality evaluation, soil function definition such as response to tillage and plant productivity are characterised by careful evaluation and judgment.

At the level of the field, farm and watershed evaluations, there would have been a transition from the experimentation with the disciplines for an understanding of soil quality. These levels are for monitoring of the quality of soil and require an interdisciplinary approach. The monitoring levels of evaluation provide an opportunity to apply acquired existing information and identify applied knowledge gaps. Land managers and decision makers are involved at these levels of soil evaluation.

Beyond monitoring is the regional/national/international level of evaluation. Soil quality evaluation at this level is factored in a generalised land quality and use policy. This generalisation of soil quality poses a big challenge for researchers and education professionals. Parameters used are still the biological, chemical and physical disciplines of soil.

Some Methods for Assessing Soil Quality

Muencheberg soil quality rating (M-SQR)

Like other purposive land classification methods such as The Classic Method (Vasiliniucing, 2014), Land Capability Classification and Parametric Evaluation (Sys, C.; Van Ranst, E.; Debaveye, 1991), the Muencheberg Soil

Quality Rating is an approach to evaluating soil quality (Mueller et al., 2012; Abdollahi, Hansen, Rickson, & Munkholm, 2015).

According to Mueller et al. (2012), the M-SQR enables a functional coding and productivity potential rating of the soil and is established on the concept of deep and well established rooting for crops. The rating in the Muencheberg Soil Quality Rating employs a semi-quantitative measure between scores of 1 and 100, using a likert- scale scoring of soil quality (good, moderate, poor and very poor soils), with a philosophy of providing results based on available data, making use of detailed information if available (Abdollahi et al., 2015; Mueller et al., 2012). Soil and topographic maps, analytical data and information on wetness or drought are required to make soil evaluations by the Muencheberg Soil Quality Ratings method a reliable evaluation (Mueller et al., 2012).

M-SQR is reliable for the long-term sustainable use of soil and applicable in on-field situations. M-SQR has a potential usage in soil resource planning, and provides guidance in land purchase and assessment of the sustainability and environmental impacts of land use (Mueller et al., 2012). However, the challenge in adopting the M-SQR approach for indexing soil quality in this study sterns from its restriction to assessing soils suitable for rainfed cropping in temperate regions (Mueller et al., 2012). The restriction of M-SQR approach to evaluating soils to only rainfed temperate soils, the focus of M-SQR on productivity function and the M-SQR method validated with crop yield data from temperate regions (Lothar et al., 2010) will render the method inefficient in a tropical irrigated scheme situation as the case is for Baafikrom.

Soil health card

The use of soil health card is another approach to evaluating soil quality. This is a qualitative evaluation which permits some interaction that links researchers, policy and extension agents in interpreting on-farm knowledge as linked to soil quality (Romig, 1995; Adeyolanu et al., 2016). A typical soil health card, as developed by Natural Resources Conservation Service of the United States Department of Agriculture as guidelines for soil quality assessment, employs ranking of soil quality from low to high (Ditzler & Tugel, 2002; Adeyolanu et al., 2016).

This is based on descriptions of soil parameters. These parameters used for ranking are earthworm counts, organic matter content, sub surface compaction, erosion, water holding capacity, drainage and crop conditions. Though easier and cheaper to assess soil quality, the subjective nature of the soil card which also requires long years of experience for accurate assessment remains a challenge for use in soil quality assessments (Adeyolanu et al., 2016).

Simple additive soil quality index

This method of evaluation is dependent on expert opinion and reviewed literature (Mukherjee & Lal, 2014). Soil parameters are assigned threshold values in literature and based on the opinion of experts, these values have their accompanying unitless scores which are summed up to give a total quality index for soil (Mukherjee & Lal, 2014). They further noted that the total soil quality index summed up, a scaled index for individual soils can be obtained. It is challenging to evaluate soil quality using this approach, especially when there is no available literature on adopted soil parameters for use in assessing the set indicators for the land use type under evaluation (Mukherjee & Lal, 2014).

Weighted additive soil quality index

This approach is based on Expert Opinion (EO) and does not require the adoption of statistical tools or literature in assigning weights (Andrews, Karlen, & Mitchell, 2002; Jha & Mohapatra, 2012; Mukherjee & Lal, 2014). They further noted that linear scoring is employed to assign scores with no units to the selected parameters.

The scoring is done based on three mathematical algorithm functions. First is the ‘‘more is better’’ function, used in observations which indicate good soil quality when the observation is higher. An example could be for higher respiration rate which indicates the higher activity level of soil microbes, flora, and fauna, an indication of a good soil quality.

Second is the algorithm ‘‘less is better’’. In this, the smaller the observation, the better it indicates good soil quality. ‘‘Optimum’’ is the third and final algorithm. Such parameters are scored as ‘‘more is better’’ up to a threshold, example, up to a pH of 7.2 and scoring beyond this threshold is then done as in ‘‘less is better’’. The linear scoring sets the highest score within a data set to 1 and the very lowest to 0 (Andrews et al., 2002; Jha & Mohapatra, 2012; Mukherjee & Lal, 2014).

According to them, averaging the scores gives the functional index. Numerical weights are assigned each indicator set for indexing the soil quality (Andrews et al., 2002; Jha & Mohapatra, 2012; Mukherjee & Lal, 2014). The assigned weights for the general indicators may be based on a number of parameters within the set indicators, the relevance of the function to the overall soil quality index, representativeness of the observation and repetitiveness of the indicator (Andrews et al., 2002; Jha & Mohapatra, 2012; Mukherjee & Lal, 2014). The products of scores and weights for each soil sample is summed to give an index for the quality of the soil (Andrews et al., 2002; Jha & Mohapatra, 2012; Mukherjee & Lal, 2014).

The minimum data set approach

With a wider application and recommendations for use in evaluating soil quality through an index (Adeyolanu et al., 2016; Mukherjee & Lal, 2014; Rezaei et al., 2006; Sağlam et al., 2015; Salvati & Colantoni, 2013; Senthilkumar et al., 2009; Singh et al., 2014; Vasiliniucing, 2014), the Minimum Data Set employs Principal Component Analysis (PCA), a quick tool to monitor the changes that occur in soil systems with changing soil management (Vasiliniucing, 2014). Indexing the quality of soils is done in a three-phase approach; selection of parameters, scoring of the selected parameters and integration into an index value (Tesfahunegn, 2014).

According to Dutta et al. (2015), Principal Component Analysis (PCA) technique describes vectors of closest fit to the ‘n’ observation in p-dimensional space, orthogonal to one another. They noted the following as steps to identifying key indicator for inclusion in the soil quality index computation. Define goals, which in the study will be soil with higher performance reflected in the computed SQI. Secondly, test significance level of the soil parameters as influenced by the soil management practices, thirdly, Select the representative minimum data set. Run a correlation check among the soil parameters with the aim of reducing inauthentic groupings among parameters that are highly weighted within each principal component. The forth step is to run a multiple regression analysis with the final minimum dataset components as the independent variables and each goal attribute as a dependent variable and lastly, score each minimum data set indicator based on its performance of soil function and finally compute Soil Quality Index (Dutta et al., 2015).

Selecting Parameters for Inclusion in a Soil Quality Index

The adoption of indices, a decisional tool used to make more accessible complex information, for evaluating soil quality in recent times, aims at simplifying the complex nature of soil systems (Vasiliniucing, 2014). Attempts to get a unique formula for indexing soils has not been successful, thus, no strict parameters or protocols exist for soil quality indexing (Vasiliniucing, 2014).

Measuring soil quality cannot be done directly, but through measurable properties and processes which indicate soil functional capabilities (Karlen et al., 1997; Franzlubbers & Haney, 2006). Soil parameters are properties or situations of soil that promptly and accurately respond to perturbation and change in the value or status of the soil (Senthilkumar et al., 2009). Parameters of soil quality, according to Senthilkumar et al. (2009), provide evidence for risk assessment on relatively high-level trends in soil quality and sustainable soil management. Their interpretation recognises conditions desirable to a particular soil function and provide information that influence soil management and policy decisions (Senthilkumar et al., 2009).

Due to the complex nature of soil quality, assessment of a specific site requires parameters that are specific to conditions of the site under evaluation, the use to which the land is put and ought to be sustainability focused, instead of productivity (Chaudhury et al., 2005; de Lima, Hoogmoed, & Brussaard, 2008). Irrespective of the wider use of Minimum Data Set (MDS) for indexing SQ, there is no universally accepted data set for this purpose (Tesfahunegn, 2014). Tesfahunegn (2014) noted that for the same minimum data set and scoring, soil quality index has varied even for the same field. The most widely reported MDS methods are expert opinion and statistical tools such as regression and principal component analysis (Tesfahunegn, 2014). Potential parameters to be included in the soil quality index should be considered based on their relevance to the function of the soil; practicable enough to be determined with proven methods; sensitive to soil management, so as to influence soil quality in the short, medium or long term; provides integrated information which could be derived from a number of subsidiary parameters and satisfies its examination against minimising cost and efficiency in assessing soil quality (Brady, 1996b; Tesfahunegn, 2014; Tóth et al., 2007).

In the assessment of soil quality with parameters, there is a range of values above or below which a change in soil quality indicator is understood as critical for the capacity or ability of the soil to function as expected (Senthilkumar et al., 2009). The authors further observed that this range of values is termed trigger value. Trigger values give rise to weighted evidence from the tested parameters, giving information which is interpreted as the quality status of the soil been assessed (Senthilkumar et al., 2009). A change in a quality parameter of soil, below or above the trigger value will require appropriate management response to improve the soil’s quality (Torbert et al., 2008). This response, they noted, will depend on soil characteristics, function and climate within which the soil is situated.

Selecting Parameters for Assessing Soil Quality of Study Area

To index soil quality, the land use goals should be clearly defined (Andrews et al., 2002). These goals, according to Andrews et al. (2002), will inform the soil parameters that will best predict the set indicators of the land use being indexed. These land use goals may be an individual, focused on the basic effects of practices on the land or could consider the broader environmental effect of the land use (Andrews et al., 2002).

Expert opinion is key in selecting these parameters (Andrews et al., 2002). Selected parameters should involve all three processes known of the soil; biological, chemical and physical processes (Lal, 2009). This will ensure the sustainable enhancement of the soil's structure, balancing and increasing its nutrient reserves and taking steps to improve the activities and diversity of soil organisms respectively (Lal, 2009). Just as will be done for parameters to be involved in a Minimum Data Set, parameters selected for evaluating any area under study ought to satisfy the requirements of functionality to the land use, practically easy to test with proven methods at affordable cost, management sensitive parameters and provides as integrated information much as possible so as to reduce duplication (Brady, 1996b; Tesfahunegn, 2014; Tóth et al., 2007).

Biological Indicator

Soil respiration rate

According to Dick et al. (2015), Evanylo & McGuinn (2009) and Rowell (1994), soil respiration rate is the gas exchange, specific for CO_2, between the atmosphere and the soil. They noted that this biological soil quality indicator is linked to the fauna, microbes and live root in the soil. High rates of respiration indicate more life activities within the soil, thus, promotes decomposition of organic matter in the soil (Rowell, 1994; Evanylo & McGuinn, 2009; Dick et al., 2015). This high respiration levels could be observed immediately after tillage, indicating the depletion of organic matter in the soil. Dark and rich coloured soils, if they record high respiration levels confirms the soil is rich (Evanylo & McGuinn, 2009). The opposite is true for pale and light coloured soils with low respiration rates (Evanylo & McGuinn, 2009).

Evanylo & McGuinn (2009) noted further that practising of conservation tillage for purposes of increasing organic matter content, cover cropping and direct application of organic matter can increase the levels of respiration rates. The increased respiration after tillage and nutrient application has the potential of degrading the quality of soils. This is so because this signals a likely decrease in soil organic matter. The respiration rate is determined from the amount of decomposition occurring within the soil at a given time, through the CO_2 evolved from microbial activities ongoing within the soil (Rowell, 1994). Limiting factors to decomposition as reflective in the respiration rate could be moisture, temperature, pH and organic carbon which serve substrate to feed heterotrophic microbes in the soil. High rates of respiration, relates to better soil quality (Rowell, 1994; Evanylo & McGuinn, 2009; Dick et al., 2015).

Physical Parameters

Texture

Soil texture influences chemical, physical and biological properties of soil. The clay component has the highest reactivity due to a higher comparative surface area. This reactivity influences chemical and physical processes in the soil, thus, clay is the most reactive. Soil texture cannot be changed except for drastic action by severe wind or water erosion (Dick et al., 2015). Soil textural determination is done by the ratio of the weights of soil particle size. This determination is done with no attention given the physical properties or the productivity of the soil.

The texture description in soils is not a full description of the soil's properties. Nonetheless, it is useful for the provision of an overview of the physical-chemical properties and fundamental fertility (Murano, Takata, & Isoi, 2015). The spatial distribution of the different soil types and many important properties of soils are given the soil from the soil forming factors (Jenny, 1994). Inherent soil properties sand, silt, and clay are more stable in space compared to acquired properties of the soil (Okae-Anti & Ogoe, 2006). Information on soil texture is important for meteorological, hydrological and land use prediction modelling in agriculture. Soil surface texture strongly influences wind erosion (Medinski, Mills, & Fey, 2009).

Soil stabilising agents such as organic matter, carbonates, sesquioxides and aluminium oxides at their higher content levels enhance the stability of soils causing an increase in the infiltration capacity within soils of decreased clay and silt. The formation of crust on the surface of the soil, however, restrict this infiltration capacity (Medinski et al., 2009). Information derived from knowing the texture of soil includes the potential amount of water to infiltrate and be retained in the soil, ease of nutrient leaching, nutrient holding capacity and erodibility, organic matter holding capacity and carbon sequestered by the soil (Dick et al., 2015)

Aggregate stability

Soil aggregates are particles of soil, which in themselves have smaller particle components as aggregates. Aggregates of soil to some extent are a permanent unit of soil structure, this quasi-permanency is not affected by the diverse seasonal variability resulting from climatic and anthropogenic factors. (Senthilkumar et al., 2009). Cultivation reduces the structural stability of soil, and this occurs with reducing organic matter content. The extent to which soil stability gets critical varies with soil type. It is therefore recommended for a maximum flexible management of vegetable farms to maintain organic matter content above critical levels for the specific soil type or use compost if economically viable as this will promote an all year round cropping (Rowell, 1994).

Soil aggregate analysis is employed in the prediction of tillage practices to adopt for less negative effects on soil quality, organic matter application decision, wind and water erosion, surface sealing and infiltration. Soil aggregate stability also provides information on soil water behaviours such as soil water redistribution, soil aeration, and root growth. The strength of aggregates is dependent on physical, chemical and biological influences from air-water surface tension, intermolecular forces between soil and water, cementation caused by precipitated solutes as well as enlarged root and fungi hyphae (Kemper & Roseneau, 1986).

The chemical composition (quick decomposing organic residues gives temporal stability, whiles longer stability is offered by slow decomposing residues) organic matter content, management practices, crop type and soil pH influences variations in the stability of soil aggregate (Taboada-Castro, Alves, Whalen, & Taboada, 2006; Senthilkumar et al., 2009). Aggregate stability gives an indication of soil's potential for erosion and crusting, influencing processes such as storage and movement of water within the soil matrix, aeration, erodibility, microbial activity and crop growth (Senthilkumar et al., 2009).

Chemical Parameters

Soil pH

The inclusion of soil pH in indexing soil quality is informed by the significant influence this chemical parameter has on nutrient availability, bio-geological cycling, structural stability and biological processes in the soil. However, pH is influenced by agronomic practices such as irrigation and fertility management (Senthilkumar et al., 2009). For agricultural soil, ideal pH ought to range between slightly acidic (6.5) to slightly alkaline (7.5). Beyond these pH levels, soils would be unsuitable for the agricultural purpose, thus, limiting the agricultural soil quality (Dadhawal, Mandal, & Shrimali, 2011).

Plant nutrients may be deficient in soils with lower or higher pH values. Such deficiencies may occur for nutrients such as P, Mn, Zn, Cu, Fe, Mo and may cause toxicity of Al and Mn as well. Significant amounts of organic matter addition positively influence the buffering capacity of soil for sustainable agricultural use (Evanylo & McGuinn, 2009).

Electrical conductivity

Irrigation exposes soil to potential salinity and sodicity problems. Electrical conductivity (EC) when monitored serves as a soil quality parameter to describe and monitor soluble salt and soil salinity impacts on soil quality changes. This monitoring, like most soil quality parameters, is reliable, fast and easy to conduct, relatively inexpensive and has also been used by many researchers to index soil salinity (Adhikari, Shukla, & Mexal, 2011; Keshavarzi, Bagherzadeh, Omran, & Iqbal, 2016). Saline soils have an electrical conductivity higher than 4 dS/m, and their soluble salt concentrations negatively impact the growth of most crops (Allotey, Asiamah, Dedzoe, & Nyamekye, 2007).

Soil organic carbon

Continuous cropping reduces the levels of organic carbon in soils (Liu et al., 2005). Low soil organic carbon contributes to the low efficiency of nutrient use and irrigation. To improve the quality of low organic carbon soils, a combination of chemical and organic manure gives an important synergistic effect in the retention and uptake of nutrients, their effective use, and conservation of soil moisture (Lal, 2009). Soil quality is very difficult or not possible to improve, without improvement of soil organic matter content. Organic carbon in the soil could be active (bioavailable) or passive (Dick et al., 2015).

The active carbon functions to improve the quality of the soil. Constant input of carbon materials into the soil influences a cycling of carbon in soil organic matter and this cycling in effect improves soil quality. The cycling is possible with changing soil management practices adopted (Dick et al., 2015). Organic materials which are the source of carbon in soil is one most important fraction of soil, formed from diverse decomposed organic materials (animals, plants, and micro-organisms). These materials decompose from organic into inorganic form and flow through soil solution to be used as a substrate for micro-organisms, nutrients for crops and improve physical conditions of the soil (Román, Martínez, & Pantoja, 2015). They further noted that soil moisture, temperature, and other environmental conditions influence the multiplication of soil micro-organisms who require carbon for their synthesis which is beneficial to improving the soil. For this reason, the addition of organic materials to the soil ought to be a permanent activity with the aim of providing the needs of soil micro-organisms and soil quality improvement.

Organic carbon may be expressed as organic matter content of the soil. This is done by multiplying the organic carbon levels determined in soil by a factor (1.74). This conversion is possible for determinations done by Combustion or Walkley-Black method. Soil organic matter, as an alternate for soil carbon, gives a reflection of the quality of the soil. Its monitoring indicates the improvement or degradation of soil quality and is important to varying chemical, physical and biological properties.

An increase in soil organic matter reflects an increase in cation exchange capacity of the soil, total N content, soil's capacity to conserve moisture and an improvement in the microbiological activities within the soil. The amount and timing of the release of N to the soil by soil organic matter, however, is dependent on temperature, moisture and soil management practice implemented (Horneck, Sullivan, Owen, & Hart, 2011).

Soil nitrogen

In almost all plant structures, nitrogen forms part of their building blocks. This makes it most important amongst the three main nutrients required by crops for their growth. In agricultural soils systems where substantial amounts of nitrogen are harvested with the products, there is recurring depletion of nitrogen. This is informed by the functional role played by nitrogen.

Nitrogen forms an essential part of chlorophyll, enzymes, and proteins. A higher amount is required by the plant for their nutritional requirements compared to the other essential nutrients. Stimulation of root growth, crop development, and nutrients uptake are done by nitrogen. Legumes fix nitrogen into the soil, thus, manage nitrogen depletion. The total estimated nitrogen content in soils is approximately 1750 to 7000 kg N ha^{-1} in the plough layer, however, less than 5% of this amount is mostly available to crops for use (Hofman & van Clemput, 2005; Tale & Ingole, 2016).

The atmosphere is filled with 78% of nitrogen in gaseous form, this form is not possible for uptake by crops, thus, rhizobia and other bacteria in the roots of legumes pick up nitrogen in gaseous form in fixing them into the soil via a symbiotic relationship with the leguminous plants. Rapid leaching of nitrogen is a serious challenge for sandy soils as its water retention is poor, compared to well-drained silt and clay. Relatively small amount of rain or irrigation water leaches nitrogen in sandy soils compared to well-drained silt and clay that will require abnormally high rains to cause a rapid leaching of nitrogen (Bundy, 1998; Walworth, 2013; Leary, Rehm, & Schmitt, 2014).

Phosphorus

Phosphorus is the most limiting crop nutrient after nitrogen. Its functional role is the storage and subsequent transfer of photosynthetic energy to plants for use in reproduction and growth. Crop roots grow to tap more sap, tillering is spurred and maturity accelerated when phosphorus concentrations are high in soil (Kakar et al., 2017). Microbes in the soil facilitate the bioavailability of phosphorus contained in organic amendments and matter within the soil system.

The bioavailability processes of these microbes are also dependent on the available decomposable organic carbon in the soil. This signifies the importance of maintaining organic matter concentrations within the soil to support large populations and activities of microbes (Friesen et al., 2006). Cool and wet soils are factors that influence a decrease in Phosphorus availability. Rainfall, soil temperature, moisture, soil aeration and salinity (predicted by electrical conductivity) affect the rate at which phosphorus is mineralized from organic matter.

In warm and humid climates, and well-aerated soils, decomposition and release of phosphorus are faster and the opposite is true for cool dry climates and saturated wet soils. The bioavailability of P occurs in soils with an ideal natural pH range of 6 -7.5. In soils with pH below 5.5 and beyond 7.5 up to 8.5, aluminium, iron and or calcium fixation occurs thus, limiting the availability of phosphorus. Soils prone to erosion and run-off or with close proximity to water bodies have a high potential of losing phosphorus (Kakar et al., 2017).

The application of fertiliser in the quest to manage phosphorus availability in soils could be reduced only to replenishing those amounts extracted by harvested crops. This is possible through the improvement of phosphorus cycle by growing tree crops to improve phosphorus availability to perennial crops (Friesen et al., 2006). The management of phosphorus in soils is efficient when soil texture (coarse-textured), existing concentrations of phosphorus in soils, soil organic carbon and calcium carbonate are considered (Prakash, Benbi, & Saroa, 2017).

Potassium

Potassium is amongst the macro nutrients required for crop growth. It is required for crop physiological processes which are inevitable for growth. These include the synthesis of protein and crop water balance maintenance. Crop take up potassium in dissolved form from soil solution, however, there is competition from sodium uptake by crops in soils that are saline. When this happens, there is an occurrence of high sodium/potassium ratio and this causes toxicity, thus, impedes growth in crops (Suzanye, Miranda, & Previatello, 2015).

It is important to ensure that, at periods when crop nutrients uptake for growth peaks, the concentration of potassium in the soil solution are at its highest. However, this could be defied by heavy rains which can cause nutrient leaching due to high soil permeability and acidity, with a potential to limit storage of base cations on the exchange sites, especially in sandy soils. It is important, therefore, to prioritise textural variation when managing potassium in soil systems (Ninh, Hoa, Ha, & Dufey, 2009). Due to leaching and fixation of potassium in weathered tropical soils, it's monitoring within soils is imperative (Igwe, Zarei, & Stahr, 2008).

The selection of these parameters for soil quality assessment was based on their ease of measurement/monitoring, ease of interpreting change, their sensitivity and connection to irrigation vegetable production. Consideration was also given unwavering soil parameters such as aggregate stability that withstand seasonal variability from climatic and anthropogenic factors (Senthilkumar et al., 2009) and also those parameters such as soil pH which provides integrated information that could be linked to soil quality over other such parameters that may not provide integrated information.

Chapter Summary

This review has looked at the degradation potential of soil from irrigation in the important role of irrigation towards the sustainable production of food for the growing population. The soil quality concept has been discussed as an approach to evaluating soils. The soil quality was reviewed in line with its evolution from earlier soil assessment with words such as good, bad, worn-out soils etc. Methods for evaluating soil quality, selecting parameters for involvement in the soil quality assessment and a review of the parameters selected for this study have also been looked at. The variability of soils for understanding current management practices to inform recommendations for practices that will improve soil quality was also discussed in this review. Most literature has focused mostly on a comparison between soil qualities of different land use. Not much literature is available on the impact of management practices such as continual vegetable production and chemical fertilizer application on soil quality.

CHAPTER THREE

METHODOLOGY

Study Area

The study was conducted at Baifikrom ($5^0$17'20.958''N; $1^0$0'58.416''W), a community in the Mfantsiman West District of the Central Region. The study site, Baifikrom Small Scale Irrigation scheme (Figure 1), has eleven registered farmers. Each registered farmer is assigned a 0.36 ha plot for the production of vegetables, especially in the dry season (GIDA, 2018). There is an annual land rate charged for the assigned plot and most of the farmers have cultivated the plot since the inception of the project in 2004 (GIDA, 2018). The irrigation is a pump and sprinkler system with water from the Ayensu river (GIDA, 2018).

Baifikrom falls within the coastal savannah ecological zone with soil type been Acrisols which are fairly suitable for the production of crops (MEST, 2011). The Coastal Savannah zone has a recorded mean annual rainfall of 800 mm, with the major rainfall recorded between March to July (FAO, 2005).

A Google Earth image of the study site is presented in Figure 1

Source: Google Earth image

Figure 1: Image of Baifikrom Irrigation Scheme Showing grids in numbers

Sampling Procedure

The entire irrigated area was considered for the study with disturbed soil samples collected from a depth of 0-30 cm, the root zone for most vegetables, with an earth chisel. Permission was obtained for sampling the farms through the chairman of the farmers within the irrigation scheme. The samples were collected separately from within an adopted grid area of 0.25 ha in each of the eleven registered farmer's plots of the scheme. Soils were sampled from five different locations within each grid, generating 55 different samples from the eleven grid cells. Consideration during sampling was given to the different cultivated crop(s), vegetation and variation in the observed soil colour within grids.

All sampling spots were defined by Global Positioning System (GPS) coordinates, using GPS coordinates version 3.3, 2016, a mobile application. In order to delineate the entire irrigation field and each adopted grid cell, GPS coordinates were taken for the boundaries of the entire field as well as for the sampling grids. The samples were then transported to the Soil Science Laboratory of the University of Cape Coast, where they were air dried, crushed and sieved through a 2-mm sieve. The sampling took place on the 22nd December 2016.

Selecting Parameters

The parameters were selected with guidance from existing literature, bearing in mind their relevance to land use, ease and practicality to test for, sensitivity to soil quality change, ability to provide integrated information on the soil system and cost (Brady, 1996b; Tóth et al., 2007; Tesfahunegn, 2014).

The adopted parameters were: physical parameters (soil texture and aggregate stability), Chemical parameters (pH, electrical conductivity, total nitrogen, extractable P, exchangeable K and organic carbon) and Biological parameters (microbial respiration). These parameters were grouped under each of the set indicators as degradation (EC and aggregate stability), Nutrient cycling (OC, pH and respiration rate) and crop productivity (N, P, and K)

Soil texture depends on soil particle fractions, and has implications for water infiltration and moisture conservation, nutrient leaching and erodibility (Senthilkumar et al., 2009; Dick et al., 2015); Aggregate Stability is directly linked to soil structure and aeration, water infiltration and redistribution, erosion resistance, surface sealing and crop emergence (Kemper & Roseneau, 1986; Torbert et al., 2008; Senthilkumar et al., 2009). Electrical conductivity is connected to the salinity status of the soil (Mueller et al., 2007).

The pH of soil was adopted as a parameter due to its connection to nutrient availability and microbial activity (Mueller et al., 2007). For the soil's ability to resist biochemical degradation and sequester nutrients, soil organic carbon was adopted due to its connection to these soil functions (Dadhawal et al., 2011). The activity of microbes in soil is mirrored in the rate of respiration in the soil, for this reason, soil basal respiration rate was adopted (Rowell, 1994; Evanylo & McGuinn, 2009; Dick et al., 2015). Soil nitrogen, available P and available K were adopted due to their connection with the soil's ability to support crop productivity (Dadhawal et al., 2011).

Soil management practices were also ascertained from farmers whose field soils were sampled for the study. A questionnaire was developed based on the three themes for this purpose and administered to registered farmers within the irrigation scheme. This was done with the purpose of finding out the previous soil management practices, which may have informed the quality indices from the different sampling points and plots in this study, informing recommendations for sustainable soil management. The three themes for the questionnaires were tillage practices, water management and fertilisation.

Laboratory Analysis

The soil samples were analysed for the adopted parameters using the following protocols.

Soil texture by pipette method (Rowell, 1994)

Ten grams of air-dried soil from each spot sampled within each grid was weighed and transferred into a 500 millilitres beaker. A 20 millilitres of H_2O_2 was added to the soil in the beaker and 100 millilitres distilled water also added. The mixer was swirled for a uniform mixture. Few drops of amyl alcohol were added to the mixture to reduce frothing. The mixture was heated on a heat plate to boiling to complete the destruction of organic matter in the soil and allowed to cool.

The peroxide treated soil was transferred quantitatively to a shaking bottle and 10 millilitres of a dispersion reagent, prepared by dissolving 50 g of sodium hexametaphosphate and 7 g of anhydrous sodium carbonate, was added to the treated soil. The treated soil was shaken overnight on a mechanical shaker.

After dispersion, the content of the shake bottle was quantitatively transferred into a 500 millilitres measuring cylinder and made up to the 500 millilitres mark with water. The dispersed soil in the measuring cylinder was manually shaken vigorously to disperse the particles and a stopwatch started, the tip of a 25 millilitres pipette was lowered to touch the surface of the soil solution, recording the distance. After 40 seconds, the pipette lowered 10 cm into the cylinder and 25 cm of the solution pipetted from the 500 ml soil solution in the cylinder. This pipetted soil solution is 25 ml of silt and clay particles.

The silt and clay particles were transferred into a weighed beaker and oven dried at 105 ^{o}C until constant weight. The beaker was cooled in a desiccator and reweighed to give the weight of silt, clay and a small residue of the dispersant. The cylinder was allowed to stand for 5 hours and the same procedure repeated for clay particles. After 5 hours, all the sand and some of the silt and clay would have settled.

Most of the supernatant liquid was gently poured out and the sediment quantitatively transferred into a beaker. Distilled water was added to the beaker stirred and the supernatant liquid rejected after 32 sec of settling. This was repeated until the supernatant was clear. At this stage, all the silt and clay had been washed out. The sand particles were then transferred into a beaker of known weight, oven dried at 105 ^{o}C, cooled and reweighed.

To determine the percentage silt, clay and sand, the following expressions were employed. The sand fraction in the soil sample was directed determined by;

$$\%\,Sand\ (m/m) = Mass\ of\ \ sand \times 100 / Mass\ of\ \ oven-dry\ soil\ ------1$$

The silt and clay fractions were determined in 25 ml of suspension, with an approximately 0.03 g of dispersant residue. This mass was subtracted from the weights to obtain the silt + clay and clay fractions. The difference silt content was then determined by the difference in weights for silt + clay and clay. The total silt content in the soil sample was determined by the expression:

$$Total\ mass\ of\ silt = mass\ of\ silt\ in\ 25ml \times 500/25 ------2$$

Percentage silt was also determined with:

$$\%Silt = Total\ silt \times 100/mass\ of\ oven-dry\ soil ------3$$

The total and percentage clay were determined as was done in the silt.

Aggregate stability by dispersion ratio (Egashlra, Kaetsu, & Takuma, 2017; Senthilkumar et al., 2009; Trakoonyingcharoen, Gilkes, & Sangkhasila, 2012).

Ten gram of air-dried soil was weighed and transferred into a 500 ml beaker. A Twenty millilitres of H_2O_2 was added to the soil in the beaker and 100 ml distilled water also added. The mixer was swirled for a uniform mixture. Few drops of amyl alcohol were added to the mixture to reduce frothing. The mixture was heated on a heat plate to boiling to complete the destruction of organic matter in the soil and allowed to cool.

The peroxide treated soil was transferred quantitatively to a shaking bottle. Two dispersions were conducted, one with distilled water and another with 10 ml of a dispersion reagent, prepared by dissolving 50 g of sodium hexametaphosphate and 7 g of anhydrous sodium carbonate, added to the treated soil. The treated soil was shaken overnight on a mechanical shaker. Another 10 g of the same soil was taken weighed into a shake bottle, 100 ml of distilled water was added and shook for thirty minutes. This time the distilled water served as a dispersant.

After dispersion, the content of the bottles was quantitatively transferred into a 500 ml measuring cylinder and made up to the 500 ml mark with distilled water. The dispersed soil in the measuring cylinder was manually shaken vigorously to disperse the particles and a stopwatch started, the tip of a 25 ml pipette was lowered to touch the surface of the soil solution, observing the distance. After 40 seconds, the pipette was lowered 10 cm into the cylinder and 25 cm of the solution pipetted from the 500 ml soil solution in the cylinder. This pipetted soil solution for both dispersion types was 25 ml of silt and clay particles which were transferred into a weighed beaker and oven dried at 105 ^{o}C until constant weight. The beakers were cooled in a desiccator and reweighed. The aggregate stability, expressed in Dispersion Ratio (DR) was determined using the expression;

$$Dispersion\ Ratio = mass\ of\ silt + clay\ dispersed\ by\ water / (mass\ of\ silt + clay\ dispersed\ by\ sodium\ hexametaphosphate)$$

Measurement of soil pH using an electrode (Rowell, 1994)

Ten grams of the sieved air dry soil was weighed into a bottle with a screw cap. Twenty-five ml of distilled water was measured with a measuring cylinder and poured into the bottle containing the soil sample. The bottle was sealed with the screw cap and shook for 15 mins on a mechanical shaker. The soil was allowed to settle at the base of the bottle to ensure the reading is done from the soil solution. The pH electrode was then inserted into the soil suspension and the pH of the soil was read, when the meter reading was stabilised and recorded.

Electrical conductivity using an electrode (Rowell, 1994)

Ten grams of the sieved air dry soil was weighed into a bottle with a screw cap. Twenty-five ml of distilled water was measured with a measuring cylinder and poured into the bottle containing the soil sample. The bottle was sealed with the screw cap and shook for 15 mins on a mechanical shaker. The soil was allowed to settle at the base of the bottle to ensure the reading is done from the soil solution. The EC electrode was then inserted into the soil suspension and the EC of the soil was read, when the meter reading was stabilised and recorded.

Determination of organic carbon by Walkley black (Rowell, 1994; FAO, 2008)

A 0.50 grams of each of the air dry soil samples were weighed into different 500 millilitres Erlenmeyer flask. Ten ml of $K_2Cr_2O_7$ solution was pipetted into each flask containing the soil sample and gently swirled to disperse the soil. Twenty millilitres concentrated H_2SO_4 was measured carefully with a measuring cylinder and added to the soil solution. The content of the flask was gently swirled for a minute, allowing for a uniform mix of the content and the reagent. The mixture was allowed to stand for thirty minutes, within which the heat evolved by H_2SO_4 drove the reaction.

After standing for thirty minutes, the solution was diluted with 200 ml of distilled water and swirled gently again to ensure thorough mixing. Ten ml of H_3PO_4, 0.2 g NaF and 1.0 ml of diphenylamine indicator were added to the content in the flask. The content was titrated with the ferrous solution until it changed from orange colour to a green endpoint. A blank titration was also carried out using the same reagent but without the soil sample. The percentage organic carbon was determined by the expression:

$$\{\ (B-S)\times molarity\ of\ Fe^{2+}\times 0.003\ \}/\ weight\ of\ soil\ sample\times(100/77)\times 100$$

Where:

B = Blank titre value, S = Sample titre value, 0.003 = Milliequivalent weight of carbon, 100/77 = the factor converting the carbon actually oxidised to total carbon and 100 = the factor to change organic carbon calculated, from decimal to percentage.

Determination of total nitrogen by Kjeldahl method(Rowell, 1994)

A 0.50 g of the soil sample was weighed into a digestion flask. A 0.2 g of catalyst and 3 ml of concentrated H_2SO_4 were added to the 0.50 g soil sample and the digestion flask was gently heated on a digester until frothing subsided and then gradually increased the heat to 360 ^{o}C, digesting for 2 hours. On completion, the digest was allowed to cool until just warm and then diluted to 100 ml with distilled water.

Distillation

A steam distillation apparatus with steam passing through it was set for about 20 minutes. After flushing out the apparatus with distilled water, a 100 ml conical flask containing 5 ml boric acid-indicator solution was placed under the condenser of the distillation apparatus. Twenty millilitres of the sample digest was transferred into the reaction chamber through the trap funnel. Ten millilitres of alkali mixture was added to the sample digest, also through the trap funnel and distillation immediately commenced. About 50 ml of the distillate was collected into the 100 ml conical flask.

Titration

The distillate was titrated against M/140 HCl from green to the initial colour of the indicator (wine red). The blanks digest was treated in the same manner and subtracted from the sample titre value.

Calculation

The total nitrogen levels for the soil samples were determined by the expression;

$$\%N = (S - B) \times Solution\ volume / 10^2 \times \text{aliquot} \times \text{sample weight}$$

Where; S = Sample titre value, B = Blank titre value

Available P by Bray-1 method(Rowell, 1994)

One gram of the soil sample was weighed into a centrifuge tube and 10 ml of the Bray-1 extraction solution (0.03MNH_4F + 0.025M HCl) was added and shook for five minutes. The tubes were then centrifuged at 3000 rpm for 10 mins. and 5 ml of the aliquot of the extract was pipetted into a 25 ml volumetric. Four millilitres of ascorbic acid and Reagent A solution was added allowing the formation of a bluish colour in 15 minutes. The flask was topped up to the 25 ml mark with distilled water. Standards were prepared without soil for calibration and soil absorbance was read after calibration with the standards on a Visible Spectrophotometer at 882 nm. A calibration curve of absorbance and concentrations was plotted for the standards and concentrations for the samples extrapolated from the standard curve.

Exchangeable K by flame photometer (Bickelhaupt & White, 1982)

Ten grams of soil sample was weighed and transferred into a bottle with cap. Ten millilitres of 1 M NH_4NO_3 was added to each sample in the bottle. The bottle was capped and shook for 30 minutes on a mechanical shaker. The mixture was then filtered and the photometer readings from a flame photometer recorded. K was determined from a calibration graph of potassium concentration on the x-axis and photometer reading on the y-axis.

Basal respiration rate by respiration experiment (Rowell, 1994)

One hundred grams of soil was weighed, moistened with 10 % water and stored in a loosely folded polyethene bag allowing access of air for seven days. The polyethene was opened daily and shook for aeration.

After the seven days, 50 g of the moistened soil was weighed into a respiration flask. Ten millilitres of approximately 0.3 M NaOH was pipetted into a phial and placed in the flask, avoiding spillage, with the moist soil around it. The flask was then sealed airtight and kept in a dark room for 8 days. Two control flasks, in the same way, were set up for the same period, but with no soil.

The soil moisture content at the time of setting up the respiration experiment was determined by weighing and recording about 10 g of the moist soil into beakers of known weights, oven dried at 105^0 for 3 days and reweighing. The weight of soil per 50g of the soil weighed for the experiment was determined.

After the 8 days period, 10 ml of 1 M $BaCl_2$ solution was added to each of the phials upon taken out of the respiration flask. Six drops of phenolphthalein indicator were added and titrated with 0.1 M HCl until the colour changes from red to colourless.

The rate of respiration was determined by the expression;

$$= Amount\ of\ CO_2\ reacting\ with\ NaOH / Actual\ weight\ of\ soil \times Respiration\ time\ in\ seconds$$

Soil Management Data Collection Instrument

A closed ended questionnaire was developed and used to ascertain the soil management practices carried out within each of the grids from where the soil was sampled (see Appendix P). The development of this instrument was done with a focus on relevant farmer demographic data, tillage practices, water management as well as supply and soil nutrients inputs. To ensure the validity of the questionnaire, a pre-test of the instrument was conducted on three farmers who cultivated a plot less than the assigned 0.25 ha on the scheme field, but not registered members of the scheme. Modifications were subsequently made to the instrument, where necessary. It must be noted that these three farmers were not included in the main data collection and their plots, though within the scheme was not captured as part of registered farmer plots of the scheme and thus soils were not sampled from their plots.

Nine out of the eleven farmers within the study area responded to the questionnaires administered. Responses from the questionnaire were grouped into their thematic areas. The frequencies of the responses were run with SPSS version 20 software. These thematic areas (tillage practices, water management and soil nutrients inputs) helped understood the soil management practised on the study field prior to and during the study.

Data Processing and Analysis

The initial intent to index the soil quality with principal component analysis was defeated. This was as a result of the inadequacy of the variability in the data derived from soil analysis of sampled soils from grids in the field. The total variable Kaiser-Meyer-Olkin Measure of Sampling Adequacy (MSA) of the data was 0.443 (**Error! Reference source not found.**), this is less than the 0.5 required for a data set to be appropriate for Principal Component Analysis (Norman, 2011; Rajalahti & Kvalheim, 2011), irrespective of eliminating lower MSA parameters from the data set. The weighted additive approach was then employed.

Linear scoring was employed to assign scores to the selected parameters. The scoring was based on ‘‘more is better’’ function for organic carbon, total nitrogen, phosphorus, available potassium and microbial respiration rate. The ‘’less is better’’ function, was used to score dispersion ratio and electrical conductivity (EC). The parameter, pH was scored with the ‘‘Optimum’’ function. The optimum function scored pH values as ‘‘more is better’’ up to a threshold of 5.5 - 6.5, beyond which less is better would have been adopted (Andrews et al., 2002; Jha & Mohapatra, 2012; Mukherjee & Lal, 2014). The scoring was based on the specific parameters and not for the indicators.

The scoring was done with the equations:

$$\textit{More is better} = (X_1 - Min)/(Max - \min) \;-----1$$

$$\textit{Less is better} = (Max - X_1)/(Max - \min) \;------2$$

Xi represented the parameter value from the laboratory analysis of soil. ‘‘Max’’ and ‘‘Min’’ represents the maximum and minimum values obtained from the analysis, respectively. The score of 1 was assigned to the highest potential function and the lowest was assigned zero in each set of parameter values, within the data from the study field. Parameter scores within each of the indicators (degradation, nutrient cycling and crop production) were summed up and subsequently multiplied by the weights assigned each indicator. The assigned weights were 0.3, 0.4 and 0.3 for degradation, nutrient cycling, and production respectively.

The assignment was based on relevance and representativeness of parameters within the indicator, and all the assigned weights summed up to 1.0 (100%). The product of all three adopted indicators (degradation, nutrient cycling and crop production), in each spot sampled, gave the SQI of the spot. Averages for the spots within a grid then gave a grid SQI (Andrews et al., 2002; Jha & Mohapatra, 2012; Mukherjee & Lal, 2014).

A one-way ANOVA, using the Fishers unprotected LSD, was run to separate the means for the indicators and SQI for each of the eleven grids, using the Genstat software. A pie chart showing the distribution of the different soil separates within the study field was also constructed using Microsoft Excel. ArcGIS version 10.1 was employed to map the parameter variability of the field. This was done for all parameters adopted for use in the SQI, by interpolating the observed values from the study field, based on the GPS coordinates taken at each spot sampled.

All raster interpolations for the parameters were classified in symbology, visualising their variability on the study field. These visualized parameters were reclassified into 1 for accepted parameter values and 0 for those values that are not accepted for the parameter. The reclassified maps were multiplied, ignoring pH which scored 0 for all sampled spots, into one map and classed into three using symbology to show variation. This final map represented the SQI for the study site, and their symbology classes scaled the SQI into three.

Chapter Summary

Chapter Three gives a description of the area within which the study was conducted. Soil sampling and soil sample preparation, parameters tested for use as parameters, soil management data collection and the statistical tools and the deployment of GIS tools as well as the analysis conducted were also discussed in this chapter. The next chapter, Chapter Four, will present the results of the statistical analysis conducted in this chapter.

CHAPTER FOUR

RESULTS

In this study, soil quality for the Baifikrom small-scale irrigation scheme was evaluated and mapped. The evaluation was done using the weighted additive indexing approach. Linear scoring of parameters selected by expert opinion and tested from sampled soils was employed in the indexing. The classified quality was mapped.

Summary Statistics for Indicators and SQI

The mean degradation indicator was 0.37, with respective maximum and minimum indicator values of 0.61 and 0.18, respectively (Table 1). The degradation indicator values show a coefficient of variation of 23% (Table 1). The coefficient of variation indicates the existence of variation in the degradation indicators amongst the grid means. With a 22.64% coefficient of variation, the nutrient cycling indicator, shows variation amongst the grids. This variation was observed from an indicator mean value of 0.63 (Table 1). The maximum nutrient cycling indicator observed was 0.31, and the minimum nutrient cycling indicator was 0.10 (Table 1). The maximum and minimum indicator values show the height of the variations as indicated by the coefficient of variation.

Unlike the degradation and nutrient cycling indicators which show minimal variation, crop productivity indicator variation was high. Minimal variation is given as all coefficients of variation values less or equal to 20%. Coefficient of variation values ranging from 21% to 50% are classified to be of high variation and coefficient of variation values beyond 50% are in the very high variation class. Inferring from the adopted classification of coefficient of variation, the crop productivity indicator shows a very high variation amongst grid means for this indicator. This is seen in the crop productivity's coefficient of variation of 49% (Table 1). This make the crop productivity indicator mean variation the highest observed variation amongst the three SQI indicators. The variation of the crop productivity indicator was observed from a mean indicator value of 0.22 (Table 1). The minimum and maximum SQI values were 0.01 and 0.18 (Table 1). With a coefficient of variation of 59.88% (Table 1) there is very high variation in the SQI grids means from a record mean SQI of 0.051(Table 1).

Summary statistics for the indicators and SQI are presented in Table 1

Table 1: *Summary statistics for indicators and SQI*

	Degrad Indicator	Nut. Cyc. Indicator	Crop Productivity	SQI
Mean	0.373	0.626	0.220	0.0507
Minimum	0.183	0.311	0.0711	0.0118
Maximum	0.577	0.996	0.543	0.175
Standard deviation	0.0858	0.142	0.109	0.0303
Standard error of mean	0.0116	0.0191	0.0148	0.00409
Sample Variance	0.00143	0.00384	0.00287	0.000291
Coefficient of variation(%)	23.01	22.64	49.80	59.88

Soil Degradation Indicator

With the highest observation of 0.13 dS/m, grid 7 recorded the highest EC followed by grid 11 (Table 2). The lowest was grid 9 with 0.04 dS/m (Table 2). The EC value with the highest frequency was 0.09 dS/m (Table 2), however, all the values of EC were below the > 4 dS/m threshold to qualify a particular soil for the saline status.

The highest AS observation was recorded on grid 5 with a value of 1.34, followed closely by grid 11 and grid 1 with observations of 1.32 and 1.30

respectively (Table 2). The lowest observation was recorded in grid 3 with 0.76, after a record of 0.81 and 0.80 in grids 10 and 2 respectively (Table 2). Six out of the eleven grids recorded observations beyond 1.0 with the other five grids not far from the > 1.0 observation (Table 2). In the prediction of soil stability, lower values of AS indicate better stability, thus, grid three which recorded the lowest AS value was more stable amongst the grids within the study site.

Summing up the parameter scores attained by each grid parameters of EC and AS, the highest observation for the soil degradation indicator was 0.46, recorded in grid 10 (Table 2). This was followed by the indicator value of 0.44 in grid 9 and 0.40 for both grids 2 and 3 (Table 2). The lowest indicator value 0.26 was observed for grid 11 (Table 2). The highest and lowest indicator values observed, did not occur in any of the grids that recorded the highest or lowest values for the parameters predicting the soil degradation indicator.

Soil degradation indicator parameters are presented in Table 2.

Table 2: *Degradation indicator parameters*

GRID No.	EC (dS/m)	AS	DEGRAD. INDICATOR	RANK
1	0.05	1.30	0.38	4
2	0.09	0.80	0.40	3
3	0.09	0.76	0.40	3
4	0.09	0.98	0.36	6
5	0.05	1.34	0.36	6
6	0.07	1.06	0.38	4
7	0.13	1.04	0.28	7
8	0.09	0.96	0.37	5
9	0.04	1.07	0.44	2
10	0.05	0.81	0.46	1
11	0.11	1.32	0.26	8

Source: Field data

Nutrient Cycling Indicator

A pH value of 5.60, observed in grid 9, was the highest recorded amongst the eleven grids within the study area (Table 3). All except grids 4 and 8, showed pH values more than 5.0 (Table 3). The lowest amongst the grid pH observation was grid 4, with a value of 4.64 (Table 3).

Grid 2 recorded the highest OC of 1.46 % (Table 3). This was followed by grids 7 and 11, both with 1.41 % (Table 3). The lowest OC recorded amongst the grids was 0.55 %, observed in grid 5 (Table 3).

Grid 5 had the highest rate of soil respiration amongst all the grids (Table 3). All grids, except grid 6 with the lowest respiration rate of $37.98gg^{-1}s^{-1}$, recorded rates higher than $38.00gg^{-1}s^{-1}$ (Table 3).

The nutrient cycling indicator was highest in grid 11, with an indicator score of 0.76 (Table 3). This was followed by scores of 0.74 and 0.72 respectively in grids 2 and 7 (Table 3). With a score of 0.46, grid 4 was the lowest in respect of cycling nutrients (Table 3). Grid 4 with a nutrient cycling indicator of 0.46 was next to grid 8 which had a nutrient cycling indicator of 0.48 in order of indicator quality (Table 3). Grid 11 recorded the highest nutrient cycling indicator value of 0.76 (Table 3). Grid 11 was not highest in value for the three nutrient cycling indicator component parameters of pH, %OC and respiration rate. Grid 4 showed the lowest pH value of 4.64 (Table 3), however, grid 4 was not the lowest in value for % OC and respiration rate.

Nutrient cycling indicator parameters are presented in Table 3

Table 3: *Nutrient cycling indicator parameters*

GRID No.	pH	%OC	RESPIRATION RATE ($gg^{-1}s^{-1}$)	NUT. CYC. INDICATOR	RANK
1	5.27	1.08	38.28	0.69	4
2	5.22	1.46	38.19	0.74	2
3	5.44	0.65	38.14	0.57	8
4	4.64	0.95	38.15	0.46	11
5	5.53	0.55	38.33	0.63	6
6	5.47	0.74	37.98	0.55	9
7	5.03	1.41	38.30	0.72	3
8	4.91	0.79	38.13	0.48	10
9	5.60	0.71	38.11	0.62	7
10	5.46	1.08	38.06	0.66	5
11	5.29	1.41	38.25	0.76	1

Source: Field data

Crop Productivity Indicator

Grid 9 had the highest observation in total N, with a value of 0.14% (Table 4). This was followed up with 0.10% in grids 2, 7, and 11 (Table 4). The minimum observation was 0.06% in grids 4, 5, and 10 (Table 4).

The highest level of P was 36.35µg/g and recorded in grid 10 (Table 4), this was followed up with 24.26µg/g, 20.92µg/g for grids 6 and 5 respectively

(Table 4). The lowest observation was 6.12 µg/g recorded for grid 8 (Table 4). Also, the observed P value for grids 4, 1 and 3 were below 10µg/g (Table 4).

Seven of the grids recorded exchangeable K values within the 0.20 cmolc/kg soil quality range (Table 4). These were the top seven observations with the highest been 0.26 cmolc/kg recorded in grid 7 (Table 4). Second highest was 0.24 cmolc/kg in grid 6 and grids 2 and grid 9 showing the third highest with 0.23 cmolc/kg (Table 4). The lowest exchangeable K value for the study field was 0.08 cmolc/kg in grid 8 (Table 4).

With the combined contribution of total N, available P and exchangeable K parameter values, the highest crop productivity indicator was 0.30 in grid 10 (Table 4). Second to grid 10 in the crop productivity indicator was grid 6 with 0.29 (Table 4). Grid 9 was the third highest in the crop productivity indicator with an indicator value of 0.28 (Table 4). The lowest crop productivity indicator value was 0.11 in grid 8 (Table 4). Grid eight showed lowest values for available P and exchangeable K amongst all the grids (Table 4), however, grid 10 did not show the highest values for total N and exchangeable K parameters amongst the grids (Table 4). Grid 10 was highest in the available P parameters amongst the grids (Table 4). This trend suggests that No single crop productivity indicator influenced the over -all crop productivity indicator quality with the study site.

Crop productivity indicator parameters are presented in Table 4

Table 4: *Crop productivity indicator parameters*

GRID No.	%N	Available P(μg/g)	Exchangeable K(c)	CROP PROD. INDICATOR	RANK
1	0.07	9.64	0.16	0.16	9
2	0.10	12.64	0.23	0.24	5
3	0.08	8.79	0.11	0.14	10
4	0.06	9.90	0.20	0.18	8
5	0.06	20.92	0.16	0.21	7
6	0.08	24.26	0.24	0.29	2
7	0.10	12.19	0.26	0.27	4
8	0.09	6.12	0.08	0.11	11
9	0.14	13.41	0.23	0.28	3
10	0.06	36.35	0.22	0.30	1
11	0.10	11.27	0.21	0.23	6

Source: Field data

Summary statistics for indicator parameters within grids soil degradation indicator

Classifying the % CV values into three as minimal variation for % CV of ≤20, high variation for % CV of 21 – 50 and % CV of >50 as very high variation in parameter values recorded, all except grid 1, showed minimal variation in EC values from the soil EC analysis done (Table 5). The mean EC value for grid one was 0.05 dS/m (Table 5) and a minimum and maximum values of 0.02 dS/m and 0.13dS/m respectively (Table 5). The highest and minimum mean EC values were however recorded for grids 7 and 9 respectively (Table 5). The highest mean value was 0.13dS/m, with a minimum EC of 0.08dS/m and a maximum EC of 0.19dS/m (Table 5). The lowest mean EC was also 0.04dS/m, with a minimum EC value of 0.03dS/m and a maximum EC of 0.05dS/m (Table 5), all values are run to 2 decimal points. The registered farmer assigned grid 1, which recorded the very high EC value, was observed to be watering crops with watering can instead of the sprinkler used for irrigation within the scheme.

Variations in DR showed all three %CV classification types. Very high DR variation was observed in grid 10. Grid 10 had a % CV of 66.59, a mean DR value of 0.81, a minimum DR of 0.38 and a maximum DR of 1.75 (Table 5). The high variation was not identified with the grid with the highest nor lowest mean DR (Table 5). The highest mean DR was observed for grid 5 (Table 5). Grid 5 had a mean DR of 1.34 and a %CV of 9.78 (Table 5), which showed a minimal variation in grid DR values. The grid with the minimum mean however, showed a high variation from the %CV. This grid with the minimum mean DR was grid 3, which recorded a %CV of 36.66 (Table 5). The mean DR of grid 3 was 0.76 (Table 5). The highest mean DR value of 1.34 (Table 5) was less than the >10 DR value to qualify for the description of soil as unstable. The registered farmers for grids 10, 5 and 3 controls weeds either by hand-held tools such as machete or with weedicides, however, grid 3 had his plot ploughed three days to collecting soil samples for the study. This ploughing was done only because the plot had been used for a potatoes project by the Ministry of Food and Agriculture.

Summary statistics for parameters forming the degradation indicator within grids is presented in Table 5

Table 5: *Summary statistics for parameters forming the degradation indicator within grids*

		Grid										
Parameter	Value	1	2	3	4	5	6	7	8	9	10	11
EC (d/ms)	Mini.	0.0185	0.0529	0.0540	0.0542	0.0275	0.0401	0.0800	0.0538	0.0267	0.0337	0.0542
	Maxi.	0.134	0.151	0.115	0.120	0.0774	0.0842	0.195	0.111	0.0509	0.0748	0.169
	Mean	0.0478	0.0858	0.0922	0.0943	0.0541	0.0707	0.133	0.0869	0.0363	0.0537	0.113
	%CV	101.6	46.03	26.98	29.25	39.34	24.80	33.87	28.45	27.60	36.80	40.02
D R	Mini.	0.857	0.632	0.357	0.812	1.167	1	1	0.773	0.381	0.375	1.125
	Maxi.	2	1.125	1.067	1.133	1.5	1.154	1.133	1.077	1.4	1.75	1.4
	Mean	1.295	0.800	0.761	0.979	1.338	1.062	1.04	0.959	1.070	0.810	1.317
	%CV	32.80	23.95	36.66	11.81	9.782	6.080	5.734	11.90	37.01	66.59	8.349

Nutrient cycling indicator

The %CV variation for soil pH and basal respiration were minimal through all the eleven grids (Table 6). This could be attributed to similarities in the management factors such as continuous chemical fertilizer application and moisture supply for pH and basal respiration respectively, within all grids. The risk level for the observed variation were very low with the highest %CV been 7.40 for pH in grid 4 and 1.05 $gg^{-1}s^{-1}$ for basal respiration in grid 1 (Table 6). Chemical fertilizers applied by all registered farmers are NPK using quantities prescribed by extension agents.

Variation in %OC as shown in the differences in %CV within the grids however showed minimal, high and very high %CV classified variations. The grids 3 and 5 were observed with very high %CV variations. The mean %OC for grid 3 was 0.65% and a %CV of 69.84 (Table 6). Grid 5 also had a mean OC of 0.55% and a % CV of 55.37 (Table 6). Minimal %CV variation was recorded for grids 2 and 7. The mean % OC for the minimal variation grids were 1.46% and 1.41% respectively (Table 6). Grid 2 had a %CV of 10.62 (Table 6), and the %CV of grid 7 was 14.51 (Table 6). Grids 1, 4, 6, 8, 9, 10 and 11 all recorded high %CV variations. The highest mean %OC was recorded in grid 2 (Table 6), and grid 5 recoded the least mean %OC for the study site (Table 6).

Summary statistics for parameters forming the Nutrient cycling indicator within grids is presented in Table 6

Table 6: *Summary statistics for parameters forming the nutrient cycling indicator within grids*

		Grid										
Parameter	Value	1	2	3	4	5	6	7	8	9	10	11
pH	Mini.	4.873	5.037	5.09	4.19	5.3	5.333	4.55	4.86	5.413	5.223	4.92
	Maxi.	5.487	5.543	5.657	5.05	5.733	5.64	5.38	5	5.893	5.72	5.677
	Mean	5.275	5.217	5.44	4.645	5.533	5.472	5.032	4.907	5.601	5.457	5.291
	%CV	4.519	3.900	4.304	7.404	3.316	2.50	6.121	1.266	3.428	4.00	5.269
%OC	Mini.	0.896	1.208	0.136	0.760	0.312	0.526	1.149	0.429	0.390	0.760	0.818
	Maxi.	1.364	1.597	1.247	1.208	1.071	1.091	1.714	1.071	1.071	1.286	1.695
	Mean	1.083	1.461	0.647	0.947	0.553	0.736	1.410	0.791	0.709	1.083	1.410
	%CV	22.84	10.62	69.84	20.76	55.37	29.78	14.51	33.80	37.09	20.29	24.31
R R (gg-1s-1)	Mini.	37.90	37.89	37.91	37.93	37.65	37.69	38.14	37.93	37.70	37.92	38.16
	Maxi.	38.96	38.48	38.22	38.52	38.54	38.16	38.55	38.2	38.53	38.57	38.48
	Mean	38.28	38.19	38.14	38.15	38.33	37.98	38.30	38.13	38.11	38.06	38.25
	%CV	1.049	0.548	0.342	0.627	0.995	0.499	0.502	0.305	0.823	0.746	0.336

Crop productivity indicator

Nitrogen variation within grids was very high for grids 1, 2, 5 and 9, whilst grids 6 and 7 were observed with minimal %CV variation within. Grid 9 recorded very high %CV and also the highest mean % N. Grid 9 had a %CV of 83.69 and a mean %N of 0.14% (Table 7). Least mean % N was observed in grid 5 with a minimum and maximum %N of 0.03% and 0.11% respectively (Table 7). Variation in grid 5 was very high, as it had a % CV 51.73 from a mean of 0.06 % of total N (Table 7). The variation explained by %CV for %N within grids could be attributed to management practices at the spots sampled.

The highest mean for available P was observed for grid 10 (Table 7). Grid 10 had a maximum available P value of 75.87µg/g (Table 7), the highest available P value observed in the study, and a minimum of 17.27µg/g (Table 7). The CV variation of 64.42% for grid 10 (Table 7) was very high in variation within grid 10. Irrespective of the highest maximum spot P value of grid 10, grid 1 had the highest variation from the %CV. Grid 1 had a maximum and minimum P value of 23.70µg/g and 2.51µg/g respectively (Table 7). The mean P value for grid 1 was 9.63µg/g and a %CV of 86.43 (Table 7). The least mean value was recorded for grid 8, grid 8 had a %CV of 44.69 from a mean of 6.12µg/g (Table 7).

The parameter K also showed variations of high and very high %CV. Very high %CV variation was observed in the grids 2, 7 and 8. Grid 7, which was highest amongst the very high variation, had a mean exchangeable K of 0.26 cmolc/kg (Table 7). The mean exchangeable K for grid 7 was also the highest amongst the K means (Table 7). The minimum and maximum K values of grid 7 were 0.10 cmolc/kg and 0.52 cmolc/kg respectively (Table 7). The % CV for grid 7 was 65.28 cmolc/kg (Table 7). Grid 2 had a % CV of 57 from a mean K of 57.0 (Table 7). The least mean K was recorded for grid 8. The least K mean was 0.08 cmolc/kg and 52.65 % CV (Table 7) varied from the mean. All grids either than 2, 7 and 8 were of high variation as classified with a % CV range from 21 – 50.

Summary statistics for parameters forming the crop productivity indicator within grids is presented in Table 7

Table 7: *Summary statistics for parameters forming the crop productivity indicator within grids*

		Grid										
Parameter	Value	1	2	3	4	5	6	7	8	9	10	11
%N	Mini.	0.0269	0.0462	0.0518	0.0072	0.0346	0.0640	0.0859	0.0692	0.0676	0.0490	0.0608
	Maxi.	0.121	0.195	0.0950	0.0833	0.114	0.110	0.133	0.129	0.336	0.0791	0.121
	Mean	0.0714	0.0974	0.0757	0.0638	0.0626	0.0839	0.104	0.0890	0.136	0.0647	0.0975
	%CV	55.47	58.59	21.71	50.05	51.73	19.73	19.94	29.68	83.69	21.02	24.16
P(µg/g)	Mini.	2.514	10.64	3.544	5.565	8.757	9.613	8.153	3.583	6.897	17.27	5.245
	Maxi.	23.70	16.82	13.89	14.43	34.29	46.76	20.48	10.52	23.95	75.87	19.53
	Mean	9.636	12.64	8.787	9.899	20.92	24.26	12.19	6.123	13.41	36.35	11.27
	%CV	86.43	19.91	51.25	34.96	48.37	67.79	42.91	44.69	47.81	64.42	56.43
K(Cmolc/Kg)	Mini.	0.0518	0.103	0.0863	0.102	0.103	0.156	0.103	0.0346	0.154	0.103	0.121
	Maxi.	0.242	0.411	0.190	0.311	0.231	0.311	0.517	0.138	0.284	0.334	0.363
	Mean	0.156	0.227	0.114	0.20	0.165	0.242	0.263	0.0759	0.227	0.216	0.207
	%CV	43.75	57.0	38.10	38.10	32.33	25.66	65.28	52.65	26.07	45.75	47.47

Grid Indicator Mean Comparison using Tukey

Significant differences were observed amongst grids for the parameters EC, pH, OC and P (Table 8), the significant differences were identified at a least significant difference of 0.05 comparing means using tukey (Table 8). The significant difference could be identified in grids such as grid 11 and 9, and grids 7 and grid 9 for the EC parameter (Table 8).

Grid 4 was significantly different from grid 5 in the pH parameter mean comparison (Table 8). Grid 1 was significantly different from grid 4 in their pH means (Table 8). The significant difference in %OC is found in grids such as 2 and 3, grid 9 and grid 11 as well as grids 8 and 2 (Table 8).

Amongst the productivity indicator parameters, significant difference was observed only in P (Table 8). Significant differences was observed between grids 10, denoted superscript "b", and all grids with means denoted superscript "a", such as grids 1, 3, 7 and 11 (Table 8).

The indicator means for each of the grids compared using tukey is presented in Table 8

Table 8: *Indicator parameter means for grid*

Grid	EC (d/ms)	D R	pH	%OC	R R (gg-1s-1)	%N	P(µg/g)	K(Cmolc/Kg)
Grid 1	0.058 ^{ab}	1.295 ^{a}	5.28 ^{bcd}	1.08 ^{ab}	38.28 ^{a}	0.071 ^{a}	9.6 ^{a}	0.156 ^{a}
Grid 2	0.086 ^{abc}	0.800 ^{a}	5.22 ^{bcd}	1.46 ^{b}	38.17 ^{a}	0.097 ^{a}	12.6 ^{a}	0.227 ^{a}
Grid 3	0.092 ^{abc}	0.761 ^{a}	5.44 ^{cd}	0.65 ^{a}	38.14 ^{a}	0.076 ^{a}	8.8 ^{a}	0.114 ^{a}
Grid 4	0.094 ^{abc}	0.979 ^{a}	4.65 ^{a}	0.95 ^{ab}	38.15 ^{a}	0.064 ^{a}	9.9 ^{a}	0.200 ^{a}
Grid 5	0.054 ^{ab}	1.338 ^{a}	5.53 ^{d}	0.55 ^{a}	38.33 ^{a}	0.063 ^{a}	20.9 ^{ab}	0.165 ^{a}
Grid 6	0.071 ^{abc}	1.062 ^{a}	5.47 ^{cd}	0.74 ^{a}	37.98 ^{a}	0.084 ^{a}	24.3 ^{ab}	0.242 ^{a}
Grid 7	0.133 ^{c}	1.040 ^{a}	5.03 ^{abc}	1.41 ^{b}	38.30 ^{a}	0.104 ^{a}	12.2 ^{a}	0.263 ^{a}
Grid 8	0.087 ^{abc}	0.959 ^{a}	4.91 ^{ab}	0.79 ^{a}	38.14 ^{a}	0.089 ^{a}	6.1 ^{a}	0.076 ^{a}
Grid 9	0.036 ^{a}	1.070 ^{a}	5.60 ^{d}	0.71 ^{a}	38.11 ^{a}	0.136 ^{a}	13.4 ^{a}	0.227 ^{a}
Grid 10	0.054 ^{ab}	0.810 ^{a}	5.46 ^{cd}	1.08 ^{ab}	38.06 ^{a}	0.065 ^{a}	36.4 ^{b}	0.216 ^{a}
Grid 11	0.113 ^{bc}	1.317 ^{a}	5.29 ^{bcd}	1.41 ^{b}	38.25 ^{a}	0.098 ^{a}	11.3 ^{a}	0.207 ^{a}
Lsd (0.05)	0.041	0.345	0.30	0.35	0.32	0.057	13.01	0.1151

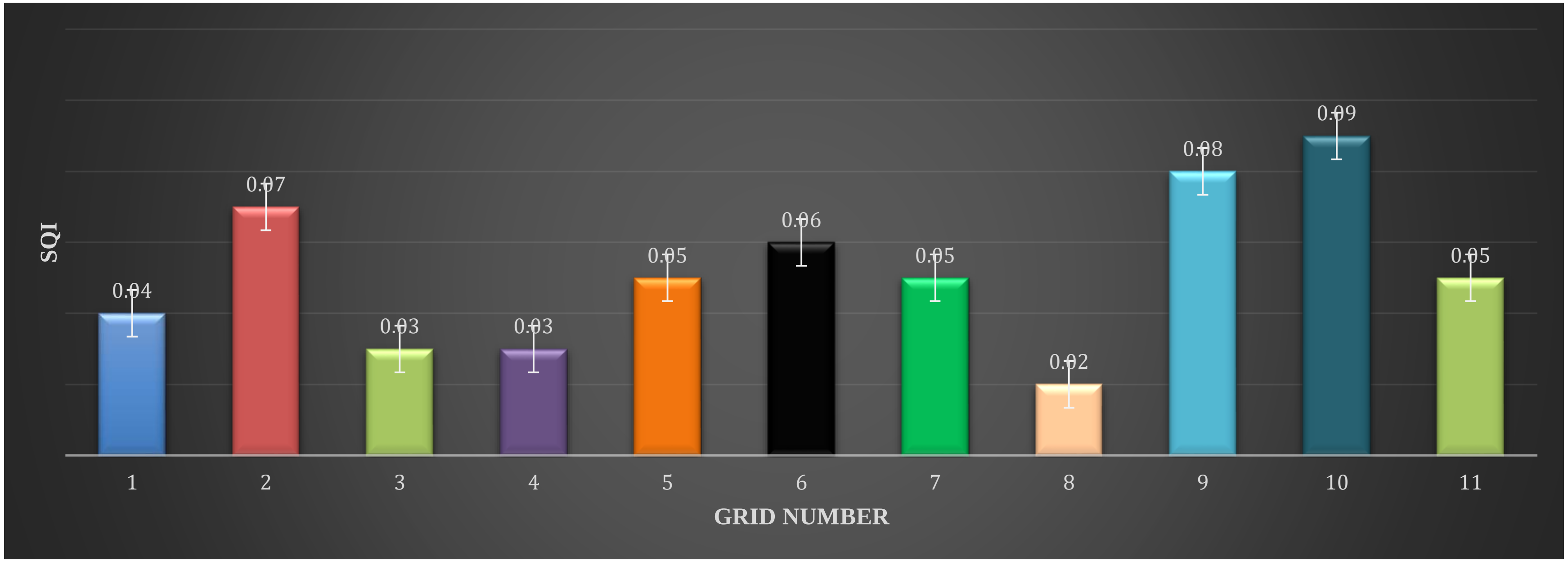
Soil Quality Index

The highest quality index for the field under study was recorded by grid 10 with a soil quality index of 0.09 (Figure 2). Grid 10 attained the highest indicator values for the soil degradation indicator (Table 2) and crop productivity indicator (Table 4). Second to the highest soil quality index was grid 9 (Figure 2). Grid 9 had a soil quality index score of 0.08 (Figure 2). Grid 9 was second to grid 10 in the soil degradation indicator (Table 2), seventh in rank for the nutrient cycling indicator (Table 3) and third ranked in the crop productivity indicator (Table 4). Grid 2, which was ranked third in the degradation indicator (Table 2), second in the nutrient cycling indicator (Table 3) and fifth in the crop productivity indicator (Table 4) was the highest scoring grid in soil quality index, with a value score of 0.07 (Figure 2). The first three ranked grids of grids 10, 9 and 2 (Figure 2) in soil quality index did not show strength of a particular indicator influencing the trends of soil quality index ratings.

The least soil quality index was recorded by grid 8 with a soil quality index value of 0.02 (Figure 2). Grid 8 scored least for the crop productivity indicator (Table 4), tenth for nutrient cycling (Table 3) and fifth for the degradation indicator (Table 2). Second to last SQI value was observed for grids 3 and 4, both with a soil quality index value of 0.03 (Figure 2). Grid 3 and grid 4 did not score same for the adopted indicators of degradation (Table 2), nutrient cycling (Table 3) and crop productivity (Table 4). For the Nutrient cycling indicator for example, grid 3 ranked eighth whilst grid 4 ranked eleventh in the Nutrient cycling indicator score (Table 3). Grid 3 ranked third for the degradation indicator as grid 4 lagged behind at the sixth position in ranking (Table 2). Same difference was observed for the crop productivity ranking for grid 3 and 4 (Table 4).

Grids 5, 7 and grid 11 all scored 0.05 in the soil quality index, attracting a medium soil quality index class (Table 9); however, they had different indicator scores under all three indicators of indicators of degradation, nutrient cycling and crop productivity. Grid 5 ranked sixth in the nutrient cycling indicator, whilst grid 7 ranked third and grid 11 first in the same nutrient cycling indicator (Table 3). These differences in grid indicator rankings for same scoring soil quality indexed grids indicates that, the soil quality as indexed is not based on influence from a particular indicator.

Soil quality indices are presented in Figure 2 and the classification of SQI in Table 9



Source: Field data

Figure 2: Soil Quality Indices at Baifikrom small-scale irrigation scheme

Table 9: *SQI classification*

GRID	SQI	SQI Class
1	0.04	Low
2	0.07	Medium
3	0.03	Low
4	0.03	Low
5	0.05	Medium
6	0.06	Medium
7	0.05	Medium
8	0.02	Low
9	0.08	High
10	0.09	High
11	0.05	medium

Source: Field data

** High SQI = 0.80 – 1.00, Medium SQI = 0.40 – 0.79, Low SQI = 0 – 0.39

Comparison of indicators and SQI among grids

Significant differences were observed amongst grids in the study field for the Degradation indicator (Table 10). These significant differences were observed amongst grid 11 and the grids 4, 5, 8, 1, 6, 3, 2 and 9; grid 10 and the grids 5, 4, 7 and 11 (Table 10).

For the nutrient cycling potential of the soils, significant differences were also observed between grids (Table 10). Grid 11 was significantly different from grids 9, 3, 6, 8, and 4 (Table 10); grid 10 was significantly different at P >

0.05 from grids 8 and 4 (Table 10); significant difference was observed between grid 8 and the grids 1, 2, 5, and 7 (Table 10). Grid 7 also showed significant difference from grids 4 and 6 (Table 10). Grid 4 was significantly different at $P > 0.05$ from the grids 1, 2, 5 and 9 (Table 10). Grid 2 and grid 3 were significantly different (Table 10).

No significant differences at $P > 0.05$ were observed between grids for the crop productivity indicator (Table 10). However, significant differences were observed in the SQI for the grids (Table 10). This significant difference among SQI grid means was observed in grid 10 and the grids 11, 8, 7, 5, 4, 3 and 1 (Table 10); grid 9 and grids 1, 3, 4 and 8 (Table 10). Grid 2 was significantly different at $P > 0.05$ from the grids 1, 3, 4 and 8, whilst grid 6 was significantly different from grids 4 and 8 (Table 10). The difference between grid 7 and grid 8 was significant at $P > 0.05$ (Table 10).

Comparison of indicators and SQI among grids is presented in Table 10

Table 10: *Comparison of indicators and SQI among grids using tukey*

	GRIDS											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Lsd**
DI	0.3789^{ab}	0.4048^{ab}	0.4012^{ab}	0.3579^{bc}	0.3604^{bc}	0.3827^{ab}	0.2814^{cd}	0.3738^{ab}	0.4396^{ab}	0.4575^{a}	0.2641^{d}	0.09151
NCI	0.686^{abcd}	0.740^{ab}	0.573^{cdef}	0.464^{f}	0.629^{abcd}	0.552^{def}	0.719^{abc}	0.482^{ef}	0.617^{bcde}	0.663^{abcd}	0.765^{a}	0.1464
CPI	0.163^{a}	0.243^{a}	0.138^{a}	0.185^{a}	0.207^{a}	0.288^{a}	0.270^{a}	0.115^{a}	0.281^{a}	0.304^{a}	0.226^{a}	0.1278
SQI	0.0375^{cde}	0.0706^{ab}	0.0313^{cde}	0.0300^{de}	0.0465^{bcde}	0.0624^{abc}	0.0525^{bcd}	0.0208^{e}	0.0732^{ab}	0.0896^{a}	0.0431^{bcde}	0.03169

Soil Quality Map

The multiplication of parameter maps, to visualize the quantified SQI in ArcGIS was done using three classes: high, medium and low (Figure 3). The highest soil quality rated class, with a class values of 4.9 – 15.8, were observed in grids 2, 7 and 11 (Figure 3). These grids also partly encompassed the medium the values of 1.50 – 4.98 (Figure 3). The second medium SQI class values were also observed in grids 10, 6 and 5 (Figure 3). The map of the study site showed that the lowest SQI class was the most frequent within the study site (Figure 3). This third class filled the grids 8, 4, 5 and 3 without competition with the high and medium SQI, and also portions of the grids showing the high and medium soil qualities as represented in the first and second classes (Figure 3). It could be said that grids 2, 7 and 11 were of the highest class within the study site (Figure 3), with grids 8, 4, 5 and 3 predominate in the least class (Figure 3).

Soil quality map for the study site is presented in Figure 3

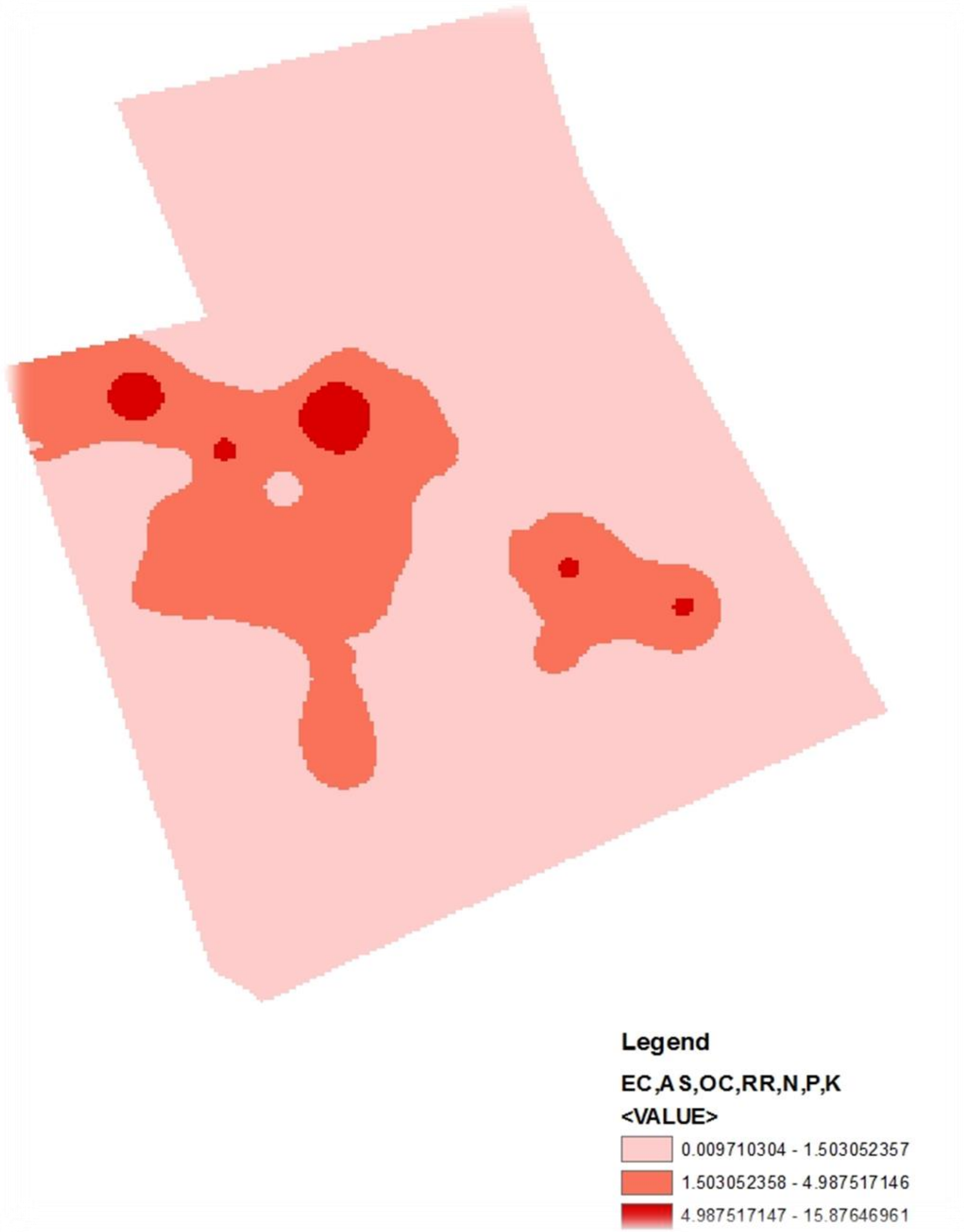


Figure 3: Quantified SQI

Soil Management Practices Employed by Farmers in the Scheme

Eleven farmers are registered under this small-scale irrigation scheme, out of this population; nine out of the total were available and responded to the questionnaire that was administered. Some background information of the farmers was sought in addition to their management practices.

Soil management practices were sought from farmers under three thematic areas of management. These were tillage practices, water management and nutrient inputs.

Background of farmers within the scheme

Of the nine respondents, 56% in the irrigation scheme under study were within 51 to 60 years, with 22% below and above this age range (Table 11). More than half of the registered farmers had been educated up to the basic level (middle school/ JHS). Females in this adult age range constituted 67% with 33% being male (Table 11). The registered farmers rely on farming techniques acquired from extension agents who were available to provide extension services at in the early years of the scheme. Periodic extension services are still sought from extension agents from the Ministry of Food and Agriculture. This is done individually by farmers who may find the need to do so. Farmers within the scheme also share knowledge on farming techniques amongst themselves.

Background to farmers registered within the scheme is presented in Table 11

Table 11: *Demographic data on farmers at Baifikrom small-scale irrigation scheme (n=9)*

		Frequency	Percent
Age	Below 50	2	22.2
	51-60	5	55.6
	Above 60	2	22.2
	Total	9	100.0
Sex	Male	3	33.3
	Female	6	66.7
	Total	9	100.0
Highest education level	Primary school	1	11.1
	Middle school/JHS	5	55.6
	Teacher/Nursing training college	1	11.1
	No Formal education	2	22.2

Source: Field data

Tillage practices

For tillage practices within the study site, 44% of the farmers manually controlled weeds with hand held tools such as machete and hoes (Table 12), 22% of them controlled weeds with the application of weedicides only (Table 12), 11% employed mechanized (plough) weeds control and another 11% also followed pesticide application with mechanized weeds control (Table 12).

Only one farmer indicated he made the extra effort to incorporate slashed weeds into the soil. The majority of the farmers left the weeds on the soil surface to decompose (Table 12). This practice by majority of farmers in the Baifikrom small-scale irrigation scheme may have mulched the soil protecting it from direct exposure to degradation, however, leaving the cleared weeds unattended to also exposed the soil to the possibility of losing organic matter improvement. Organic matter improves on the nutrient content and soil aggregate formation (Dick et al., 2015).

Tillage practices practices and carried out by farmers within the irrigation scheme is presented in Table 12

Table 12: *Tillage and rotation management practices of farmers (n=9)*

	Frequency	Percent
How did you prepare the land for your current production		
Mechanized	1	11.1
Manual (hand-held tool)	4	44.4
Mechanized followed with weedicide	1	11.1
Weedicide only	2	22.2
Weedicide followed by mechanised	1	11.1
Total	9	100.0
How have crop residues been managed after harvest in your past productions		
Incorporated into the soil	1	11.1
Left on plot to decompose	8	88.9
Total	9	100.0
Have you ever practised rotation on this land		
Yes	6	66.7
No	3	33.3

Source: Field data

Out of the respondent farmers, 66% indicated practising rotation (Table 13). The rotation for the six farmers as indicated in (Table 13), had some farmers divided and grew two crops at a time on the plot. This was then followed by two different crops as was done for the first cycle. This was observed for grids 1, 3 and 4 (Table 13). This approach could be the reason for the variation observed in the crop productivity parameters (Table 8). Differences in the nutrient requirements for crops such as cabbage, okra and garden eggs as seen in the rotation cycle of grid 6 (Table 13) has a potential to influence the amounts of N, P and K for the different portions of grid 6.

Rotation Cycle Practised by some farmer is presented below in Table 13

Table 13: *Rotation cycle for farmers practising rotation*

GRID	1	2	3
1	Pepper/ Aubergine	Cabbage/ maize	
3	Maize/ Aubergine	Potatoes	Okra
4	Maize/ Aubergine	Potatoes	Okra
6	Green Pepper	Okra	Cabbage
9	Watermelon	Tomatoes	Eggplant
10	Maize	Pepper	Aubergine

Source: Field data

Water management

The study area is an irrigation scheme; however, the amount and frequency of water application to a plot is the responsibility of each registered farmer for his/her plot. Registered farmers take charge of the sprinklers and sets it on his/her plot, thus farmers manage the irrigation of their crops. Weekly application of irrigation was done by 66% of the farmers (Table 14). The remaining 33% applied irrigation manually every three days when crops are younger and continue with the weekly schedule as done by the other registered farmers within the scheme (Table 14). For irrigation application, the sprinkler is set for two hours and then relocated to a different spot on the field to irrigate the portions not irrigated yet. The periodic relocation of the sprinkler is necessary to ensure full coverage of the 0.36 ha assigned each registered farmer. Beyond the two hours assigned each farmer for usage of the sprinklers, 22% of them do additional one or two more hours of irrigation (Table 14).

None of the farmers who responded to the questionnaires indicated their observation of surface sealing on their fields. One farmer indicated prevention of surface sealing as a reason for leaving weeds to cover (mulch) soil surface.

Irrigation management practiced by the registered farmers is presented in Table 14.

Table 14: *Farmer irrigation management (n=9)*

	Frequency	Percent
How often do you water your crops		
Weekly	6	66.7
Every three day when young and weekly when they are established	3	33.3
Total	9	100.0
For how long do you set the sprinkler to irrigate your crops		
1hrs - 2hrs	7	77.8
3hrs - 4hrs	2	22.2
Total	9	100.0
Have you ever observed thin and hard layer formed on the surface of bare soil (surface sealing) on your plot during watering		
No	8	88.9
Not observed	1	11.1
Total	9	100.0
Have you observed any difficulty of water entry into the soil (infiltration) on any area of your plot during watering		
Yes	2	22.2
No	7	77.8

Source: Field data

Nutrient inputs

All the farmers in the study site indicated they apply chemical fertilisers (NPK), however, 33% of them apply Sulphate of Ammonia in addition to the

NPK (Table 15). The majority of these farmers, however, indicated they dissolved chemical fertilisers in water to apply, with 11% doing side dressing and another 11% do both side dressing and broadcast application using knapsack sprayer (Table 15). The rate of application is informed by extension information and previous knowledge shared amongst farmers. Only 222% out of the population had applied manure (Table 15).

Methods adopted by farmers in applying fertilizers are presented in Table 15

Table 15: *Fertiliser application and methods (n=9)*

	Frequency	**Percent**

Were any inorganic/chemical fertilisers applied to your field in the last 3 cropping seasons		
Yes	9	100.0
If Yes, indicate which type(s)		
NPK	6	66.7
NPK & Sulphate of ammonia	3	33.3
Total	9	100.0
What methods did you use to apply the inorganic/chemical fertiliser		
Side dress in row or beside row	1	11.1
knapsack sprayer	7	77.8
Side dress and Knapsack sprayer	1	11.1
Total	9	100.0
Have you ever applied manure in your production		
Yes	2	22.2
No	7	77.8

Source: Field data

CHAPTER FIVE

DISCUSSION

Soil Quality Indicators

Degradation indicators

The observed differences in the grid means for the degradation indicator were significant (Table 5). This shows that the capacity of soils to withstand degradation such as erosion and salinity vary amongst the grids. Most farmers practice tillage that involves the use of weedicides or hand-held tools (Table 12). This form of tillage compared to conventional and ridge tillage in a study by Paul et al. (2013) was observed to have posed no negative effect on the aggregate stability of soils. The highest mean DR value for the study site was 1.33 (Table 8), this high mean is less than a DR value of 10 for which aggregates of any soil is described as unstable. The observed significant difference in grid means however, tell the variations in management practices employed by farmers.

All the grids within the study site were subjected to sprinkler irrigation. The highest mean EC was 0.13dS/m. soil is said to have developed saline conditions when its EC is higher than 4dS/m (Allotey et al., 2007). The sprinkler method of irrigation supplies the crop water needs without degrading the soils (Grieve et al., 2003). Differences in the irrigation water management practices amongst farmers in the study site (Table 14) could be the reason for the differences in EC. Al thuogh the soils are stable with no saline conditions, variation in the EC parameter amonsgt the grids, contributed to the degradation capacity differences observed among the grids.

Nutrient cycling indicator

Significant differences were observed in the soil's potential to cycle nutrients. The soil's ability to cycle nutrients was different amongst the grids within the study site (Table 10). Soil pH amongst the grids was generally low, thus, soils within these grids could be described as acidic. The recommended pH for agricultural soil is slightly acidic to slightly alkaline soils (Evanylo & McGuinn, 2009; Dadhawal et al., 2011). They observed further that, nutrient deficiency and toxicity of Al and Mn could occur in soils which are beyond the slightly acidic to slightly alkaline range. Senthilkumar et al. (2009) noted that soil pH influences the availability of soil nutrients to crops, biological processes and structural stability of soils.

The organic carbon contents for the grids varied from low, through moderate to high organic carbon (Table 6). During the study, some farmers were observed to have partitioned their 0.25ha. This partitions were done to cultivate different crops on same plot. There were some othere who had cultivated some partitions of their plot and left some other portions not cultivated, thus, left to fallow, whilst other continuously cultivated their entire 0.25ha plots. According to Bationo, Kihara, Vanlauwe, Waswa, & Kimetu (2007), continuous cultivation of a land could cause a decline in the soil organic carbon contents. Laudicina, Novara, Barbera, Egli, & Badalucco (2015) also observed that improvement of chemical and biochemical properties of soil organic matter was influenced by no tillage and rotation. Soil organic carbon is vital in the nutrient management of soils (Bationo et al., 2007). Soil organic carbon has the potential to improve the buffering capacity of soil, influencing its microbial activity

(Evanylo & McGuinn, 2009). The observed differences in the soil's ability to cycle nutrients were likely an influence of its variation in soil organic carbon. This variation could be influenced by continuous cultivation, soil texture and Tillage practices.

Crop productivity indicator

No significant difference was observed between grid means for the crop productivity indicator (Table 10). There were no differences in the means of crop productivity indicator within the grids. This could have resulted from the common application of either NPK or NPK and Sulphate of ammonia with empty tins of milk by all farmers. Farmers had similar rate of application and the application of this chemical fertilizers are continuously done for all vegetables cultivated. Subehia, Verma, & Sharma (2005) observed that the continuous application of chemical fertilizer makes soils acidic. This observation by Subehia et al., (2005), could be the explanation to the low productivity in soils observed by farmers within the study area. Senthilkumar et al. (2009) noted that, at lower soil pH, nutrients are not availability to crops.

Soil Quality Index

Significant differences were observed between the grids in SQI (Table 10). These significant differences shows that the capacity of the grid soils to function without degrading the environment was variable. The indexed SQ was not based only on the influence of one or two indicators but the combined impacts from all selected indicators. This was seen from the differences in indicator scores for grids and the SQI for these same grids. Nutrient cycling indicators for grids 5, 7 and grid 11 for example, show different indicator scores of 0.63, 0.72 and 0.76 respectively (Table 3). Though the indicator means for grids 5, 7 and 11 were not significatly different, they shared similarities in the nutrient cycling grid means with grids such as grids 1, 10 and 2 (Table 10). Grids 5, 7 and 11 had same soil quality index of 0.05 (Figure 2). The soil quality index for grids 5, 7 and 11 was however different from those of grids 1, 10 and 2 which had similar grid means in nutrient cycling indicator. The observed significant differences observed in the soil quality index for the grids may have resulted from variation in indicator parameters for the grids.

Farmer Soil Management

With a majority of the farmers practising manual slashing and or weedicides application (Table 12), little disturbance is caused to the soils. Two farmers who ploughed their plots (Table 12) indicated they had a challenge with implements and only got the fields ploughed by the Ministry of Food and Agriculture after adopting one of the plots, grid 3, for a demonstration. Microbial biomass was observed in a study to significantly influence aggregate stability. Microbial biomass was higher under no tillage compared to ridge and conventional tillage practices (Zhang et al., 2012).

The frequency at which farmer's apply irrigation is influenced by stage of crop development and the level of soil moisture, however, farmers had no option than to wait for their time as scheduled by the scheme. However, some farmers did apply water to younger crops every three days when their scheduled time was not due. This was a practice to improve on the growth of the crops in their younger stage, still with the same source of water, but not with the sprinkler pumps. In all this, there is a simulation of the sprinkler application of water, thus not causing development of saline conditions. Tsay & Ju (2012) noted that sprinkler irrigation supplies crop water needs, not causing surface run-off. However, in sprinkler irrigation, potential toxic ions are absorbed in the foliar parts of crops due to the over-canopy nature of water application (Grieve, Wang, Shannon, Brown, & Salinity, 2003). The inconsistent application of irrigation on farmer plot, as seen in differences in frequency, amount of water and method of irrigation application by the different farmers could account for the variation in grid EC values and grid mean % CV for the EC parameter.

The continuous application of NPK and sulphate of ammonia fertilizers was observed as means of farmer's nutrient input within the study area. The only different nutrient input method was from two farmers who had some time in the past applied poultry manure in the planting holes, prior to planting. Unlike the combined application of farm yard manure and chemical fertilizers, chemical fertilizers alone do not improve the physical properties of soil (Bhatia & Shukla, 1982). This rather is a potential for acidification, enhancing low pH and Al toxicity. Al toxicity is a significant factor that limits production of crops (Delhaize & Ryan, 1995). The continuous application of NPK and sulphate of ammonia fertilizers could have accounted for the acidic soils observed in the study site. The highest among the grid mean pH values for the study site was a pH of 5.6 (Table 6), observed in grid 9. This mean was from pH values whose maximum was 5.8 and with a minimum pH of 5.4 (Table 6). The acidity of the study site is between medium acid and strongly acid. Nutrients inputs made are may not be available as required within these category of acidity compared to slightly acid category. It is not surprising though that all farmers who were respondents to the questionnaires administered indicated low yields from their plots.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This study was conducted to evaluate the quality of soils in the Baifikrom small scale irrigation scheme. The soil management practices by farmers were ascertained and soil quality was indexed using the weighted additive indexing method. Raster reclassification was used to generate maps that portray the variability in the classified soil quality. Findings from the study will help understand and manage soil quality in the irrigation site for sustainable production of vegetable, as well as contribute to the dearth of knowledge on soil quality.

Conclusions

At the end of the study the following conclusions were made;

1. The estimation of the quality of soils in Baifikrom irrigation scheme shows a medium (0.05) SQI. The index as estimated was based on the combined impacts of all three indicators (degradation, nutrient cycling and crop productivity) with no indicator showing dominance in its influence on the final soil quality index. Medium soil quality supports the production of vegetables, however, there is the need to improve on the pH and OC of the soils as this may improve on the quality of soils.

2. The mapped Soil Quality was based on the estimated SQI for each spot. The map showed SQI in three symbology classes, the highest SQI class (Red) ranged from a class value of 4.9 to 15.9 and the lowest class (Pink) ranged from 0 to 1.5.

Recommendations

From the conducted study, the following recommendations are proposed:

1. Farmers on the study site may adopt integrated fertility management practices (chemical and organic fertilization), as this will improve on the

low organic Carbon contents observed, thus improve on the soil ecology and quality.

2. With the highest mean DR value of 1.338, the soils in the site are stable. This high mean value is below the DR threshold value of 10 to described soil as unstable. Minimum tillage practices carried out on the study site is thus recommended for irrigated soils.
3. A similar study is carried out by the Ghana Irrigation Authority to evaluate and monitor soil quality of all public irrigation schemes. This will inform irrigated soil management, planning and policy crafting.

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APPENDICES

APPENDIX A:

TEXTURE AND SQI FOR SPOTS SAMPLED

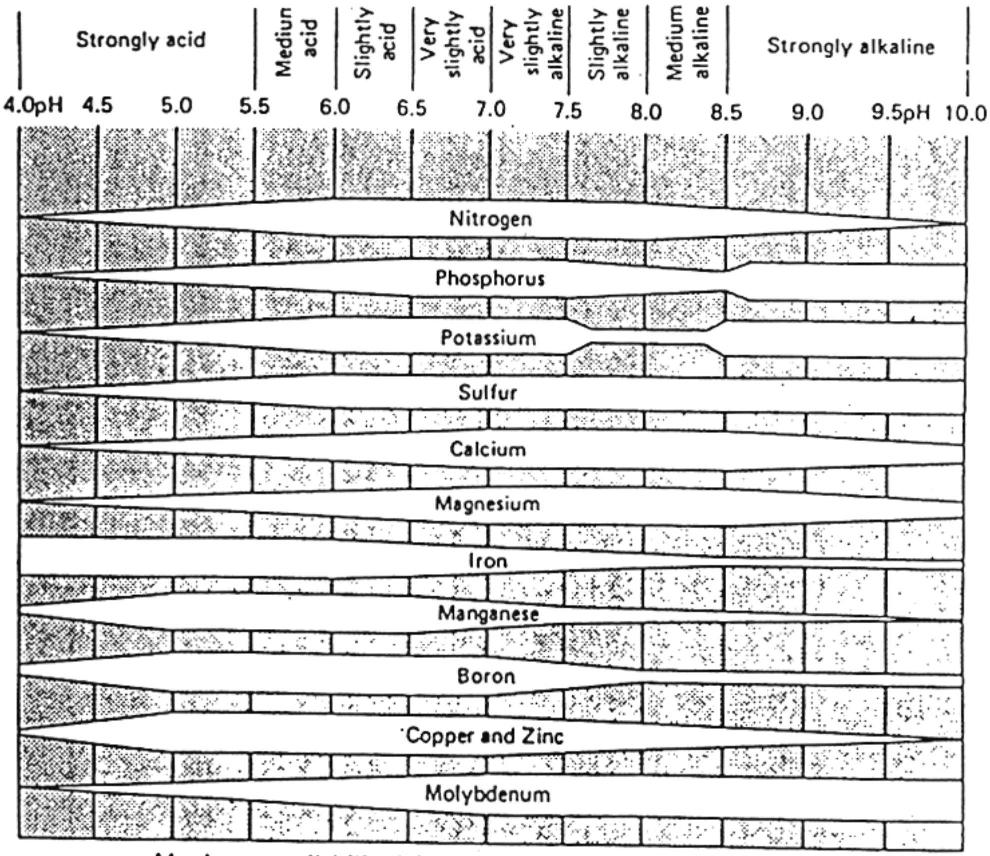
SAMPLE GRID NO.	**TEXTURAL CLASS**	DEGRAD. INDICATOR	NUT. CYC.INDICATOR	**CROP PROD. INDICATOR**	SQI
BfP1a	**loamy Sand**	0.41	0.58	0.13	0.03
BfP1b	**loamy Sand**	0.45	0.63	0.10	0.03
BfP1c	**Sandy loam**	0.50	0.60	0.11	0.03
BfP1d	**Sandy loam**	0.26	0.65	0.32	0.05
BfP1e	**loamy Sand**	0.28	0.97	0.16	0.04
BfP2a	**Sandy loam**	0.31	0.78	0.44	0.11
BfP2b	**Sandy loam**	0.48	0.64	0.12	0.04
BfP2c	**Sandy loam**	0.40	0.66	0.19	0.05
BfP2d	**Sandy Clay loam**	0.40	0.80	0.18	0.06
BfP2e	**Sandy loam**	0.43	0.83	0.29	0.10
BfP3a	**Sandy loam**	0.35	0.66	0.21	0.05
BfP3b	**Sandy loam**	0.41	0.49	0.13	0.03
BfP3c	**Sandy loam**	0.41	0.51	0.09	0.02
BfP3d	**Sandy loam**	0.34	0.70	0.15	0.03
BfP3e	**Sandy loam**	0.49	0.50	0.11	0.03

BfP4a	**Sandy Clay loam**	0.34	0.60	0.19	0.04
BfP4b	**Sandy loam**	0.42	0.46	0.15	0.03
BfP4c	**Sandy loam**	0.35	0.31	0.24	0.03
BfP4d	**Sandy loam**	0.32	0.52	0.19	0.03
BfP4e	**Sandy loam**	0.36	0.43	0.16	0.02
BfP5a	**Sandy loam**	0.32	0.79	0.27	0.07
BfP5b	**loamy Sand**	0.35	0.73	0.25	0.07
BfP5c	**Sand**	0.42	0.35	0.21	0.03
BfP5d	**Sand**	0.38	0.56	0.13	0.03
BfP5e	**loamy Sand**	0.34	0.71	0.17	0.04
BfP6a	**Sandy loam**	0.42	0.47	0.27	0.05
BfP6b	**Sandy loam**	0.37	0.46	0.26	0.04
BfP6c	**loamy Sand**	0.37	0.58	0.33	0.07
BfP6d	**Sandy loam**	0.38	0.74	0.37	0.10
BfP6e	**Sandy loam**	0.37	0.52	0.21	0.04
BfP7a	**Sandy loam**	0.38	0.75	0.21	0.06
BfP7b	**Sandy Clay loam**	0.18	0.83	0.47	0.07
BfP7c	**Sandy loam**	0.28	0.81	0.34	0.08
BfP7d	**Sandy loam**	0.23	0.55	0.18	0.02
BfP7e	**Sandy loam**	0.34	0.66	0.14	0.03
BfP8a	**Sandy loam**	0.42	0.39	0.07	0.01

BfP8b	**Sandy loam**	0.40	0.48	0.10	0.02
BfP8c	**Sandy loam**	0.33	0.54	0.10	0.02
BfP8d	**Sandy Clay loam**	0.38	0.50	0.19	0.04
BfP8e	**Sandy Clay loam**	0.34	0.51	0.12	0.02
BfP9a	**Sand**	0.35	0.58	0.54	0.11
BfP9b	**Sandy loam**	0.58	0.69	0.24	0.10
BfP9c	**loamy Sand**	0.41	0.68	0.26	0.07
BfP9d	**Sand**	0.42	0.63	0.16	0.04
BfP9e	**Sand**	0.43	0.50	0.20	0.04
BfP10a	**Sandy loam**	0.57	0.64	0.18	0.07
BfP10b	**loamy Sand**	0.48	0.66	0.30	0.09
BfP10c	**Sandy loam**	0.53	0.69	0.17	0.06
BfP10d	**Sandy loam**	0.46	0.71	0.54	0.18
BfP10e	**loamy Sand**	0.25	0.62	0.33	0.05
BfP11a	**Sandy loam**	0.28	0.78	0.11	0.02
BfP11b	**Sand**	0.36	0.60	0.17	0.04
BfP11c	**loamy Sand**	0.29	0.69	0.19	0.04
BfP11d	**Sandy loam**	0.19	0.76	0.29	0.04
BfP11e	**Sandy loam**	0.20	1.00	0.37	0.07

APPENDIX B:

RELATIONSHIP BETWEEN PLANT NUTRIENT AVAILABILITY AND SOIL REACTION (U.S Department of Agriculture, 2006; Yeboah, Kahl, & Arndt, 2012)



Maximum availability is indicated by the widest part of the bar

APPENDIX C:

SOIL TEST INTERPRETATION GUIDE

Element	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Extraction Method	Kjeldahl	Bray	Ammonium Acetate
Units	%	ppm	$Meq100g^{-1}$
Levels:	0.05 – 0.13	> 20	< 0.45
Low			
Adequate	0.13 – 0.23	20 - 40	0.45 – 0.70
High	0.23 – 0.30	40 - 100	0.7 – 2.0

Source: (Yeboah, Kahl, & Arndt, 2012)

APPENDIX D:

ACCEPTABLE THRESHOLD VALUES FOR PARAMETERS

INDICATOR	ACCEPTABLE THRESHOLD VALUES (1)	NON-ACCEPTABLE THRESHOLD VALUES (0)
Aggregate Stability	< 5.0 – 10	> 10
Electrical Conductivity	≤ 4.0	> 4.0
Organic Carbon	1.0 – 3.0	<1.0
Soil pH	6 – 6.5	<6.0 ; > 6.5
Respiration Rate		
Nitrogen	0.13 – 0.30	<0.13
Phosphorus	20 - 100	< 20
Potassium	0.45- 2.0	<0.45

Source:(Senthilkumar et al., 2009; U.S Department of Agriculture, 2006; Yeboah et al., 2012)

APENDIX E:

DISPERSION RATIO AND CORRESPONDING INTERPRETATION

Dispersion Ratio	Interpretation
<5	Very stable
6-10	Stable
11-15	Fairly stable
16-25	Somewhat stable
26-30	Unstable
>31	Very stable

Source: (Senthilkumar et al., 2009)

APENDIX F:

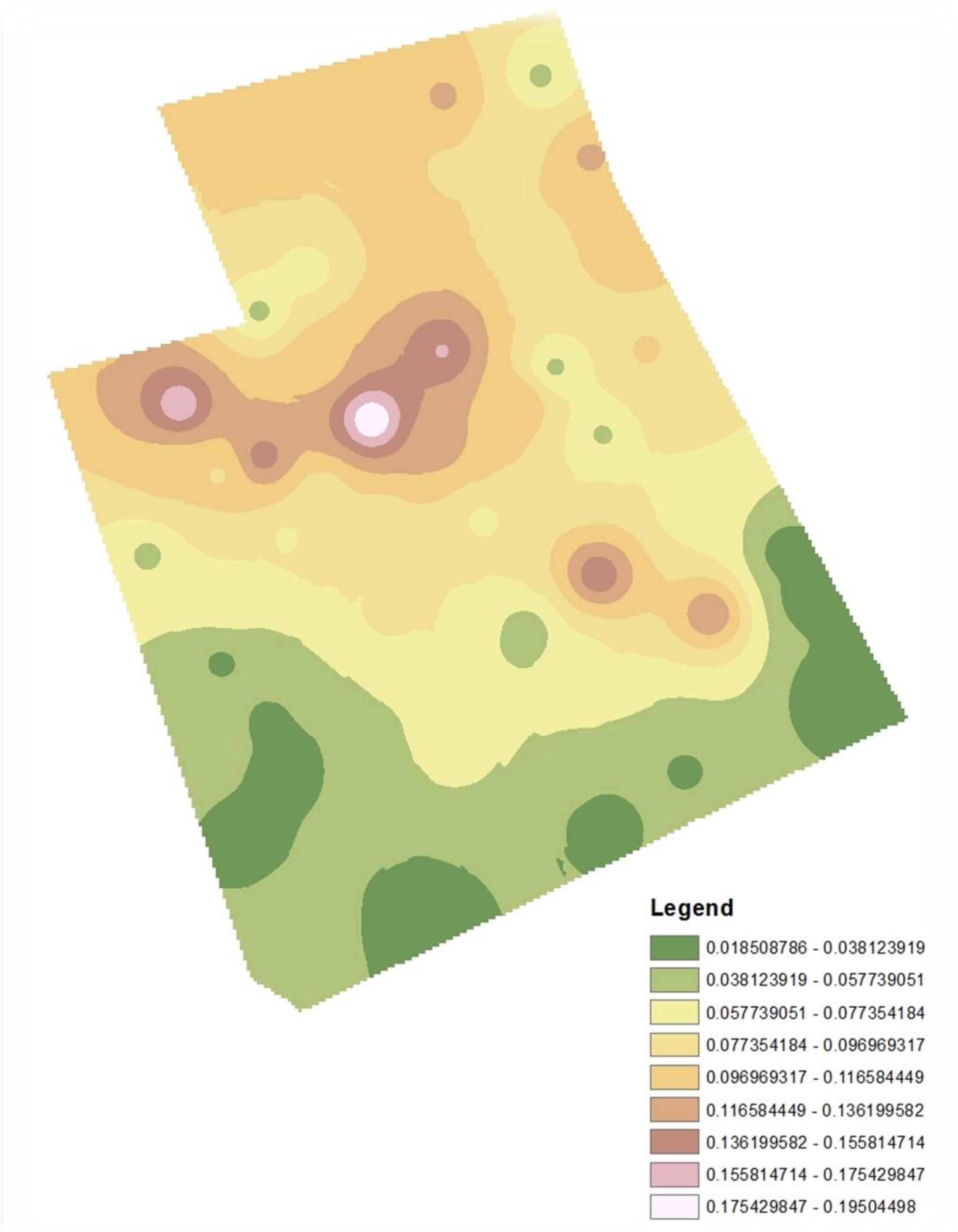
INTERPRETION FOR SOIL ORGANIC CARBON (OC) RESULTS IN RELATION TO SOIL CONDITION/QUALITY

Description	Value	Soil condition
Very low	<0.4	Degraded or severely eroded topsoil
Low	0.4–1.0	Poor structural condition and stability
Moderate	1.0–1.8	Moderate structural stability, condition, pH buffering, nutrient levels, water holding capacity
High	1.8–3.0	Good structural condition and stability, high pH buffering capacity, high nutrient levels, high water holding capacity
Very high	>3.0	Dark colour, large amount of organic material, soil often associated with undisturbed woodland/forested areas

Source: (Hazelton & Murphy, 2007)

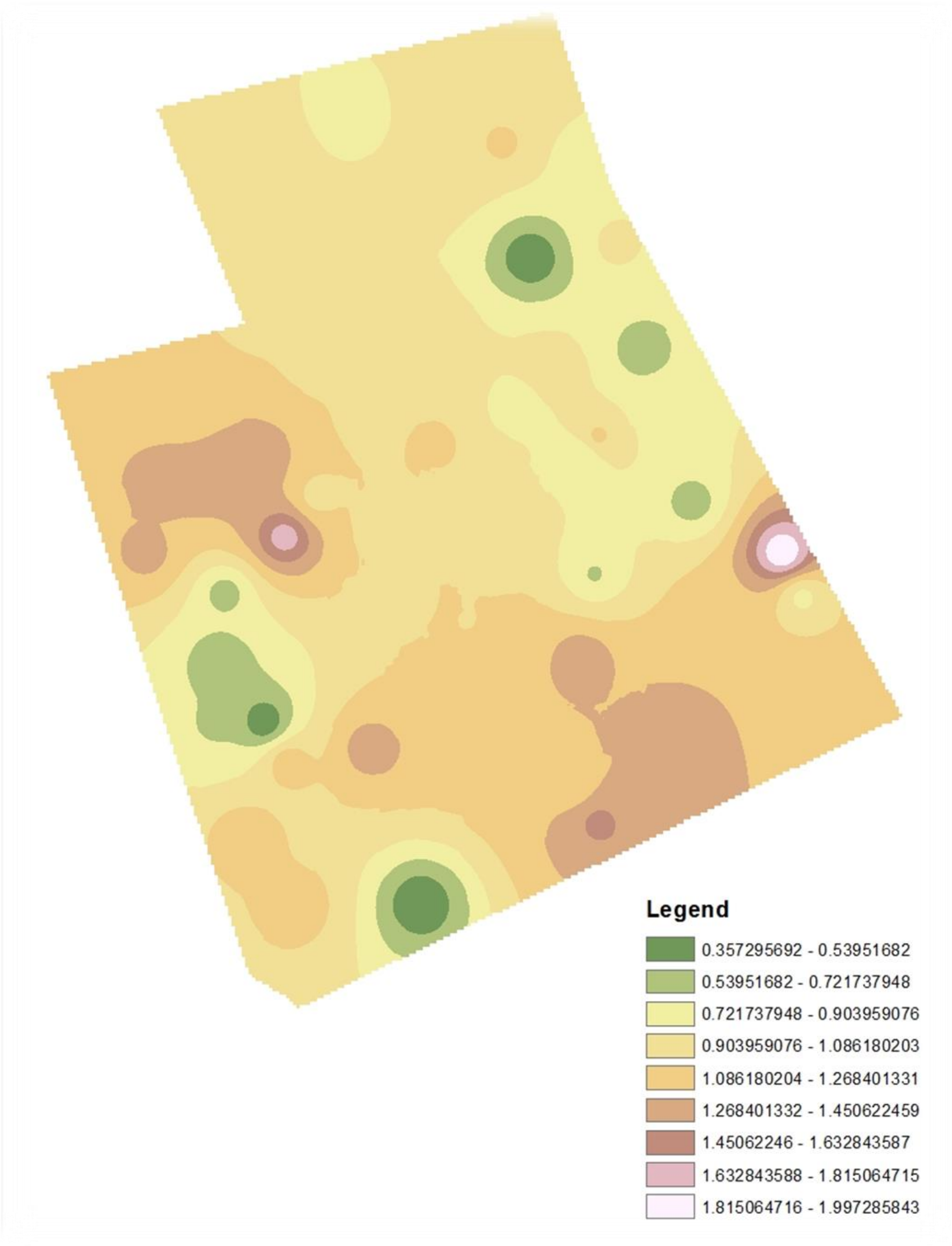
APPENDIX G:

FIELD VARIABILITY MAP FOR ELECTRICAL CONDUCTIVITY



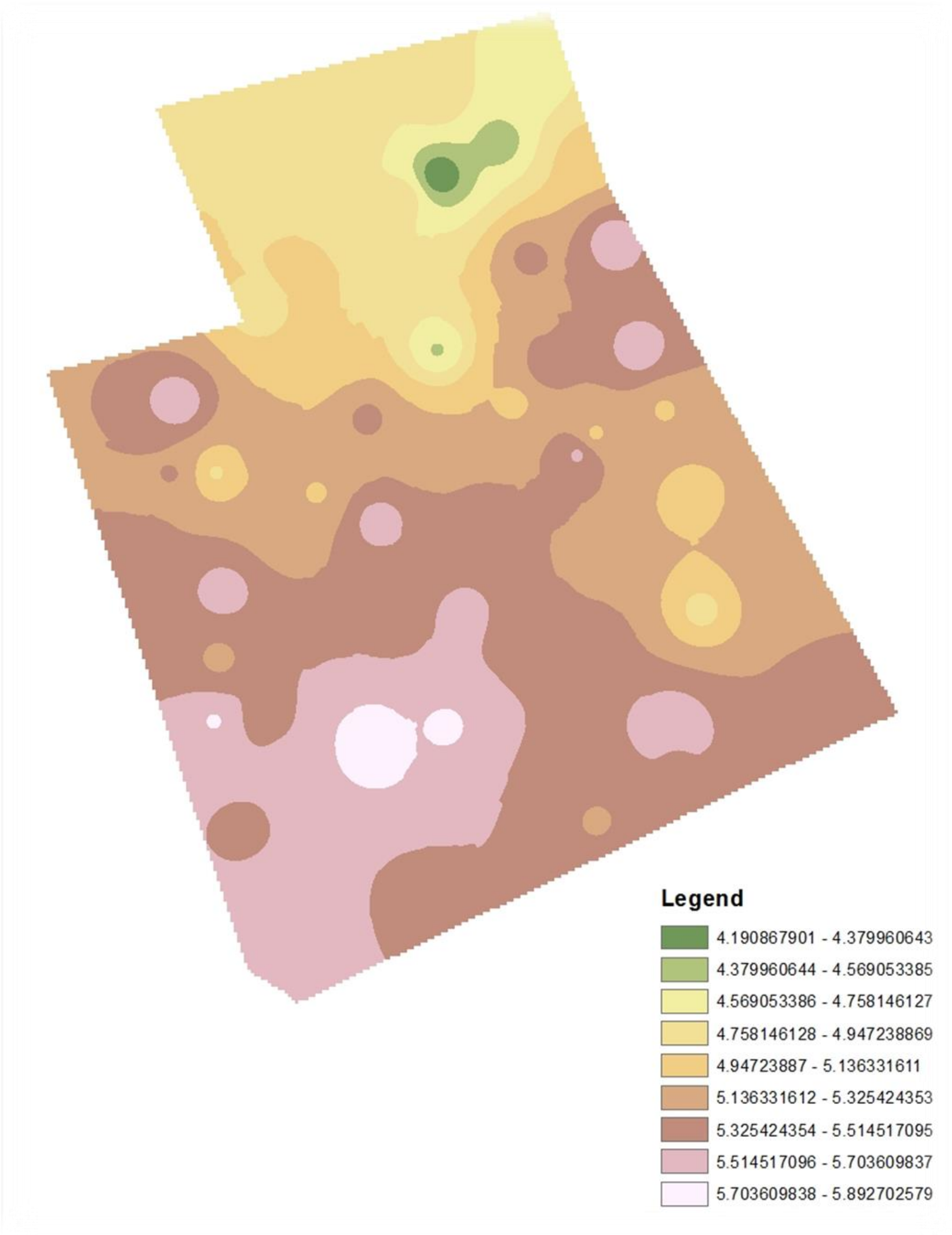
APPENDIX H:

FIELD VARIABILITY MAP FOR AGGREGATE STABILITY



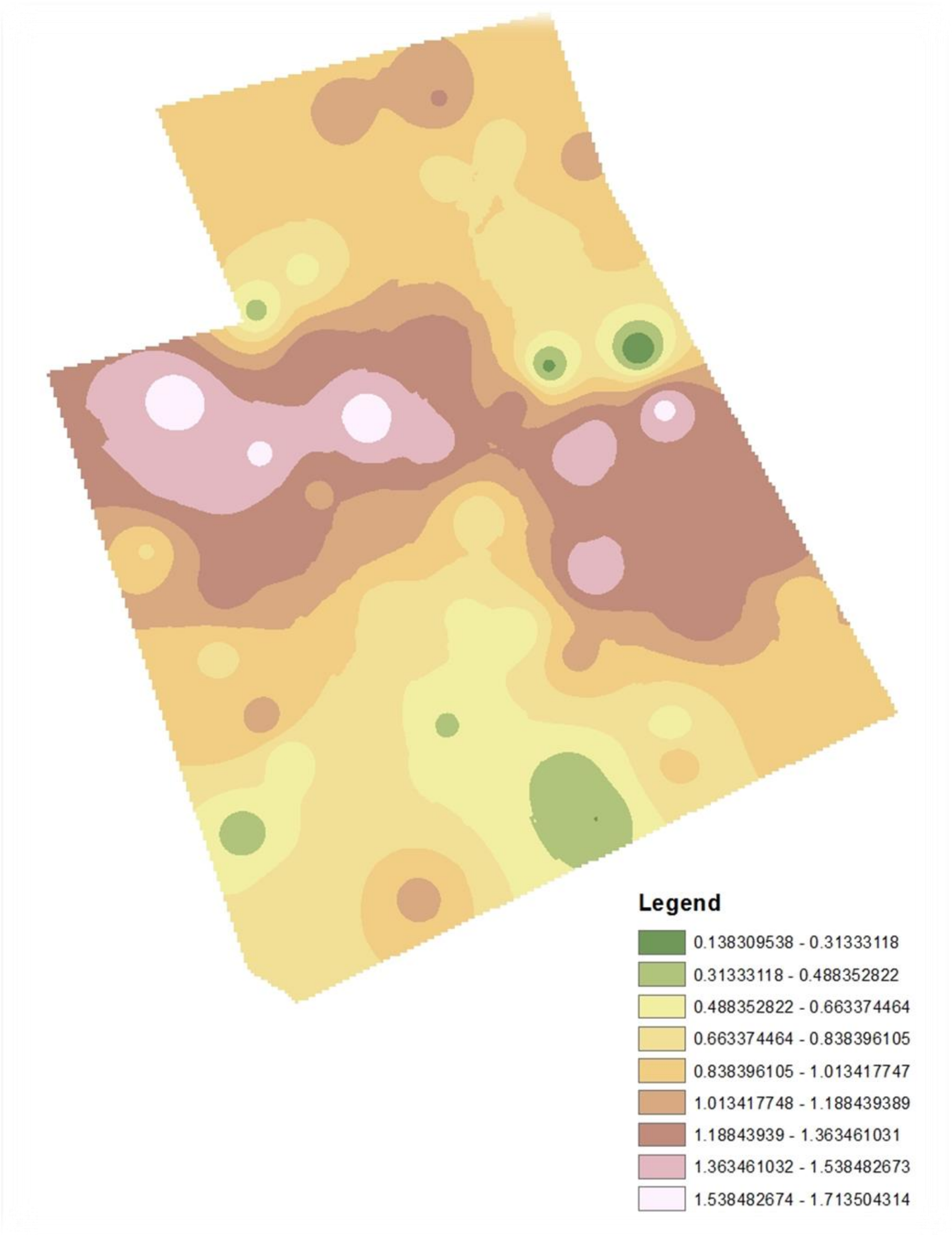
APPENDIX I:

FIELD VARIABILITY MAP FOR SOIL pH



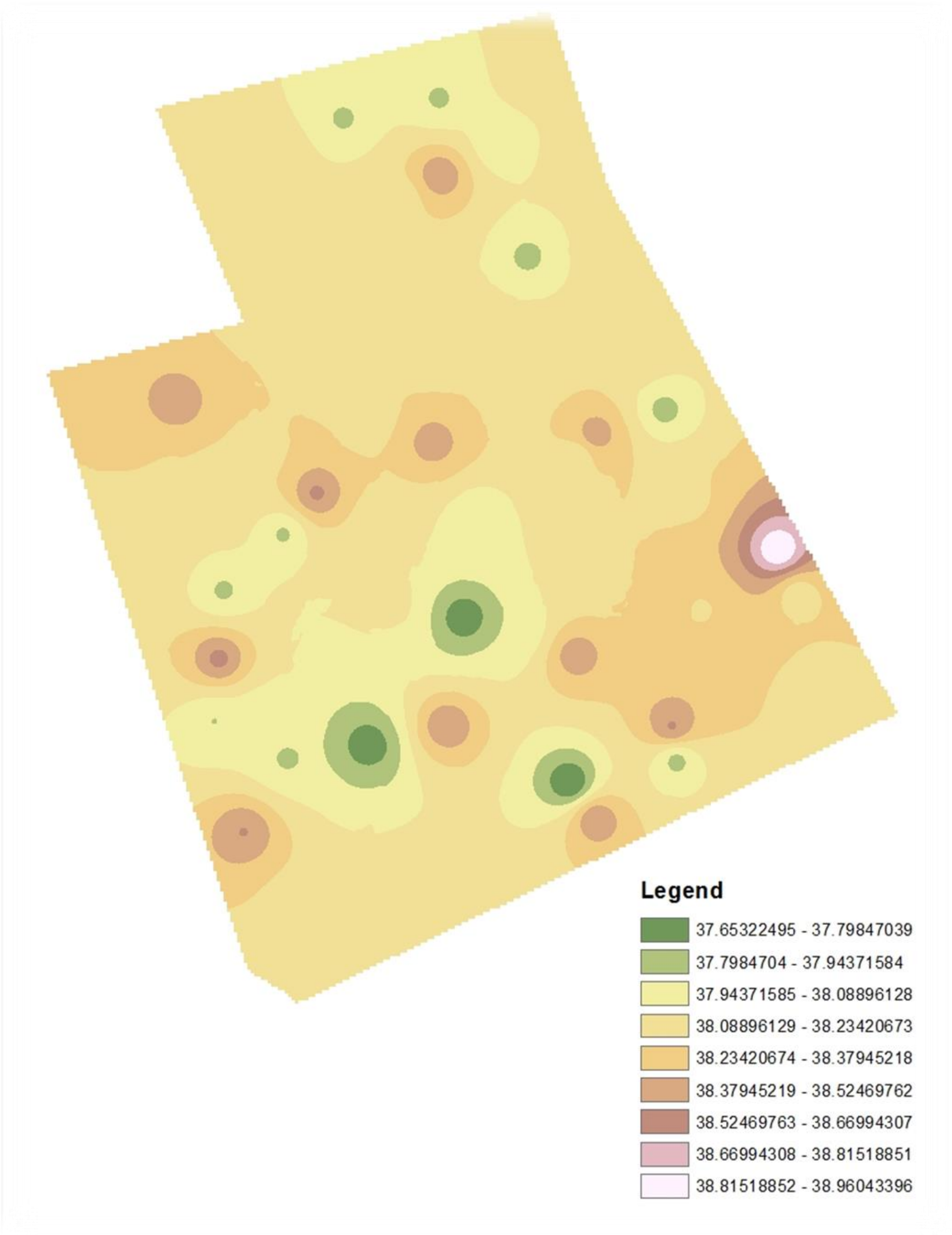
APPENDIX J:

FIELD VARIABILITY MAP FOR ORGANIC CARBON



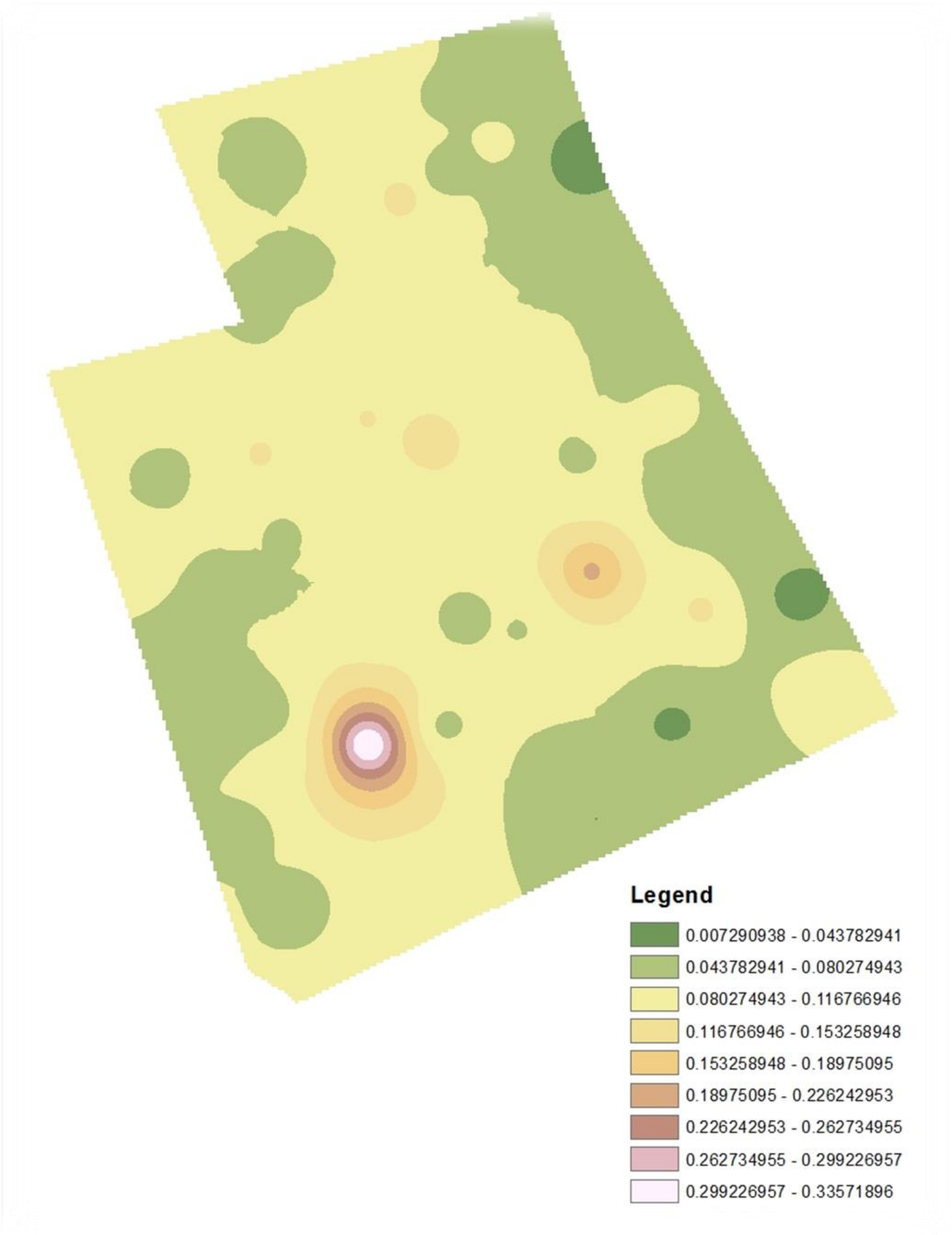
APPENDIX K:

FIELD VARIABILITY MAP FOR SOIL RESPIRATION RATE



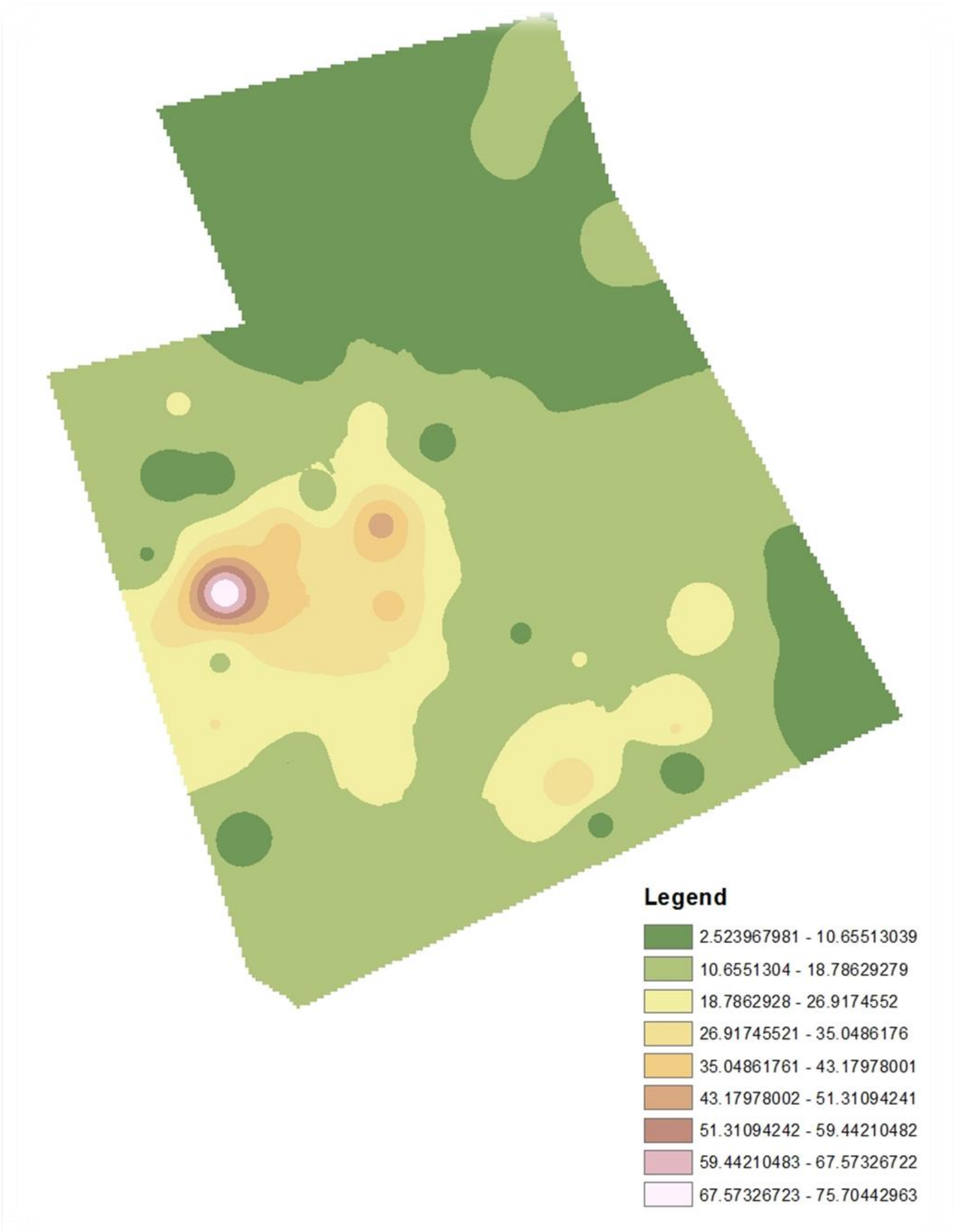
APPENDIX L:

FIELD VARIABILITY MAP FOR NITROGEN



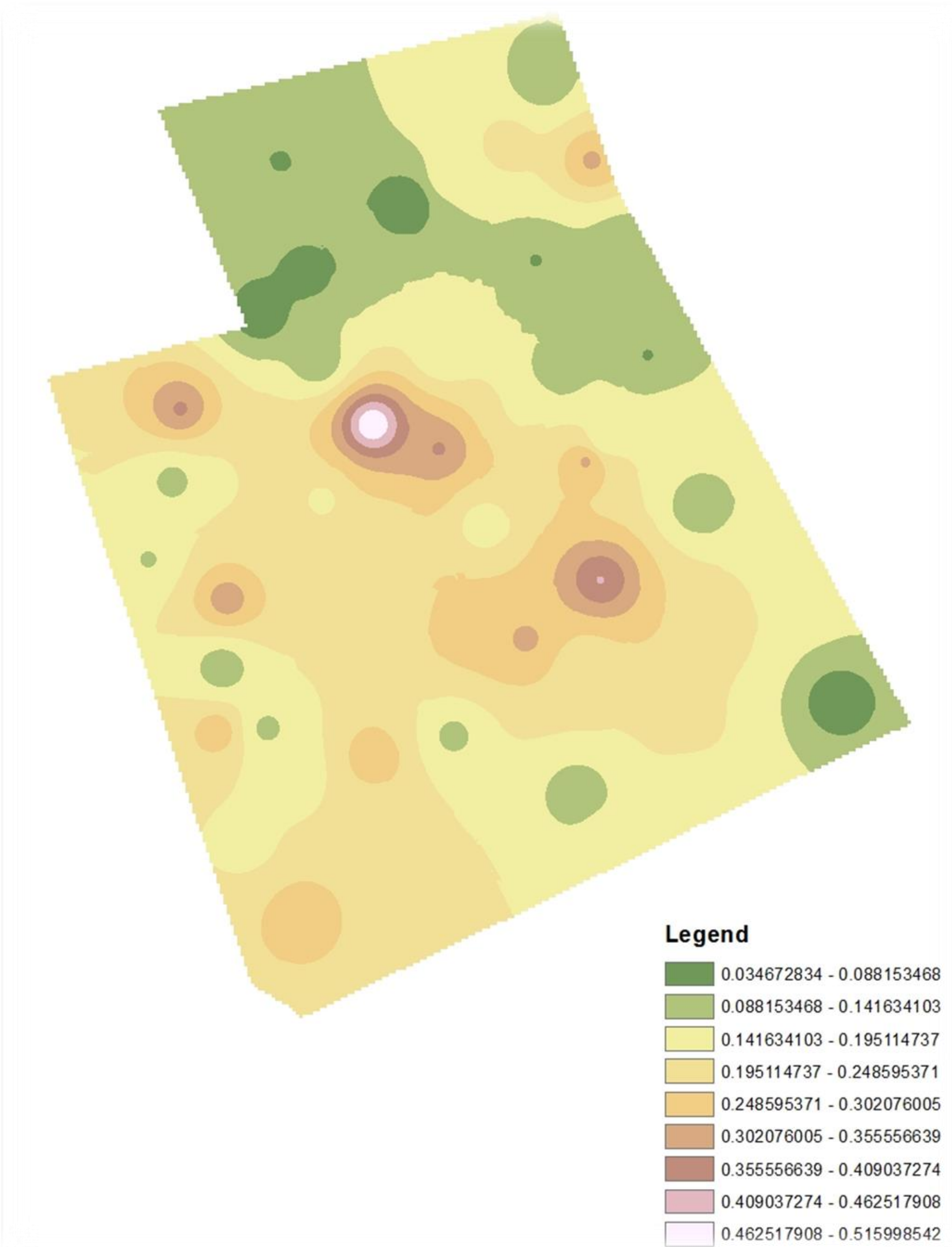
APPENDIX M:

FIELD VARIABILITY MAP FOR PHOSPHORUS



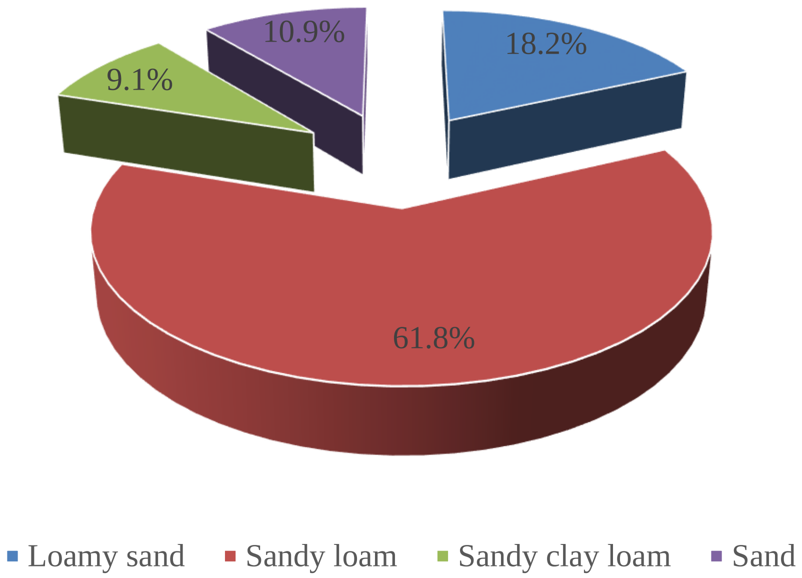
APENDIX N:

FIELD VARIABILITY MAP FOR POTASSIUM



APPENDIX O:

A PIE CHART FOR TEXTURAL CLASSIFICATION FOR STUDY SITE



APENDIX P: QUESTIONNAIRE FOR ASSESSING SOIL MANAGEMENT

UNIVERSITY OF CAPE COAST

COLLEGE OF AGRICULTURE AND NATURAL SCIENCES

DEPARTMENT OF SOIL SCIENCE*Case no.*

Questionnaire for assessing soil management practices employed by farmers of Baafikrom Small scale Irrigation Scheme

This questionnaire is intended solely for academic work. Any information provided by the respondent shall be treated with the highest confidentiality

Sex ☐ Age ☐

Highest level of Education: ………………………………..

SECTION I: Tillage Practices

1. For how long have you cultivated this land? ....years

2. What is the ownership arrangement for this land?
   Share cropping ☐ Periodic rent payment ☐ Own land ☐

3. How did you prepare the land for your current production?
   Mechanized by scheme ☐ Manual (hand-held tool) ☐
   Mechanized followed with weedicide ☐
   Manual followed with weedicide ☐
   Weedicide only ☐

4. What crop(s) was harvested before the current crop(s) on the field? (*If there were more than one crop, indicate the one that occupied the largest area.)*

   ……………………………………………………………

5. How have crop residues been managed after harvest in your past productions?
   Burned ☐ Incorporated into the soil ☐ Cleared of the land ☐
   Left on plot to decompose ☐ Other specify: …………………….

6. What do you do on this plot between harvest and new planting?

   …………………………………………………

7. Have you ever practised rotation on this land?

Yes ☐ No ☐

8. ***If Yes***, How many years have you grown crops in rotation cycle? *(State)*……….years

9. List the crops in their order of rotation?

……………………………………..…………………………………

SECTION II: Water Management

10. What factors affect you decision to water your crops?

……………………………………………………………………………

11. How often do you water your crops? ………………………………………………
Daily ☐ Weekly ☐ Fortnightly ☐ Others specify ☐

12. For how long do you set the sprinkler to irrigate your crops? ……………………

13. Have you ever observed thin and hard layer formed on the surface of bare soil (surface sealing) on your plot dur☐watering? ☐Yes No

14. Have you observed any difficulty of water entry into the soil (infiltration) on any area of your plot during watering?

Yes ☐ No ☐

SECTION III: Fertilisation

15. Were any inorganic/chemical fertilizers applied to your field in the last 3 cropping seasons?
Yes ☐ No ☐

16. ***If Yes***, indicate which type(s) ………………………………

17. What methods did you use to apply the inorganic/chemical fertilizer?
Broadcast and not worked into the soil ☐
Broadcast and worked into soil ☐
Side dress in row or beside row ☐
Sprinklers/ knapsack sprayer ☐

18. How much did you apply? ……………………………

19. What informs your decision on the rate of fertilizer to apply?
    Soil/plant analysis
    Fertilizer Cost
    Stage of crop / Product Label
    External information (e.g. extension agents, fertilizer dealer, neighbours etc.)

    Other (Specify)…………………………………………………..

20. Have you ever applied manure in your production?
    Yes No

21. ***If yes***, which type of manure do you apply?
    Animal manure Crop residue
    Other Specify: …………….

22. What was the method used to apply manure to your plot?
    Broadcast and not worked into the soil
    Broadcast and worked into soil
    Side dress in row or beside row
    Sprinklers/ knapsack sprayer

23. How often is manure applied to your farm?
    Once every season Crop dependant
    Other specify: ……………..

24. Is your choice of inorganic/chemical fertilizer or manure influenced by the specific crop grown or rotation cycle? Yes No

25. ***If yes****, indicate which (crops) receive manure and or commercial fertilizers respectively*

    Manure: ……………………………………………………

    Commercial fertilizers: ………………………………………………

26. How do you perceive the productivity of your soil? ……………………………………………

APENDIX Q: *KMO and Bartlett's Test for Parameters for Indexing Soil Quality*

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**.443**
Bartlett's Test of Sphericity	Approx. Chi-Square	518.760
	df	55
	Sig.	.000

APENDIX R: *Parameter Values Scoring for Raster Reclassification*

Parameter	Accepted value (1)	Not Accepted Value (0)

AS	< 5.0 – 10	> 10
EC (ms)	≤ 4.0	> 4.0
OC (%)	1.0 – 3.0	<1.0
pH	6 – 6.5	<6.0 ; > 6.5
RR ($gg^{-1}s^{-1}$)		
N (%)	0.13 – 0.30	<0.13
P (µg/g)	20 - 100	< 20
K (Cmolc/Kg)	0.45- 2.0	<0.45

Source: (Senthilkumar et al., 2009; U.S Department of Agriculture, 2006; Yeboah et al., 2012)