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

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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.

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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.

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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!
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<th>Definition</th>
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<tbody>
<tr>
<td>AU</td>
<td>African Union</td>
</tr>
<tr>
<td>AFSIS</td>
<td>African Soil Information Service</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analyze of Variance</td>
</tr>
<tr>
<td>CEC</td>
<td>Cation Exchangeable Capacity</td>
</tr>
<tr>
<td>CIAT</td>
<td>Centre International d’Agriculture Tropicale</td>
</tr>
<tr>
<td>DRC</td>
<td>Democratic Republic of the Congo</td>
</tr>
<tr>
<td>DSRP</td>
<td></td>
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<tr>
<td>EC</td>
<td>Electrical Conductivity</td>
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<tr>
<td>EDTA</td>
<td>EthyleneDiamineTetraacetic Acid</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information system</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>ICRAF</td>
<td>International Center of Research of Agroforestry</td>
</tr>
<tr>
<td>IR</td>
<td>Infrared</td>
</tr>
<tr>
<td>ISFM</td>
<td>Integrated Soil Fertility Management</td>
</tr>
<tr>
<td>KU</td>
<td>Kenyatta University</td>
</tr>
<tr>
<td>MIR</td>
<td>Mid-Infrared</td>
</tr>
<tr>
<td>NIR</td>
<td>Near Infrared</td>
</tr>
<tr>
<td>PLS</td>
<td>Partial Least Squares regression</td>
</tr>
<tr>
<td>PNE</td>
<td>Programme National Engrais</td>
</tr>
<tr>
<td>PRAGMA</td>
<td>Programme Régional Agricole de gestions de Marais</td>
</tr>
<tr>
<td>PSI</td>
<td>Phosphorus Sorption Index</td>
</tr>
<tr>
<td>RMSD</td>
<td>Root Mean Square Deviation</td>
</tr>
<tr>
<td>SOC</td>
<td>Soil Organic Carbon</td>
</tr>
<tr>
<td>SOM</td>
<td>Soil Organic Matter</td>
</tr>
<tr>
<td>SSA</td>
<td>Sub-Sahara Africa</td>
</tr>
<tr>
<td>TSBF</td>
<td>Tropical Soil Biology and Fertility</td>
</tr>
<tr>
<td>VLIR</td>
<td>Vlaames Interuniveistaire Road</td>
</tr>
<tr>
<td>VNIR</td>
<td>Visible near Infrared</td>
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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 characterize soil based on infrared spectroscopy. This method was 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 km². After minimal sample preparation, the MIR spectrum of a soil takes about two minutes for the analyses. Differences 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 et 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 most 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 particularly 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 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.
*Poor laboratory equipment
*No qualified laboratory staff

*Few soil information available
*Soil analysis is expensive and takes time
*Use of old information for research

*No use of specific fertilizers to each region
*Soil fertility increasing
*Poor crop yielding

Development of new approach of soil analysis based

Avail the results of the soil for different stakeholders active in

Technical and material support soil analysis

*Specific recommendation on each soil parameter constraint control.
*Use of specific fertilizers for each region

Training on nutrient deficiency handling

Crop yielding improvement

Development of local and regional markets of input and outputs (Fertilizers, seed,

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:

<table>
<thead>
<tr>
<th>Designation</th>
<th>Abbreviation</th>
<th>Wavelength</th>
</tr>
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<tbody>
<tr>
<td>Near-Infrared</td>
<td>NIR</td>
<td>(0.7–1) to 5 μm</td>
</tr>
<tr>
<td>Mid-Infrared</td>
<td>MIR</td>
<td>5 to (25–40) μm</td>
</tr>
<tr>
<td>Far-Infrared</td>
<td>FIR</td>
<td>(25–40) to (200–350) μm.</td>
</tr>
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</table>

- **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

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

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.

![Electromagnetic spectrum of different spectroscopy zones](image)

**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

<table>
<thead>
<tr>
<th>Chemical properties</th>
<th>Physical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic carbon, charcoal, particulate organic, inorganic C, Total N</td>
<td>Bulk density</td>
</tr>
<tr>
<td>Exchangeable cations (Ca, Mg, K, Na) and CEC</td>
<td>Particle size: Clay, silt, sand</td>
</tr>
<tr>
<td>Phosphorus buffering index</td>
<td>Volumetric water content</td>
</tr>
<tr>
<td>PH, water and CaCl₂</td>
<td>Quantitative X Ray Reflectance</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>XRD content: quartz, kaolinite, smectites</td>
</tr>
<tr>
<td>Exchangeable sodium percentage</td>
<td>Quantitative XRR: Si, Al, Fe, Ca, Mg</td>
</tr>
</tbody>
</table>

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.

Figure 2.2: 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.
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 Luhii are the two site selected for this study as shown on Figure 3.1.

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 vulgaris*) and banana (*Musa spp*).
3.2. Sampling framework and soil sampling

The sampling plan involved 16 clusters with each cluster subdivided into 10 plots/clusters (Figure 3.1). The number of samples to be collected was calculated as follows; 2 sites* 16 cluster per site * 10 plots per cluster * 2 depths per plot (0-20 cm 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.

![Figure 3.2: (a) 10 km x 10 km for a sentinel site (block) with it 16 sampling clusters (with 1 km$^2$ 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 (altitude, 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. 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 7000 cm\(^{-1}\). 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 CH₃COOH + 0.25 N NH₄NO₃ + 0.015 N NH₄F + 0.013 NHNO₃ + 0.001 M EDTA : ethylenediaminetetraacetic acid: [(HOOCCH₂)₂NCH₂N(CH₂COOH)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

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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 software 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):

$$\text{RMSD} = \sqrt{\frac{\sum (Y_{\text{pred}} - Y_{\text{meas}})^2}{N}}$$

Where,

$Y_{\text{pred}}$ = predicted value of the validation set using PLS model

$Y_{\text{meas}}$ = 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 $P<0.05$. 

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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
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
to Shepherd 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 ($R^2 = 0.71$ 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.
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.

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

![Nitrogen correlation graph](image)

**Figure 4.5:** 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 ($R^2 = 0.8$). Similarly, 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.
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.

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.

Figure 4.7: Correlation between measured and predicted values of extractable K
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.
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 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 Luhiti 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 Luhhi and Burhale

<table>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Luhhihi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topsoil (n=137)</td>
<td>Topsoil (n=153)</td>
</tr>
<tr>
<td></td>
<td>Subsoil (n=110)</td>
<td>Subsoil (n=130)</td>
</tr>
<tr>
<td>Cropped</td>
<td>3.03 (±0.42)</td>
<td>3.93(±0.57)</td>
</tr>
<tr>
<td></td>
<td>2.82 (±0.37)</td>
<td>2.91(±1.68)</td>
</tr>
<tr>
<td>Un cropped</td>
<td>3.77 (±0.97)</td>
<td>5.23(±1.55)</td>
</tr>
<tr>
<td></td>
<td>3.68(1.14)</td>
<td>4.25(±1.68)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>0.003</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

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 Mokolbte (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 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 uncropped 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).

Table 4.2. Total N (%) for top and sub soils sampled from cropped and non cropped land in Luhihi and Burhale

<table>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Luhiji</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topsoil (n=137)</td>
<td>Subsoil (n=110)</td>
</tr>
<tr>
<td>Cropped</td>
<td>0.25 (+0.04)</td>
<td>0.215 (+0.01)</td>
</tr>
<tr>
<td>Uncropped</td>
<td>0.295 (+0.12)</td>
<td>0.27 (+0.08)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.04</td>
<td>0.053</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Luhhihi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topsoil (n=137)</td>
<td>Subsoil (n=110)</td>
</tr>
<tr>
<td>Copped</td>
<td>196.015(±21.32)</td>
<td>112.7 (±50.97)</td>
</tr>
<tr>
<td>Uncropped</td>
<td>159.07 (±70.57)</td>
<td>114.565(±44.22)</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;0.001</td>
<td>0.01</td>
</tr>
</tbody>
</table>

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±0.28 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>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Luhhihi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topsoil (n=137)</td>
<td>Subsoil (n=110)</td>
</tr>
<tr>
<td>Cropped</td>
<td>5.77 (±2.61)</td>
<td>1.13 (±0.42)</td>
</tr>
<tr>
<td></td>
<td>1.07 (±0.21)</td>
<td>2.01 (±0.46)</td>
</tr>
<tr>
<td>Un cropped</td>
<td>3.33(±2.19)</td>
<td>0.86(±0.28)</td>
</tr>
<tr>
<td></td>
<td>4.47(±4.45)</td>
<td>3.41 (±2.42)</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;0.001</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>0.03</td>
<td>0.04</td>
</tr>
</tbody>
</table>

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 Luhhi 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 $241.12S\pm4S.12$ to $463.52S\pm6S.18$ and from $187.28S\pm16S.77$ to $486.77S\pm23S.06$ in Burhale and Luhii 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 Luhii except for the sub soils from this site (Luhii) where both land use systems had the same amount of Calcium.

<table>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Luhii</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topsoil (n=137)</td>
<td>Topsoil (n=153)</td>
</tr>
<tr>
<td></td>
<td>subsoil (n=110)</td>
<td>Subsoil (n=130)</td>
</tr>
<tr>
<td>Cropped</td>
<td>463.52S(±66.18)</td>
<td>421.89S(±48.7)</td>
</tr>
<tr>
<td></td>
<td>380.12S(±50.40)</td>
<td>486.77S(±230.46)</td>
</tr>
<tr>
<td>Uncropped</td>
<td>399.34S(±88.87)</td>
<td>241.12S(±45.42)</td>
</tr>
<tr>
<td></td>
<td>215.12S(±45.42)</td>
<td>304.17(±80.41)</td>
</tr>
<tr>
<td></td>
<td>187.28S(±16S.77)</td>
<td>187.28S(±16S.77)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.01</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

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 acidity 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 Luhishi and Burhale

<table>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Luhishi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topsoil (n=137)</td>
<td>subsoil (n=110)</td>
<td>Topsoil (n=153)</td>
</tr>
<tr>
<td>Cropped</td>
<td>159(±70.57)</td>
<td>92.7(±50.97)</td>
</tr>
<tr>
<td>Uncropped</td>
<td>196(±21.32)</td>
<td>94.6(±44.22)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.01</td>
<td>0.12</td>
</tr>
</tbody>
</table>

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 Luhishi 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 acidity 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 ± 102.62 5 to 419.925 ± 100.67 and from 264.085 ± 85.88 to 358.01 ± 77.16 Burhale and Luhiihi 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 Luhiihi and Burhale

<table>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Luhiihi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topsoil</td>
<td>subsoil</td>
</tr>
<tr>
<td>Copped</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(n=137)</td>
<td>(n=110)</td>
</tr>
<tr>
<td></td>
<td>285.6</td>
<td>392(±65)</td>
</tr>
<tr>
<td></td>
<td>(±102.62)</td>
<td></td>
</tr>
<tr>
<td>Uncropped</td>
<td>377.8 (±66.9)</td>
<td>420(±100.67)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.01</td>
<td>0.05</td>
</tr>
</tbody>
</table>

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 Luhiihi 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 Luhiihi 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 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 Luhiji and Burhale

<table>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Luhiji</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topsoil</td>
<td>subsoil</td>
</tr>
<tr>
<td>Cropped</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n=137)</td>
<td>2033.83</td>
<td>2343.28</td>
</tr>
<tr>
<td>(±408.02)</td>
<td>(±143.7)</td>
<td>(±136.38)</td>
</tr>
<tr>
<td>Uncropped</td>
<td>2461.74</td>
<td>2430.85</td>
</tr>
<tr>
<td>(±198.97)</td>
<td>(±474.1)</td>
<td>(±386.2)</td>
</tr>
</tbody>
</table>

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 Luhiji 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 Luhiihi 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 Luhiihi 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

<table>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Luhiihi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topsoil (n=137)</td>
<td>subsoil (n=110)</td>
</tr>
<tr>
<td>Cropped</td>
<td>0.875(±0.43)</td>
<td>1.345(±0.32)</td>
</tr>
<tr>
<td>Uncropped</td>
<td>2.31 (±1.26)</td>
<td>3.18 (±1.18)</td>
</tr>
</tbody>
</table>

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 (CaCO₃ 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 Luhiihi, 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, therefore the top soils, all these two location are identical. The uncropped areas are more acidic than cropped soils for both depths. The degree of acidity 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

<table>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Luhihi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topsoil</td>
<td>subsoil</td>
</tr>
<tr>
<td></td>
<td>(n=137)</td>
<td>(n=110)</td>
</tr>
<tr>
<td>Cropped</td>
<td>4.63 (±0.17)</td>
<td>4.6 (±0.13)</td>
</tr>
<tr>
<td>Uncropped</td>
<td>4.42 (±0.34)</td>
<td>4.5 (±0.47)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.04</td>
<td>0.02</td>
</tr>
</tbody>
</table>

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 Luhii 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

Lushihi 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 Lushihi top soils, cropped have more concentration than uncropped zone (p=0.04).

<table>
<thead>
<tr>
<th>Region</th>
<th>Burhale</th>
<th>Lushihi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Topsoil (n=137)</td>
<td>subsoil (n=110)</td>
</tr>
<tr>
<td></td>
<td>2.545 (±0.33)</td>
<td>2.53 (±0.55)</td>
</tr>
<tr>
<td></td>
<td>2.595 (±0.71)</td>
<td>2.545 (±0.7)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.18</td>
<td>0.06</td>
</tr>
</tbody>
</table>

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: Luhiri 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 Luhiri 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 (Luhiri top soils, Burhale top and sub soils) but for Luhiri 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 Luhhi top soils, where there was more concentration for the cropped plots. For Luhhi 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 Luhhi 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 uncropped plots in Luhhi 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


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Appendix

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

BU CR SUB: Sub soil for Burhale in cropped plots
BU CR TOP: Top soil for Burhale in cropped plots
BU NA SUB: Sub soil for Burhale in uncropped plots
BU NA TOP: Top soil for Burhale in uncropped plots
LU CR TOP: Top soil for Luhihi in cropped plots
LU CR SUB: Sub soil for Luhihi in cropped plots
LU NA SUB: Sub soil for Luhihi in uncropped plots
LU NA TOP: Top soil for Luhihi in uncropped plots
Appendix 2: Soil nutrient threshold

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<th>High</th>
<th>excessive</th>
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<td>&gt;7.5</td>
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<td>&gt;4.0mmho/cm</td>
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<td>150-250</td>
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<tr>
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<tr>
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Appendix 3: Wet chemistry soil analysis results

```
| Cluster | C (%) | N (%) | pH1 | EC  | Al  | B   | Ca  | Cu  | Fe  | K   | Mn  | Na  | P   | S   | Zn  | CEC | acidity | Ca  | Mg  | K  |
|---------|-------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|-----|-----|----|
|         |       |       |     |     |     |     |     |     |     |     |     |     |     |     |     |        |      |     |----|
| Burhale | Top soil | | | | | | | | | | | | | | |        |      |     |----|
| 1       | 3.44  | 0.27  | 4.73| 202 | 1.779| 0.16 | 707 | 2.10| 152 | 231 | 190 | 31  | 46  | 3   | 16  | 6.80  | 14.2 | 7.178| 3.535|
| 2       | 3.24  | 0.25  | 4.90| 133 | 1.949| 0.13 | 836 | 2.16| 157 | 129 | 171 | 51  | 61  | 2   | 37  | 2.36  | 13.7 | 6.420| 4.180|
| 3       | 4.85  | 0.37  | 4.44| 74  | 2.906| 0.06 | 135 | 1.34| 104 | 43  | 33  | 13  | 56  | 3   | 52  | 3.73  | 3.7  | 2.072| 0.675|
| 4       | 1.40  | 0.14  | 4.53| 37  | 1.309| 0.07 | 115 | 2.35| 338 | 55  | 31  | 6   | 59  | 1   | 21  | 1.39  | 3.3  | 1.787| 0.575|
| 5       | 1.98  | 0.15  | 4.61| 216 | 1.947| 0.09 | 660 | 4.74| 315 | 82  | 166 | 103 | 62  | 5   | 21  | 6.73  | 13.7 | 7.220| 3.300|
| 6       | 1.83  | 0.14  | 4.54| 90  | 1.708| 0.14 | 565 | 4.50| 113 | 173 | 65  | 1   | 117 | 1.7  | 12.4 | 6.730 | 13.7 | 6.420| 4.180|
| 7       | 5.02  | 0.32  | 4.30| 99  | 2.600| 0.12 | 111 | 1.94| 122 | 77  | 28  | 18  | 57  | 2   | 47  | 2.74  | 3.9  | 2.275| 0.555|
| 8       | 4.14  | 0.37  | 4.71| 191 | 2.438| 0.18 | 733 | 2.18| 103 | 163 | 112 | 51  | 48  | 4   | 16  | 2.32  | 12.7 | 6.419| 3.665|
| 9       | 2.05  | 0.17  | 4.81| 84  | 1.832| 0.09 | 846 | 3.71| 134 | 223 | 183 | 62  | 171 | 51  | 61  | 2.36  | 13.7 | 6.420| 4.180|
| 10      | 4.73  | 0.42  | 4.71| 198 | 2.560| 0.20 | 572 | 1.96| 92  | 161 | 116 | 55  | 58  | 2   | 26  | 3.02  | 10.9 | 5.539| 2.860|
| 11      | 4.49  | 0.29  | 4.10| 113 | 2.566| 0.15 | 4.27| 1.96| 92  | 161 | 116 | 55  | 58  | 2   | 26  | 3.02  | 10.9 | 5.539| 2.860|
| 12      | 1.69  | 0.13  | 4.42| 97  | 2.400| 0.03 | 563 | 3.83| 126 | 68  | 125 | 106 | 68  | 2   | 39  | 3.50  | 13.5 | 7.804| 2.965|
| Burhale | Sub soil | | | | | | | | | | | | | | |        |      |     |----|
| 1       | 2.15  | 0.16  | 4.72| 122 | 1.678| 0.07 | 352 | 1.83| 100 | 124 | 101 | 17  | 57  | 2   | 29  | 3.51  | 7.6  | 3.863| 1.760|
| 2       | 3.19  | 0.25  | 4.96| 110 | 1.857| 0.11 | 733 | 2.00| 124 | 163 | 162 | 43  | 63  | 2   | 36  | 3.50  | 12.3 | 5.652| 3.665|
| 3       | 4.91  | 0.37  | 4.15| 90  | 3.315| 0.07 | 178 | 1.08| 116 | 33  | 27  | 10  | 61  | 1   | 37  | 6.12  | 13.0 | 2.503| 0.595|
| 4       | 0.73  | 0.09  | 4.53| 32  | 1.386| 0.03 | 110 | 2.03| 185 | 41  | 29  | 2   | 58  | 1   | 46  | 2.50  | 3.1  | 1.670| 0.550|
| 5       | 1.79  | 0.14  | 4.78| 124 | 1.900| 0.07 | 671 | 4.60| 363 | 54  | 172 | 152 | 63  | 5   | 85  | 7.25  | 12.1 | 5.983| 3.355|
| 6       | 1.69  | 0.13  | 4.42| 86  | 1.783| 0.09 | 441 | 4.96| 145 | 141 | 120 | 178 | 66  | 1   | 130 | 2.25  | 11.1 | 6.289| 2.205|
| 7       | 3.51  | 0.22  | 4.63| 49  | 2.581| 0.08 | 102 | 1.94| 89  | 58  | 24  | 13  | 40  | 1   | 39  | 1.49  | 2.7  | 1.388| 0.510|
| 9       | 3.36  | 0.30  | 4.80| 80  | 2.420| 0.12 | 609 | 2.30| 109 | 112 | 94  | 64  | 61  | 2   | 59  | 2.38  | 10.1 | 4.955| 3.045|
| 10      | 1.80  | 0.14  | 4.77| 85  | 1.932| 0.08 | 723 | 3.08| 128 | 118 | 160 | 243 | 63  | 0   | 49  | 3.09  | 13.0 | 6.463| 3.615|
| 11      | 3.95  | 0.34  | 4.69| 140 | 2.530| 0.14 | 523 | 2.15| 104 | 105 | 107 | 90  | 54  | 2   | 41  | 2.10  | 9.8  | 5.022| 2.615|
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<p>| | | | | | | | | | | | | | | | | | | | | | | | | |
|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 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 |</p>
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Luhiji: Top soil

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2. 3.28 0.26 4.17 162
3. 2.63 0.24 4.74 100
4. 1.80 0.13 4.31 44
5. 2.05 0.16 4.52 75
6. 4.84 0.29 3.95 99
7. 3.95 0.24 3.93 97
8. 2.75 0.21 5.08 230
9. 2.10 0.20 6.47 136
10. 1.94 0.14 3.98 65
11. 1.29 0.09 4.05 170
12. 3.89 0.22 4.16 75
13. 1.88 0.14 4.34 89