CHARACTERIZATION OF SOILS USING INFRARED SCANNING IN SOUTH KIVU PROVINCE, DEMOCRATIC REPUBLIC OF CONGO

JANVIER BASHAGALUKE BIGABWA

(Bsc. Agriculture)

A148F/20182/2010

A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Integrated Soil Fertility Management in the School of Agriculture and Enterprise Development of Kenyatta University

June, 2014

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or for any other award.

29/06/2014

Janvier Bashagalueke Bigabwa
(A148F/20182/2010)

Date

We confirm that the work reported in this thesis was carried out by the candidate under our supervision

29/06/2014

Dr. Jayne Mugwe
Department of Agricultural Resource Management

School of Agriculture and Enterprise Development

Kenyatta University

30/06/2014

Dr. Pieter Pypers
Tropical Soil Biology and Fertility Institute of the
International Centre for Tropical Agriculture
(TSBF-CIAT), Nairobi-Kenya

Date

DEDICATION

This thesis is dedicated to my parents and all my primary school teachers. Thank you, God for your blessing.

ACKNOWLEDGEMENTS

Thank you, God for this great achievement of my life and many other blessings in our family.

I wish to express gratitude to my supervisors, Dr Jayne Mugwe and Dr Piter Pypers for their guidance and support throughout my research and for offering valuable comments on this work. In addition I cannot forget the contribution of Prof Benson Mochoge to this work. I came to Kenyatta University and he was the first person I met. He agreed to admit me because you could read French and understand my transcripts. I wish to thank other Kenyatta University Lecturers from the school of Agriculture for taking care of us during the hard time of course work; especially when it was hard with the language issues. I would also like to thank my friends and colleagues at the faculty of Agriculture of Catholic University of Bukavu (UCB) for their assistance during the soil survey within the hills of South Kivu. I thank them for climbing mountains and hills together during the soil survey; some of you have never forgotten that moment with our GPS guidance; and asking every time how many meters remaining and celebrating in the evening after being able to cover ten plots. Appreciation goes to the International Center of Research of Agro forestry (ICRAF) and International Centre of Tropical Agriculture (CIAT) Institutes for supporting my research in laboratory analysis and also data analysis. For the African soil information service team I cannot forget your support for this study by accepting to train us on land degradation surveillance framework (LDSF) to conduct this research in Democratic Republic of Congo especially Dr Markus Walsh ; Dr Keith Shepherd; Dr Tor Vagen; Dr Leigh; Mr. Andrew Sila.

Many thanks to my parents: Bonaventure Bigabwa and Ernestine M 'Banywesize for their contribution to my education. To all the family members and friends, I appreciate your support and I'm very grateful. I cannot forget you Gilba, as a friend and old brother for helping me to understand social relationship.

I would also like to thank all the contributors of scholarships that I have received during the time at Kenyatta University from Vlaames Interuniveistaire Road (VLIR) write in full through Prof Dr Ir Pascal Bockx and Prof Dr Ir Jean Walangululu.

I have been involved into soil science through Dr Sangainga Nteraya for his encouragement to discover this huge and important area of development when my dream was to do Biotechnology during my postgraduate study. Many thanks to Dr Bernard Vanlauwe for his critical and oriented comments for this study and during our stay at TSBF. Dr Pieter Pypers you did more than a supervisor can do, through CIALCA and VLIR activities; I learnt much from you.

All of you friends with whom we shared great moments, I cannot forget you. I am grateful to the land owners for cooperating and allowing access to their land during the survey; we are doing all this research to get a sustainable food security for all of us.

May the Almighty God abundantly bless you!

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AU	African Union
AFSIS	African Soil Information Service
ANOVA	Analyze of Variance
CEC	Cation Exchangeable Capacity
CIAT	Centre International d'Agriculture Tropicale
DRC	Democratic Republic of the Congo
DSRP	
EC	Electrical Conductivity
EDTA	EthyleneDiamineTetraacetic Acid
GIS	Geographical Information system
GPS	Global Positioning System
ICRAF	International Center of Research of Agroforestry
IR	Infrared
ISFM	Integrated Soil Fertility Management
KU	Kenyatta University
MIR	Mid-Infrared
NIR	Near Infrared
PLS	Partial Least Squares regression
PNE	Programme National Engrais
PRAGMA	Programme Régional Agricole de gestions de Marais
PSI	Phosphorus Sorption Index
RMSD	Root Mean Square Deviation
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSA	Sub –Sahara Africa
TSBF	Tropical Soil Biology and Fertility
VLIR	Vlaames Interuniveistaire Road
VNIR	Visible near Infrared

ABSTRACT

Understanding soil properties is an essential pre-requisite for sustainable land management. Assessment of soil properties has long been done through conventional laboratory analysis, which is costly and time consuming. Therefore, there is a need to develop alternative cheaper and faster techniques for soil analysis. In recent years, special attention has been given to Infrared Reflectance Spectroscopy and chemometrics. Near Infrared Reflectance (NIR) and mid-infrared (MIR) spectroscopy techniques are rapid, convenient and simple non-destructive techniques for quantifying several soil properties. This study aims to characterized soil based on based on infrared spectroscopy. This method were to predict soil pH, soil organic C, total N, exchangeable Al, Ca, Mg, and K, CEC and soil texture for soil samples collected in Sud-Kivu province, Democratic Republic of Congo. A total of 530 composite soil samples were taken from two locations (Burhale and Luhihi) at two depths (0-20 and 20-40 cm) using a spatially-stratified random sampling design within an area of 100 km^2. After minimal sample preparation, the MIR spectrum of a soil takes about two minutes for the analyses. Ddifferences in characteristics were evaluated between the two locations, land use (cultivated vs. non-agricultural land) and soil depth. A random subset of the samples (10%) were analyzed using standard wet chemistry methods, and calibration models developed using MIR data to estimate soil properties for the full soil sample set. Partial least squares regression (PLS) method gave acceptable coefficients of determination between 0.71 and 0.93 for all parameters hence good prediction. Soil organic matter levels were higher in cultivated plots in Luhihi (3.9% C) than in Burhale (3.0% C), suggesting lower levels of soil fertility in the latter area. For both sites, soil pH (water) was generally very low (less than 4.8) This indicates high levels of acidity, which is likely to limit crop production in the area. Phosphorus deficiency was acute for both locations but more for Burhale (2.4 mg P kg^{-1}) than Luhihi (5.4 mg P kg^{-1}). Aluminium toxicity was prevalent in both sites which is attributed to low pH values. The recommended soil management strategies therefore involve liming with dolomite material since Ca/Mg > 4. In both locations, low levels of Ca and Mg indicate that soils may be susceptible to deficiencies of both elements. No risk of K deficiency was observed in the area. These findings suggest new opportunities for monitoring soil quality in the region which can benefit multiple actors in the agricultural and environmental sectors. More efforts are needed to improve the use of these new technologies of monitoring soil and land degradation across developing countries.

CHAPTER ONE

INTRODUCTION

1.1. Background

Soil degradation is one of the most important constraints to food security in developing countries. Science based approaches to agricultural and environmental management are needed to accelerate development progress in the world's poorest countries (Shepherd and Walsh, 2007) so as to improve food security. It is imperative now to increase productivity by investing in soil health across the world. Information on soil chemical and physical properties is needed as guidance in providing advice on land management. This is especially true in developing countries, where soil diagnostic surveillance systems have been proposed to overcome data shortages (Shepherd and Walsh, 2007; Terhoeven et *al.,* 2010). The Democratic Republic of Congo (DRC) is one of the signatories of 2006 Abuja commitment, which recommends to increase the amount fertilizer used from the current average of 8 kg to 50 kg per ha by 2015 (AU, 2006). This declaration is very important to help African countries to improve and sustain their agricultural production. However, before using any kind of fertilizers, it is crucial to have some guidelines related to the nature of the soils according to different agro-ecological variability.

In Sub-Sahara Africa (SSA), although the income is low (DSRP, 2005), it is possible to assist farmers access different kinds of inputs by doing different preliminary studies on soil characterization for sustainable soil management. The adoption of precision agricultural technologies is probably one of the opportunities of the 21st century to expand the horizon of soil and plant analyses by matching the spatial variability of soil properties and crop demand with a variable input of agro-resources in the field (Meyer et *al.*, 2005). Although the area of study, east of the DRC, has high agricultural potential; the few available data on soil are very old from the colonial period and therefore there is a need to update them using new techniques.

Soil physical and chemical properties are important in crop production since they control the availability of plant water and nutrients (Kyou e*t al.*, 2000). The high cost of soil sampling and chemical and physical analysis by conventional laboratories has restricted the full use of this technique at field level (Meyer *et al.,* 2005). New technologies that provide rapid analysis of soil properties are in urgent need across the globe. Such technologies will promote the quantitative assessment of large-scale land management problems, and satisfy the environmental and economic need to manage agricultural land at a much smaller scale and promote the more efficient use of agricultural inputs. Infrared soil analysis approach could be cost and time effective solution (Williams, 1987). Infra Red (IR) reflection spectroscopy is rapid, cheap and non-destructive technique for analysing soils that has attracted interest among soil scientists. It is very useful in determination of several soil properties simultaneously (Viscarra *et al.*, 2006). However, minimal research has been done to promote its accuracy especially in supporting soil health monitoring in small scale farmer conditions from developing countries of SSA. This has contributed to inappropriate recommendations on fertilizers use by farmers since they don't know the state of the quality of their soils:

1.2 Statement of the problem

Soil fertility decline is a major cause of food insecurity in the world. Farmers in DRC lack information on soil fertility management even from extension services or research institutes that can help them understand the health of their soil. The lack of information on soil management and sustainability at farm level reduce soil productivity since farmers are not able to use adequate techniques for yield improvement. In DRC must of the information related to nutrient content in the soil is not available and at the same time most of the research centres do not have adequate equipments for undertaking research. Laboratory costs for soil analysis are very high and unaffordable to majority of the farmers. The current methods (wet chemistry) of soil analysis in most research centres take long to avail results in good time due to many processes involved in wet chemistry methods of analysis. The need, for sustainable and rapid techniques of soil analysis to improve fertilizer use for increased agricultural productivity is urgent particularity pronounced in SSA. Infrared spectroscopy is a new, rapid and inexpensive method of soil analysis but needs to be well understood before it is recommended for wide use. There is currently scanty data to show its accuracy and hence limited applicability for use in making land management decisions. The purpose of this study was therefore to assess the accuracy of this new method as well as use it's results to analyze differences in soil chemical sampled from different areas of east of RDC.

1.3 Broad objective

This study aimed to use Mid-Infrared approach to characterize soil in east of Democratic Republic of Congo. It assesses the ability of this new method of soil analysis to provide rapid and reliable quantification of soil properties.

1.4 Specific objectives

1. To determine the degree of relationship between values of soil parameters determined through MIR and measured values by the wet method of soil analysis.
2. To identify differences in soil parameters between cropped and uncropped areas in different agro-ecological zones.
3. To examine differences in soil parameters between top soil and sub soil in different agro-ecological zones.

1.5 Research Hypotheses

1. There is a good correlation between measured values from wet chemistry and estimated values from MIR scanning.
2. Soil properties are significantly different between cropped and un-cropped soils.
3. Soil organic matter and available P is significantly higher in top soil than sub soil.

1.6 Significance of the study

The findings of this study will benefit both farmers and researchers. Researchers from national and international organisations in the region will be provided with accurate soil information, and indications on the predominant soil constraints for crop production. This will provide a framework for diagnostic trials which will link prevailing soil conditions with response to specific nutrients, lime and organic amendments, and ultimately provide farmers with site-specific recommendations for soil fertility management and crop production.

1.7. Conceptual framework

As described by the Figure 1.1, the poor laboratory equipment observed in the region affects strongly the agricultural development. Few soil data are available and soil analysis with the poor equipped labs takes time for results to be released and this is expensive. Active stakeholders from the region lack information which can be used for making specific soils fertility management strategies therefore a deterrent to addressing soil degradation. . To address this problem a new approach based on infrared scanning as it is widely used in medicine actually but not much used in soil science for soil aptitude assessment. However, it is better is better to have a technical and material support for these new materials of soil analysis. To address the problem of soil degradation, trainings are also required by the involved agents of research and extension centers.

The results from the new methods will be used for specific recommendations on soil fertility degradation addressing improving crop yielding from the region. This will also open an opportunity for local and regional markets for: inputs since stakeholders know already how to apply them. Therefore markets will be provided with agricultural products since there is already improvement of the yield and this will allow farmers to invest by buying again agricultures inputs.

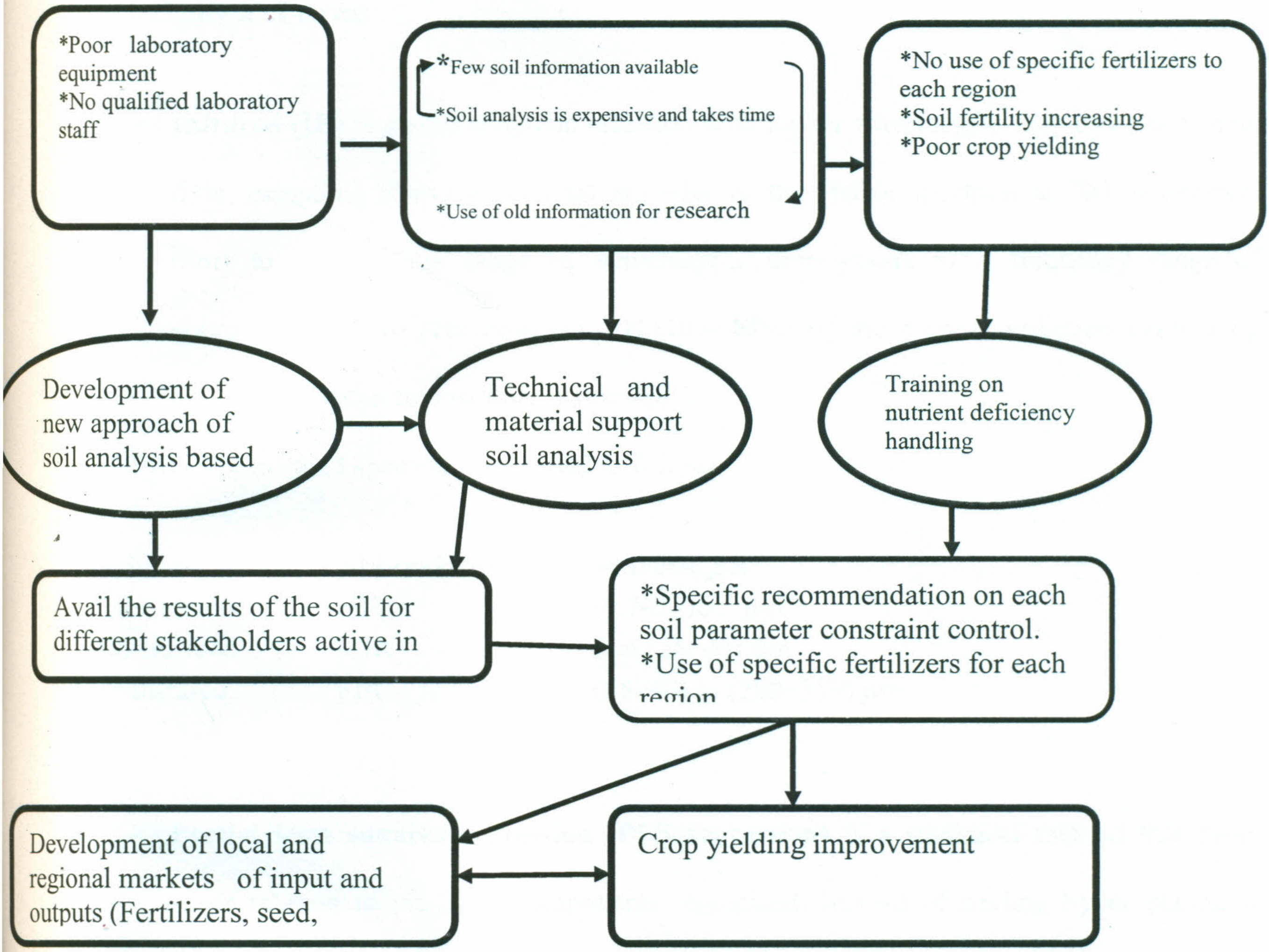


Figure: 1.1. Conceptual framework showing linkage of availability of good soil analysis tools and the potential to address soil degradation.

1.8 Definition of terms

- **Infrared (IR)** is electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 700 nanometers (nm) to 1 mm. This range of wavelengths corresponds to a frequency range of approximately 430 THz down to 300 GHz. Most of the thermal radiation emitted by objects near room temperature is infrared.

Typically infrared spectrum is divided as follows:

Designation	**Abbreviation**	**Wavelength**
Near-Infrared	NIR	(0.7–1) to 5 μm
Mid-Infrared	MIR	5 to (25–40) μm
Far-Infrared	FIR	(25–40) to (200–350) μm.

- **Partial least squares regression (PLS regression)** is a statistical method that bears some relation to principal components regression; instead of finding hyper planes of minimum variance between the response and independent variables, it finds a linear regression model by projecting the predicted variables and the observable variables to a new space. Because both the *X* and *Y* data are projected to new spaces, the PLS family of methods are known as bilinear factor models. (Abdi, H. 2010; (Haynes and William M.2011; Jones *et al.*, 2001).
- **Wet chemistry** is a term used to refer to chemistry generally done in the liquid phase. It is also known as bench chemistry because many of the tests performed are done at a lab bench. Traditionally, it involves the use of laboratory glassware, such as beakers and

flasks, and excludes quantitative chemical analysis using instrumentation. Many high school and college laboratories teach students basic wet chemistry methods.

- **Exchangeable cations**: The clay mineral and organic matter components of soil have negatively charged sites on their surfaces which adsorb and hold positively charged ions (cations) by electrostatic force. This electrical charge is critical to the supply of nutrients to plants because many nutrients exist as cations (e.g. magnesium, potassium and calcium). In general terms, soils with large quantities of negative charge are more fertile because they retain more cations (McKenzie *et al.* 2004) however, productive crops and pastures can be grown on low CEC soils. The main ions associated with CEC in soils are the exchangeable cations calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}), and are generally referred to as the base cations. However, as soils become more acidic these cations are replaced by H^{+}, Al^{3+} and Mn^{2+}, and common methods will produce CEC values much higher than what occurs in the field (Abdi, 2010).
- **Phosphorus sorption index:** is a soil parameter indicating how strongly soluble P is sorbed by the soil. Low levels (<50 units) present a risk of P leaching, especially at high P test levels. If PSI is High (>250 units), large initial dressings can be used to build up soil P stocks. If annual dressings are made then fertilizer should be placed or banded near the plants to increase uptake efficiency. Organic matter applications may reduce P fixation and increase P availability on soils with High PSI (ICRAF, 2009).
- **Soil organic matter** (SOM) is the organic matter component of soil, consisting of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by soil organisms. SOM exerts numerous positive

effects on soil physical and chemical properties, as well as the soil's capacity to provide regulatory ecosystem services. Particularly, the presence of SOM is regarded as being critical for soil function and soil quality (Périé and Ouimet. 2008).

- **Total nitrogen**: is the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+) in the chemical analysis of soil, water, or wastewater.
- **Land use:** It concerns the products and/or benefits obtained from use of the land as well as the land management actions (activities) carried out by humans to produce those products and benefits."[2] As of the early 1990s, about 13% of the Earth was considered arable land, with 26% in pasture, 32% forests and woodland, and 1.5% urban areas.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil characteristics determination

2.1.1 Simple observation

Simple observations on soil surface can give information on soil properties, such as, soil color, type of vegetation present on soil and their health status can help to assess soil characteristics (Walsh and Vågen, 2009). The observation method, however, may have some limitations due to complexity and interaction between different factors in the soil (Westhephal, 2005). There is, therefore, a need for laboratory analysis that will quantify soil parameters. This approach (laboratory analyses) is not very useful in rural areas due to some financial limitation to prevent small scale farmers from taking advantage of laboratory soil results Although all laboratories will analyze soils for with payment, these laboratories are few comparing to farmer's need (Sanginga and Woomer, 2009).

2.1.2 Laboratory analysis

For more detailed information on soil characterization, laboratory analyses are the most commonly used. In this method of soil analysis chemical and physical properties are determined by using different procedures of measurement mainly by wet chemical analysis. However, for African researchers, there is still many constraints in regard to availability of well equipped laboratories. Examples of some of the most common analysis and using wet chemistry are shown in Table 2.1 (Okalebo *et al.,* 2002). In general, soils are either extracted or digested, chemically reacted and then differences determined using titration or spectrometers. The only exception is the use of atomic adsorption spectrophotometers in the determination of Mg, Ca and micronutrients (Sanginga and Woomer, 2009).

Table 2.1: Chemical analyses and procedures routinely practiced in African laboratories

Analysis /Parameters	General procedure
Organic C	Heated acid digestion and titration or colorimetric determination
Total N	Kjeldahl digestion and colorimetric determination
Ammonium and nitrate	Extraction, distillation and colorimetric determination
Extractable P	Olsen or Bray 2 extraction and colorimetric determination
Exchangeable K, Mg and Ca	Ammonium acetate extraction followed by flame photometry for K and atomic adsorption spectrophotometry for Mg and Ca
Exchangeable acidity	KCl extraction and titration to neutrality with sodium hydroxide
Soil extractible sulphate	Extraction with potassium phosphate followed by UV spectrophotometry for turbidity
Soluble Cu, Zn, Fe and Mn	Chelation with EDTA followed by AA spectrophotometry

Source: Okalebo, 2002

Physical properties of soil depend on the size of particles (sand, silt, clay). Soil particles occupy roughly more than half the space in the soil, the remaining space between the particles, called the pore space, and is occupied by water and air. The stability of soil aggregates depends on the organic matter content of individual soils and the nature of microbial products which binds particles together (Okalebo, 2002).

Due to the constraints related to the cost and complexity of the current laboratory analysis methods, there is a need to develop practical new tools of soil analysis. The need for rapid and inexpensive techniques for soil characterization to support agricultural and agro-ecological management decisions has led to the use of modern technologies (Shepherd and Walsh, 2002; Mckenzie *et al.*, 2000) such as reflectance spectroscopy.

2.2 Use of infrared spectroscopy in analysis of soil properties

Infrared spectroscopy is a well established technique for the identification of chemical compounds and/or specific functional groups in compounds, and thus is a useful tool for soil applications (Du *et al.*, 2008). Spectroscopy is the study of light as a function of wavelength that has been emitted, reflected, or scattered from a solid, liquid, or gas (Clark, 1999). When light strikes a material, it is absorbed, reflected, or transmitted, and spectral measurements can quantify the amount of light reflected or transmitted (Workman and Shenk, 2004). Figure 2.1 presents wavelengths for different spectroscopy zones. MIR and NIR zone as the most used as Infrared zones for the soil properties analyzes ranged from 25000nm to 2500 nm^{-1} and 2500 to 780 nm, respectively

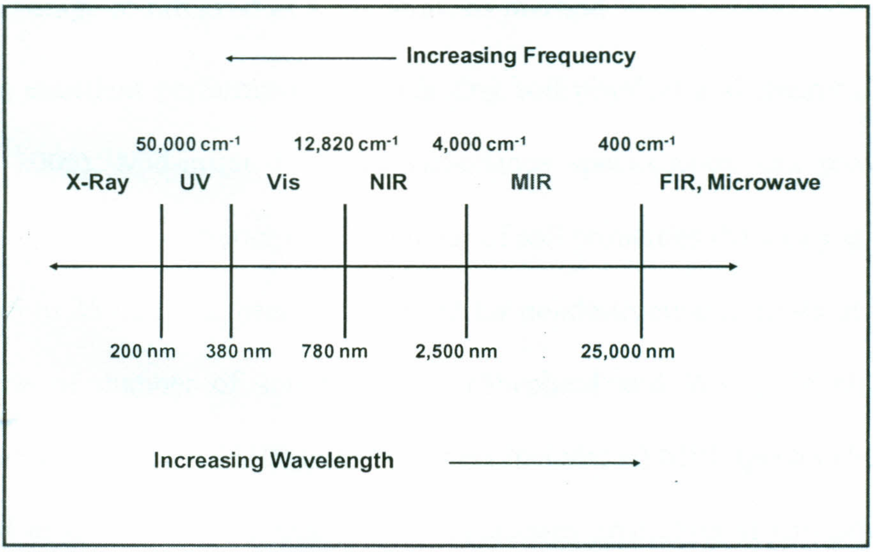


Figure 2.1: The electromagnetic spectrum of the different spectroscopy zones (ICRAF, 2009)

Diffuse reflectance spectroscopy measures the scattering of light reflected at all angles from a surface. When the diffuse reflectance of a material is measured, the absorbance bands provide information about the material's molecular composition. Absorbance peaks are viewed as valleys of the spectral signature when presented as reflectance (Reeves *et al*., 1999). The three key parameters in a spectrum that are important are ; 1) the wavelength at which peaks occur, 2) the amplitude of the peak compared with a 100% reflected or transmitted standard, and 3) the bandwidth, which refers to the broadness of the peak (Workman and Shenk, 2004). Visible to mid-infrared (MIR) spectroscopy has been used to quantify soil properties with varying accuracies of results (Reeves *et al*., 1999). . The visible, near-infrared (NIR), and MIR spectral ranges are 350 to 700 nm, 700 to 2500 nm, and 2500 to 25000 nm, respectively. Mid-infrared spectroscopy works better because the fundamental absorptions of interest in soils exist in the MIR range (Mcarty *et al*., 2002).

2.3 Advantage of infrared as a soil analysis method

IR is an excellent performance of predicting soil physical and chemical properties (Carty and Reeves 2006). Mid-infrared diffuse reflectance spectroscopy can provide rapid, cheap and relatively accurate predictions for a number of soil properties (Minasny et *al*., 2008). In addition, MIR (2.5 to 25 mm) has been investigated for nondestructive analysis of soils and simultaneous prediction of number of soil properties (Shepherd and Walsh, 2009). In addition to these important advantages of MIR analysis others include; (i) MIR spectra (from 30 to 50 scans) are acquired in less than one minute and simultaneous prediction of soil properties takes only few seconds and it is possible to achieve throughput in excess of 200 samples in 7 hours using IR methods (Mcarty *et al*., 2002); (ii) samples used for MIR analysis require minimal treatment and only a few grams of powdered, air-dry soil are required; (iii) better analyses can be obtained if samples are ground to less than about 0.1 mm particle size, but re-designed systems may avoid this and its associated costs.

The use of a dry soil samples has several advantages, for example expensive or toxic chemicals are not required, soil samples need not be air dry, or in a near dry, standard state, simultaneous analyses for more than more parameter can be carried out. This makes the analysis to be fast, with fast turn around times and digital output that can be directly applied using decision support systems (Malley *et al.*, 2005). Also, MIR instruments can be calibrated to predict some useful functional soil parameters that are not commonly performed in the current laboratories because they are overly time-consuming (Xiaomei, 2006).

2.4 Predicting soil properties using mid-infrared spectroscopy

Mid-infrared (MIR) can predict a wide range of chemical and physical soil properties that are closely related to many properties of soil e.g., clay, organic matter, moisture content, cation capacity and mineralogy). It must be remembered that, the MIR technique predicts many soil properties; it does not measure them directly, but by prediction using modeling (Næs et *al.*, 2002). Because of the specific infrared signatures of the organic and mineral components, it is possible to predict many of the soil properties from single MIR spectra using PLS (Partial Least Squares Regression) analysis or PCA (principal component analysis) (Malley *et al,* 2005). Many soil characteristics can be assessed by MIR (Table 2.2).

Table 2.2: Typical soil properties predictable by Mid Infrared

Chemical properties	**Physical properties**
Organic carbon, charcoal, particulate organic, inorganic C, Total N	Bulk densisty
Exchangeable cations (Ca, Mg,K,Na) and CEC	Particle size : Clay, silt, sand
Phosphorus buffering index	Volumetric water contents
PH, water and $CaCl_2$	Quantitative X Ray Reflectance XRD content :quartz, kaolinite, smectites
Electrical conductivity	Quantitative XRR: Si, Al, Fe, Ca, Mg
Exchangeable sodium percentage	

Source: ICRAF, 2009

This means that MIR as well as other methods of IR (Visible near infrared: VNIR) have many applications in soil analysis and can provide high quality results with more advantages than traditional methods of soil analysis (ICRAF, 2009).

2.5. Land use and soil nutrients

Continuous cropping without adequate restorative practices may endanger the sustainability of agriculture. Nutrient depletion is a major form of soil degradation. A quantitative knowledge on the depletion of plant nutrients from soils helps to understand the state of soil degradation and may be helpful in devising nutrient management strategies. Annual cropping reduces the amount of time decomposition occurring without crop residue inputs (Lich 2003).The effects of soil and crop management practices on nutrient dynamics especially SOC and TN , in part, depend on soil properties and environmental factors, such as soil texture, clay mineralogy, topography, and climate. Therefore, an understanding of possible differential effects of management practices on soil nutrients dynamics of different soil types and under different production areas is essential in developing best management practices (Campbell et al., 200). Prudent management of row-crop fields can increase soil C stocks. Reduced tillage, nutrient management, and water conservation are management practices that can be implemented to promote C sequestration and other soil elements (Lal, 2004). Higher residue producing crops in top soils such as corn can increase SOC better than crops that produce fewer residues, such as soybean. Cropping systems can impact soil microbial biomass, which is an important component of the SOC pool and may be an early indicator of SOC changes. (Hargreaves *et al.* 2003) and Ma et al. (2000) found that microbial biomass C (MBC) content can increase as much 168% 2 years after switch grass establishment on previously cropped soils and this is also an important source of nutrient in the soil that is not very high when microbial activities are not active.

2.6. Soil nutrient parameters variation with the depth

The variability in the soil of nutrient according to the depth is also associated to that microbial activity that is not very important at the deep level (Liebig, 2004). The soil metabolisms are therefore affected by the low oxygen and only anaerobic microorganisms can slowly continue the mineralization. As the interface between the atmosphere, biosphere, and lithosphere, soil undergoes an intense vertical exchange of materials resulting in steep chemical and physical gradients from surface to bedrock. Soil stratification is the most visible result of this exchange, and its extensive observation and synthesis form the basis of pedogenetic and taxonomic study The suite of mechanisms that shape the vertical distribution of soil nutrients can be grouped in at least four major processes: weathering, atmospheric deposition, leaching, and biological cycling. Weathering dissolution and atmospheric deposition affect the depth at which nutrient inputs occur (Kirby 1985). Leaching and biological cycling influence the vertical transport of nutrients in opposite way. Acting in isolation, leaching moves nutrients downward and may increase nutrient concentrations with depth. In contrast, biological cycling generally moves nutrients upwards because some proportion of the nutrients absorbed by plants are transported aboveground and then recycled to the soil surface by litter fall and through fall. Plant cycling should therefore produce nutrient distributions that are shallower or decrease with depth (Charley and West, 2005). The distribution of different soil nutrients according to different depths (Figure 2.1) makes understand that all the soil elements don't follow the same variation with de depths. This is specifically related to the different soil processes that affect each element individually.

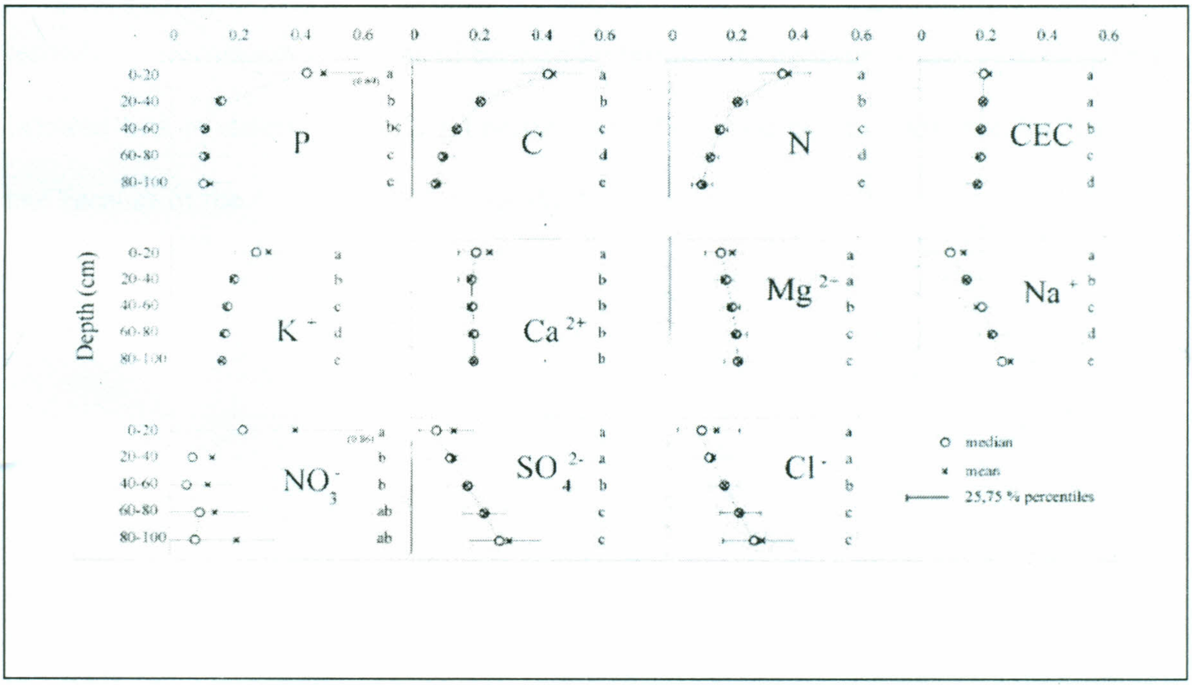


Figure2.2: Soil parameters variation according to the depths (Charley and West, 2005)

2.7. Summary of Research gaps

Infrared spectroscopy applied in agricultural science is giving good success for soil characteristics assessment. However, this approach is still new and not many scientists have been able to use it. This method cannot also be used alone without the combination of wet chemistry results even at low level. Therefore, the development of this new method cannot be an option to abandon totally the classic methods of soil analysis. The results need to be interpreted by qualified scientists and this might be a challenge for some researchers without a good background in this area. In the literature, anywhere farmers are concerned by the output directly. They will still need the feedback from scientists to take decision on their farms management for addressing soil fertility depletion. This means that this area, is very scientific and the secondary information is the one to be used by farmers. Even there is under development of new infrared kits to determine soils properties directly on farms, this will not be also for farmers use because of the complexity of the method.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted in the eastern region DRC within South Kivu province. This region is characterized by highland features with a very high population density and high rain fall (Farrow *et al.,* 2006). Burhale and Luhihi are the two site selected for this study as shown on Figure 3.1.

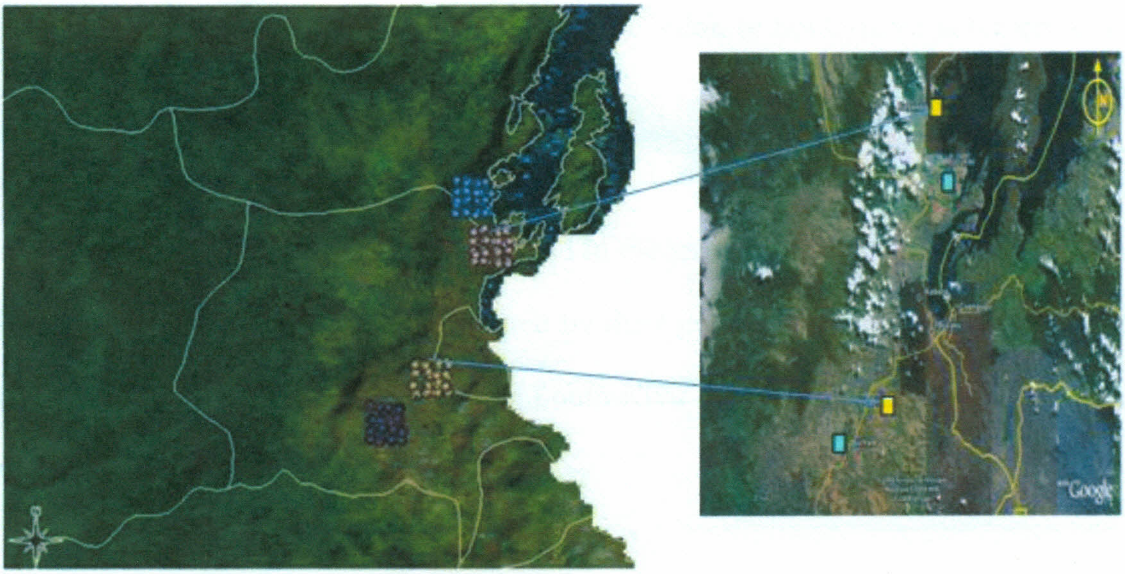


Figure 3.1: the Study area with the two sites: Burhale and Luhihi

In 1996, South-Kivu had a population of 2,830,033 inhabitants, with a density of 43.5 inhabitants /km^2. In 2005, the population density in the territory of Walungu (Burhale) was 265 inhabitants/ km^2. This population density keeps rising, as the total population in 2005 was estimated to be 3,500,000 inhabitants (DSRP, 2005) in South Kivu Highland. Population densities are highest in high-altitude areas (PNE, 1998). The high population density in Kivu can partly be explained by the good agro-ecological conditions for crop production of the region relative to other regions in the Democratic Republic of Congo. Nevertheless, the yearly rise in agricultural production in Kivu is as low as 2% compared to a demographic rise of 3.3%. About 70% of the population depends on agriculture (CATALIST, 2007). Overpopulation causes the soils in South-Kivu to become impoverished through erosion and nutrient mining that also causes decreased land area for livestock production resulting in a reduction in the number of animals able to provide the farmers with manure (DSRP, 2005).

The main activity in the region is agriculture. Traditional livestock comprises of cattle, sheep, goats, chicken and pigs. The biggest zone of animal production in South-Kivu is located in the plain of Uvira. In Burhale (Walungu) and Luhihi (Kabare), on the other hand, number of cattle has decreased due to decreasing grazing space as a result of overpopulation. In addition, big plantations of tea, coffee and quinquina can be found in the area (Mateso *et al.*, 1998). Soil types in South-Kivu are diverse, and mainly determined by their geological parent material (Mateso, 1998). Based on the parent material, the soils of South-Kivu can be subdivided into four major groups:

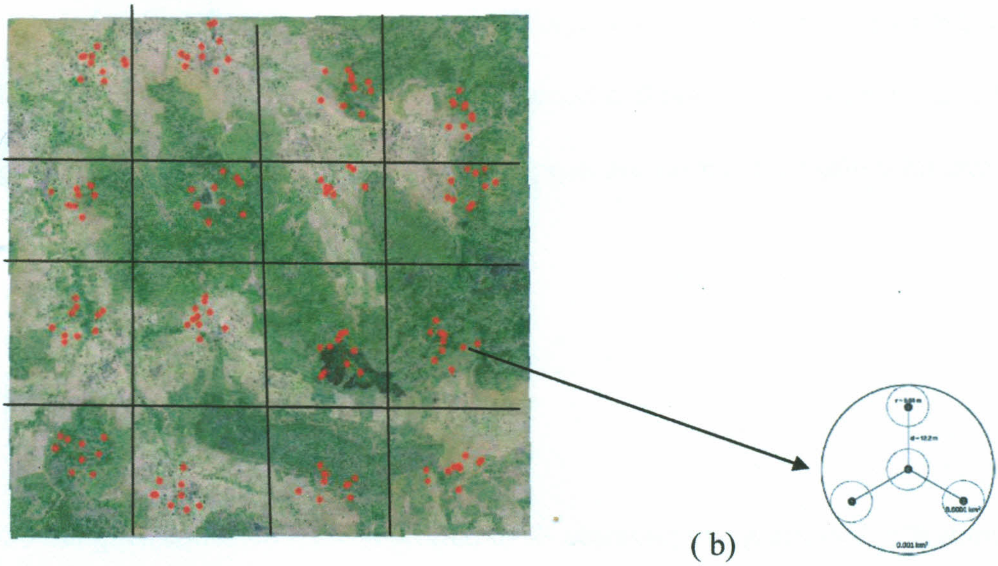
1. Soils that have recently formed on volcanic substrate;
2. Soil developed on old volcanic substrate, mainly basaltic ;
3. Soils formed on old sedimentary and metamorphic rocks (cover extensive areas) and,
4. Alluvial soils and lacustrin and fluviatile deposits of the plains of Rusizi.

3.2 Sites of soil samples collection

Soil samples were collected from two agro ecological zones (Luhihi: latitude: -2.308703°, longitude: 28.863660° and altitude: 1776 m and Burhale latitude: -2.697011° longitude: 28.635356° and altitude: 1623 m) in South Kivu province in East of DRC. Both sites are located not far from each other (93 km) but are in different agro ecological zones. Burhale is dominated by Oxisols with low agricultural potential while Luhihi has Ultisols with relatively high agricultural potential (Ellen, 2008). Most common crops in these two site are; cassava (*Manihot esculenta*), sweet potato (*Ipomea batatas*), common bean (*Phaseolus vulggris*) and banana (*Musa spp*).

3.2. Sampling framework and soil sampling

The sampling plan involved 16 clusters with each cluster sub divided into 10 plots/clusters (Figure 3.1). The number of samples to be collected was calculated as follows; 2 sites* 16 cluster per sites * 10 plots per cluster *2 depths per plot (0-20cm and 20-40 cm) making a total of 640 samples. Stratified random sampling design was used within an area of 200 km^2 for the two sites. Each site of 100 km^2 was divided into 16 equal parts called clusters. Because of some restrictions and two clusters that were not characterized because of lack of access due to security measures (military areas), instead of 640 samples only 530 samples were collected. All observations and soil sampling were done at plot level, meaning that all the data were taken within the plot.



(a)

Figure 3.2: (a) 10 km x10 km for a sentinel site (block) with it 16 sampling clusters (with 1km^2 per cluster), each single red dot =plot) (Walsh and Vågen, 2009)

3.3 Data collection framework

The GPS was the most important tool used for locating the plots. The coordinates for each of the plots were put into the GPS for their identification and localization during the sampling process. The information that was collected from the GPS, during the sampling, for each plot, included:

- Name of the block
- Number of the cluster
- Number of the plot
- Geographical coordinates (altutude ; longitude, latitude)

By moving from a specific place, the GPS showed the distance from the reference place to a targeted plot and the direction to use to get there. The soil sampling was done with augers up to each depth as mentioned above: 0-20 cm and 20-40 cm and after each collection, the augers were cleaned to avoid contamination during the next sampling. Samples were put in paper bags and properly labeled before transferring them to the laboratory at ICRAF in Nairobi for analysis.

The land use factor concerned two elements: cropped and uncropped plots. Cropped plots those with crops during the sampling period and uncropped are farms cultivable with any crop during the three last seasons before the sampling.

4. 4. Soil analysis using Infrared scanning

All the 530 Samples collected were subjected to IR scanning using infrared reflectance spectra in the range of 400 to 7000cm^{-1}. Only a few grams of soil were obtained for the samples (approximately 20 to 30 mg). Air-dried samples were finely ground to powder (approximately

N<100 μm), using an agate pestle and mortar. The samples were loaded into aluminum micro titer plates using a micro spatula to fill the 6-mm-diameter wells and level the soil by taking care to avoid spillage into neighboring wells. The plate had a total of 96 wells; an empty well was used to measure background signal (Figure 3.2) (ICRAF, 2009). Background measurements of the first empty well were taken before each single measurement to account for changes in temperature and air humidity (Mevik and Wehrens, 2007). Aluminum is suitable as a reference material because it does not absorb infrared light (Terhoeven *et al.,* 2010). The bottoms of the Al wells were roughened to minimize specular reflectance. Soil samples were loaded into four replicate wells, each scanned 32 times (figure 3.2), and the four spectra averaged to account for within-sample variability and differences in particle size and packing density.

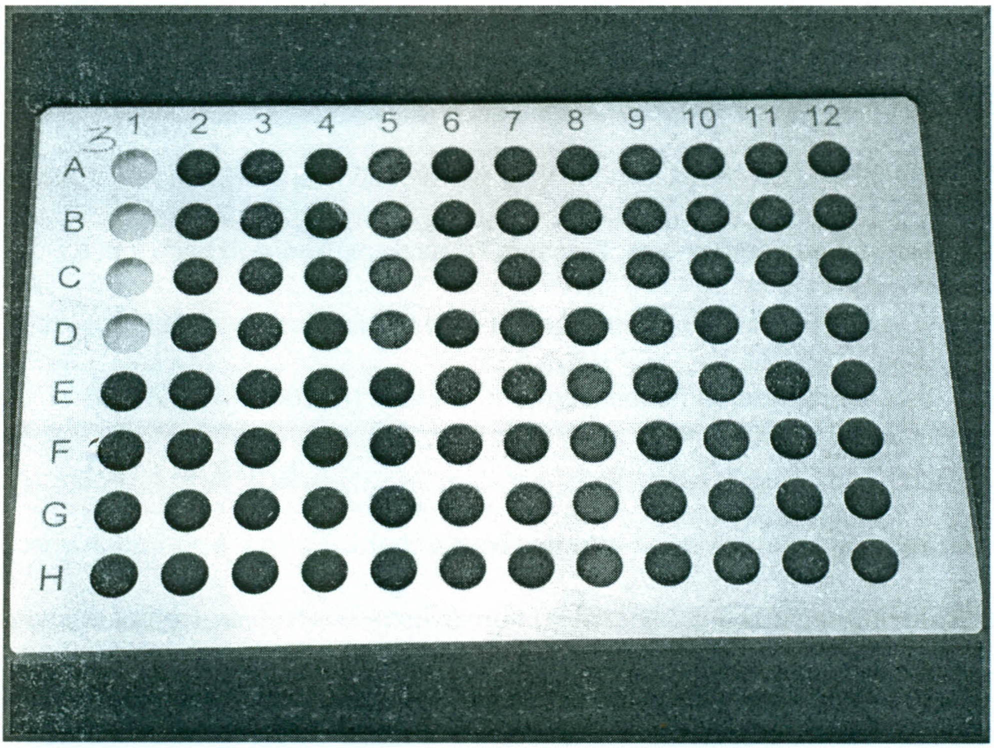


Figure 3.3 : Sample holder: Aluminum micro plate used at ICRAF Laboratory in Nairobi

3.5 Laboratory soil analysis using wet chemistry

Only 60 samples (around 10 % of the 530 samples collected as recommended by AFSIS) were analyzed using wet chemical analysis according to AFSIS approach (Table 3.1) (Vagen et *al.* 2010). This means that the 60 samples were analyzed twice: by scanning and by wet chemistry. Since two clusters were characterized, for the two sites, only 30 clusters instead of 32 were used in the current study. The samples of wet chemistry were taken (10%) every time from the first plots for each cluster of ten plots. The 60 sub samples were selected from the 30 plots with one plot per cluster at the 2 depths (0-20 cm and 20-40 cm). Samples were dried, ground, and stored dry prior to the measurements. For each of the samples the following parameters were determined; pH, organic C, total N, available P, exchangeable bases, acidity, Al, and soil particles size. The different parameters were analyzed by the following procedures (Okalebo, 2002):

3.5.1 **Extraction and analysis of macro & microelements by Mehlich 3:** P, K, Ca, Mg,Al

a) Mehlich 3 Extractant: (0.2 N CH_3COOH + 0.25 N NH_4NO_3 + 0.015 N NH_4F + 0.013 $NHNO_3$ + 0.001 M EDTA : ethylenediaminetetraacetic acid: $[(HOOCCH_2)2NCH_2N(CH_2COOH)_2])$)

Scoop 4 cm3 or 4 g of air-dried, sieved soil into a 100 mL extraction bottle. If a colorless filtrate is needed, add 1 cm3 of activated carbon (NoritTM SG Extra or equivalent) to each flask.

b) Add 40 mL of the Mehlich 3 extracting solution to each bottle.

c) Shake for 5 minutes on a reciprocating shaker.

d) Filter through a medium-porosity filter paper (Whatman No. 42 or equivalent).

e) Analyze filtrate for P, K, Ca, Mg, , Al .

3.5.2 Determination of Soil Phosphorus Sorption Index

The P sorption index (PSI) equals the quotient $X/\log_{10}C$, where X equals P sorbed and C equals the P concentration remaining in solution.

The value of the result depends on the time and temperature of equilibration. These may be adjusted to suit the laboratory facilities and conditions, but it is recommended that the time and temperature ranges should be between 16 and 24 hours and 20° and 30° respectively.

3.5.3 Determination of exchangeable acidity

Exchangeable acidity is determined for 1N KCl extracts of soils, and on soils with pH in water of 5.5 or lower. In this method, a 1:10 soil to extractant volume ratio is used, and mostly applies with soils of higher acidity levels. The acidity is determined by titration with standardized base, sodium hydroxide (Okalebo, 2006).

3.5.4 Determination of soil pH

a) Immerse electrode into the bottle with soil. Always immerse the electrode to the same depth in the bottles, (ensured by marking the immersion depth on the electrode), because repeatability of readings depends upon the procedure being exactly the same each time. Take care not to strike the bottom of the sample bottle with the electrode tip.

b) Record pH reading after reading stabilizes. About 1 seconds to 3 minute is usually sufficient. If pH reading is very slow to stabilize, it is probably due to malfunction of the combination electrode or the meter. Follow manufacturer's instruction for maintenance of electrodes before proceeding.

c) Remove electrode from bottle, rinse with distilled water, and continue with samples.

e) After each 15 samples, re- check one of the buffer solutions to ensure instrument and electrode stability. After each batch of 30 samples, check and record pH values for both buffer solutions. If values are more than ± 0.02 from theoretical, recalibrate the meter before continuing with samples.

3.5.5 Determination of total Nitrogen

Analysis for total nutrient content requires complete breakdown or oxidation of organic matter. Wet oxidation is based on a Kjeldahl digestion with sulphuric acid.

Hydrogen Peroxide is added as an additional oxidising agent. Selenium takes the place of the traditional mercury catalyst, while lithium sulphate is used to raise the boiling point. Only one digestion is required to bring all the nutrients into solution.

3.6. Data handling and statistical analysis

The values of soil parameters of the 530 samples obtained through IR scanning and values obtained from 60 samples through wet chemistry analysis were subjected to correlation analysis (ICRAF, 2009). The quality of prediction was determined by using PLS (Partial Least Squares Regression) model that combine the two data type for the prediction (Næs et *al.*, 2002). For the measured values and estimated values, the coefficient of regression (R^2) and root mean square deviation (RMSD) (Tillmann, 2000; Brown et *al.*, 2005) were used to assess the quality of the prediction. Calculations and statistical analysis were done using R soft ware version 2.7.1 (R Development Core Team, 2008). For interpretation the high R^2 and low RMSD show that, the calibration and prediction were good; the estimated values are closer to true values that have been measured by direct wet chemistry. Good predictions for such a diverse data set are regarded as having an $R^2 \geq 0.75$ (Shepherd and Walsh, 2002; Chang *et al.*, 2001). Satisfactory predictions have an R^2 from 0.65 to 0.75 and predictions below those values were considered to be poor, (Shepherd and Walsh, 2002; Chang et *al.*, 2001; Terhoeven et *al,* 2010).

The root mean square deviation (RMSD) was determined using the following formula according to Brown *et al* (2005):

$$\text{RMSD}= \sqrt{\frac{\sum_{n} (Ypred - Ymeas)^2}{N}}$$

Where,

Ypred = predicted value of the validation set using PLS model

Ymeas = the laboratory measurement of the validation

N = the total number of samples in the validation data

The *t-test* analysis was used to compare the values of the different parameters within a site, the type of land use (cultivated and uncultivated), and depth (topsoil and subsoil) using p-value with Genstat 12th edition software. The variability of each parameter was given by the standard error deviation. This value helps to understand how the different plots of sampling were different. Significance of difference was evaluated at $P<0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Soil parameters prediction

4.1.1 Soil organic carbon

Soil organic C was well predicted for the validation set (R^2= 0.72 and RMSE = 1.07; (Figure 4.1.). This shows that the prediction for this parameter was good. This finding agrees with other soil studies (Barthe et *al.* 2008; Ludwig et *al.* 2008). The results also agree with those of Viscarra Rossel et *al.* (2006) who reported similar accuracy (R^2 = 0.73) for a much less diverse validation set of 118 samples from 18 ha agricultural field in Australia. Similarly, from a global study, Terhoeven *et al.* (2010) reported *an* R^2= of 0.8

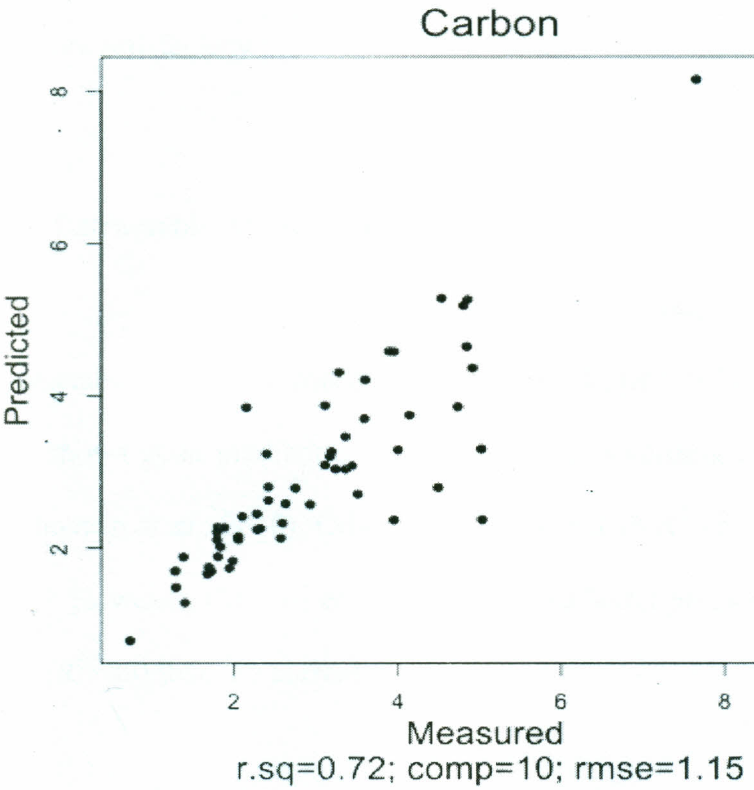


Figure 4.1: Correlation between measured and predicted values of soil organic C

Soil organic carbon (SOC) is a key attribute of soil quality, which influences a variety of biological, chemical and physical properties of soils (Carter, 2002). Consequently, methods to accurately determine SOC are necessary to achieve a better understanding of the nature and dynamics of SOC (Denef *et al.*, 2009). Soil organic carbon is an indication of soil organic matter content, which acts as both a source and sinks for nutrients. Soil organic carbon is linked to soil chemical, physical and biological health, and is strongly correlated with soil nitrogen supply in term of soil fertility management. The satisfactory prediction of SOC (R^2<0.75) helps to monitor the soil status from the study area for a sustainable soil management. A study in Canada reported good prediction (R^2=0.92) (Madari et *al.,* 2006) than the current study. However, according toShepherd and Walsh (2002) and Chang *et al.*(2001) predictions of R^2 ranging from 0.65 to 0.75) are satisfactory.

4.1.2 Extractable Aluminum

Extractable Aluminum was also well predicted t (R^2= 0.71 and RMSE = 1.07 (Figure 4.2). This shows good prediction of this parameter according to the standard of prediction provided (Terhoeven *et al.,* 2010). Other studies reported an R^2 of 0.71 (Brusetal, 2002; Borggaard *et al.*, 2004). However, (Madari *et al* 2006) reported better prediction from his findings using Canadian soils (R^2=88) than the current study.

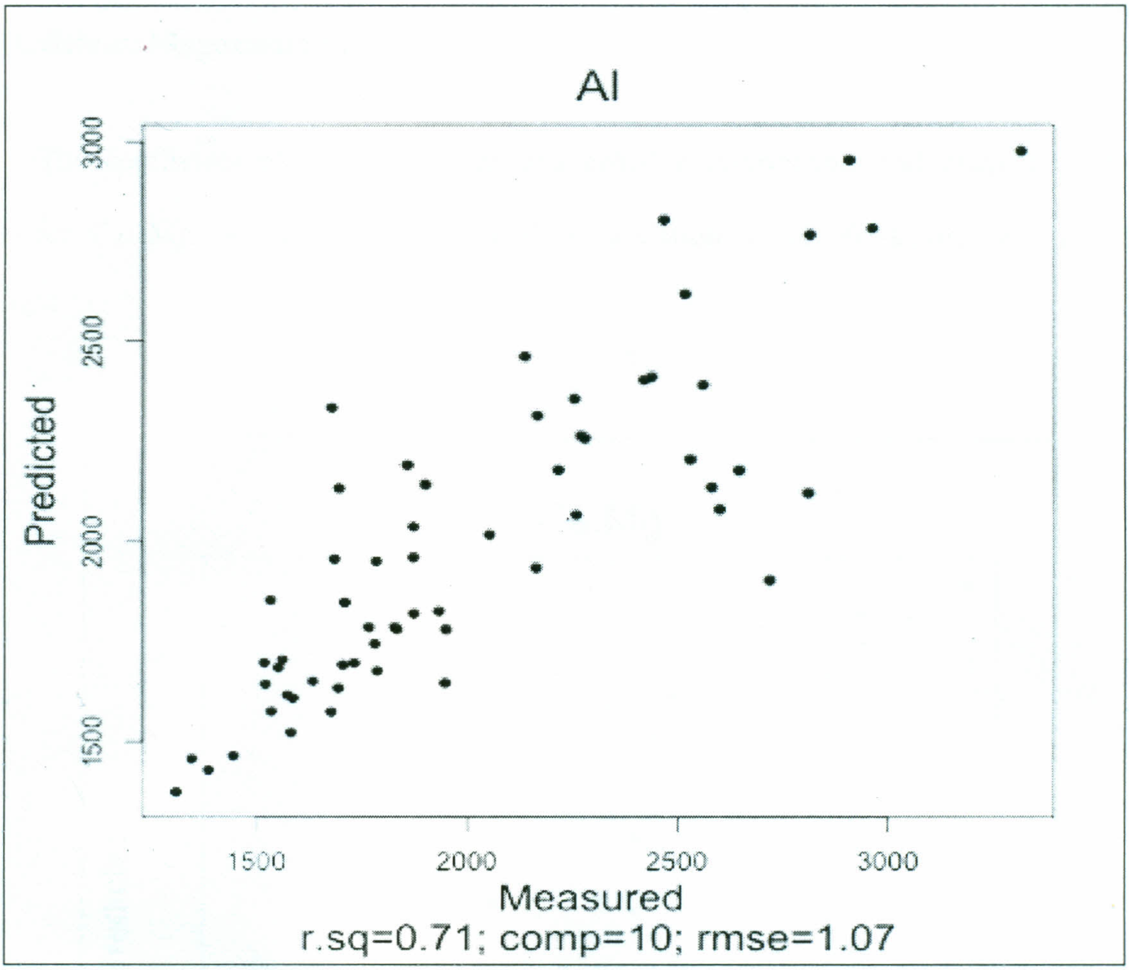


Figure 4.2 : Correlation between measured and predicted values of extractable Al

Soil iron and aluminum oxides bind phosphate that may otherwise be lost from the soil rooting depth. Cheaper determinations of iron and aluminum oxide content will promote better phosphorus management and help alleviate nutrient pollution. The prediction of this parameter by the MIR gives a new area of monitoring soil fertility within the highlands of East of DRC.

4.1.3 Calcium: Magnesium ratio

The coefficient of correlation between actual measurements and predictions by PLS model for Ca: Mg ratio using the independent validation set of 60 samples was R^2 of 0.81 (Figure 4.3).

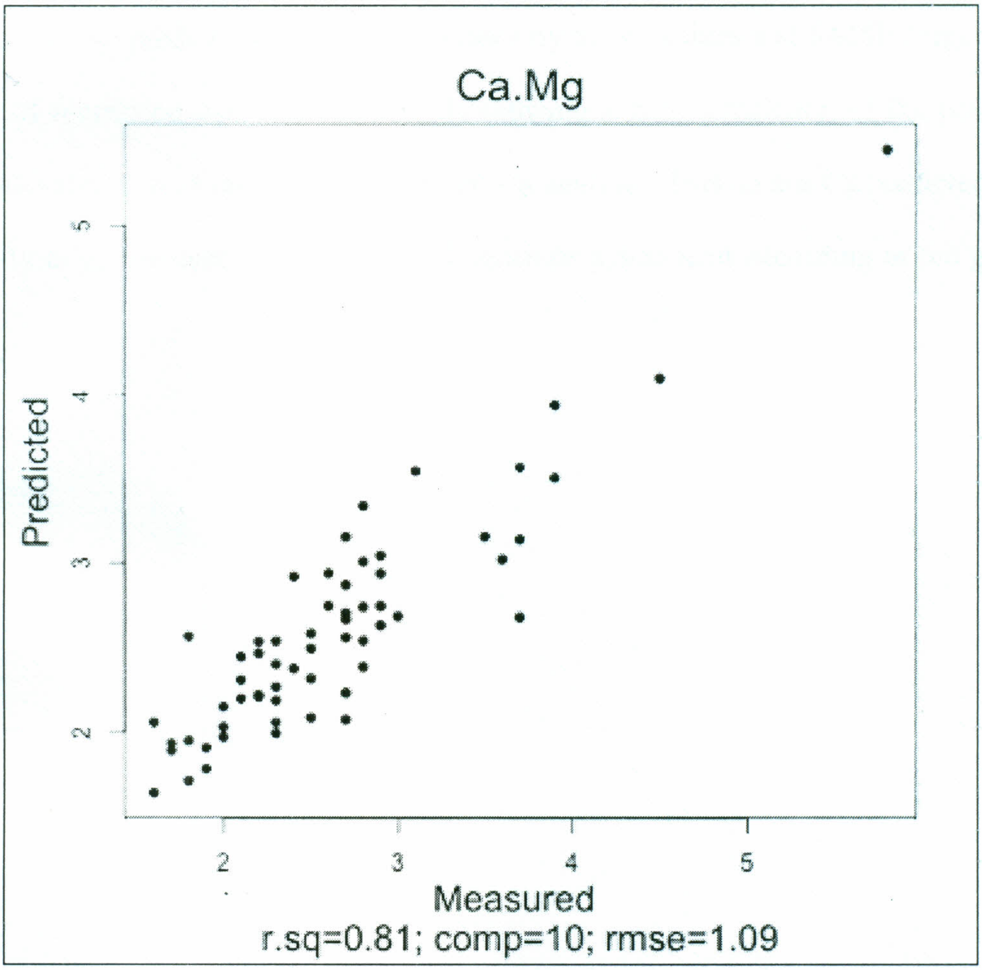


Figure 4.3: Correlation between measured and predicted values of Ca:Mg ratio

The current study gave a better prediction (R^2=0.81) than the results obtained in Australia (Minasny et *al.*, 2009) of R^2=0.30 stating that MIR cannot predict the Ca:Mg accurately from that region. However, Dunn et *al.,* 2002 obtained results that are showing the currency of Ca/Mg ratio prediction (R^2=0.81) from the 178 samples collected from Canada which matches with the current study.

4.1.4. Exactable Calcium

Extractable calcium prediction was good as shown by the R^2 values and RMSE (Figure 4.4). The coefficient of regression was high (R^2 =0.93) showing a good prediction of the parameter and therefore the validation of the model for the soil Ca analysis. This means Ca predicted within the current study might be used correctly for soil aptitude assessment according to the good model prediction.

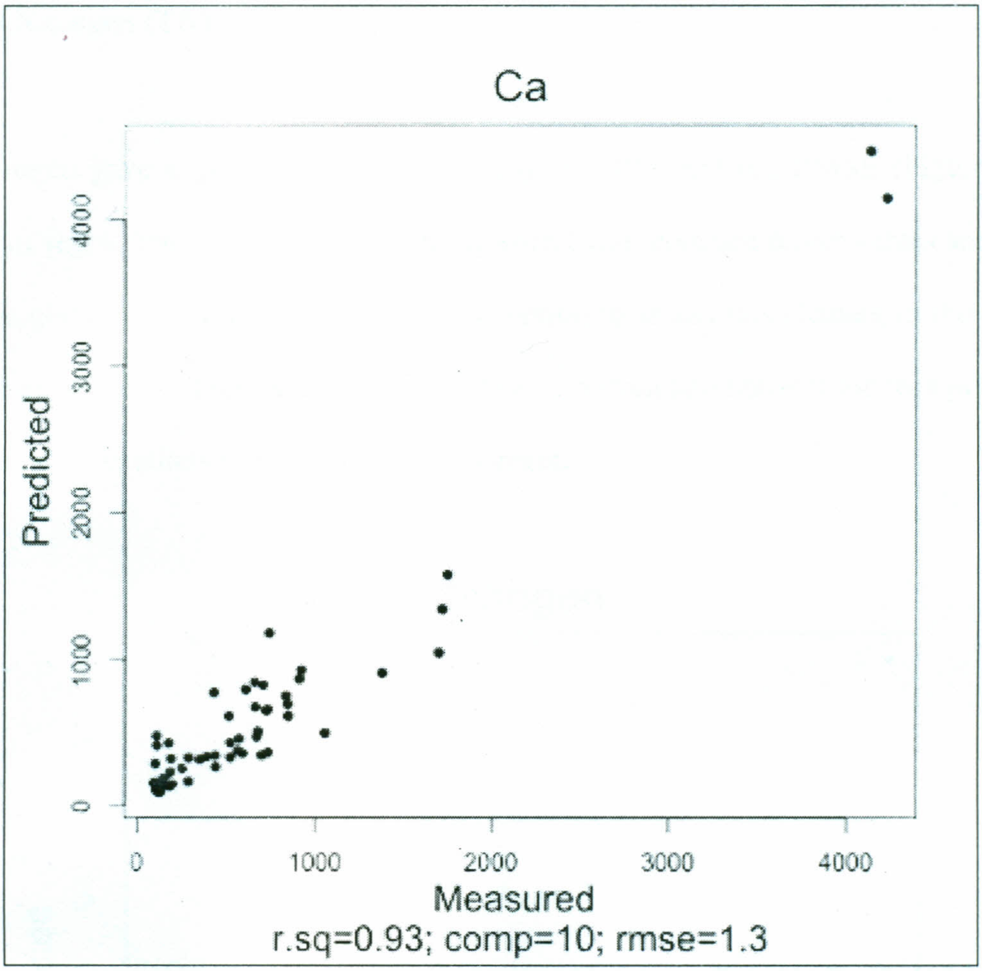


Figure 4.4: Correlation between measured and predicted values of exctactable Calcium

Validation predictions for Ca for this study are better compared to results reported by several authors. For example, in a study carried out in the USA, McCarty and Reeves (2006) reported R^2 of 0.77 for extractable calcium which is still lower compared to, current study. Similary, Viscarra et *al* (2006) and McCarty and Reeves (2006) reported prediction values of $R^2 = 0.84$. Moreover, the model developed in the current study showed better results than those reported globally, for instance, by Terhoeven *et al,* 2010 who reported $R^2 = 0.61$ and RMSE =1.64). This good prediction of Ca, from the current study, is useful for the soil nutrient assessment and allows to recommend the use of IR scanning approach for this element.

4.1.5 Total Nitrogen (TN)

. Total Nitrogen gave a good prediction regarding the R^2 and the RMSE (Figure 4.5). The coefficient of regression of 0.76 shows a strong correlation between direct values and predicted values. This good prediction of TN gives a new option to assess this element in the soil easily. This is new opportunity of soil analysis of the most important soil nutrient for crop production in SSA gave new orientations of soil nutrient assessment.

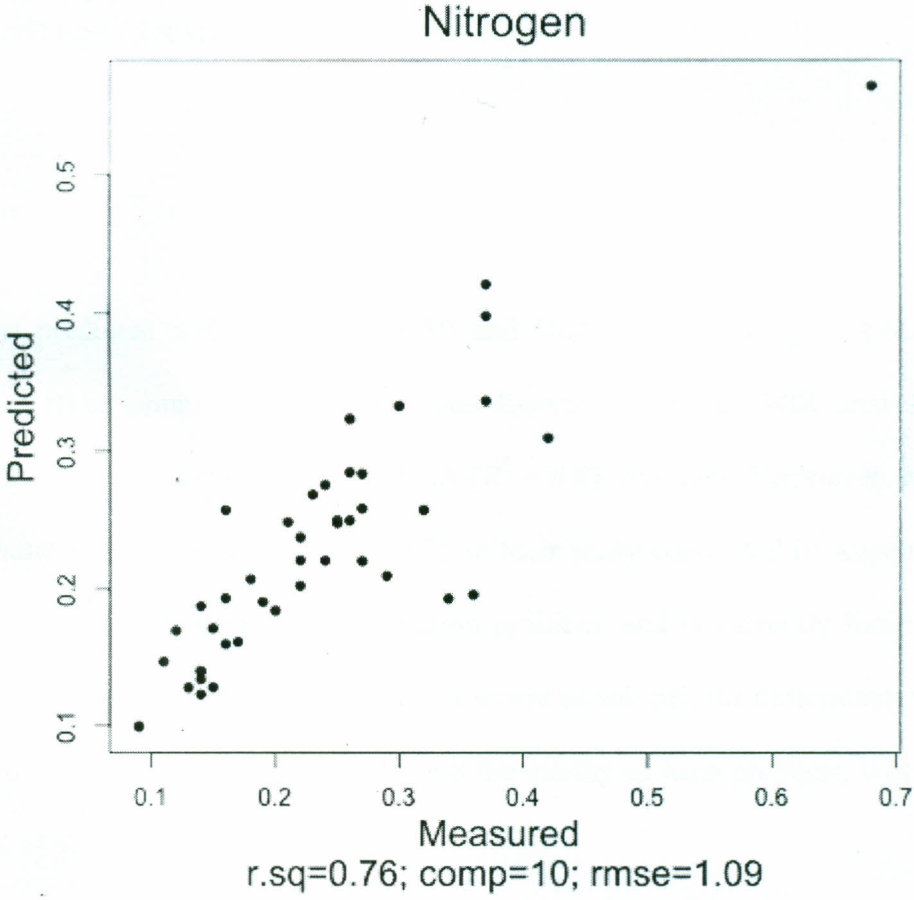


Figure4.5: Correlation between measured and predicted values of Total N

These results agree with those reported by other authors; for example, Minasny *et al.* (2009) who reported the same ratio (R^2= 0.76) in a study conducted for Australian soils. Reeves *et al.* (2006); Cozzolino and Moro (2006); Barthe *et al.* (2008); and Vasques *et al.* (2009) reported the same value of R^2=0.76 in studies carried out in regions with high agroecological variability. But the accuracy is still well since the prediction is good (R^2>0.75) according to the standard. This means that the goodness for the prediction is also related on soil variability within the region. Therefore, that high calibration performance observed, from the study carried out from Canada, could be associated with the fact that the soil samples used were from the same area and belong to the same soil type (Reeves, 2006).

4.1.6 Soil pH

Soil pH was predicted well with R^2 = 0.80 and RMSE = 2.21 (Figure 4.6). These values correspond to those obtained by McCarty and Reeves (2006) for MIR analysis of 544 soil samples (272 locations) in one field from USA (R^2 = 0.8). Similary, Terhoeven et *al, (*2010) got globally a value of R^2 =0.8 and RMSE = 0.75 in their study conducted in Australian landscape. Soil acidity is DRC's greatest land degradation problem, and is currently limiting agricultural production. Techniques that promote the measurement of soil pH, the determination of the rate of lime required to achieve an acceptable pH, and the quality of lime products, will greatly aid the management of soil acidity.

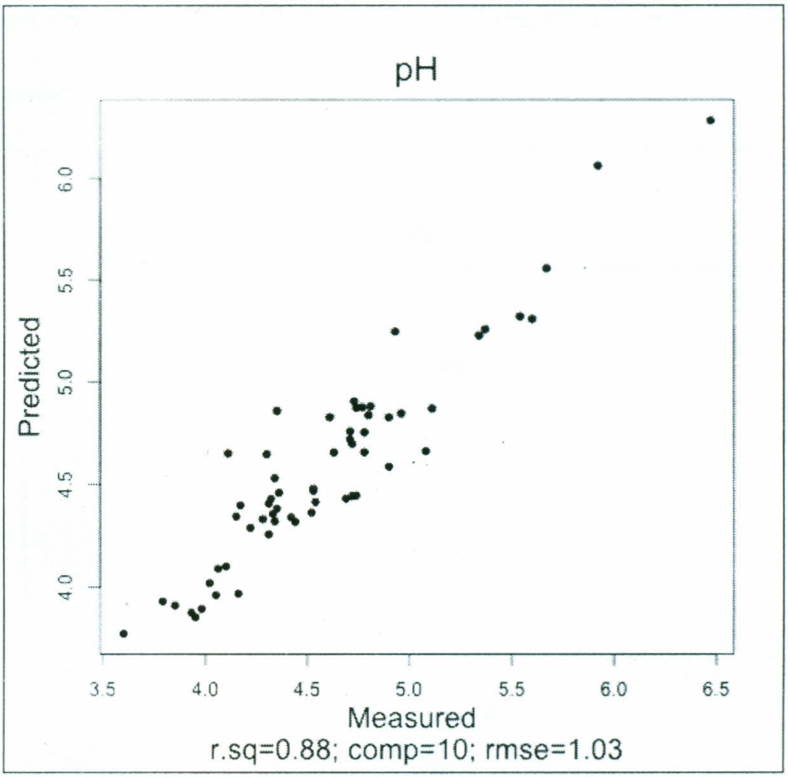


Figure 4.6: Correlation between measured and predicted values of pH

The results of the current study are slightly better than that obtained by Janik and Skjemstad (1995), who reported an R^2 of value 0.72 (satisfactory prediction) for 291 Australian soils. Reeves (2009) indicated that the ability of infrared to predict pH is related to other factors such as organic acids and carbonates. According to these results of satisfactory prediction, this parameter has the potential to be predicted by MIR spectroscopy

4.1.7. Extractable Potassium

Extractable potassium was well predicted with the regression model having R^2=0.87 (Figure 4.7). These results show the goodness of spatial prediction of potassium within the study area.

This good prediction (Shepherd and Walsh, 2002; Chang *et al.*, 2001) of K make the model useful for this parameter.

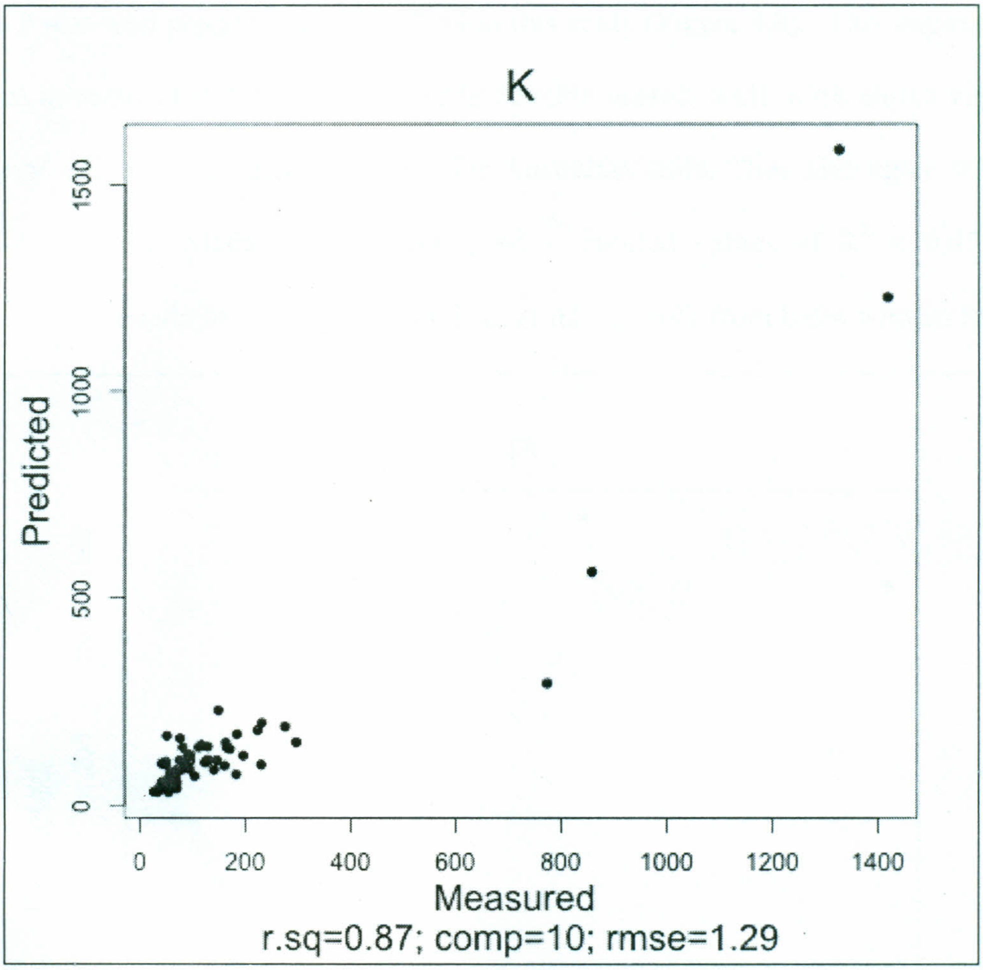


Figure 4.7: Correlation between measured and predicted values of extractable K

This is consistent with results of Lark (2009); Haskard and Lark (2009) and Hartemink (2006) who found good prediction of K from 178 samples from Australian landscape. The accuracy of the prediction opens the option of using the estimated values for K to assess soil state in the region of the study.

4.1.8 Extractable Phosphorus

Extractable P was well predicted with R^2=0.89 in this study (Figure 4.8). This implies validation of the model in terms of P determination. This results match well with those reported by Minasny *et al.* (2009) in a study conducted for Australian soils. They also agree with those of Hartemink (2006) and Madari, *et al.* (2006) who reported values of R^2 = 0.85 and 0.93, respectively from Canada landscape and Sellitto *et al.* (2009) from India with an R^2 of 0.90.

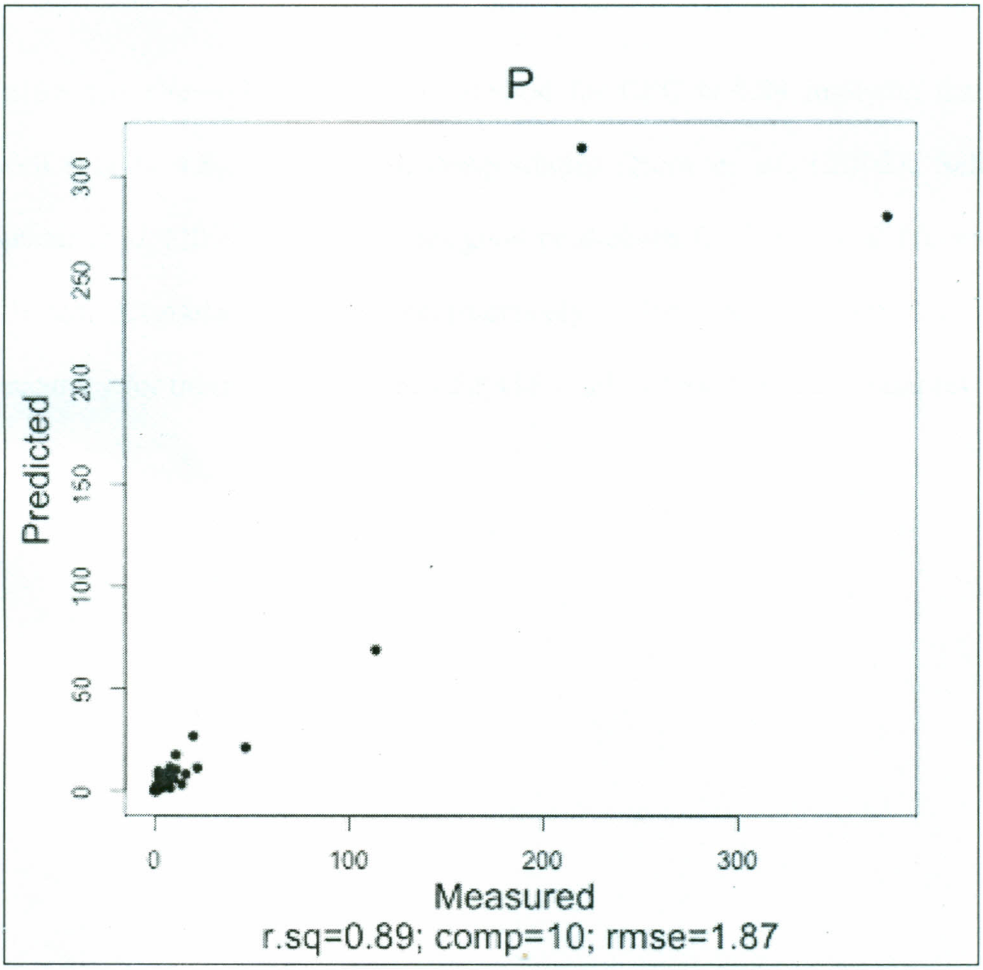


Figure 4.8: Correlation between measured and predicted values of extractable P

However, many studies from Canada have reported poor prediction eg Haskard and Lark (2009) with an R^2 of 0.48 and satisfactory prediction of this parameter; Hartemink (2006) with an R^2 of 0.57, this study gave good prediction as that by Madari *et al* (2006) from Canada landscape and Sellitto *et al.* (2009) from India. This is good modeling of P in the eastern of DR Congo opens a new opportunity for assessing this important nutrient of crop production.

4.1.9 Cation Exchangeable Capacity

The R^2 value for the validation of this method for CEC is 0.84 implying that CEC was predicted well (Figure 4.8). As found in many studies Dunn *et al.* (2002), Sellitto *et al.* (2009), Richter *et al.* (2009), MIR provides good predictions for CEC in different regions eg from India, Canada and US, respectively. Pirie *et al.* (2005) showed similar prediction accuracy for these this parameters for 415 southeastern Australian samples.

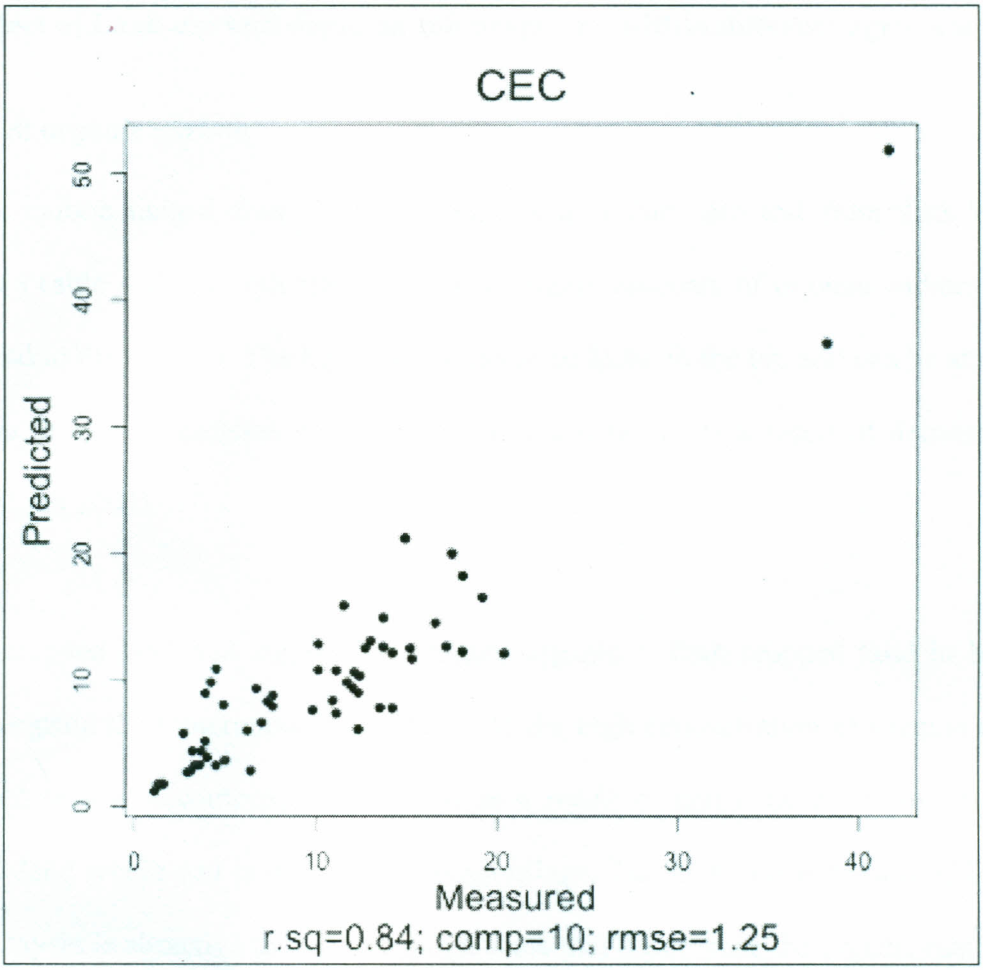


Figure 4.9: Correlation between measured and predicted values of CEC

For CEC, R^2 is 0, 84 (Figure .4.9) in the current study area and this shows that predicted and therefore estimated and direct values for are closer for this parameter. Sellitto *et al.* (2009), from India, got also good prediction for this parameter as found with also Pirie *et al.* (2005) from south Australian soils. This good modeling of CEC is welcome for the soil science research to avoid many constraints associated to traditional laboratory analysis.

4.2. Effect of Land use and depth on soil properties within different agro-ecological zones

4.2.1 Soil organic carbon

Organic carbon ranged from 2.91% to 5.23 % in Luhihi site and from 2.88 %to 3.77 % in Burhale (Table 4.1). In both sites there were higher amounts of organic carbon in the top soil compared to the sub soil. The high concentration of SOM in the top soil can be attributed to high numbers of microorganisms within the surface soil layers as a result of decomposing organic matter (Lich 2003).

The uncropped land had significantly higher organic C than cropped land in both sites. The higher organic C in uncropped is attributed to the high concentration of organic matter. This is attributed to low decomposition of SOM as a result of non disturbance of soil compared to cropped land where soil is disturbed through tillage. The high concentration of SOC within the surface layers is attractive to soil microorganisms that decompose the organic matter (Cécillon *et al.*, 2009). Other authors from India (Dunn *et al.*, 2002; Sellitto *et al.* 2009) reported similar results of high concentration of organic matter within the undisturbed soils.

Table 4.1: Organic carbon (%) in top and sub soil sampled from cropped and non cropped land in Luhihi and Burhale

Region	Burhale		Luhihi	
	Topsoil **(n=137)**	subsoil **(n=110)**	Topsoil **(n=153)**	Subsoil **(n=130)**
Cropped	3.03 (±0.42)	2.82 (±0.37)	3.93(±0.57)	2.91(±1.68)
Un cropped	3.77 (±0.97)	3.68(1.14)	5.23(±1.55)	4.25(±1.68)
p-value	0.04	0.003	0.02	<0.001

Values in brackets after the means= standard error deviation

In these areas, SOC is at an acceptable level for crop growth. According to rating by Haynes and Mokolbate (2006) a SOM amount greater than 10% is toxic, while a concentration of less than 1.5% is deficient. The standard error deviation of these results shows high variability of SOM possibly due to due to the differences between the different plots where soils sample were taken. Soil organic matter (SOM) is a very important soil fertility parameter. It affects many soil factors (Vanlauwe *et al.* (2001); Bationo 2003)). For example SOM, improves the physical properties of soil; increases the cation exchange capacity (CEC) and water-holding capacity of sandy soil, and it contributes to the structural stability of clay soils by helping to bind particles into aggregates. In addition the SOM holds a great proportion of nutrients and trace elements that are of importance to plant growth. It prevents nutrient leaching and is integral to the organic acids that make minerals available to plants. It also buffers soil from strong changes in pH. It is widely accepted that the carbon content of soil is a major factor in its overall health (FAO, 2012)

4.2.2 Total Nitrogen

Total Nitrogen ranged from 0.155 % to 0.395 % and from 0.18 % to 0.32 % for cropped and un-cropped sites, respectively (Table 4.2). The two locations recorded differences in total N for cultivated plots. But in Burhale, no differences were observed following the land use but for Luhihi top soil, uncultivated and cultivated soils are different ($P<0.05$).

Table4.2. Total N (%) for top and sub soils sampled from cropped and non cropped land in Luhihi and Burhale

Region	Burhale		Luhihi	
	Topsoil **(n=137)**	subsoil **(n=110)**	Topsoil **(n=153)**	Subsoil **(n=130)**
Cropped	0.25 (±0.04)	0.215(±0.01)	0.395(±0.09)	0.155(±0.11)
Uncropped	0.295(±0.12)	0.27 (±0.08)	0.325(±0.13)	0.18 (±0.11)
p-value	0.04	0.053	0.08	0.12

Values in brackets after the means= standard error deviation

The top soils within Burhale and Luhihi areas had more nitrogen than the sub soil; a similar trend to that of SOM. SOM is known to be the main source of N in soil, which is released upon decomposition (Bationo 2003). The current concentration in this study is however still very low (<5%) to support a good crop growth. This agrees with other results that have reported N to be one of the most frequently limiting nutrient in IDRC (Ellen, 2008; Pypers *et al.,* 2011). Worldwide, also, the deficiency soil N is the most limiting constraint to crop production and especially in Africa (Brown *et al.*, 2005).

4.2.3 Extractable Potassium

In the region, the concentration of K at good and might be a limiting element for crop production in the region. Both sites with thee two land use system, K was very high level (Table 4.3).

Table 4.3: Extractable Potassium (mg kg^{-1}) for top and sub soils sampled from cropped and non cropped land in Luhihi and Burhale

Region	Burhale		Luhihi	
	Topsoil (**n=137**)	subsoil **(n=110)**	Topsoil **(n=153)**	Subsoil **(n=130)**
Cropped	196.015(±21.32)	112.7 (±50.97)	173.175(±68.11)	105.515(±24.55)
Uncropped	159.07 (±70.57)	114.565(±44.22)	140.015(±64.20)	66.995(±40.38)
p-value	<0.001	0.01	0.01	<0.001

Values in brackets after the means= standard error deviation

Generally the concentration of K element is at an acceptable level according for most of African soils ICRAF, (2009) The explanation for this is that the parental minerals in this region contains a good quantity of K (Ellen, 2008). This means that the priority should not be focused on K-based fertilizers but on the other macronutrients, especially N and P, which are more limiting in the region. It has been reported that in most of the tropical soils, K is not very limiting element for crop production compared for the two other primary element (N and P) (Dobermann *et al.*, 2003).

4.2.4. Extractable Phosphorus

Extractable P concentration ranged from 0.86±028 to 5.765 ±2.61 and from 1.07 ±0.21 to 47±4.45 for Burhale and Luhihi sites, respectively (Table 4.4). These results show differences in P concentration between cropped and uncropped land. Burhale top soils have more P for cropped and uncropped than subsoil for both land use systems in Luhihi. According to these results, this area has very low P according to the rating by Pypers (2011). Very Low levels (<5 mg kg^{-1}) indicate acute deficiency and most crops will respond to P fertilizers application. According to (ICRAF, 2009) at such low levels (<30 mg kg^{-1}) P-demanding crops, such as vegetables, or high yielding crops, may be expected to respond to fertilization.

Table 4.4. : Extractable Phosphorus (mg kg^{-1}) in top and sub soil in soils sampled from cropped and non cropped sites in Luhihi and Burhale

Region	Burhale		Luhihi	
	Topsoil **(n=137)**	subsoil **(n=110)**	Topsoil **(n=153)**	Subsoil **(n=130)**
Cropped	5.77 (±2.61)	1.13 (±0.42)	1.07 (±0.21)	2.01 (±0.46)
Un cropped	3.33(±2.19)	0.86(±028)	4.47(±4.45)	3.41 (±2.42)
p-value	<0.001	0.07	0.03	0.04

Values in brackets after the means= standard error deviation

Soil phosphorus is a very important element for crop production. However, it has been reported to be one of the nutrients that are most deficient within the tropical soils due to highly weathered soil minerals present in those soils and also due to poor soil management (Ludwig *et al.*, 2008). The acute P deficiencies in these sites indicate that there is a need for specific P fertilizer recommendation for good crop production. The study carried out by Ellen (2008), supported this need of P fertilizer use in the east of Congo. But for Luhihi area, P is still lower but not acutely as Burhale, and P fertilizers will be also needed in this area. Oxides (from Al, Fe) in the soil can absorb P into their layers, making it not available for the plant nutrition process (Haynes, 2001; Haynes and Mokolbate, 2006). This is highly correlated with soil degradation and nutrient deficiency affecting productivity in the study area,. In addition, highly weathered, soil acidity and high concentration of exchangeable Al which might co -precipitate with phosphate ions that might increase the soil degradation and lower crop yielding.

In both sites (Luhihi and Burhale), P acute deficiency was observed. The high soil acidity observed within the region and the poor soil management practices present in the region contribute this soil status. High spatial variability was observed for both sites and Luhihi subsoil seems to have some improvement for this element compared to the other site but it is still low for a sustainable and good crop production. Soil phosphorus addition is still required for all the sites for good crop yielding.

4.2.5. Extractable Calcium

Extractable calcium ranged from 241.125±45.42 to 463.525±66.18 and from 187.285±165.77 to 486.775±230.46 in Burhale and Luhihi sites, respectively (Table 4.5). This element shows difference between the two land use types ($P<0.05$). All the cropped plots from Burhale had more amount of Ca compared to non cropped areas as for Luhihi except for the sub soils from this site (Luhihi) where both land use systems had the same amount of Calcium.

Table 4.5: Extractable Calcium ($mgkg^{-1}$) in top and sub soil in soils sampled from cropped and non cropped land in Luhihi and Burhale.

Region	Burhale		Luhihi	
	Topsoil **(n=137)**	subsoil **(n=110)**	Topsoil **(n=153)**	Subsoil **(n=130)**
Cropped	463.525(±66.18)	380.125(±50.40)	421.895(±48.7)	486.775(±230.46)
Uncropped	399.345(±88.87)	241.125(±45.42)	304.17(±80.41)	187.285(±165.77)
p-value	0.01	<0.001	<0.001	<0.001

Values in brackets after the means= standard error deviation

The differences between the two regions are evident due to the current soil management practices present within each region and the different socio-economic factors that are specific to each area. For the Exchangeable Ca, the concentration of calcium is globally high for top soils compared to sub soils for both sites but for the content the values are still low according to the requirements. Very low levels of exchangeable calcium (<2 cmolc kg^{-1}) indicate very low fertility potential and in extreme cases calcium deficiency can occur. Calcium levels <5 cmolc kg^{-1} indicate low to moderate fertility levels. Low Ca levels in the soil can be corrected by adding agricultural lime, which also raises soil pH, or as carrier materials of other fertilizers, such as super phosphate or calcium ammonium nitrate (Sanginga and Woomer, 2009), but the type of lime materials to add depend to the ratio Ca/Mg (Morris *et al.,*2007). The high soil degradation in the east of DRC related on soil acidity reduces highly soil fertility potential in the areas where is possible to have volcanic soils. This element is important within the study area due to the high soil acidity relevant in two the region. For some plots, soil pH was up to 3.6 and this real threat for the crops. Supported ISFM approaches are needed to reduce the high soil acidy and making the others nutrients available for the crops, especially P that is the most deficient element in south Kivu (Ellen, 2008). Calcium management is therefore necessary required to reduce this high risk of soil degradation due to the high acidity.

4.2.6. Extractable Magnesium

Extractable magnesium ($mgKg^{-1}$) ranged from 92.7 ±50.97 to 159.07 ±70.57 and from 66.99 ± 40 to 173.17 ±68.11 Burhale and Luhihi site, respectively (Table 4.6). The difference is remarkable between the two sites ($p<0.05$) except for top soil in Luhihi where both land use types are not different ($p>0.05$). The table 4.6 presents the results of Extractable Mg of the soil samples collected from the two area of study for each depth and uncropped and uncropped zones.

Table 4.6: Extractable Magnesium (mgKg^{-1}) in top and sub soil in soils sampled from cropped and non cropped land in Luhihi and Burhale

Region	Burhale		Luhihi	
	Topsoil **(n=137)**	subsoil **(n=110)**	Topsoil **(n=153)**	Subsoil **(n=130)**
Cropped	159(±70.57)	92.7 (±50.97)	90.(±64.20)	55.515(±24.55)
Uncropped	196(±21.32	94.6(±44.22)	173.2 (±68.11)	67(±40.38)
p-value	0.01	0.12	<0.001	0.03

Values in brackets after the means= standard error deviation

Generally the cultivated land recorded more Mg than the uncultivated land except the sub soils from Luhihi site. The sustainability of this element in soil requires good cropping systems that maintain good organic matter from the crop residue. Very low levels of exchangeable magnesium (<2 cmolc kg^{-1}) (using conversion with CEC and extractable Mg: mgKg^{-1}) indicate possible magnesium deficiency, and dolomitic lime (containing Mg) should be applied. At Low levels (<5 cmolc kg^{-1}) dolomitic lime sources should also be used if liming acid soils (Brown *et al*, 2006, Janik *et al.*, 2007).

In this condition the quantity of exchangeable Mg was very low (<1 cmolc kg^{-1} for both sites. For all the locations, Mg deficiency was present and there is a need of a external source of Mg. The high variability among sites was due to the differences observed within the randomized sampling plots. However the source of Mg will be not the liming materials since Ca/Mg ration is < 4 (Figure 4.7). This high soil acidy correction should be done through liming without using dolomite materials that contain already Mg but with Ca- basic materials and it should help to reduce Mg deficiency. Mg should therefore be added as micronutrient form to correct its deficiency but not through the lime. For all the sites, un cropped sites had more Mg concentration comparing cropped plots ($P<0.05$) except for sub soil in Burhale where both soil depths have the same concentration< ($p=0.12$).

4.2.7. Phosphorus sorption index

Phosphorus sorption index (PSI) ranged from 285.595 ± to 102.62 5 to 419.925 ± 100.67 and from 264.085 ± 85.88 to 358.01 ± 77.16 Burhale and Luhihi sites, respectively (Table 4.7). These results show high variability of PSI within the study areas.

Table 4. 7: Phosphorus sorption index in top and sub soil in soils sampled from cropped and non cropped land in Luhihi and Burhale

Region	Burhale		Luhihi	
	Topsoil **(n=137)**	subsoil **(n=110)**	Topsoil **(n=153)**	Subsoil **(n=130)**
Cropped	285.6 (±102.62)	392(±65)	358.01 (±77.16)	264.085(±85.88)
Uncropped	377.8 (±66.9)	420(±100.67)	301.8 (±95)	292.9(±91.28)
p-value	0.01	0.05	0.02	0.04

Values in brackets after the means= standard error deviation

The PSI is higher within the uncultivated zones ($p<0.05$) for both sites, expect in Luhihi top soils, there was more concentration for the cropped plots (<0.05). P sorption index was how strongly soluble P is sorbed by the soil. Low levels (<50 units) present a risk of P leaching, especially at high P test levels. If PSI is high (>250 units), large initial dressings may be required to build up soil P stocks. Although P is slightly important for Luhihi than Burhale, PSI is not showing the same framework. There was no difference between the different types of land use within each area but between the two areas there was a difference of PSI values. But there was no risk of leaching of P (Brown *et al*, 2006) (all values are >250 for both sites because above this level, P start leaching). For this parameter, the two sites are significantly different considering the land use factor (Morris *et al.,* 2007).

4.2.8. Extractable Aluminum

Extractable aluminum ranged from 2033.83±408.02 $mgKg^{-1}$ to 2461.74 ±198.97 $mgKg^{-1}$ and from 1555.48 $mgKg^{-1}$ ±136.38 $mgKg^{-1}$ to 2430.85 $mgKg^{-1}$ ±474.12 $mgKg^{-1}$ for $mgKg^{-1}$Burhale and Luhihi sites, respectively (Table 4.8). For Luhihi site un cropped have more concentration of Al for both depth (top and sub soil) ($p<0.05$) while for Burhale there is no difference between the two land use types for each depth. The high concentration for this element in uncropped plots in Luhihi should be due to the high concentration of minerals of Al in depth soil while top soils are well managed with some good cropping systems to reduce soil acidify degradation. Burhale, with poor cropping systems related on soil management (Pypers, 2011) that affects soil degradation, had the same quantity of Al for both land use types for the two depth

Table 4.8: Extractable Aluminum (mgKg^{-1}) in top and sub soil in soils sampled from cropped and non cropped land in Luhihi and Burhale

Region	Burhale		Luhihi	
	Topsoil **(n=137)**	subsoil **(n=110)**	Topsoil **(n=153)**	Subsoil **(n=130)**
Cropped	2033.83 (±408.02)	2343.28 (±143.7)	1555.48 (±136.38)	1746.88 (±301.43)
Uncropped	2461.74 (±198.97)	2430.85 (±474.1)	2299.68 (±386.2)	2161.35 (±422.85)
p-value	0.12	0.073	0.04	0.017

Values in brackets after the means= standard error deviation

Extractable aluminum is used to help predict phosphorus sorption characteristics. High levels of Al, especially in combination with high M3-Fe levels, indicate potential for high P sorption capacity in acid soils. The low (<800 mg kg^{-1}) and High (>1500 mg kg^{-1}) limits provide a general guide in relation to expected values (25% and 75% of expected range). For all the sites, extractable Al (>1500 mg kg^{-1}) show the risk of Al toxicities to make P not available for plant The high amount of this parameter given further explanation of soil constraint relevance in East of DRC. There is a high concentration within the soils from the study area with no difference between cropped and uncropped zones ($p>0.05$). Only for Luhihi where uncultivated zones have 2299.68 ±386.2 mgKg^{-1} have more concentration 1555.48 ±136.38 mgKg^{-1} with $p<0.05$.

The high concentration of Al is correlated with high soil acidity within the region that increases the risk of degradation. At low soil pH values (<5.5 units), strong soil acidity constrains the availability of most nutrient elements and there is a high risk of aluminum and magnesium toxicity. Liming and planting of aluminum tolerant crops is recommended. On the other hand, High pH (>8.3 units) can induce phosphorous deficiency and micronutrient deficiencies (Fe, Mn, B, Cu, Zn), so that crop nutrition will need careful management (ICRAF ,2009). High pH values also pose a high risk of raised sodium levels that may cause soil structural problems and sodium toxicity. Al^{3+} becomes the predominant exchangeable cation in leached soils with a pH lower than 5 as is the case for Burhale and Luhihi zone (Table 4. 10). Therefore, because of the leaching intensity in the tropics, Al toxicity is a common problem (Davies, 1997). Soil iron and aluminum oxides bind phosphate that may otherwise be displaced from the soil rooting depth. Displaced phosphate is not only a loss in potential crop productivity, but in many regions results in the eutrophication of wetlands and waterways (Lofts *et al*, 2002). Cheaper method of determination of iron and aluminum oxide content will promote better phosphorus management and help alleviate nutrient pollution (Chutichudet *et al.*, 2009).

4.2.9. Exchangeable acidity

Exchangeable acidity ranged from 0.875 ±0.43 cmolc kg^{-1} to 3.18 ±1.18 0.875 ±0.43 cmolc kg^{-1} and from 2.15 ±1.84 to 4.075 ±1.102 0.875 ±0.43 cmolc kg^{-1} Burhale and Luhihi site respectively (Table 4.9). The variability of this parameter is shown from Table 4.17 to determine the character of the soils from the study area. For all locations there are difference between the land use types for each soil depth ($p<0.05$) considering the exchangeable soil acidity.

Table 4.9: Exchangeable acidity (μS cm^{-1}) in top and sub soil in soils sampled from cropped and non cropped land in Luhihi and Burhale

Region	Burhale		Luhihi	
	Topsoil **(n=137)**	subsoil **(n=110)**	Topsoil **(n=153)**	Subsoil **(n=130)**
Cropped	0.875(±0.43)	1.345(±0.32)	2.43 (±1.08)	2.15 (±1.84)
Uncropped	2.31 (±1.26)	3.18 (±1.18)	2.665(±1.98)	4.075(±1.102)
p-value	0.001	0.001	0.02	0.03

Values in brackets after the means= standard error deviation

Aluminum toxicity can be confirmed by levels of exchangeable acidity: High (>0.5 cmolc kg^{-1}) or Very high (>1.0 cmolc kg^{-1}). High subsoil acidity can limit root growth of sensitive crops. As a general guide, a minimum lime requirement ($CaCO_3$ equivalent) of 1 t ha^{-1} for every 1 cmolc kg^{-1} of exchangeable acidity above the critical limits will be required. But to grow highly sensitive crops, up to three times this rate may be required. At Luhihi, sub soils seem to have more exchangeable acidity than topsoil. For all the sites, the level of exchangeable acidity is high and this could Al toxicity. For the pH, the values are also lower; therefore soil acidity in these areas was a big constraint of crop production in these areas which may affect strongly other nutrient essential for crops.

4.2.10 Soil pH

Soil pH is a key driving factor of crop production. For this parameter, the two sites were different in both land use and depth factors ($p<0.05$) (Table 4.10). Under continuous cultivation, both the non-use of fertilizers, as well as the sole use of fertilizer with a so-called 'negative base equivalent' (e.g. CAN and DAP) will cause rapid soil acidification. Acidification increases concentrations of Al in the soil solution, which is toxic to plants. African soils are highly susceptible to this phenomenon due to their inherent low buffering capacity (Derpsch, R 2008, Dobermann *et al* 2003). From Luhihi and Burhale, thefore the top soils, all these two location are identical. The uncropped areas are more acidic than cropped soils for both depths. The degree of acidy is very high is these region (<5 pH unit) (Table 4.10), therefore a soil nutrient management coupled with adequate liming practices is required to address this high soil acidity from the region. Lime application can be used to alleviate soil acidity but liming is too often an overlooked component of ISFM practice. Raising soil pH results in greater activities of soil bacteria, which in turn mineralizes other nutrients. This priming effect is significant but usually short-lived. Raising pH also results in conversion of many micronutrients into forms and valence states that are preferred by plants. In this way, effects of liming are confounded by creating a more favorable pH in the soil, selectively promoting beneficial soil organisms and directly supplying calcium and magnesium to plants (Gockowski, *et al.,* 2004).

Table 4.10: Soil pH in top and sub soil in soils sampled from cropped and non cropped land in Luhihi and Burhale

Region	Burhale		Luhihi	
	Topsoil **(n=137)**	subsoil **(n=110)**	Topsoil **(n=153)**	Subsoil **(n=130)**
Cropped	4.63 (±0.17)	4.6 (±0.13)	4.61 (±0.73)	4.78 (±0.37)
Uncropped	4.42 (±0.34)	4.5 (±0.47)	4.37 (±0.36)	4.382 (±0.36)
p-value	0.04	0.02	0.03	004.

Values in brackets after the means= standard error deviation

At low soil pH values (<5.5 units), strong soil acidity constrains the availability of most nutrient elements and there is a high risk of aluminum and magnesium toxicity. Liming and use of aluminum tolerant crops is recommended. On the other hand, High pH (>8.3 units) can induce phosphorous deficiency and micronutrient deficiencies (Fe, Mn, B, Cu, Zn), so that crop nutrition will need careful management. High pH values also pose a high risk of raised sodium levels that may cause soil structural problems and sodium toxicity. Burhale and Luhihi are very acidic (Table 4. 10) zones and this is a big constraint for a good crop production within this zone. The soils are very acid for within these areas study and might affect so much nutrient availability within the soil. Fertility problems associated with acidity affects more than 40% of all tropical soils (Smithson and Giller, 2002). Therefore the liming is required to support soil fertility management in this zone. However, over liming may induce micronutrient deficiencies and can also cause certain imbalances of other nutrients likely. These problematic acid soils are found wherever rainfall is high and the loss of bases by leaching is pronounced (Davies, 1997).

For this parameter, the most directing the soil reaction and soil chemical properties, it is very critical for all the sites. Very low values are observed, it must affect dramatically soil fertility and crop growth in the region. This will be correlated by Al toxicities and P deficiency. The mean of around 4.5 for the pH parameter, for both locations, shows a very strong acidity. Any difference was observed between the depths for all the locations. Therefore soil fertility management in this study area should be mixed with specific liming approaches. As showed by Table 4.10, liming based on Ca should be the most useful.

4.2.11 Ca: Mg ratio

Luhihi sub soils have higher value of Ca:Mg ratio than the top soil; while for Burhale the all the two depths have the same value for this parameter. The Table 4.11 shows the variability of this parameter among the two sites but with no effect of land use within each site in general ($p>0.05$) but only for Luhihi top soils, cropped have more concentration than uncropped zone ($p=0.04$).

Table 4.11: Soil Ca: Mg ratio in top and sub soil in soils sampled from cropped and non cropped land in Luhihi and Burhale

Region	Burhale		Luhihi	
	Topsoil **(n=137)**	subsoil **(n=110)**	Topsoil(**n=153)**	Subsoil **(n=130)**
Cropped	2.545(±0.33)	2.53 (±0.55)	2.45 (±0.38)	2.2 (±0.47)
Uncropped	2.595(±0.71)	2.545(±0.7)	2.38 (±0.47)	2.125(±0.48)
p-value	0.18	0.06	0.04	0.08

Values in brackets after the means= standard error deviation

Agricultural liming materials are composed of calcium and magnesium carbonates that are capable of neutralizing soil acidity, stimulating soil microbial activity and supplying calcium and magnesium to plants (van Straaten 2002). Limestone is rich in calcium and dolomite is also higher in magnesium, with dolomite being slightly more reactive (Meertens, 2003). The type of liming materials to use might depends on the soci-economic factors such as the availability of the resources. But technically the Ca/Mg ratio gives more efficient possibilities. The Table 4.11 gives the variability of this parameter within the study areas under the different land use system for the two depths of soil sampling. The Ca: Mg ratio provides a further indication of cation balance (especially Ca and Mg). When Low (<4), calcium-based lime sources are preferred when liming acid soils, but when High (>8), dolomite lime sources should be used when liming acid soils. When very high, magnesium deficiencies are likely. According to these results, there is a need of calcium-based lime sources in both areas: Luhihi and Burhale. As the soil is highly acid, the liming is an important practice in such zone for the productivity improving. However even the top soils from Luhihi seem to have higher values than the sub soils, the quantity is still lower, therefore the standard (Ca: Mg < 4) shows that calcium based lime sources are still required. Some few samples had this ratio > 4 (Luhihi top soils, Burhale top and sub soils) but for Luhihi sub soils all the values are below the 4 units of the ratio.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The aim of this study was to evaluate a novel approach of soil characterization based on Infrared scanning (IR) technique and assess its ability to provide rapid and reliable quantification of soil properties. Generally the results showed good and satisfactory prediction model with more than 75%, for all the chemical parameters under study (pH, Al, P, N, Ca, K , PSI, Exchangeable acidity, CEC) as well as for soil physical properties. Among the parameters under study, phosphorus gave the best prediction with R^2=0.93, while the others gave R^2 higher than 0.75 except SOM and TN which gave R^2 of 0.73 and 0.71, respectively. The good prediction of all chemical parameters implies that the method of IR scanning is reliable and hence recommended for use in determination of soil properties in the study area. In addition the method is fast and economical. Analysis of the 530 samples took 2 days to scan while it could have taken more than 2 months with the conventional methods of soil analysis. Soil particles prediction was also good for all the three parameters, with R^2= 0.81; 0.84 and 0.74 for sand, silt and clay, respectively. This is an implication that the infrared scanning technique is reliable for determination of soil texture.

Phosphorus was found to be deficient in both sites and was more acute for Burhale than Luhihi with 2.4 mg P $kg^{-1}$and 5.4 mg P kg^{-1}, respectively. The results also showed differences in P amount between cropped and un-cropped land. Burhale top soils had more P for cropped and uncropped than subsoil for both land use systems in Luhihi. All the cropped plots from Burhale had more amount of Ca compared to non cropped areas. For all the sites, uncropped sites had more Mg concentration compared to cropped plots except for sub soil in Burhale where both soil depths had the similar amount. P sorption index was found to be higher within the uncultivated zones than cultivated for both sites; expect in Luhihi top soils, where there was more concentration for the cropped plots. For Luhihi site uncropped plots had more concentration of Al for both depth (top and sub soil) while for Burhale there was no difference between the two land use types for each depth. For Luhihi site, uncropped plots had more concentration of Al for both depth (top and sub soil) while for Burhale there is no difference between the two land use types for each depth. The high concentration for this element in un cropped plots in Luhihi should be due to the high concentration of minerals of Al in depth soil while top soils are well managed with some good cropping systems to reduce soil acidify. Burhale site, with poor cropping systems related on soil management that affects soil degradation, has the same quantity of Al for both land use types for the two depths. Aluminum toxicity is also an important crop constraint present within this region. This is likely associated with to high soil acidity (pH <5).

For all locations there were differences between the land use types for each soil depth ($p<0.05$) considering the exchangeable soil acidity. Results of soil pH in different land use and the depth factors, showed a strong soil acidity which might affect the availability of other nutrient within the soil.

5.2 Recommendations

1. Explore use of IR scanning in characterization of soils of the whole region of East of DR Congo.
2. Farmers need to be made aware of the acidity and p deficiency of their soils.

3. Universities and research centers involved in soil analysis should focus on this new technology by training their laboratory staff and getting help and support from other organization already using the new approach to realize rapid but accurate determination of nutrient status.
4. More efforts are needed to improve the use of IR scanning in monitoring soil and land degradation across developing countries.
5. Though IR is cheap for analyzing soil properties it requires high investment at the beginning. There is therefore need of technical and material support to make this technology useful in developing countries.

REFERENCES

Abdi, H. (2010). "Partial least squares regression and projection on latent structure regression (PLS-Regression)". *Wiley Interdisciplinary Reviews: Computational Statistics* **2**: 97–106.

AU, 2006: Africa Fertilizer Summit African Union Special Summit of the Heads of State and Government .Abuja Declaration on Fertilizer for an African Green Revolution; Abuja

Al-Juaidi, F. Millington, A. C. and McLaren, S. J. (2003). Merged remotely sensed data for geomorphological investigations in deserts: Examples from central Saudi Arabia. *Geogr. J.,* 169:117–130.

Bationo, A. (2003). Managing Nutrient Cycles to sustain soil Fertility in Sub Saharan Africa.

Bache, B. W. and Williams, E. G. (2001). A phosphate sorption index for soils. *Journal of Soil Science,* 22:289-301.

Banin, A. and Amiel, A. (2009). A correlation study of the chemical and physical properties of a group of natural soils of Israel *Geoderma,* 3:185–198

Barthe , B. G., Brunet, D., Hien, E., Enjalric, F., Conche, S., Freschet, G. T., d'Annunzio, R. and Toucet-Louri, J. (2008). Determining the distributions of soil carbon and nitrogen in particle size fractions using near-infrared reflectance spectrum of bulk soil samples. *Soil Biol. Biochem,* 40: 1533-1537.

Ben-Dor, E. (2002). Quantitative remote sensing of soil properties. Adv. Agron. 75:173–243

Borggaard, O. K., Szilas, C., Gimsing, A. L. and Rasmussen, L. H. (2004). Estimation of soil phosphate adsorption capacity by means of a pedotransfer function. *Geoderma,* 118:55-61

Bronson, K., Zobeck, T., Chua, T., Acosta-Martinez, V., van Pelt, R. S. and Booker J. D. (2004). Carbon and nitrogen pools of Southern High Plains cropland and grassland soils. *Science Society of America Journal,* 68:1695-1704.

Brown, D. J., Shepherd, K. D., Walsh, M, G., Mays, M. D. and Reinsch, T. G. (2006) Global soil characterization with VNIR diffuse reflectance spectroscopy. Geoderma, 132, 273-290

Brown, D. J., Bricklemyer, R, S., Miller, P, R. (2005). Validation requirements for diffuse reflectance soil characterization models with a case study of VNIR soil C prediction in Montana. *Geoderma,* 129: 251–267.

Brus, D. J., de Gruijter, J. J., and Breeuwsma, A. (2002). Strategies for updating soil surveyinformation, a case study to estimate phosphate sorption characteristics. *Journal of Soil Science* 43, 567–581.

Budiman, M. (2007). Predicting soil properties. *Jurnal Ilmu Tanah dan Lingkungan,* **7** : 54-67.

Canadell J, Jackson RB, Ehleringer JR, Mooney HA, Sala OE & Schulze ED (20066) Maximum rooting depth of vegetation types at the global scale. Oecologia 108: 583–595

Carter, M. R. (2002). Soil quality for sustainable land management: Organic matter and aggregation interactions that maintain soil functions. *Agron. J., 94: 3 8-47.*

Charley JL and West NE (2005) Micro-patterns of nitrogen mineralization activity in soils of some shrub-dominated semi-desert ecosystems of Utah. Soil Biol Biochem 9: 357–365.

Campbell, C.A., Zenter, R.P., Selles, F., Biederbeck, V.O., McCon-key, B.G., Blomert, B., 2000. Quantifying short-term effects of crop rotations on soil organic carbon in southwestern Saskatch- ewan. Can. J. Soil Sci. 80, 193-202.

Cécillon, L., Cassagne, N., Czarnes, S., Gros, R., Vennetier, M. and Brun, J. J. (2009). Predicting soil quality indices with near infrared analysis in a wildfire chronosequence. *Science of the Total Environment,* 407: 1200-1205.

Chang, C. W., Laird, D. A, Mausbach, M. J. and Hurburgh, C. R. (2001). Near-infrared reflectance spectroscopy-principal components regression analyses of soil properties. *Soil Science Society of.America Journal,* 65: 480–490.

Chen, L. S., Qi, Y. P. and Liu, X. H. (2005). Effects of Aluminium on light energy utilization and photoprotective Systems in citrus leaves. *Ann. Bot. (Lond.),* 96: 35–41.

Christy, C. D. (2008). Real-Time Measurement of Soil Attributes Using On-the-go Near Infrared Reflectance Spectroscopy. *Computers and Electronics in Agriculture,* 61:10-19.

Chutichudet, P., Chutichudet, B., and Kaewsit, S. (2009). Effect of Gypsum Application on Enzymatic Browning Activity in Lettuce. Pakistan *Journal of Biological Sciences,* 12: 1226-1236.

Cozzolino, D. and Moro´n, A. (2006). Potential of near-infrared reflectance spectroscopy and chemometrics to predict soil organic carbon fractions. *Soil Tillage Res,* 85: 78_85.

Davies, B. E. (1997). Deficiencies and toxicities of trace elements and micronutrients in tropical soils: limitations of knowledge and future research needs. *Envir. Tox. Chem.,* 16 (1): 75-83.

Denef, K., Plante, A. F. and Six, J. (2009). Characterization of soil organic matter. Pages 91_126 in W. Kutsch, M. Bahn and A. Heinemeyer, eds. Soil carbon dynamics: An integrated methodology. Cambridge University Press, London, UK.

Derpsch, R. (2008). No-tillage and Conservation Agriculture: A progress report. In: Goddard, T., Zoebisch, M.A., Gan, Y.T., Ellis, W., Watson, A. and Sombatpanit, S. (eds). *No-Till FarmingSystems.* World Association of Soil and Water Conservation, Bangkok. pp 7-39.

Dhruba P. (2007). Image transformatiom and geo-statistical techniques to enhance and map soil features: an application in assessing sedimentation problem in southern Nepal. *International Institute for Geo-Information Science and Earth Observation (ITC).*

Dobermann, A.,Witt, C., Abdulrachman, S., Gines, H. C., Nagarajan, R., Son, T. T., Tan, P. S., Wang, G. H., Chien, N. V., Thoa, V.T., Phung, C. V., Stalin, P., Muthukrishnan, P., Ravi, V., Babu, M., Simbahan, G. C. and Adviento, M. (2003). Soil fertilizer and indigenous nutrient supply in irrigated rice domains of Asia. *Agronomy Journal,* 95:913-923.

DSRP. (2005). Document de Strategie de Reduction de la Pauvrete. Province du Sud-Kivu. Republique Démocratique du Congo, Ministère du Plan, Unité de Pilotage de Processus du DSRP, Kinshasa. p96.

Dunn, B. W.,Beecher, H. G., Batten, G. D. and Ciavarella, S. (2002).Thepotentialofnear-infraredreflectance spectroscopy for soil analysis a case study from south-eastern Australia. *Australian Journal of Experimental Agriculture,* 42, 607-614.

Elberling, B. and Jakobsen, B. H. (2000). Soil solution pH measurements using in-line chambers with tension lysimeters. *Can. J. Soil Sci.,* 80: 283–288.

Ellen, V. (2008). Nutrient deficiencies in soils of Walungu, South-Kivu, Democratic Republic of Congo. MSC theisis, KU Leuven, Belgium

Farrow, A., Businye, L. and Bugenze, P. (2006). Characterisation of Mandate Areas for consortium for improving Agriculture based Livelihoods in Central Africa: pp 138.

FAO. (2012). Soil carbon monitoring using surveys and modelling. General description and application in the United Republic of Tanzania. *FAO Forestry Paper 168 Rome*

FAO. (2003). Assessment of soil nutrient balance. Approach and methodology. FAO fertilizer and plant nutrition bulletin. Rome, Italy.

Goĉkowski, J., Tonye, J., Baker, D., Legg, C., Weise, S., Ndoumbé, M., Tiki-Manga, T., and Fouaguègué, A. (2004). Characterization and diagnosis of farming systems in the forest margins benchmark of Southern Cameroon. *Social Science Working Paper Series No 1.* International Institute of Tropical Agriculture (IITA). Ibadan, Nigeria. pp 154-156.

Gupta, P. K. (1999). Soil, Plant, water and Fertilizer Analysis; *ISBN: 81-87167-25-4, 1ST edition 1999-2000*

Hargreaves, P.R., P.C. Brookes, G.J.S. Ross, and P.R. Poulton. 2003. Evaluating soil microbial biomass carbon as an indicator of long-term environmental change. Soil Biol. Biochem. 35:401–407

Hartemink, A. E. (2006). Assessing soil fertility decline in the tropics using soil chemical data. *Advances in Agronomy,* 89: 179–225.

Haynes, R. and Mokolbate, M. (2006). Amelioration of Al toxicity and P deficiency in acid soils by addition of organic residues: a critical review of the phenomenon and the mechanisms involved. *Nutr. Cycl. Agroecosys,* 59: 47-6.

Haynes, J. and William M., (2011). *CRC Handbook of Chemistry and Physics* Press. p. 10.233.

Haaland, D. M. and Thomas, E. V. (1988). Partial least-squares methods for spectral analyses. 1. Relation to other quantitative calibration methods and the extraction of qualitative information. *Anal. Chem.,* 60: 1193-1202.

ICRAF. (2010). List and cost estimate for the materials for soil laboratory. ICRAF, NAIROBI.

ICRAF. (2009). Soil Mid Infrared spectroscopy. ICRAF, NAIROBI.

Jaber, N . Mehanna, S. Sultan, J. (2009): Determination of ammonium and organic bound nitrogen by inductively coupled plasma emission spectroscopy. Talanta, 78 (4-5) 1298-1302.

Janik, L., Skjemstad, J., Shepherd, K., and Spounce, L. (2007). Prediction of soil carbon fractions using mid-infrared-partial least square analysis. *Australian Journal of Soil Research,* 45, 73–81.

Jones, B.S.; Lynn, W.F.; Stone, M.O. (2001). "Thermal Modeling of Snake Infrared Reception: Evidence for Limited Detection Range". *Journal of Theoretical Biology* **209** (2): 201–211. doi:10.1006/jtbi.2000.2256. PMID 11401462.

Knox, N. M., Skidmore, A. K., Schlerf, M., de Boer, W. F., van Wieren, S. E., van der Waal, C., Prins, H.H. and Slotow, R. (2010). Nitrogen prediction in grasses: effect of bandwidth and plant material state on absorption feature selection, International Journal of Remote Sensing, 31(3), 691-704

Kyou, S., Kenneth, A., and Sun-ok, C. (2009). Ampling and calibration requirements for soil property estimation using NIR spectroscopy. *(*Proceedings of the International Conference on Ande 2007 *Busan, Korea, 17 - 19 October 2007)accessed on 7th Janaury 2010 http://eproceedings.worldscinet.com/9789812793034/9789812793034_0030.html*

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science 304:1623–1627

Lark, R. M. (2009). Kriging a soil variable with a simple non-stationary variance model, J. Agric. *Biol.Env. Stat.,* 14, 301–321.

Lark, R. M. and Webster, R. (2009). Changes in variance and correlation of soil properties with scale and location: analysis using an adapted maximal overlap discrete wavelet transform, *Eur. J. Soil Sci.,* 52, 547–562.

Lark, R. M., Bellamy, P. H. and Kirk, G.J.. (2006). Baseline values and change in the soil, and implications for monitoring. *European Journal of Soil Science 57: 916-921.*

Liebig, M.A., H.A. Johnson, J.D. Hanson, and A.B. Frank. 2004. Soil carbon under switchgrass stands and cultivated cropland. Biomass Bioenergy 28:347–354

Licht, M.A., (2003). Comparative influence of tillage systems and nutrient timing on the soil environment and crop response in Iowa soils. M.S. Thesis, Library of Iowa State University.

Lofts, S., Woof, C., Tipping, E., Clarke, N. and Mulder, J. (2001). Modelling *p*H buffering and aluminium solubility in European forest soils. *Eurapean Journal of Soil Science.* 52: 189–204.

Ma, Z., C.W. Wood, and D.I. Bransby. 2000a. Carbon dynamics subsequent to establishment of switchgrass. Biomass Bioenergy 18:93–104

Madari, B. E., Reeves, J. B., Machado, P. L., Guimara˜ es, C. M., Torres, E. and McCarty, G. W. (2006). Midand near-infrared spectroscopic assessment of soil compositional parameters and structural indices in two Ferralsols. *Geoderma,* 136: 245-259.

Malley DF, Yesmin L, Eilers RG (2005) Rapid analysis of hog manure and manure-amended soils using near-infrared spectroscopy. *Soil Science Society of America Journal* **66**, 1677–1686.

Mateso, W., Nyamugwabiza, I. and Mabiala-ma-Khete. (1998). Programme national de relance du secteur agricole et rural (PNSAR) 1997-2001. Monographie de la province du Sud-Kivu. Ministères de l'agriculture et de l'élevage, du plan, de l'éducation nationale et de l'environnement, conservation de la nature, forets et peche, Kinshasa. p160

McCarty, G. W. and Reeves, I. J.. (2006). Comparison of near infrared and mid infrared diffuse refl ectance spectroscopy for fi eld-scale measurement of soil fertility parameters. *Journal of Soil Science,* 171:4–102.

Mccarty, G. W., Reeves L. B., Reeves, V. B., Follett, R. F. and JKimble. M. (2002). Mid- infrared and near-infrared diffuse reflectance spectroscopy for soil C measurement. *Science Society of America Journal,* 66:640-646.

Meertens, H.C. (2003). The prospects for integrated nutrient management for sustainable rain fed lowland rice production in Sukuma land, Tanzania. *Nutrient Cycling in Agroecosystems,* 65:163-171.

Mehlich, A. (1984). Mehlich 3 soil test extracting: A modification of the Mehlich 2 extractant. Commun. *Soil Science Plant Analysis,* 15(12):1409-1416.

Mevik, B. H. and Wehrens. R. (2007). The pls package: Principal component and partial least squares regression in R. *Journal of Statistical Soft ware,* 18 : 1–24.

Meyer, T., Vuuren, V. and Anwterpen, V. (2005). The potential of Near Infraread reffelectance of monotiring in precision agriculuturE. *South Africa Pro S Afr Sugar Technol ASS,* 60:203-207

Minasny, B., Tranter, G., McBratney, A., Brough, M. and Murph, M. (2009). Regional transferability of mid-infrared diffuse reflectance spectroscopic predictionfor soil chemical properties. *Geoderma,* 153: 155-162.

Minasny B., McBratney, A., Tranter, G. and Murphy, M. (2008). Using soil knowledge for the evaluation of mid-infrared diffuse reflectance spectroscopy for predicting soil physical and mechanical properties. *European Journal of Soil Science*, 59: 960-971.

Morris, M., Kelly, V. A., Kopicki, R. J. and Byerlee, D. (2007). *Fertilizer Use in African Agriculture: Lessons Learned and Good Practices Guidelines.* World Bank,Washington, D.C. pp 144.

Naess, T., Isaksson, T., Fearn, T. and Davies, T. (2002). A User-friendly Guide to Multivariate Calibration and Classification. NIR publications: Chichester, UK,

Noble, A. D., Gillman, G. P.. Nath, S. and Srivastava, R. J. (2001). Changes in the surface charge characteristics of degraded soils in the wet tropics through the addition of beneficiated bentonite. *Aust. J. Soil Res.,* 39: 991–1001.

Périé, C. and Ouimet, R. 2008. Organic carbon, organic matter and bulk density relationships in

boreal forest soils. Canadian Journal of Soil Science 88: 315-325.

Pirie, A., Balwant, S., and Kamrunnahar, I. (2005). Ultra-violet, visible, nearinfrared, and mid-infrared diffuse reflectance spectroscopic techniques to predict several soil properties. *Aust. J. Soil Res,* 43:713–721.

PNE . (1998). Programme National Engrais. Synthèse agronomique des essais de fertilisation dans la province du Kivu. Republic Democratic du Congo. Rapport technique. FAO, Rome. p 42.

PRAGMA. (1987). Région du Kivu : étude régionale pour la planification agricole. Département de l'agriculture et du développement rural, Kinshasa. p365.

Pypers, P., Sanginga, J. M., Bishikwabo, K., Walangululu, M. and Vanlauwe B. (2011). Increased productivity through integrated soil fertility management in cassava-legume intercropping systems in the highlands of Sud-Kivu, DR Congo. *Field Crop. Res.,* 120, 76-85.

Richter, N., Jarmer, T., Chabrillat, S.,Oyonarte, C., Hostert, P. and Kaufmann, H. (2009). Freeiron oxide determination in Mediterranean soils using diffuse reflectance spectroscopy. *Soil Science Society of America Journal,* 73: 72–81.

Rijpma, J. and Fokhrul, I. M. (2003). Nutrient mining and its effect on crop production and environment in Bangladesh. Paper presented at seminar on "Soil Health Management"; DAE - SFFP Experience,Bangladesh.

Reeves, J. B. (2009). Near- versus mid-infrared diffuse reflectance spectroscopy for soil analy-sis emphasizing carbon and laboratory versus on-site analysis: Where are we and what needs to be done? *Geoderma,* 148, 149-158.

Reeves, J. B., Follett, R. F., McCarty, G. W. and Kimble, J. M. (2006). Can near or mid-infrared diffuse reflectance spectroscopy be used to determine soil carbon pools? Commun. *Soil Sci. Plant Anal.,* 37: 2307-2325.

Reeves, J. B.; McCarty, G. W., and Meisinger, J. J. (1999). Near infrared reflectance spectroscopy for the analysis of agricultural soils. *Journal of Near Infrared Spectroscopy*, **9** (1): 25-34.

Russell, A. E., Laird, D. A., Parkin, T. B. and Mallarino, A. P. (2005). Impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern mollisols. Soil Sci. Soc. Am. J., 69:413-422.

Sanchez, P. A. (1976). Properties and management of soils in the tropics. John Wilieu and sons, New York. p618.

Sanginaga, N. and Woomer, P. (2009). Integrated Soil Fertility Management in Africa: Principles, Practices and Developmental Process. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT).

Sellitto, V. M., Fernandes, R. B., Barrón, V., and Colombo, C. M. (2009). Comparing two different spectroscopic techniques for the characterization of soil iron oxides: diffuse versus bi-directional reflectance. *Geoderma,* 149: 2–9.

Sheldrick, W. F., Syers, J. K. and Lingard, J. (2002). A conceptual model for conducting nutrient audits at national, regional, and global scales. *Nutrutient Cycling in Agroecosystem*, 62: 61–72.

Sheldrick, W. F., Syers, J. K. and Lingard, J. (2003). Contribution of livestock excreta to nutrient balances. *Nutrutient Cycling in Agroecosystem*, 66: 119–131.

Scoones, I. and Toulmin, C. (1998). Soil nutrient balances: what use for policy? *Journal Agriculture Ecosystem and Environment*, 71:255–267.

Shephertd, K. and Walsh, M. (2009). Diffuse Reflectance Spectroscopy for Rapid Soil Analysis, World Agroforestry Centre (ICRAF), Nairobi, Kenya.

Shephertd, K. and Walsh, M. (2007). Infrared-Spectrocopy –enhabling an evidence based diagnostic surveillance approach to agricultural and environmental management in developing countries. *Journal of Near Infrared Spectroscopy,*. 15:1–19.

Shepherd, K. and Walsh, M. (2002). Development of reflectance spectral libraries for characterization of soil properties. Soil Sci. Soc. Am. J., 66:988–998.

Smithson, P. C. and Giller, K. E. (2002). Appropriate farm management practices for alleviating N and P deficiencies in low-nutrient soils of the tropics. *Plant Soil,* 24(1):169-180.

Terhoeven, T., Vagen, T., Spaargaren, O., and Shepherd, K. (2010). Prediction of Soil Fertility Properties from a Globally Distributed Soil Mid-Infrared Spectral Library. *Science Society of America Journal*, 74:1792–1799.

Tillmann, T. (2000). Kalibrationsentwicklung für NIRS-Geräte.Cuvillier-Verlag, Göttingen, Germany.

Vagen T., Shepherd, K., Walsh, M., Winowiecki, L., Desta, L. and Tondoh, J. (2010). AfSIS Technical Specifications Soil Health Surveillance. Africa Soil Information Service. p18.

Vanlauwe, B. and Giller, K. E. (2006). Popular myths around soil fertility management in sub-Saharan Africa. *Agriculture Ecosystems and Environment,* 166:43-46.

Vanlauwe, B., Diels, J., Sanginga, N. and Merckx, R. (2002). Integrated plant nutrient management in sub-Saharan Africa: from concept to practice. Wallingford, UK, CABI Publishing

Vanlauwe, B., Wendt, J. and Diels, J. (2001). Combined application of organic matter and fertilizer. In: Sustaining Soil Fertility in West-Africa (Eds G Tian,F Ishida and J D H Keatinge), SSSA Special Publication Number 58, Madison, USA, pp 247-280.

Vanlauwe, B.. Tittonell, P. and Mukulama, J. (2006). Within-farm soil fertility gradients affect response of maize to fertiliser application in Western Kenya. *Nutrient Cycling in Agroforestry,* 76:171-182.

Viscarra, R. A., Jeon, I. O., Odeh, A. and McBratney, A. B. (2008). Using a legacy soil sample to develop a mid-IR spectral library. *Aust. J. Soil Res*. 46:1–16.

ViscarraRossel, R., Walvoort, D., McBratney, A. B., Janik, L. J. and Skjemstad, J. O. (2006). Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties. *Geoderma,* 131(1-2), 59-75.

Walsh, M. and Vågen ,T. (2009). Guide to Field Sampling and Measurement Procedures. The land degradation surveillance framework; AFISIS.

WESTPHAL, E. ; EMBRECHETS, J. ; FERDWERDA, J. ; VAGILS-MECUS, H.A.E ; MUSTERS, H.J.W. et WESTPHAL et AL-STEVEL, J., 1985 : Cultures vivrières tropicales avec référence spéciale au Cameroun. Pudoc Wageningen : 514 pp.

Williams, P. C. (1987). Variables affecting near-infrared reflectance spectroscopic analysis. In: Williams, P., *et al.* (Eds.) Near-Infrared Technology in the Agricultural and Food Industries. St. Paul, MN: *Am. Assoc. Cereal Chem. pp. 143-167*

Whittig, L. D. and Jackson, M. L. (2008). Mineral content and distribution as indexes of weathering in the omega and ahmeek soils of northern wisconsi mineral content and distribution as indexes. *J. Phys. Coll. Chem*., 52 : 1237-1260.

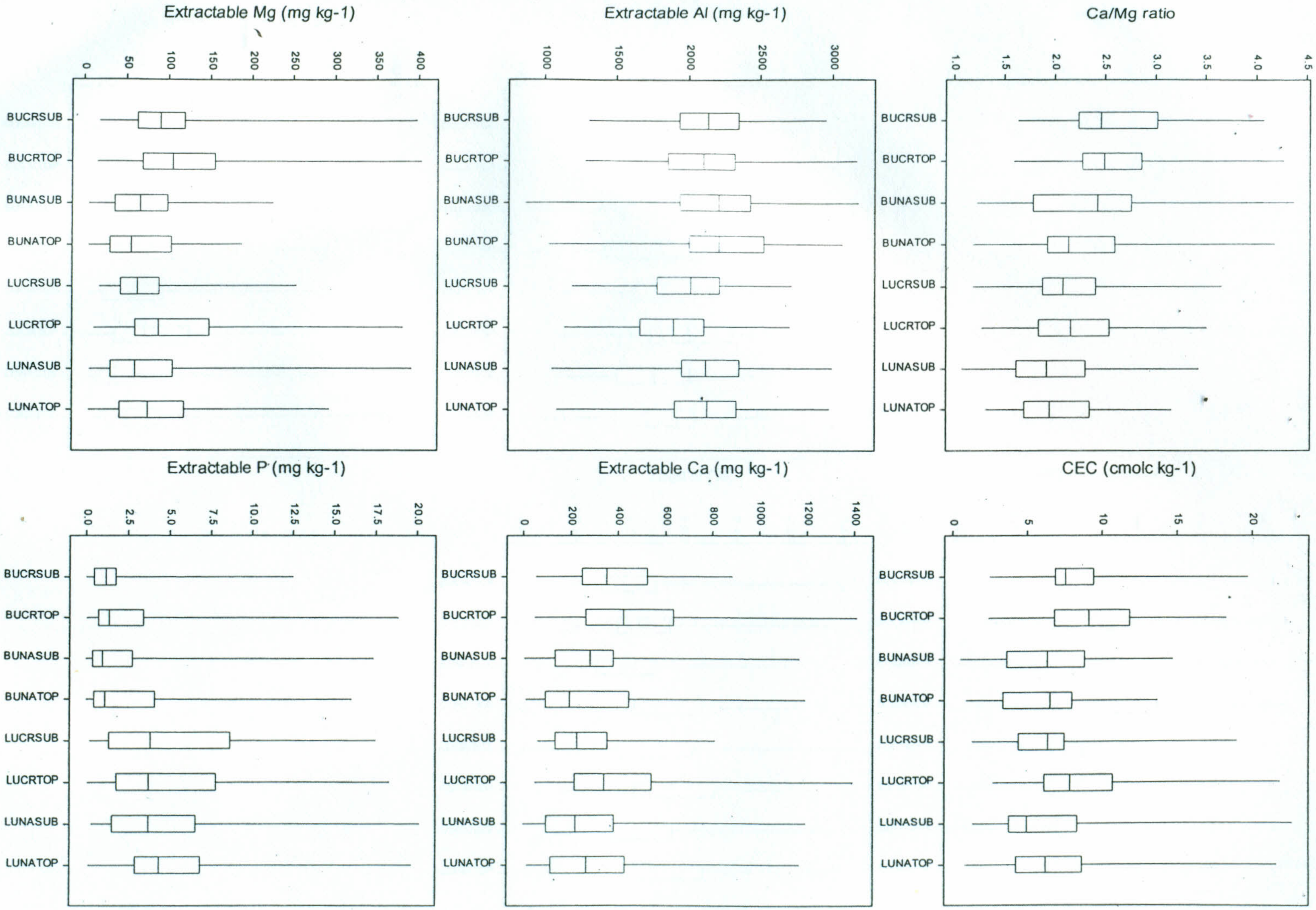
Wright, A. L. and Hons, F. M. (2005). Tillage impacts on soil aggregation and carbon and nitrogen sequestration under wheat cropping sequences. *Soil Tillage Res.,* 84:67-75.

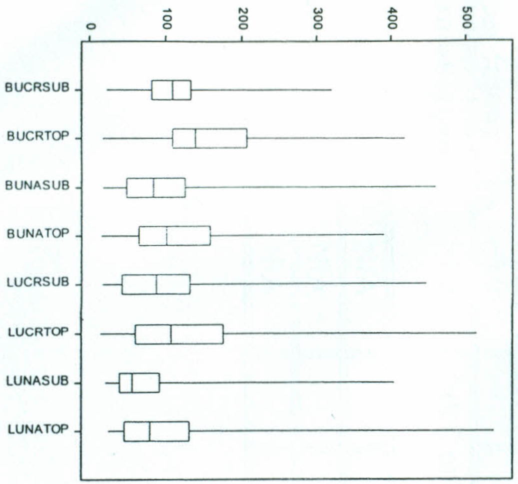
Xiaomei, J.2 006: Analysis of soil potassium. In 'Soil and agrochemical analytic methods'. (Ed. RK Lu) pp. 194–195. (China Agricultural Science and Technology Press: Beijing)

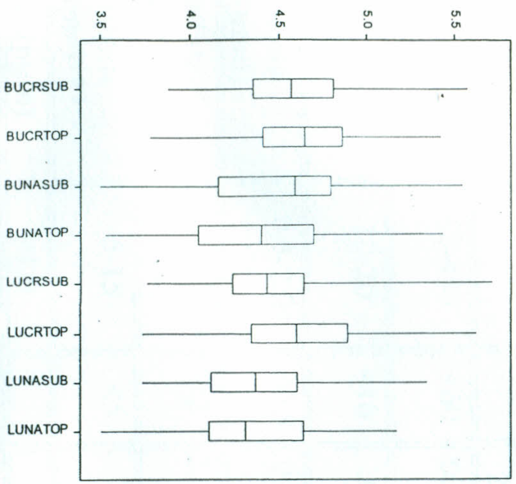
Appendix

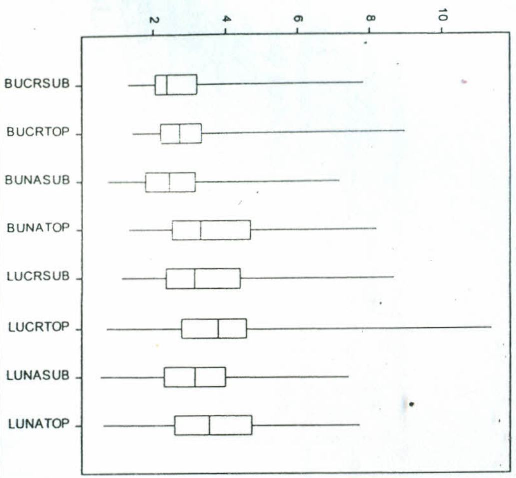
Appendix 1: Soil parameters distribution under different depths and land use

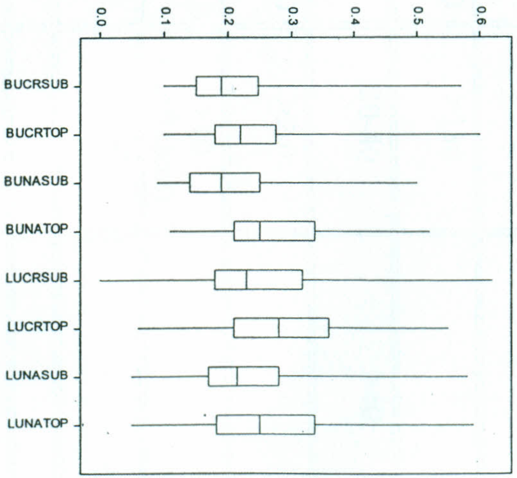
BUCRSUB: Sub soil for Burhale in cropped plots
BUCRTOP: Top soil for Burhale in cropped plots
BUNASUB: Sub soil for Burhale in uncropped plots
BUNATOP: Top soil for Burhale in uncropped plots
LUCRTOP: Top soil for Luhihi in cropped plots
LUCRSUB: Sub soil for Luhihi in cropped plots
LUNASUB: Sub soil for Luhihi in uncropped plots
LUNATOP: Top soil for Luhihi in uncropped plots

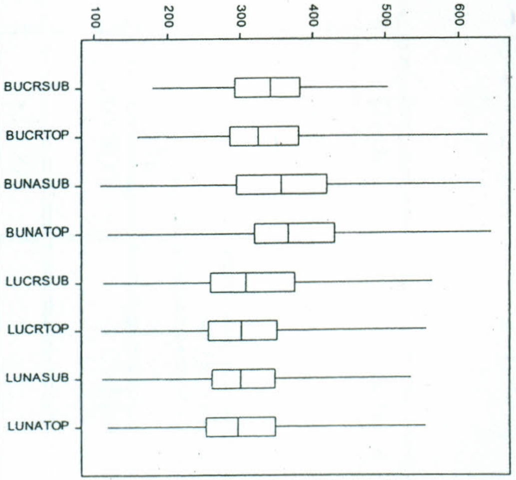

Extractable Mg (mg kg-1)
0 50 100 150 200 250 300 350 400
Extractable Al (mg kg-1)
1000 1500 2000 2500 3000
Ca/Mg ratio
1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
Extractable P (mg kg-1)
0.0 2.5 5.0 7.5 10.0 12.5 15.0 17.5 20.0
Extractable Ca (mg kg-1)
0 200 400 600 800 1000 1200 1400
CEC (cmolc kg-1)
0 5 10 15 20
BUCRSUB
BUCRTOP
BUNASUB
BUNATOP
LUCRSUB
LUCRTOP
LUNASUB
LUNATOP


Extractable K (mg kg-1)


pH (H2O)


organic C (%)


Total N (%)


P sorption index (mg P kg-1)

Appendix 2: Soil nutrient threshold

Soil Parameters	optimal	low	med	High	excessive
pH	6.0-7.5	<5.0		>7.5	
Soil organic carbon (%)	1-6	<5%		>10	
soluble salts	<1.0			>3.0mmho/cm	>4.0mmho/cm
sodium (ESP)	<15%			>15%	
potastium (ppm)*	120-200	< 150	150-250	250-800	>800
calcium (ppm)*	600-4000	<1000	1000-2000	>2000	
magnesium (ppm)*	60-480	<60	60-180	>180	
phosphorus (ppm)	10-20	<10	10-20	20-40	>40
boron (ppm)	0.5-2.0	<0.5	0.5-2.0	>2.0	
sulfate-S (ppm)	6-20	<2	2.0-10.0	>10 (sufficient)	
nitrate (ppm)***	5-15	<5		>100	
zinc (ppm)	>1.0				
copper (ppm)	>0.6				
manganese (ppm)	>1.5	def. only on soils pH > 7.0			toxicities may occur on acid soils
iron	N/A				
molybdenum	N/A				
Chloride	N/A				

*

Appendix 3: Wet chemistry soil analysis results

Cluster	C	N	pH1	EC	Al	B	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Zn	CEC	acidity	Ca	Mg	K	PSI	clay	sand	Silt
	---- (%) ----			(µS cm^{-1})	---------------------- Mehlich-extractable elements (mg kg^{-1}) ----------------------												----------------- (cmol$_c$ kg^{-1}) -----------------					(mg kg^{-1})	--------- (%) ---------		
													Burhale: Top soil												
1	3.44	0.27	4.73	202	1779	0.16	707	2.10	152	231	190	31	46	3	16	6.80	14.2	7.178	3.535	1.583	0.592	249	62	18	20
2	3.24	0.25	4.90	133	1949	0.13	836	2.16	157	129	171	51	61	2	37	2.36	13.7	6.420	4.180	1.425	0.331	289	56	28	16
3	4.85	0.37	4.44	78	2906	0.06	135	1.34	104	43	33	13	56	3	52	3.73	3.7	2.072	0.675	0.275	0.110	467	28	54	18
4	1.40	0.14	4.53	37	1309	0.07	115	2.25	338	55	31	6	59	1	21	1.39	3.3	1.787	0.575	0.258	0.141	175	42	28	30
5	1.98	0.15	4.61	216	1947	0.09	660	4.74	315	82	186	103	62	5	21	6.73	13.7	7.220	3.300	1.550	0.210	220	36	24	40
6	1.83	0.14	4.54	90	1708	0.14	565	4.50	113	196	128	173	65	1	117	1.70	12.4	6.730	2.825	1.067	0.503	315	74	12	14
7	5.02	0.32	4.30	99	2600	0.12	111	1.94	122	77	28	18	57	2	47	2.74	3.9	2.275	0.555	0.233	0.197	456	50	30	20
9	4.14	0.37	4.71	191	2438	0.18	733	2.18	103	163	112	51	48	4	16	2.32	12.7	6.419	3.665	0.933	0.418	366	33	49	18
10	2.05	0.17	4.81	84	1832	0.09	846	3.71	134	223	183	274	62	1	48	4.03	15.2	7.402	4.230	1.525	0.572	343	65	19	16
11	4.73	0.42	4.71	198	2560	0.20	572	1.96	92	161	116	55	58	2	26	3.02	10.9	5.539	2.860	0.967	0.413	410	27	47	26
12	4.49	0.29	4.10	113	2646	0.12	113	2.78	122	71	29	38	60	3	64	1.29	4.5	2.819	0.565	0.242	0.182	427	45	39	16
13	2.42	0.21	5.60	134	1533	0.23	1702	3.44	130	184	276	117	42	3	6	3.45	17.2	4.625	8.510	2.300	0.472	203	41	37	22
14	1.79	0.16	5.34	52	1827	0.17	516	3.57	91	91	102	112	59	2	55	1.27	6.7	2.349	2.580	0.850	0.233	273	61	23	16
15	2.28	0.15	4.22	67	1871	0.09	106	3.33	78	43	25	44	79	1	168	1.99	3.9	2.360	0.530	0.208	0.110	398	53	29	18
16	2.40	0.20	4.35	97	2280	0.04	593	3.83	126	68	125	106	68	2	39	3.50	13.5	7.804	2.965	1.042	0.174	377	53	29	18
													Burhale: Sub soil												
1	2.15	0.16	4.72	122	1678	0.07	352	1.83	100	124	101	17	57	2	29	3.51	7.6	3.863	1.760	0.842	0.318	210	68	20	12
2	3.19	0.25	4.96	110	1857	0.11	733	2.00	124	183	162	43	63	2	36	3.50	12.3	5.652	3.665	1.350	0.469	285	62	26	12
3	4.91	0.37	4.15	90	3315	0.07	119	1.08	116	33	27	10	61	1	67	3.12	4.0	2.503	0.595	0.225	0.085	538	24	58	18
4	0.73	0.09	4.53	32	1386	0.03	110	2.03	185	41	29	2	58	1	46	2.50	3.1	1.670	0.550	0.242	0.105	203	54	18	28
5	1.79	0.14	4.78	124	1900	0.07	671	4.60	363	54	172	152	63	5	85	7.25	12.1	5.983	3.355	1.433	0.138	218	34	24	42
6	1.69	0.13	4.42	86	1783	0.09	441	4.96	145	141	120	178	66	1	130	2.25	11.1	6.289	2.205	1.000	0.362	343	74	14	12
7	3.51	0.22	4.63	49	2581	0.08	102	1.94	89	58	25	13	40	1	39	1.49	2.7	1.388	0.510	0.208	0.149	441	68	16	16
9	3.36	0.30	4.80	80	2420	0.12	609	2.30	109	112	94	64	61	2	59	2.38	10.1	4.955	3.045	0.783	0.287	365	47	35	18
10	1.80	0.14	4.77	85	1932	0.08	723	3.08	128	118	160	243	63	0	49	3.09	13.0	6.463	3.615	1.333	0.303	350	67	17	16
11	3.95	0.34	4.69	140	2530	0.14	523	2.15	104	105	107	90	54	2	41	2.10	9.8	5.022	2.615	0.892	0.269	407	37	43	20

12	4.00	0.26	4.11	99	2719	0.05	110	2.71	117	52	28	36	60	2	65	1.39	4.2	2.654	0.550	0.233	0.133	436	47	35	18
13	2.57	0.22	5.67	216	1561	0.25	1753	3.55	130	275	282	133	56	5	8	4.07	17.5	4.366	8.765	2.350	0.705	197	35	45	20
14	1.38	0.12	4.93	52	1730	0.07	663	2.98	108	50	111	114	68	2	96	3.65	10.1	4.683	3.315	0.925	0.128	291	69	13	18
15	1.72	0.11	4.28	46	2053	0.03	94	3.03	73	27	23	47	62	0	229	1.86	3.2	1.872	0.470	0.192	0.069	433	63	19	18
16	2.42	0.19	4.36	98	2217	0.07	523	3.72	113	95	118	106	62	2	50	2.60	12.3	7.081	2.615	0.983	0.244	383	53	29	18

Cluster	C	N	pH1	EC	Al	B	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Zn	CEC	acidity	Ca	Mg	K	PSI	clay	sand	Silt
	---- (%) ----			(µS cm^{-1})	---------------------- Mehlich-extractable elements (mg kg^{-1}) ----------------------												---------------- (cmol$_c$ kg^{-1}) ----------------					(mg kg^{-1})	-------- (%) --------		
Luhihi: Top soil																									
1	3.36	0.26	4.74	202	1695	0.13	698	2.00	135	230	188	29	65	4	17	4.69	14.2	7.114	3.490	1.567	0.590	241	45	35	20
3	9.54	0.68	4.90	108	1684	0.12	677	1.82	111	171	151	38	58	2	35	2.89	11.7	5.515	3.385	1.258	0.438	293	27	39	34
4	3.11	0.27	4.78	171	1704	0.11	923	3.27	178	87	314	210	62	1	14	2.57	18.1	8.944	4.615	2.617	0.223	310	59	24	17
5	4.53	0.28	4.02	135	2271	0.08	180	1.07	524	76	31	4	62	1	23	1.95	6.2	4.016	0.900	0.258	0.195	347	65	17	18
6	3.60	0.27	4.31	155	2255	0.12	289	2.20	278	96	62	34	58	11	19	5.26	7.6	4.473	1.445	0.517	0.246	264	23	49	28
7	7.65	0.46	3.79	259	2960	0.01	113	1.53	316	69	33	21	69	11	38	2.85	1.5	0.979	0.565	0.275	0.177	480	67	15	18
8	4.80	0.31	4.06	116	2517	0.04	196	4.28	246	50	41	119	60	10	37	5.29	6.4	4.056	0.980	0.342	0.128	394	47	33	20
9	3.17	0.24	5.11	265	1551	0.19	912	5.54	295	858	335	234	65	20	25	5.32	19.2	7.975	4.560	2.792	2.200	169	39	39	22
10	3.59	0.35	5.92	311	1581	0.66	4141	2.56	268	1326	919	48	71	220	25	6.20	41.6	7.228	20.705	7.658	3.400	228	33	39	28
11	2.32	0.16	3.60	239	1765	0.04	152	2.56	466	59	33	31	57	8	22	4.30	1.6	1.104	0.760	0.275	0.151	170	.	.	.
12	3.11	0.23	3.85	441	1871	0.06	288	3.25	398	129	74	143	61	16	28	7.79	2.9	1.956	1.440	0.617	0.331	188	57	17	26
13	. .	.	4.33	91	1872	0.04	252	2.73	101	56	76	54	79	6	69	3.20	7.3	4.247	1.260	0.633	0.144	318	23	47	30
14	5.03	0.36	4.32	117	1693	0.10	392	4.25	175	127	127	51	66	3	46	2.00	11.1	6.514	1.960	1.058	0.326	214	61	21	18
15	2.28	0.19	5.54	41	1633	0.22	1722	7.50	391	165	178	264	57	114	10	11.2	16.6	4.807	8.610	1.483	0.423	82	27	43	30
16	1.28	0.12	4.72	206	1521	0.15	1057	4.79	230	296	254	217	63	6	34	4.81	20.4	10.330	5.285	2.117	0.759	155	73	11	16
Luhihi: top soil																									
1	2.93	0.18	4.34	61	2259	0.03	178	2.11	222	42	29	14	57	2	29	7.40	4.5	2.606	0.890	0.242	0.108	314	47	31	22
3	3.28	0.26	4.17	162	2809	0.04	191	1.11	276	80	72	33	68	14	26	4.90	7.0	4.300	0.955	0.600	0.205	450	43	37	20
4	2.63	0.24	4.74	100	1676	0.06	741	2.71	164	50	261	152	56	1	27	3.58	14.9	7.495	3.705	2.175	0.128	332	61	25	14
5	1.80	0.13	4.31	44	2167	0.06	114	5.45	91	34	26	59	65	0	156	1.29	3.6	2.106	0.570	0.217	0.087	397	37	23	40
6	2.05	0.16	4.52	75	2164	0.03	185	2.75	365	70	55	54	57	8	18	2.06	4.9	2.664	0.925	0.458	0.179	253	23	47	30
7	4.84	0.29	3.95	99	2813	0.04	109	2.54	201	39	29	15	66	4	38	1.73	1.3	0.845	0.545	0.242	0.100	475	33	41	26
8	3.95	0.24	3.93	97	2467	0.01	128	4.68	227	34	28	112	59	5	36	4.21	1.3	0.880	0.640	0.233	0.087	406	41	31	28
9	2.75	0.21	5.08	230	1518	0.22	849	5.37	290	773	307	223	68	22	23	4.28	18.1	7.676	4.245	2.558	1.982	122	63	15	22
10	2.10	0.20	6.47	136	1445	0.72	4231	3.60	239	1418	980	95	71	377	21	7.62	38.2	3.023	21.155	8.167	3.636	151	33	41	26
11	1.94	0.14	3.98	85	1785	0.05	149	2.73	454	46	31	29	59	6	18	5.64	1.5	0.990	0.745	0.258	0.118	176	29	43	28
12	1.29	0.09	4.05	170	1346	0.03	133	2.49	392	63	42	87	61	5	21	10.2	1.1	0.715	0.665	0.350	0.162	136	25	45	30
13	3.89	0.22	4.16	75	2137	0.07	130	2.61	384	71	43	7	66	5	28	3.34	5.0	3.105	0.650	0.358	0.182	312	51	27	22
14	1.88	0.14	4.34	89	1573	0.09	438	4.45	169	96	148	50	68	2	39	2.66	12.0	6.995	2.190	1.233	0.246	222	63	17	20