SPATIAL VARIABILITY OF SOIL FERTILITY DISTRIBUTION IN KYEE INN VILLAGE TRACT, PYINMANA TOWNSHIP, NAYPYITAW

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A thesis submitted to the post-graduate committee of the Yezin Agricultural University as a partial fulfillment of the requirements for the degree of Master of Agricultural Science (Soil and Water Science)

Department of Soil and Water Science
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The thesis attached hereto, entitled **"Spatial Variability of Soil Fertility Distribution in Kyee Inn Village Tract, Pyinmana Township, Naypyitaw"** was prepared under the direction of the chairperson of the candidate supervisory committee and has been approved by all members of that committee and board of examiners as a partial fulfillment of the requirements for the degree of **Master of Agricultural Science (Soil and Water Science).**

…………………………………

Dr. Swe Swe Mar
Chairman, Supervisory Committee
Lecturer
Department of Soil and Water Science
Yezin Agricultural University

…………………………………

Dr. Ni Ni Tint
External Examiner
Research Officer
Soil Science Research Section
Department of Agricultural Research

…………………………………

Dr. Aung Kyaw Myint
Member, Supervisory Committee
Associate Professor and Principal
Yezin Agricultural University
Kyaukse Campus

…………………………………

Dr. Kyi Toe
Member, Supervisory Committee
Professor and Principal
Yezin Agricultural University
Hlegu Campus

…………………………………

Dr. Kyaw Ngwe
Professor and Head
Department of Soil and Water Science
Yezin Agricultural University

Date ……………………………

This thesis was submitted to the Rector of the Yezin Agricultural University and was accepted as partial fulfillment of the requirements for the degree of **Master of Agricultural Science (Soil and Water Science).**

……………………………………

Dr. Nang Hseng Hom

Rector

Yezin Agricultural University

Date ……………………………

DECLARATION OF ORIGINALITY

This thesis represents the original works of the author, except where otherwise stated. It has not been submitted previously for a degree at any other University.

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Naing Naing Moe

Date ……………………………

DEDICATED TO MY BELOVED PARENTS

U HLA SHWE AND DAW MAR MAR SAW

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ABSTRACT

A case study was conducted in Kyee Inn Village Tract, Pyinmana Township, Naypyitaw area during 2017 and 2018 to generate the spatial distribution maps by evaluating soil fertility status showing chemical and physical soil properties. It also aimed to suggest the farmers for proper site-specific fertilizer management for the study area using Geographic Information System (GIS). Soil sampling was done as grid method 300 m × 300 m and soil samples were collected from three sites in each grid at 0-15 cm depth using Global Positioning System (GPS) to determine the coordinate of sampling points from total area of 480 hectares. The collected soil samples were composited to 80 soil samples for conducting the analysis of soil pH, electrical conductivity, cation exchange capacity, soil organic matter, soil moisture, bulk density and the total content of nitrogen, phosphorus and potassium. Farmers were interviewed to identify the soil management practices of the sampling area. Different thematic maps for the spatial distribution of each parameter were generated using the Inverse Distance Weighted (IDW) interpolation in the ArcGIS software version 10.5. Among the statistical results, total nitrogen showed the highest variability and soil pH showed the least variability with a coefficient of variation (CV) 66.84% and 5.08% and the values ranged from 0.01% to 0.33% and 5.48 to 7.58, respectively. The Electrical Conductivity with an average of 0.095 dS m^{-1} was obtained. The Cation Exchange Capacity exhibited the lower level ranged from 2.13 meq100 g^{-1}soil to 11.05 meq100 g^{-1}soil. Low to medium range of total phosphorus was observed between 0.017% and 0.024%. Higher bulk density values were found with the mean value of 1.52 g cm^{-3} and lower content of total potassium ranged from 197.5 mg kg^{-1} to 601.4 mg kg^{-1}. The calculated Nutrient Index Value for all nutrient in soils of this area was classified as low class. The result of insufficient organic matter level of 0.2% to 1.7% and the variability of soil characteristics existed largely due to the differences in management practices by the farmers, and therefore, farmers should be encouraged to adopt organic matter improvement practices for improving the long-term storage of soil fertility level in crop production. The observed various spatial variability of soil properties that affected soil fertility would provide the information of effective management and decisions making for crop cultivation in Kyee Inn area.

Keywords: GIS, GPS, spatial variability, soil properties

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CHAPTER I

INTRODUCTION

Ensuring food security for the ever-increasing world population has direct relation with physicochemical property, fertility and productivity of soil. The overall productivity and sustainability of a given agricultural sector is highly dependent upon the fertility and physicochemical characteristics of soil resources (Mohammed, Leroux, Barker & Heluf, 2005). Soil fertility is recognized as a primary constraint to agricultural production in developing countries (Staal et al., 2003). Soil fertility varies throughout the growing season each year due to alteration in the quantity and availability of mineral nutrients by the addition of fertilizers, manure, compost, mulch, and lime or sulfur, in addition to leaching (Ravikumar & Somashekar, 2014). Periodic assessment of essential soil properties is necessary to apply appropriate soil fertility management techniques, and to improve and maintain fertility and productivity of soil (Wakene & Heluf, 2003).

Understanding the spatial variability in soil properties and its interaction with soil fertility parameters is very important for site-specific nutrient management to improve the production. Soil properties change in time and space continuously (Rogerio, Ana & de Quirijn, 2006). Soil properties vary spatially and temporally from a field to a larger region scale, and are influenced by both intrinsic (soil forming factors, such as parent materials) and extrinsic factors (soil management practices, fertilization and crop rotation) (Cambardella & Karlen, 1999).

Soil fertility mapping is the way of assessing soil nutrients on the basis of soil test results and preparation of soil fertility maps at the required scale. A survey of soil fertility status which includes soil sampling, analysis and preparation of soil fertility maps would provide valuable information for diagnosis and predication of fertilizer application needs (Rawal, Acharya, Bam & Acharya, 2018). Soil testing provides information regarding nutrient availability in soils which forms the basis for the fertilizer recommendations for optimizing crop yields (Lelago, Mamo, Haile & Shiferaw, 2016).

Fertilizer management is a major consideration in agricultural production. Inadequate fertilizer application limits crop yield, results in nutrient mining and causes soil fertility depletion. An excessive or imbalanced application not only wastes a limited resource, but also pollutes the environment. With consideration of both economic optimization and environmental concerns, farmers are forced to face with an ever-increasing demand for effective soil fertility management. An approach towards justifying such concerns is site specific nutrient management which takes into account spatial variations in nutrients status cutting down the possibility of over or under use of fertilizer (Aishah, Zauyah, Anuar, & Fauziah, 2010). Fertilizer application based on soil fertility may also lead to reduced fertilizer inputs without reducing yield (Jalali, 2007). Therefore, understanding the spatial variability of soil nutrient is the first step and the pre-condition for precision fertilizer application (Yang & Zhang, 2008).

There have been growing interests in the study of spatial variation of soil characteristics using geostatistics since 1970s (Aishah et al., 2010). A standard method for creating maps of topsoil properties is to sample the targeted area using a grid sampling scheme, the density of which depends on the heterogeneity of the area. Then, a prediction map can be made by interpolating the measured property values of the samples (Karydas, Gitas, Koutsogiannaki, Lydakis-Simantiris & Silleos, 2009). Describing the spatial variability across area was difficult until new technologies such as Global Positioning Systems (GPS) and Geographic Information Systems (GIS) were introduced (Lelago et al., 2016).

GPS has been widely adopted in the area of agriculture in preparation of thematic maps like land use, land cover, soil fertility maps, etc. GIS is a powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data (Burrough & McDonnell, 1998). Inverse Distance Weighting (IDW) is a good interpolator for phenomena whose distribution is strongly correlated with distance (Mustafa et al., 2011). GIS generated soil fertility maps may serve as a decision support tool for nutrient management (Iftikar, Chattopadhayaya, Majumdar & Sulewski, 2010) and it also helps to determine plant nutrient availability and distribution and the pattern of nutrient depletion in the project area (Rawal et al., 2018).

Soil fertility is one of the primary constraints to agricultural production in tropical countries including Myanmar. Baroang (2013) reported that there was limited information on dynamics of soil and erosion pattern in Myanmar, and what exists were largely based on decades of old data and establishment of monitoring stations and appropriate monitoring design would be very valuable. It was pointed out that there is a need to update the data of agricultural soils status in Myanmar. MacCarthy, Agyare, Vlek, and Adiku (2013) stated that without precision-agriculture technologies, which can adapt soil management to the location specific fertility status, it is conceivable that formulating recommendations for managing soils with highly variable properties, based on a few selected sites analysis, may lead to erroneous outcomes. Besides, some information on spatial variability within soil fertility parameters should be considered as one of the fundamental issues for local management in precision agriculture. Currently, there was little information on spatial variability of soil fertility parameters and very few efforts of generating soil fertility maps for agricultural soils in Myanmar. Keeping these facts, the present study was conducted with the specific objectives of developing the spatial distribution maps by evaluating soil fertility status showing soil chemical and physical properties, and providing important basis to the farmers for proper site-specific fertilizer management in the study area.

CHAPTER II
LITERATURE REVIEW

2.1 Importance of Soil Fertility

Soil is a valuable non-renewable resource for the sustained quality of human life and the foundation of agricultural development (Das, Bandyopadhyay & Chakraborty, 2009) because, once degraded its regeneration is an extremely slow process (Camarsa et al., 2014; Lal, 2015). Soil is a heterogeneous, diverse and dynamic system and investigation of its temporal and spatial changes is essential (Kavianpoor, Esmali, Jafarian & Kavian, 2012). Different types of soil exhibit diversed behaviors and physical properties and exist throughout the World in a broad diversity (Aksoy, Ozsoy & Dirim, 2009).

Soil fertility is the inherent capacity of soil that enables it to provide essential plant elements in quantities and proportions for the growth of specified plant when other factors are favorable (Panda, 2010). To implement suitable management options, the fundamental element to start with is to identify the fertility status of the soils under the existing system of management practice (Wakene & Heluf, 2003).

2.2 Soil Fertility Evaluation and Management

Declining Soil fertility remains one of the most serious problems facing the world. In many developing countries nutrient depletion already threatens food production (Hartemink, 2003). Depletion of soil fertility can decrease the soil productivity and crop production (Polyakov & Lal, 2008). Soil fertility must be periodically estimated because there is continuous removal of macro nutrients by the crop intensively grown in every crop season (Dhamak, Meshram & Waikar, 2014).

Soil fertility evaluation of an area or region is the most basic decision making tool for the sustainable soil nutrient management. Its evaluation includes the measurement of available plant essential nutrients and estimation of capacity of soil to maintain a continuous supply of plant nutrients for a crop. (Khadka, Lamichhane, Shrestha & Buddhi, 2017).

Soil test based fertility management is an effective tool for agricultural soils that have high degree of spatial variability which find out the soil fertility related production constraints of the study area and suggest the remedial measures for optimum production of the crops (Rawal et al., 2018).

Among the aids available to manage soil fertility, soil sampling and analysis is the first of three equally important steps in managing the nutrients required by plants. The second is the interpretation of the analytical data leading to the third step, recommendations for nutrient additions, as fertilizers or manures, to optimize crop yields while minimizing any adverse environmental impact from their application (Ravikumar & Somashekar, 2014).

2.3 Soil Fertility Mapping

Soil fertility mapping is essential when planning land use and developing crop fertilization strategies (Samira, Ahmed & Lhoussaine, 2014.) and mapping of soil properties is an important operation as it plays an important role in the knowledge about soil properties and how it can be used sustainably (Denton et al., 2017). Soil nutrients variability mapping had been reported as an important component because these digital maps could be used to delineate management zone for variable rate fertility in site specific nutrient management (SSNM) systems (Yesrebi et al., 2009).

Soil fertility maps are meant for highlighting the nutrient needs, based on fertility status of soils (and adverse soil conditions which need improvement) to realize good crop yields. Obviously, a soil fertility map for a particular area can prove high benefit in guiding the farmers, manufacturers and planners in ascertaining the requirement of various fertilizers in a season or year and making projections for increased requirement based on cropping pattern and intensity (Thakor et al., 2014).

2.4 Variability of Soil Properties

The spatial variability of soil properties is the variation of soil chemistry, physics, and biological properties in the spatial location. Even in the same soil type, soil characteristics have a huge difference. The spatial variability of soil includes two aspects: one is the vertical profile of the soil spatial variability; another is the spatial variation of soil plane (Li, Chen, Zeng, & Ye, 2013). Soil variability is due to the product of soil forming factors which are operating and interacting over large distance and are modified and changes by other processes that operate more frequently or more locally (Tahir et al., 2016).

Knowledge of the spatial variation of soil properties is also needed for agricultural productivity, food safety and environmental modeling (Bhunia, Shit & Chattopadhyay, 2018). Determining soil variability is important for ecological modelling, environmental predictions, precise agriculture and management of natural resources (Hangsheng, Dan, Jay & Wilding, 2005). On the other hand, spatial variability of soil properties can be used for interpolation of soil test values at un-sampled locations using limited data on sampling locations and has been used for development of fertility management strategies and mapping of fields on small scale and districts on large scale (Bhatti & Mulla, 1995).

Variability in soil properties causes uneven crop growth, confounds treatment effects in field experiments and decreases the effectiveness of uniformly applied fertilizer on a field scale (Mulla, Bhatti, Hammond & Benson, 1992). Spatial variability of soil characteristics can strongly affect the outcomes of logical, empirical, and physical models of soil and landscape processes (Lin, Wheeler, Bell, & Wilding, 2005). Thus, an adequate understanding of soil variability as a function of space becomes essential (Corstanje, Grunwald, Reddy, Osborne & Newman, 2006).

2.4.1 Soil reaction (pH)

Soil pH is an important chemical parameter as it helps in ensuring availability of plant essential nutrients (Deshmukh, 2012). It indicates acidity, alkalinity, or neutrality of a soil and pH 7.0 is a neutral value. Above this pH, soils are designated as alkaline, and below this, soils are acidic in reaction (Fageria, Carvalho, Santos, Ferreira & Knupp, 2011). Soil pH affects all the physical, biological and chemical soil properties and the growth of specific organisms, soil microbial biomass, and microbial activity (Brady & Weil, 2002). The soil fertility decreases with decreasing pH which can be induced by acidifying nitrogen fertilizers, nitrate leaching and agricultural practices (McKenzie, Jacquier, Isbell & Brown, 2004). The degree and nature of soil reaction influenced by different anthropogenic and natural activities including leaching of exchangeable bases, acid rains, decomposition of organic materials, application of commercial fertilizers and other farming practices (Brady & Weil, 2002).

In strongly acidic soils, Al^{3+} becomes soluble and increase soil acidity while in alkaline soils, exchangeable basic cations tend to occupy the exchange sites of the soils by replacing exchangeable hydrogen and aluminum ions (Brady & Weil, 2002). Descriptive terms commonly associated with certain changes in pH are strongly acidic (pH < 5.4), moderately acidic (pH 5.5- 6.4), slightly acidic (pH 6.5-6.9), neutral (pH 7.0), slightly alkaline (pH 7.1-7.5), moderately alkaline (pH 7.6-8.3), and strongly alkaline (pH > 8.4) (Hughes, Davenport, & Dohle, 1994). Ketterings, Albrecht and Jen

(2005) has been described to monitor soil pH on a regular basis possibly once every 3 years or twice during a rotation for optimum crop management and yield.

2.4.1.1 Soil pH influencing nutrients availability

To understand plant nutrient availability and optimal growing conditions for specific plant, it is important to understand soil chemistry and interacting factors that affect soil pH (McCauley, Jones & Jacobsen, 2009). Soil pH influences the solubility and availability of plant nutrients. Low pH causes deficiency and unavailability of plant nutrients like P, Ca, K, Mg and Mo (Wang, Raman, Zhang, Mendham & Zou, 2006). It has been determined that most plant nutrients are optimally available to plants within 6.5 to 7.5 pH range and this range of pH is generally very compatible to plant root growth (Jensen & Thomas, 2010).

A number of plant nutrients are unavailable at extremely acidic or extremely alkaline soils due to the different reactions in the soil which fix the nutrients and transform them to the state that is unavailable for the plants (Brady & Weil, 2002). The survival of the microbes related to the soil pH (Khadka, Lamichhane & Thapa, 2016) which affects the activity of microorganisms responsible for breaking down organic matter and most chemical transformations in the soil (Rawel et al., 2018).

At pH is near neutral (pH 7.0), the microbial conversion of NH_4^+ to nitrate (nitrification) is rapid, and crops generally take up nitrate. In acid soils (pH < 6), nitrification is slow, and plants with the ability to take up NH_4^+ may have an advantage. Under conditions of low soil moisture or poor incorporation, volatilization loss can be considerable even at pH values as low as 5.5 (McKenzie, 2003).

Phosphorus and micronutrients such as copper and zinc also decrease in their plant availability at high pH (Hanlon & Jones, 1993). At alkaline pH values, greater than pH 7.5, the HPO_4^{2-} phosphate ions tend to react quickly with calcium and magnesium to form less soluble compounds. At acidic pH values, the $H_2PO_4^-$ phosphate ions react with aluminum and iron to again form less soluble compounds (Jensen & Thomas, 2010).

The fixation of potassium and entrapment at specific sites between clay layers tends to be lower under acid conditions. The availability of the micronutrients manganese, iron, copper, zinc, and boron tend to decrease as soil pH increases (McKenzie, 2003). The exception is molybdenum, which appears to be less available under acidic pH and more available at moderately alkaline pH values (Jensen & Thomas, 2010).

2.4.1.2 Causes of soil acidity and alkalinity

Soil acidification is a natural process and is generally accelerated by agriculture. The rate of acidification varies enormously depending on the soil type, land use, productivity and management of the farming system. The key changes connected with acidification are an increase in the concentration of hydrogen ions, increased solubility of aluminum and manganese, and changes in the availability of several nutrients. These factors are responsible for decreased plant production on acid soils (Moore, 2001).

Acidity is a soil property that has a devastating effect on crop growth, because acidification causes a reduction in the availability of some essential nutrients (e.g. calcium and molybdenum) and also an increase of other nutrients to toxic levels (e.g. manganese and aluminum) (Charman, 2000).

The term soil alkalinity refers to soils that are alkaline (pH >7.5 measured in a 1:5 soil: water suspension) in one or more layers. Alkalinity of soils is caused by carbonates of calcium and/or sodium. If the pH is above 10 then either sodium-rich clays or sodium carbonate are present. A high pH value is caused mainly by the hydrolysis of salts of weak acids and strong bases. High alkalinity leads invariably to sodicity in soils (sodium enrichment on the exchange sites of clays), but not all sodic soils are alkaline (Moore, 2001).

2.4.2 Cation exchange capacity

Cation exchange capacity (CEC) is a measure of the soil’s ability to hold positively charged ions (Hazleton & Murphy, 2007) and also represents the capability of soil to attract, retain and hold exchangeable cations such as K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}, etc. (Tomasic, Zgorelec, Jurisic, & Kisic, 2013). The CEC is now widely used in the characterization and study of soil fertility. By analyzing the CEC of a soil, the cost of application of nutrients (NPK) can be significantly reduced (Aprile & Lorandi, 2012).

Soil CEC is an important soil properties in assessing soil fertility status, because sharing direct in system transfer of ion between soils solutions with crop root area (Susanto & Sunarminto, 2013). According to Landon (1991), rating of CEC results for top soils are very low level (CEC < 5), low level (CEC 5-15), medium level (CEC 15-25), high level (CEC 25-40), and very high level (CEC > 40).

In general terms, soils with large quantities of negative charge are more fertile because they retain more cations (McKenzie et al., 2004). Pure sand has a very low

CEC, less than 2 meq100 g^{-1} soil. Organic matter has a very high CEC ranging from 250 to 400 meq100 g^{-1} soil (Moore, Dolling, Porter & Leonard, 1998).

2.4.2.1 Factors influencing soil CEC

Many soil parameters influenced the soil exchangeable capacity especially soil pH, soil texture, and organic matter content up to a certain extent (Tomasic et al., 2013). CEC is strongly dependent on physical-chemical variables such as pH, salinity and alkalinity of the soil, and partly independent of temperature, pressure, composition and concentration of electrolytes (Bache, 1976). Soils with large amount of clay and organic matter have higher CEC than sandy soils low in organic matter (Brady & Weil, 2002).

2.4.2.2 Changes in soil CEC

Cation exchange capacity (CEC) has a significant influence on the physical and chemical behavior of soil (Khorshidi & Lu, 2017). Knowledge of the CEC in the soil can also be of great importance to characterize the soil on the content of ionic elements, concentration of clay and mud, texture, degree of compression levels of porosity and permeability. High CEC may indicate low permeability and internal drainage due to high soil compaction. Already low levels of CEC may indicate a soil texture ranging from sandy caly to sandy, with variable grain size and high permeability. Generally, tropical soils have low CEC and minerals as oxides of aluminum, iron and manganese that are very abundant in tropical soils also contribute to the low CEC (Aprile & Lorandi, 2012).

Soils with a low CEC are more likely to develop deficiencies in potassium (K^+), magnesium (Mg^2+) and other cations while high CEC soils are less susceptible to leaching of these cations (Cornell University Cooperative Extension [CUCE], 2007). The addition of organic matter will increase the CEC of a soil but requires many years to take effect. It is necessary with the application of a fertilizer to practice the introduction of plant cover (live coverage and/or mulch) which is essential to protect leaching of the soil, thus increasing the capacity of cation exchange in crops. (Aprile & Lorandi, 2012).

2.4.3 Soil organic matter

Soil organic matter is a principal component of soil and is the key indicator of soil quality and health (Farquharson, Schwenke & Mullen, 2003) and has a vital role in agricultural soil. It supplies plant nutrient, improve the soil structure, water infiltration and retention, feeds soil micro-flora and fauna, and the retention and cycling of applied fertilizer (Johnston, 1986). Soil organic matter is defined as any living or dead plant and animal materials in the soil and it comprises a wide range of organic species such as humic substances, carbohydrates, proteins, and plant residues (Foth & Ellis, 1997). Descriptive terms commonly associated with certain ranges in organic matter are very low (OM < 2.0%), low (OM 2.0- 3.0%), optimum (OM 3.0 -7.0%), high (OM 7.0-8.0%) and very high (OM >8.0%) (Ethiopia Soil Information System [ETHIOSIS], 2014).

2.4.3.1 Role of soil organic matter

Soil organic matter has a vital role in agricultural soil and it supplies plant nutrient, improve the soil structure, water infiltration and retention, feeds soil micro-flora and fauna, and the retention and cycling of applied fertilizer (Johnston, 1986). It affects the chemical and physical properties of the soil and its overall health, and is actually a key parameter of soil quality and a soil fertility indicator (Marchetti, Piccini, Francaviglia & Mabit, 2012). Besides providing nutrients and habitat to soil organisms, organic matter influences soil physical properties in binding soil particles into aggregates, and in improving soil water holding capacity (Lal, 2007). In cultivated land without restoring the organic matter and nutrient contents, nutrient cycles are broken, soil fertility declines and the balance in agro-ecosystems is impaired (Marchetti et al., 2012).

2.4.3.2 Factors effecting amount of soil organic matter

Soil organic matter varies from place to place and it is generally enhanced in thickly vegetated areas. The variation largely depends on soils, climate, plant and animal species (Brady, 1995). Uncultivated soils have higher in soil organic matter (both on surface and in soil) than those soils cultivated yearly (Miller & Gardiner, 2001). Organic matter build-up is often the result of the application of fertilizers, and the break-down of dead soil organisms and plant residues (Charman, 2000).

The clearing of forests for annual crop production invariably resulted in a loss of soil organic matter because of the removal of large quantities of biomass during land clearing, a reduction in the quantity and quality of organic inputs added to the soil and increasing soil organic matter decomposition rates (Barber, 1995).

Depending on cultivation practices, plant cover, soil drainage and agro-climatic conditions, agricultural practices generally accelerate soil organic matter decomposition, and therefore increase arable land vulnerability and susceptibility to erosion processes (Bot & Benites, 2005).

2.4.3.3 Functions of soil organic matter

Cook and Ellis (1987) and Tisdale, Nelson, Beaton and Havlin (1995) reported that some of the functions of organic matter/ humus are: (a) aids in water management as residues or plants to protect the soil surface from rain drop impacts, resist wind action, and thus, greatly aid in erosion control. Furthermore, decomposing organic matter causes soil aggregation, which aids infiltration and increases pore space in clay soils. Thus, water and oxygen holding capacity is increased, even beyond the absorptive capacity of organic matter, (b) increased exchange and buffering capacity since well decomposed organic matter or humus has a very high CEC that adds to the buffering capacity of the soil, (c) minimizes leaching loss because organic substances have the ability of holding substances other than cations against leaching, (d) sources of nutrients (N, P, S and most micronutrients) and growth promoting substances, that is, hormones or growth- promoting and regulating substances valuable to plants may be produced by organisms that decompose soil organic matter, (e) stabilizes soil structure, and (f) provides energy for microbial activity.

2.4.4 Soil electrical conductivity (EC)

The Electrical Conductivity (EC) of a solution is a measure of the ability of the solution to conduct electricity and indicates the presence or absence of salts, but does not indicate which salts might be present (Hanlon & Jones, 1993). Electrical conductivity can be defined as the ability of a material to transmit or conduct electrical current (Molin, Di & Faulin, 2013). Soil electrical conductivity is an effective and rapid indicator of soil variability and production potential (Corwin & Lesch, 2005). It is also a measure of the amount of salts in soil (salinity of soil) and is an excellent indicator of nutrient availability and loss, soil texture, and available water capacity. Although EC does not provide a direct measurement of specific ions or salt compounds, it has been correlated to concentrations of nitrates, potassium, sodium, chloride, sulfate, and ammonia (United State Department of Agriculture [USDA], 2014).

2.4.4.1 Factors affecting EC and its status in soil

Inherent factors affecting EC include soil minerals, climate, and soil texture. Other factors include bulk density, soil structure, water potential, and timing of measurement, soil aggregation, and electrolytes in soil water. Soils that have a higher content of smaller soil particles (higher content of clay) conduct more electrical current than do soils that have a higher content of larger silt and sand particles (lower content of clay) (USDA, 2014).

Soil electrical conductivity relates directly to salinity and more alkaline soil will have less amount of soluble salt (Provin & Pitt, 2001). In addition to soil moisture content, soil electrical conductivity is associated to soil salinity, clay content and cation exchange capacity, clay minerals, pore size and distribution, organic matter and temperature (Sudduth, Drummond & Kitchen, 2001). According to Bruckner (2012), low soil pH due to large number of hydrogen ions in the soil may encourage soil electrical conductivity.

Salinity, assessed in soil via EC, is one of the most important factors in agriculture and irrigation management. The increase of soil salinity may lead to aggregation of soil particles, but due to the increase in osmotic potential, it reduces the absorption of water and nutrients by plants from the soil (Pisinaras, Tsihrintzis, Petalas & Ouzounis, 2010). According to Moore (2001), rating of EC (1:5) levels are low level (EC <0.5 dS m^{-1}), medium level (EC 0.5-2.0 dS m^{-1}), and high level (EC >2.0 dS m^{-1}).

2.4.5 Bulk density

Soil bulk density is one of the most frequently used measures of compaction (Abu-Hamdeh & Al-Jalil, 1999) and it can be defined as the ratio of oven-dried mass weight to its bulk volume depends on the soil particles densities such as sand, silt, clay and organic matter and their packing arrangement (Askin & Ozdemir, 2003). Soil bulk density should be used as an indicator of soil quality parameter. Knowledge of soil bulk density is essential for soil management, and information about it is important in soil compaction as well as in the planning of modern farming techniques (Chaudhari, Ahire, Ahire, Chkravarty & Saroj, 2013).

The critical value of bulk density for restricting root growth varies with soil type (Hunt & Gilkes, 1992) but in general bulk densities greater than 1.6 g cm^{-3} tend to restrict root growth (McKenzie et al., 2004). Sandy soils usually have higher bulk densities (1.3 - 1.7 g cm^{-3}) than fine silts and clays (1.1 - 1.6 g cm^{-3}) because they have larger, but fewer, pore spaces. In clay soils with good soil structure, there is a greater amount of pore space because the particles are very small, and many small pore spaces fit between them. Soils rich in organic matter (e.g. peaty soils) can have densities of less than 0.5 g cm^{-3} (Smitha & Sobha, 2014). Most mineral soils have bulk densities between 1.0 and 2.0 g cm^{-3} (Blake & Hartge, 1986).

Dry bulk density is determined by the value of weight (mass) of dry matter in a soil sample that occupies a core of known volume. The core sampling method usually determines bulk density (Abu-Hamdeh & Al-Jalil, 1999).

2.4.5.1 Factors effecting bulk density

Factors affecting bulk density are porosity, texture and organic matter content. However, the relationship between texture and bulk density is tenuous and depends on a variety of factors such as organic matter content and depth in the soil profile (Chaudhari et al., 2013). Soil bulk density is a basic soil property influenced by some soil physical and chemical properties and it is a dynamic property that varies with the structural condition of the soil. This condition can be altered by cultivation, trampling by animals, agricultural machinery, weather, i.e. raindrop impact (Arshad, Lowery & Grossman, 1996).

Variation in bulk density is influenced by the amount of organic matter in soils, their texture, constituent minerals and porosity (Chaudhari et al., 2013). Bulk density is likely to change under cropping but much depends on the cropping system (Hartemink, 2003). In mechanized annual cropping systems, where tractor traffic is common, compaction may occur (Soane, 1990) and it may severely reduce nutrient availability (Arvidsson, 1999). Compaction of agricultural soils results in increased soil bulk density (Ngunjiri & Siemens, 1993).

2.4.6 Soil moisture content

The soil moisture content may be expressed by weight as the ratio of the mass of water present to the dry to the dry weight of the soil sample, or by volume as ratio of volume of water to the total volume of the soil sample (Black, 1965). Accurate characterization of near-surface soil water content is vital for guiding agricultural management decisions and for reducing the potential negative environmental impacts of agriculture (Grote, Anger, Kelly, Hubbard & Rubin, 2010). Soil moisture varies not only in space, but also in time (Hu, Shao, Han, Reichardt & Tan, 2010).

Monitoring of the soil water content is also needed to ensure efficient use of irrigation water, where the scheduling and volume of irrigation must be optimized to appropriately allocate limited water supplies (Grote et al., 2010). Predicting the spatial and temporal distribution of soil moisture is affected by climate, topography, groundwater level, soil physical properties, and surface cover (Wilson, Western & Grayson, 2004).

Knowledge of the spatial distribution of soil moisture can therefore aid us in determining the potential for infiltration, overland flow, floods, and erosion as well as the resultant impacts on streams, reservoirs, infrastructure, and, most importantly, human life (Hebrard, Voltz, Andrieux, & Moussa, 2006). In addition, it can inform sustainable water resources management, the study of ecosystems and ecological processes (Choi et al., 2009), plant water requirements, plant growth and productivity, as well as irrigation management and deciding when to carry out cultivation procedures (Yang, Cong, Liu & Lei, 2010).

Soil moisture near the land surface affects a wide variety of earth system interactions over a changing spatial and temporal scale. Maintaining a high level of soil moisture content can improve the capacity of ecological systems to conserve water (Brooks & Spencer, 1997).

Gravimetric moisture is where the total mass of the soil, including the water, is 100 percent, and the mass of the water within the soil is calculated as the percent moisture. Because soil weighs more than water, the percent water in a gravimetric calculation will be smaller than the same sample calculated volumetrically. The gravimetric method is often used by scientists in research reports (Black, 1965).

2.5 Spatial Variability of Soil Nutrients

Soil nutrients are an important symbol of soil fertility, and play an important role in the sustainable utilization of land, therefore, analyzing the variability of soil nutrients is very important for protecting the traditional eco-agricultural model (Yao, Zhou & Cai, 2005).

Soil nutrients show high spatial heterogeneity, is the main factor that influences the yield and quality of crops (Eghball & Schepers, 2003). Therefore, it is of great significance to strengthen the study of spatial heterogeneity of soil nutrients to realize the spatial layout of agricultural production and also provide basic information and suggestions for food production and land use planning (Jing et al., 2014).

The tedious and costly conventional methods needed to obtain soil nutrient information will also be reduced when nutrient levels are mapped because those conventional methods are no more affordable. Accordingly, mapping of the nutrient levels will provide spatial soil nutrients information that can be used as a decision support tool (Behrens & Scholten, 2006). Mapping of soil nutrient levels, especially nitrogen (N), phosphorus (P) and potassium (K) would also facilitate proper monitoring and review of recommended farming technologies at locations from time to time (Wang & Gong, 1998).

The differences in the spatial distribution of the soil nutrient concentrations across the region may thus be attributed to differences in nutrient management practices (Tsirulev, 2010), differences in soil forming processes, inherent heterogeneity in parent material at the different locations, as well as land use pattern and amount of fertilizer used (Liu et al., 2006) by the farmers.

2.5.1 Total nitrogen

2.5.1.1 Importance of nitrogen

Nitrogen is an essential nutrient for all living things on earth and plays a major role in regulating the composition, structure, and function of ecosystems (Leip et al., 2008). Nitrogen is one of the most important plant nutrients and the most frequently deficient of all nutrients (Havlin, Beaton, Tisdale & Nelson, 2010). It is an integral component of many essential plant compounds such as amino acids, which are the building blocks of all proteins including enzymes, nucleic acid and chlorophyll (Brady & Weil, 2002). It is also the basic nutrient that helps in seed formation and increases the food and feed value of crops and usually has greater effect on crop growth, crop quality and yield (Rawal et al., 2018). It is the fourth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen, and hydrogen, but it is one of the most deficient elements in the tropics for crop production (Mesfin, 1998).

2.5.1.2 Forms of nitrogen

Nitrogen in the soil exists mainly in organic forms. The main part of organic nitrogen occurs in soil humus as the protein fraction and as the products of their hydrolysis, amino acids bounded with polyphenols, sugars, and compounds of these products with soil minerals (Wyczolkowski & Dabek-Szreniawska, 2005). Mineral forms of Nitrogen, such as ammonium ($NH4^{+}$) and nitrate ($NO3^{-}$), usually account for a small portion of total nitrogen, but they are considered to be the preferred source of Nitrogen for microorganisms and plants (Singh & Kumar, 2008).

2.5.1.3 Nitrogen content in soil

The nitrogen content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub-humid tropics due to leaching and in highly saline and sodic soils of semi-arid and arid regions due to low organic matter content

(Tisdale et al, 1995). Average total nitrogen increased from cultivated to grazing and forest land soils, which again declined with increasing depth from surface to subsurface soils (Nega, 2006).

Paz-Gonzalez, Vieira and Castro (2000) reported that fertilizer application did not change total or inorganic nitrogen content. Jaiyeoba (2003) found that total nitrogen content of the topsoil was greater in 3-year cultivated soil compared to 20-year. In the study area, farmers removed the crop residues continuously from the field and completely cut their crops during harvesting very near to the ground surface. As a result, with the short stubble left on the surface of the land, not much organic matter would be available as a source of total nitrogen in the field (Kedir, Mohammed & Kibret, 2016).

Most of the soil nitrogen is tied to organic matter and only a small percentage of the total nitrogen is avail-able to plants through nitrogen mineralization. The efficiency of nitrogen use in agricultural fields varies only slightly between 40-50%, which may be attributed to improper nitrogen use management, imbalanced fertilization and losses through leaching, volatilization and immobilization (Parama & Munawery, 2012).

2.5.1.4 Spatial distribution of nitrogen

The spatial pattern of soil organic carbon and total nitrogen densities are influenced by the distribution of soil types and land uses, as well as by the topography (Smith et al., 2000). Researchers have conducted many studies about the spatial distribution characteristics of soil nutrients, and the results showed that the spatial distribution of soil total nitrogen and soil total phosphorus exhibited random or structured spatial variation characteristic because of the significantly different soil physical, chemical, and biological processes in different directions (Wang, Zhang, Yu, & Zhang, 2006).

2.5.1.5 Depletion and major losses of nitrogen

Nitrogen may be removed from soil by crop and grazing, as elemental nitrogen and ammonia. In undisturbed natural forests and grasslands with no massive nitrogen removals in crop production and grazing, the nitrogen in precipitation serves to restore the small quantities that are lost from these soils (Khattak & Hussain, 2007). Increasing pressure on land has necessitated continuous cropping, which has exposed the soils to nutrient deficiencies especially nitrogen and phosphorus (Bationo, Mokwunye, Vlek, Koala & Shapiro, 2003). This has been aggravated by the negative nutrient balances of most cropping systems (Vlek, Kuhne & Denich, 1997).

Ammonia volatilization is the conversion from ammonium (NH^{4+}) to the ammonia (NH_3) form in flooded water under conditions of high pH and temperature (Kennedy, 1992). Ammonia volatilization losses in the flooded soils range from negligible to almost 60% of the applied nitrogen (Xing & Zhu 2000). Fillery, Simpson and Datta (1984) highlighted that NH_3 loss accounted for a 30-50% loss of the nitrogen applied to floodwater 2-3 days after transplanting.

Denitrification occurs in the flooded soils following the nitrification of ammonium into NO^{3-}. In this process, NO^{3-} is reduced by a series of steps to nitric oxide (NO), nitrous oxide (N_2O), and nitrogen (N_2) gases, which are then released into the atmosphere (Reddy & Patrick, 1984). Factors contributing to denitrification include pH, temperature, organic matter, wet-dry cycles, and fertilizer management (Mutters et al., 2006).

Nitrogen loss by surface runoff can occur through over flown flood water in undulating lands. Rain or irrigation water easily flows through the gradient and causes loss of nitrogen along with surface of soil (Peng, Wan & Yu, 1995).

The downward movement of NO^{3-} in the soil profile is called nitrate leaching. In well-drained sandy soils, much of the nitrate can be lost by leaching as water moves nitrate down through the soil profile (Camberato, Brad & Nielsen, 2008). It is one of the major pathways for nitrogen loss in terrestrial eco-systems because nitrate is relatively mobile in soils and it is easily leached by percolating water (Charman, 2000).

Descriptive terms commonly associated with certain ranges in total nitrogen are very low (<0.1%), low (0.1 – 0.15%), optimum (0.15 to 0.3%), high (0.3 – 0.5%) and very high (>0.5%) (ETHIOSIS, 2014).

2.5.2 Total phosphorus

2.5.2.1 Role of phosphorus

Phosphorus is one of the important primary elements essential for plant growth and development (Rawal et al., 2018). It plays an important role in regulation of various enzymatic activities and constituent for energy transformations and metabolic processes in plants (Rai et al., 2012). The phosphorus also plays a significant role in many metabolic processes including energy generation, respiration, membrane synthesis and its integrity, nucleic acid synthesis, photosynthesis, activation or inactivation of enzymes, signaling, and carbohydrate metabolism (Zhang, Liao & Lucas, 2014). It is an essential element for cell division as it is a constituent element of nucleoproteins, carbohydrate synthesis and degradation (Salem, Al-Ethawi, Eldrazi & Nouraldien, 2014).

The phosphorus constraint directly decreases photosynthesis through its negative effects on vegetative crop growth of leaf area development and photosynthetic ability per unit leaf area (Sulieman, Van & Schulze, 2013). Likewise, inadequate supply of phosphorus can also affect carbon absorption and distribution between plant shoots and its underground parts (Zhang et al., 2014). The phosphorus also plays a crucial role in the development of the symbiotic relationship between legumes and bacteria as a certain amount of phosphorus is required to carry out biological nitrogen fixation (Rotaru & Sinclair, 2009). Zhang et al. (2014) found that some molecules which contain phosphorus include nucleic acids, proteins, lipids, sugars are required for the functioning of plant cells.

2.5.2.2 Forms of phosphorus

The mineral phosphorus sources are non-renewable, unlike nitrogen and it is the most commonly plant growth limiting nutrient in the tropical soils next to water and nitrogen (Dawit, Fritzsche, Tekaligne, Lehmann & Zech, 2002). The forms and dynamic of soil phosphorus can be greatly affected by land use changes, which often involve changes in vegetation cover, biomass production and nutrient cycling in the ecosystem (Momeni, Kalbasi, Jalalian & Khademi, 2009).

Phosphorus in organic form is the most stable form in the soil, whereas the inorganic form, it is stable and readily absorbed and used by plants if it is not fixed (Hinsinger, 2001). Over 80% of phosphorus becomes immobile and unavailable for plants uptake because of adsorption, fixation, conversion of phosphorus to organic form and precipitation, inorganic forms of phosphorus are usually exist in virgin soils which are derived from the parent rocks, inorganic phosphorus form can be converted to organic form by soil age, microbial populations, animals, and plants (Anderson, 1980). Phosphorus exists in soil solution must be continuously decomposed (Salem et al., 2014).

2.5.2.3 Phosphorus dynamic

In most soils, phosphorus content is very low in the surface layer. It represents less than 1% of total phosphorus. However the total phosphorus content of any soil may vary widely and depend on some factors such as organic matter content, climatic conditions, parent materials and amount of fertilizer application (Salem et al., 2014). In acidic soils, phosphorus can be dominantly adsorbed by Al/Fe oxides and hydroxides, such as gibbsite, hematite, and goethite (Parfitt, 1989). Phosphorus can be first adsorbed on the surface of clay minerals and Fe/Al oxides by forming various complexes and can be released by desorption reactions (Shen et al., 2011).

Applications of chemical P fertilizers and animal manure to agricultural land have improved soil phosphorus fertility and crop production, but caused environmental damage in the past decades (Shen et al., 2011). About 90% of the inorganic Phosphorus fertilizers are used in agriculture crop production produced from high-grade rock phosphates which expected to be depleted shortly within 30–50 years (Cordell & Drangert, 2009). Therefore, P- deficient soil and low availability impose major restrictions on the vegetative and reproductive growth development of crop (Zhang et al., 2014).

Losses of P occur through leaching and erosion. Leaching represents a major mechanism of P loss from forestland (Khattak & Hussain, 2007). The deficiency of Phosphorus is mainly caused either by the inherent characteristics of the parent materials or by the strong sorption of PO_4^{3-} to Al and Fe hydroxides and oxides, which turns large proportion of total soil P into unavailable forms. The problem is further exacerbated by nutrient mining due to the low input agriculture practiced in the region (Solomon, Fritsch, Tekalign, Lehman & Zech, 2002). The amount of total phosphorus for rating classes are low level (P_{total} < 0.02%), medium level (P_{total} 0.02-0.08%), and high level (P_{total} > 0.08%), respectively (Moore, 2001).

2.5.3 Total potassium

2.5.3.1 Role of potassium

Potassium (K) is an essential nutrient for crop production and fulfils a number of important roles in plant growth (Wolde, 2016) and one of the three main macronutrients together with Nitrogen and Phosphorus (Martin & Sparks, 1985). Potassium is the third most required element by the plants and it is not an integral part of any major plant component but it plays a key role in a vast array of physiological process vital to plant growth from protein synthesis to maintenance of water balance in plants or regulation of osmosis (Sumithra, Ankalaiah, Rao & Yamuna, 2013).

2.5.3.2 Forms of soil potassium

Potassium (K) in soils is typically found as soil solution K, exchangeable K, non-exchangeable K, and K in minerals. Different forms of K are in equilibrium with each other (Jalali, 2007). Among these different forms, dynamic equilibrium reactions control the release and/or fixation of K according to soil biogeochemical properties and processes (Zorb, Senbayram & Peiter, 2014). Based on the degree of availability to crops, soil K can be partitioned into four forms (Pal, Wong & Gilkes, 1999): (a) soil solution K (1-10 mg kg^{-1}) which is usually considered the primary source of K absorbed by plant root; and its concentration is a function of soil weathering, past cropping and K fertilization practices, (b) exchangeable K (40-600 mg kg^{-1}) which is held by the negative charges on soil clay and organic matter exchange sites, (c) non-exchangeable K (50-750 mg kg^{-1}) which is held as fixed ions in the lattice structure of clay minerals and that which forms part of the structures of minerals, (d) mineral K (5000-25000 mg kg^{-1}) which is found in K-bearing minerals in soils depending primarily on the source of the parent material.

2.5.3.3 Sources of soil potassium and its status

Potassium is a major constituent of the earth crust contained more in igneous rocks than the sedimentary rocks. Potassium comprise on an average of 2.6% of the earth crust, making it the seventh most abundant element and fourth most abundant mineral nutrient in the lithosphere. Among the important K bearing minerals that are found in soil are feldspars and micas as primary and illites and transitional clay as secondary minerals (Dhakad et al., 2017).

Clay minerals are the most important sources of soil K aside that from fertilizers. They hold the bulk of mobile K and release it when the concentration of the soil solution falls due to uptake by plants or to an increase in soil moisture (Afari-Sefa, Kwakye, Okae-Anti, Imoro & Nyamiah, 2004). Olaitan and Lombin (1984) observed that over 95 percent of the K in tropical soils is contained in primary and secondary minerals. Potash feldspars, muscovite and biotite are generally considered the original sources of K in soils. At equal clay content, the K concentration of soil solution depends on the nature of the clay minerals.

Total potassium (K) content of the soil is not commonly estimated in agronomic research because this total pool of K constitutes mostly forms that are extracted with difficultly, which are available in the long term only. In contrast to other macronutrients, potassium is the most abundant in the lithosphere as well as the soils (Andrist Rengel, 2008). Understanding soil K status is important when developing appropriate K nutrient management. Potassium fertilization strategies and recommendations essentially rely on soil analyses using different extraction methods to assess its availability with respect to plant uptake and crop production (Zorb et al., 2014).

The average potassium concentration of the earth's crust is 23 g kg^{-1} (Helmke, 2000) in which most important potassium-bearing minerals in soils are alkali feldspars (30 to 20 g K kg^{-1}), muscovite (K mica, 60 to 90 g K kg^{-1}), biotite (Mg mica, 36 to 80 g K kg^{-1}), and illite (32 to 56 g K kg^{-1}). These are the main natural potassium sources from which K- is released by weathering and plants feed. The weathering of the mineral begins at the surface and is associated with the release of K. This process is promoted by very low K- concentrations in the soil solution in contact with the mineral surface, and these low concentrations are produced by K- uptake by plants and microorganisms and by K- leaching (Sparks, 2003). Natural sources of supplying potassium are minerals, organic matter, irrigation water, sediments and dissolved material from flood water and atmospheric deposition (Dobemann, Cassman, Mamaril & Sheehy, 1998).

2.5.3.4 Potassium in agricultural soils

The availability and spatial distribution of potassium in agricultural soils is influenced by many agro-environmental factors. It is generally abundant in soil as it constitutes about 2% of the earth's crust (Schroeder, 1978). In Europe, soil K deficiencies are not widespread, but deficiencies or reduction of soil K are reported at the regional scale, especially in countries around the Baltic Sea and in the United Kingdom (Toth, Jones & Montanarella, 2013). In Switzerland, there has been no study on soil K status on a national scale, as K deficiencies in crops are scarce and only reported at the plot scale. However, there are increasing concerns about the quality of fodder as a consequence of potential K over-fertilization (Kessler, 1997).

There is a general assumption that most tropical soils contain adequate amounts of K to sustain crop growth most probably due to the dominance of K bearing minerals such as illite etc, but the increase in intensity of cropping, leaching and introduction of high yielding varieties in various cropping systems (Moshen, 2007) have resulted in considerable drain of soil K reserves (Bukhsh et al., 2012).

According to Jones (1982) soil K can be lost through leaching in drainage waters, crop removal and utilization by living organisms. Furthermore, continuous cropping in agricultural systems results in excessive uptake of K by plants especially from the labile K pool. The labile K pool is made up of the water soluble and exchangeable K forms. In some soils the exchangeable K, which is held onto the soil colloidal surface may be released for plant uptake when the labile K pool is exhausted, but Bhaskarachary (2011) noted that the release of exchangeable K is not fast enough to meet the requirement of rapidly growing crops.

Long-term intensive cropping, in the absence of K inputs, adversely affected the K supply to crop plants and consequently crop yields (Swarup & Ganeshmurthy, 1998). Higher crop K requirement comes with higher crop yields. Most crops take up as much or more K than N, about 70 to 75% of the K absorbed is retained by leaves, straw, and Stover. The remainder is found in harvested portions such as grains, fruits, nuts, etc. Thus, it is clear that for the long term and sustainable use of agricultural lands, the removal of K needs to be balanced by adequate K inputs if a decline in soil fertility is to be avoided (Wolde, 2016).

2.6 Global Positioning Systems (GPS)

Remote Sensing (RS) to identify and Global Positioning Systems (GPS) to locate and define spatial features or activities contribute to the quality of site-specific practices. For collecting data on the ground, Global Positioning System (GPS) receivers are commonplace. GPS is a satellite navigation system developed by the Department of Defense that can pinpoint a location anywhere on earth. GPS receivers are able to obtain signals from satellites orbiting the earth (Memon, Khalid, Mallah & Ahmed, 2011).

Global Positioning System (GPS) has been widely adopted in the area of agriculture in preparation of thematic maps like land use, land cover, soil fertility maps, etc. Determination of available soil nutrients status of the area using GPS helps to formulate site specific nutrient management practice of the location, understand the soil fertility spatially and temporally for better production of the crops and also helps to determine the crop suitability in that specific area. GPS provides valuable support to handle voluminous data which were generated through conventional and spatial format. It was widely used to locate the location of soil sampling pits (Rawal et al., 2018).

2.7 Geographic Information Systems (GIS)

Geographic Information System (GIS) is a system designed to capture, store, manipulate, analyze, manage and present spatial or geographic data (Tomlinson, 1987). GIS is a powerful set of tool for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world (Borrough, 1986). In the field of soil, GIS technology has opened newer possibilities of improving soil statistic system as it offers accelerated, repetitive, spatial and temporal synoptic view (Thakor et al., 2014).

The term GIS involves powerful, complex computer databases that organize information around a specific location. GIS maps are digital, interactive, loaded with information. Each category of information is called a theme or layer. It is GIS that can integrate layers of information in one place. The GIS technology is fast, becoming an efficient tool in research of all kinds that relate to geographic location in one way or other (Memon et al., 2011).

GIS is a potential tool for handling voluminous data and has the capability to support spatial statistical analysis, thus there is a great scope to improve the accuracy of soil survey through the application of GIS. The development of plans and processes of data acquisition and analysis is very fast through the use of GIS as compared to conventional methods (Mohamed & Abdo, 2011).

2.7.1 Use of GIS in agriculture

In agricultural, geographical information system (GIS) technology has been adopted for better management of land and other resources for sustainable crop production (Palaniswami, Gopalasundaram & Bhaskaran, 2011). GIS based soil fertility maps outline a cost effective option for implementing improved nutrient management in large tracts. With the incorporation of this method, agricultural areas with very high or low nutrient loading can be easily determined to enable the development of appropriated and economically sound management recommendations (Rawal et al., 2018). These maps can also be used to develop solutions of natural resources management issues such as urban planning, soil erosion, soil degradation, desertification and water quality assessment (Tomlinson, 1987).

2.7.2 Overview on GIS based spatial mapping

It is pointed out that for collecting, storing, retrieving, transforming and displaying spatial data, GIS is a powerful set of tools and useful for producing a soil fertility map of an area, which will help in formulating site-specific balanced fertilizer recommendation and to understand the status of soil fertility spatially and temporally (Thakor et al., 2014). As a GIS software, the ArcView GIS's key function is the desk mapping and spatial analysis, etc (Rawal et al., 2018). Geographical distribution maps of soil properties may help in correct management of soil nutrients (Brevik et al., 2016). These maps are required to understand the patterns and processes of soil spatial variability, which is the combined effect of soil physical, chemical and biological processes operating at different spatiotemporal scales combined with anthropogenic activities (Goovaerts, 1998).

Researchers can get benefit from the use of a GIS to more fully investigate data and develop spatially accurate graphical data displays (Ahmad, Sherazi & Shah, 2010). Advent of GIS technology and its great potential in the field of soil have opened newer possibilities of improving soil statistic system as it offers accelerated, repetitive, spatial and temporal synoptic view (Mohamed & Abdo, 2011).

A detailed soil fertility status of different Village Development Committees (VDCs) of Sunsari district in Nepal was investigated using GIS during 2015 by Rawal et al. (2018) and soil related crop production constraints were identified for proper utilization of agricultural land. Li et al. (2013) have been studied on soil fertility spatial variation feature based on GIS and data mining at GongPeng Town, Yushu City of Jilin province in China and provided the effective way for simulations which can be closer to the farmland soil fertility variability.

2.7.3 Geostatistics for spatial variability

Geostatistics is a powerful tool for determining the spatial variability (Sauer, Cambardella & Meek, 2006). Geostatistical methods are also essential for the investigation of spatial variations of soil and crop parameters across agricultural fields, which can lead to the efficient implementation of site-specific management systems (Najafian, Dayani, Motaghian & Nadian, 2012). It can be used to characterize the spatial behavior and spatial distribution of a parameter and to use this information to predict the value of this variable between sampled points and to minimize estimation error (Webster & Oliver, 2001).

Geostatistical methods have been widely applied to evaluate spatial correlation in soils and to analyze the spatial variability of soil properties, such as soil physical, chemical and biological properties (Liu et al., 2014). Furthermore, geostatistical methods have been adopted and used in site-specific management applications, soil sampling strategies and assessment of farm management decisions (Ingle et al., 2018). Spatial investigation of soil nutrient fertility relies on geostatistical methods, which allow the continuous prediction of soil properties from a network of sampling points (Webster & Oliver, 2007). Recently, Khadka et al. (2019) conducted the research at Agricultural Research Station, Bijaynagar, Jumla in Nepal using geostatistical interpolation methods to investigate the soil fertility status and mapping their spatial distribution which provided valuable information relating agricultural research strategy development.

2.7.4 Interpolation in GIS

Interpolation is the procedure of predicting the value of attributes at un-sampled sites from measurements made at point locations within the same area. It is used to convert data from point observations to continuous fields so that the spatial patterns sampled by these measurements can be compared with spatial patterns of other spatial entities. The rationale behind spatial interpolation is the very common observation that, on average, values at points close together in space are more likely to be similar than points further apart. Interpolation is one aspect of spatial analysis that is used in GIS which is applied for soil analysis (Karydas et al., 2009). The spatial interpolation methods make available a tool for estimating the values of soil variable at un-sampled points using data from point observations (Hengl, 2007).

Kravchenko and Bullock (1999) described that the interpolation techniques commonly used in agriculture to produce continuous maps of soil properties, in approximate order of use are: kriging (in a broad sense), inverse distance weighting (IDW) and splines. All three methods are exact, which means the interpolation of the values at sampled points is unchanged, or in other words the prediction honors the data (Laslett et al., 1987). Both inverse distance weighting and kriging estimate values at unsampled locations based on the measurements from the surrounding locations with certain weights attached to each of the measurements (Kravchenko & Bullock, 1999), whilst splines join together a series of polynomials of degree p, which attempt to describe the surface (Webster & Oliver, 2001).

An evaluation of spatial interpolation techniques for mapping agricultural top soil properties such as organic matter, total CaCO3, electric conductivity, Fe content, and clay content in a Mediterranean agricultural system was performed by Karydas et al. (2009).

In Tuz Lake Basin located in the Central Anatolian Region of Turkey, scientists analyzed various interpolation approaches for characterizing spatial variability of soil properties. The results indicated sample size, sampling strategy and data properties were the main factors, which affect performance and estimation of interpolation approaches (Gorji, Sertel, & Tanik, 2017).

2.7.5 Inverse distance weighting interpolation

Among spatial interpolation methods, Inverse Distance Weighting (IDW) method is based on the assumption that the value of an attribute z at some unvisited point is a distance-weighted average of data points occurring within a neighborhood or window surrounding the unvisited point. This is one of the simplest and most available methods. Inverse distance weighting directly implements the assumption that a value of an attribute at an un-sampled location can be approximated as a weighted average of values at points within a certain cut-off distance, or from a given number m of the closest points (typically 10 to 30). Weights are usually inversely proportional to a power of distance (Watson, 1992).

This method is one of the mostly applied and deterministic interpolation techniques in the field of soil science and estimates were made based on nearby known locations. The known sample points are implicit to be self-governing from each other (Robinson & Metternicht, 2006). The formula of this exact interpolator is (Burrough & McDonnell, 1998):

$$\widehat{Z}(x_0)=\frac{\sum_{i=1}^{n} Z(x_i)d_{ij}^{-r}}{\sum_{i=1}^{n} d_{ij}^{-r}}$$

Where, x_0 is the estimation point and *xi* are the data points within a chosen neighborhood. The weights (*r*) are related to distance by *dij*, which is the distance between the estimation point and the data points. The IDW formula has the effect of giving data points close to the interpolation point relatively large weights whilst those far away exert little influence. The higher the weight used the more influence points close to *x*0 are given. Instead of using inverse distances raised to the power of 2 (the most common form), other exponents can be used to change the rate of decay of the weighting function with increasing distance (Bonham-Carter, 2014).

The best results from inverse distance interpolation are obtained when sampling is sufficiently dense with regard to the local variation that are attempting to simulate. If the sampling of input points is sparse or very uneven, the results may not sufficiently represent the desired surface (Watson & Philip, 1985). This is important information considering the sparsity of the dataset used in this research. IDW is also sensitive to clustering and the presence of outliers (Johnston, Ver Hoef, Krivoruchko & Lucas, 2001). However, IDW may be more applicable to small datasets for which the modelled variogram is hard to fit (Tomczak, 1998).

2.7.6 Spatial distribution using IDW method

Gotway, Ferguson, Hergert and Peterson (1996) found that the IDW method generated more accurate results than Kriging for mapping soil organic matter and soil NO_3 levels. Wollenhaupt and Wolkowski (1994) compared these two interpolation techniques and concluded that IDW was more accurate for mapping P and K levels of soil, too. It was observed that for the optimal parameters of the method, the accuracy of IDW interpolation generally equaled or exceeded the accuracy of Kriging at all scales of measurement (Mueller et al., 2004; Krivoruchko & Gotay, 2003). Indicatively, Schloeder, Zimmerman and Jacobs (2001) observed that Ordinary Kriging and IDW were similarly accurate and effective methods, while thin-plate smoothing spline with tensions was not.

Tuncay, Bayramin, Atalay, and Unver (2016) performed an assessment of IDW interpolation on spatial variability of selected soil properties such as calcium carbonate ($CaCO_3$), organic matter (OM), cation exchange capacity (CEC), and clay content at the lower Seyhan River Basin in Cukurova, Turkey. They concluded that $CaCO_3$, OM, CEC, and clay content values obtained from IDW interpolation were consistent with the soil analysis results, thus enabling the extension of the obtained values to any similar none-sampled region. In another study, researchers have compared performance of interpolation methods for estimating spatial distribution of top soil pH and EC in Hamadan Province, Western Iran. The result demonstrated high performance of spatial estimation of inverse distance weighting (IDW) and radius basis function (RBF) methods (Attaeian, Farokhzadeh, Akhzari, & Artimani, 2015).

2.8 Grid Sampling

Grid soil sampling is typically used for establishing management zones for site-specific application of nutrients (Fathi & Mirzanejad, 2015). Wollenhaupt and Wolkowski (1994) described that the common approach to achieve systematic soil sampling is to overlay a square or rectangular grid on a map or photograph of the field, identify and drive to the middle of each grid cell, and collect a soil sample at that point. The soil sample consists of several soil cores collected within a small radius of the cell center. The soil cores are composited and bagged as one soil sample for analysis at a soil testing laboratory. The purpose of compositing several cores is to average or "bulk" out variability in soil test properties that occurs over small distances.

Grid cell sampling can be efficiently conducted by counting crop rows and using distance measuring devices to locate sampling points. While easy to implement in the field, this practice can lead to bias. If the grid sampling pattern is a multiple or fraction of other patterns, the soil samples may not correctly represent the soil test variability within the field. The potential for bias can be minimized by shifting the sampling locations to the right or left of the cell center in alternating rows perpendicular to the management pattern (e.g. row direction). The resulting sampling grid takes on the appearance of a diamond pattern. This sampling pattern can also be implemented by counting rows and measuring distances (Wollenhaupt & Wolkowski, 1994).

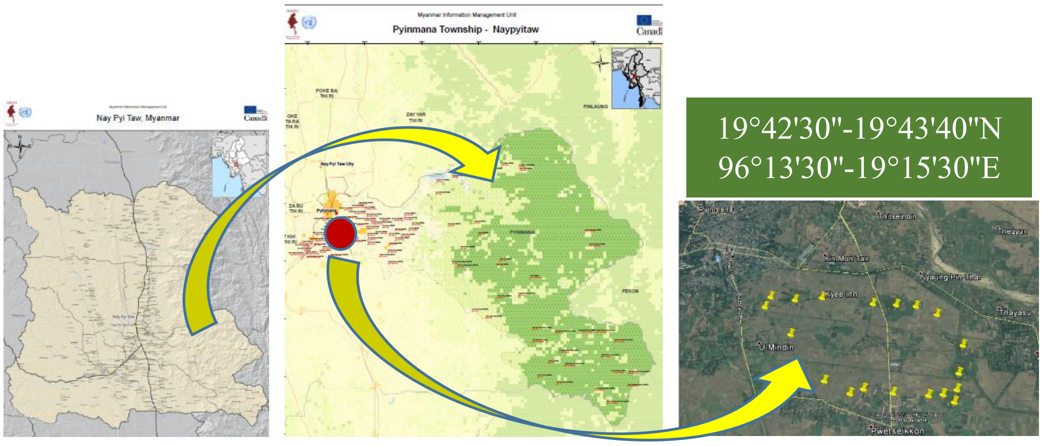
CHAPTER III
MATERIALS AND METHODS

3.1 Pilot Survey

A pilot survey was conducted in Kyee Inn and Kin Pon Tan villages, Pyinmana Township, Nay Pyi Taw Area for selecting the appropriate site for conducting experiment. The required secondary data were collected by interviewing with village-head, by meeting with township managers from the Department of Agriculture and also Department of Agricultural Land Management and Statistics. The selected five farmers from each village were interviewed and recorded the required information using well-prepared questionnaires. According to pilot survey data such as social-economic condition; especially in educational standard, villagers in Kyee Inn village were very willingly to be selected their village as an experimental site, multiple land preparations, different cropping patterns, unbalanced fertilizer application and poor water management problem, map preparation, household condition and less land conflicts, Kyee Inn village was suitable for conducting the experimental site. Finally, Kyee Inn village tract was selected as the study area according to this pilot survey for relevant implementation of all research works.

3.2 Description of Study Area

The research extent covers a total area of 480 hectares locating the middle part of the Myanmar, Pyinmana Township, Kyee Inn Village Tract and situated between 19°42'30"-19°43'40" N and 96°13'30"-19°15'30"E (Figure 3.1). Myanmar experiences three distinct seasons, summer (mid-February to beginning of May), rainy (mid-May to end of October) and winter (late-October to mid-February). The study area receives a mean annual rainfall of about 1420 mm and the average temperature of 26.8°C. Kyee Inn village tract has the population of approximately two thousands, but farmer population occupied only about one thousand and total sown area was estimated about 480 hectares. Farmers have usually practiced the dominant cropping pattern of monsoon rice and pulses with rain-fed and irrigated farming practices in the study area. The source of water availability for rice cultivation was supported by the government supply of Nga Lite Dam for this area.



Naypyitaw | Pyinmana Township | Kyee Inn Village Tract (480 hectares)

Figure 3.1 Location of the study area

3.3 Collection of Secondary Data and Ground Truth Data

The required secondary data such as location coordinates of Kyee Inn sown area, number and name of farmers, land-holding acres for each farmer by separating their possession remarks, and digitized field base-map hardcopy of this area were taken from the township level office of Department of Agriculture and Department of Agricultural Land Management and Statistics. Then ground truth data were taken by checking the location points directly to the field of the whole study area using Global Positioning System (GPS) with drone flying committee members.

3.4 Drone Flying and Preparation of Digitized Base Map

Drone flying was done to prepare the research area base-map for using GIS software. Before the drone flying, the mission plan was definitely prepared for specific flying area that can effectively take the picture in planned area more properly. The drone flying speed and altitude were adjusted for getting good resolution of drone image and therefore the mission plan was prepared and adjusted with 18 m s^{-1} of flying speed, 150 meter of altitude, and 75 resolution pixels per inches and 2.26 seconds per picture for all flying plan of the whole area. After well-preparing the mission plan, it was imported to the Litchi software and drone flying was accomplished with internet connection. DJI Phantom 4 drone was used in all drone flying programs that is provided by Japan International Cooperation Agency (JICA) through Yezin Agricultural University and Japan International Cooperation Agency Technical Cooperation Project (YAU_JICATCP). Since the total study area occupied 480 hectares including four blocks namely Block No. 1698, 1699, 1708 and 1709, the drone flying was taken many time to accomplish approximately 4 days per block. After finishing the complete flying program, the drone images were processed using pix 4D software for overlapping the images, checking the unnecessary images, geo-referencing and digitizing the images for preparation of digital base map of the study area.

3.5 Grid Map Preparation

The original digital map of study area was transformed into grid map for relevant implementation of research works systematically. The area was divided into grid plots (300 m × 300 m) according to original scale of the map (i.e. 10 km 5 min). Finally, 80 total grid plots were laid out for the entire study area.

3.6 Soil Sampling

Sampling was done as grid method 300m×300m at 0-15cm depth using Global Positioning System (GPS) to determine geodetic coordinate of the sampling points. All samples were taken after the harvest of the previous crops and before the land preparation of the next cropping season on May, 2017 to avoid the undesirable effect for soil analysis due to fertilizer application. Three replicated soil samples were taken from each grid plot to become a representative sample, however, some grid plots have one or two samples because of inconvenient for sampling such as presence of standing crop of sugarcane and sesame in some fields, and some grids are not enough for taking sample since these are marginal grid plots. Therefore, the total of 178 soil samples were collected from the 80 sampling grids plots using hand-hoe across the diagonal for each grid (Figure 3.2). All collected soil samples were marked with systematic labelling and then immediately transferred into the laboratory at Soil and Water Science Department, YAU. At sampling time, soil core samples were taken for each sample to measure the soil bulk density.

3.7 Laboratory Analysis

The collected soil samples were firstly composited to 80 soil samples. Air-drying of soil samples was done at ambient temperature round about 7 days and grinded using motor and pestle. Then, sieving was done passing through a 2.0 mm sieve, and keeping the 80 composite soil samples in 4°C cooled room of the laboratory. There was taken into precaution for undesirable contamination. Then, soil samples were analyzed through standard soil analysis methods to determine major soil fertility parameters including soil pH, organic matter, cation exchange capacity, electrical conductivity, soil bulk density, soil moisture, total content of nitrogen, phosphorus, and potassium at laboratory of Department of Soil and Water Science, YAU. The analytical methods used for conducting the soil analysis were described in Table (3.1).

3.8 Survey (Interview)

In this study, a survey in a form of the interview with farmers was conducted using a set of structured questionnaire to identify the soil management practices of sampling area more clearly. There are total number of 68 farmers from the sampling area and they were interviewed individually using their language in Myanmar.

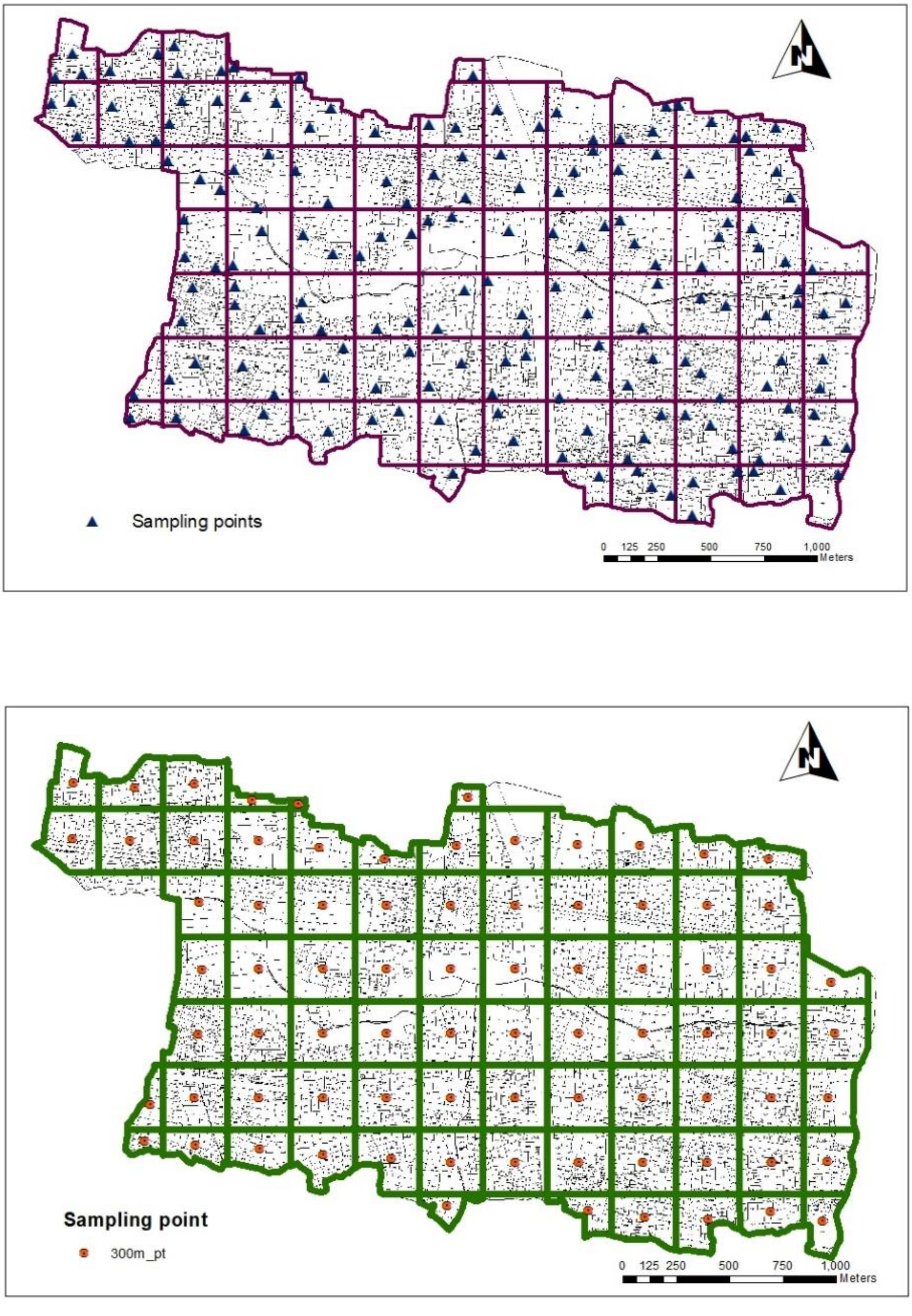


Figure 3.2 Sampling area and grid sampling points

Table 3.1 Soil parameters and analytical methods adopted for the laboratory analysis at Soil and Water Science Department, YAU

	Soil Parameters	**Unit**	**Analytical Methods**
Physical	Bulk Density	g cm^{-3}	Core sampler method (Black, 1965)
	Soil Moisture	%	Gravimetric method (Black, 1965)
Chemical	Soil pH	$-log[H^+]$	1:5 (soil: water) pH meter (Hesse, 1971)
	Electrical Conductivity	dS m^{-1}	1:5 (soil: water) EC meter (Hesse, 1971)
	Cation Exchange Capacity	meq100 g^{-1} soil	Bascomb's method (Bascomb, 1964)
	Organic Matter	%	Walkley and Black method (Walkley & Black, 1934)
	Total Nitrogen	%	Modified Kjeldahl Digestion method (Ohyma et al., 1991)
	Total Phosphorus	%	Molybdivanado phosphoric acid method (Spectrophotometer) (Murphy & Riley, 1962)
	Total Potassium	mg kg^{-1}	Atomic Absorption Spectrophotometer (AAS) (Flame method)

The questionnaire consisted of a structured questions including social information such as farmers' farming experience, allocation of labor, land-holding, education standard, field and crop history information such as soil fertility status, method of land preparation, cropping pattern, and soil management practices information such as fertilizer application (i.e. organic, inorganic or foliar), name and type of fertilizers, fertilizer application rate and cost, time of application (i.e. basal or top dressing), number of fertilizer application, number of years for fertilizer application, use of herbicides, practices of incorporating straw, method of harvesting and yield per acre.

3.9 Statistical Analysis

The laboratory results of all parameters were subjected to the descriptive statistic (minimum, maximum, mean, standard deviation, standard error, and coefficient of variation) using statistix (8^{th} version). Correlation analyses was carried out to detect functional relationship among soil parameters using statistix (8^{th} version). The coefficient of variation (CV) was also ranked for determination of nutrient variability according to the procedure of Ogunkunle (1993), where, soil properties having a coefficient of variation (CV) between 0 and 15% are considered least variable, 15 and 35%, moderately variable, and larger than 35% highly variable.

3.10 Soil Fertility Mapping

Different thematic maps for the spatial distribution of each parameter were generated using the Inverse Distance Weighted (IDW) interpolation in the ArcGIS software version 10.5. Using the base map of study area developed by processing geo-referencing and digitizing of drone photos, soil fertility maps were produced through ArcGIS software. Firstly, mosaic to new raster tool was used to combine all processed photos in data management tool, and then clip this mosaic TIFF file to continue the grid process using grid index features in cartography tools. After grid setting, split and merge process were continued to transform these grids plots into point features which is necessary process for generating the interpolation maps.

The interpolation maps were generated using inverse distance weighting methods by joining this point feature shape file with attribute table of soil analysis results. The soils were classified into different fertility categories, i.e., very low, low, medium, high and very high on the basis of the content of each selected soil parameters.

For each fertility class, different symbol, colors, and patterns were selected from symbol selector of Arc Map 10.5.

Finally, the fertility status of the various soil parameters was mapped using the respective legend symbols. Selected soil parameters such as soil pH, electrical conductivity, cation exchange capacity, soil organic matter, bulk density, soil moisture, total nitrogen, total phosphorus, and total potassium content were mapped.

Nutrient index was also calculated by the formula given by Ramamoorthy and Bajaj (1969). Then interpretation was done as values shown on the Table (3.2).

$$\text{Nutrient index (N.I.)} = \frac{(N_L \times 1 + N_M \times 2 + N_H \times 3)}{N_T}$$

Where,

N_L, N_M, N_H	=	number of samples falling in low, medium and high classes of nutrient status
N_T	=	total number of samples analyzed for a given area

Table 3.2 Rating chart of nutrient index

S.N.	Nutrient Index	Value
1	Low	<1.67
2	Medium	1.67-2.33
3	High	>2.33

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Descriptive Statistics of Soil Parameters

Descriptive statistics results (minimum, maximum, mean, standard error, standard deviation, and coefficient of variation) for each soil parameter of 80 soil samples up to (0-15cm) depth were presented in (Table 4.1). There was a great variation in soil properties existed across the study area. The coefficient of variation (CV), which is the ratio of the standard deviation to mean expressed as a percentage is a useful measure of overall variability (Tagore, Bairagib, Sharmab, & Vermab, 2014). The range of CV for the study area mentioned different degrees of heterogeneity among the soil properties studied. High CV value implies that the data distribution is more variable (dispersed) and, hence, less stable and less uniform (nCalculators, 2013).

The CV values for all soil parameters ranged from 5.08% to 66.84% indicating least to high variability. Among the statistical results, total nitrogen showed the highest variability with 66.84% of CV, followed by soil electrical conductivity 54.36% of CV value indicating more dispersion in their distributions. However, least variability has been found in 5.08%, 6.57%, and 6.68% of CV values for soil pH, bulk density and total phosphorus content that signified relatively low dispersion across the area. Moderately variability was recorded in total potassium content, cation exchange capacity, soil moisture percent and organic matter exploring CV values of 21.20%, 28.02%, 31.6% and 35.93%, respectively.

4.2 Spatial Variation in Soil Properties

4.2.1 Soil pH

The soil pH is an indicator of the acidity or alkalinity of soil (Amacher, O'Neil & Perry, 2007) and is an important chemical parameter as it helps in ensuring availability of plant essential nutrients (Deshmukh, 2012). The soil of the study area was found to be moderately acidic to moderately alkaline in soil reaction showing mean value of soil pH 6.25 and ranged from 5.48 to 7.58. Notably, majority of the soil samples have pH value within moderately acidic in reaction. The spatial distribution map and classified soil pH status generated using Inverse Distance Weighting (IDW) interpolation technique were displayed in Figure 4.1 (a) and (b).

Table 4.1 Descriptive statistics of soil parameters

Variables	Unit*	Minimum	Maximum	Mean	SE	SD	CV%
Bulk Density	g cm^{-3}	1.130	1.720	1.520	0.011	0.099	6.57
Soil Moisture Content	%	1.790	9.640	4.920	0.174	1.556	31.60
pH	$-\log[H^{+}]$	5.480	7.580	6.240	0.035	0.317	5.08
Electrical Conductivity	dS m^{-1}	0.051	0.506	0.095	0.005	0.052	54.36
Cation Exchange Capacity	meq100 g^{-1} soil	2.130	11.050	6.220	0.194	1.742	28.02
Organic Matter	%	0.200	1.700	0.870	0.035	0.314	35.93
Total Nitrogen	%	0.010	0.330	0.110	0.008	0.076	66.84
Total Phosphorus	%	0.017	0.024	0.019	0.0001	0.001	6.68
Total Potassium	mg kg^{-1}	197.500	601.400	391.100	9.260	82.900	21.20

SE: Standard Error, SD: Standard Deviation, CV: Coefficient of Variation

* Units represent for the columns of minimum, maximum and mean in the table

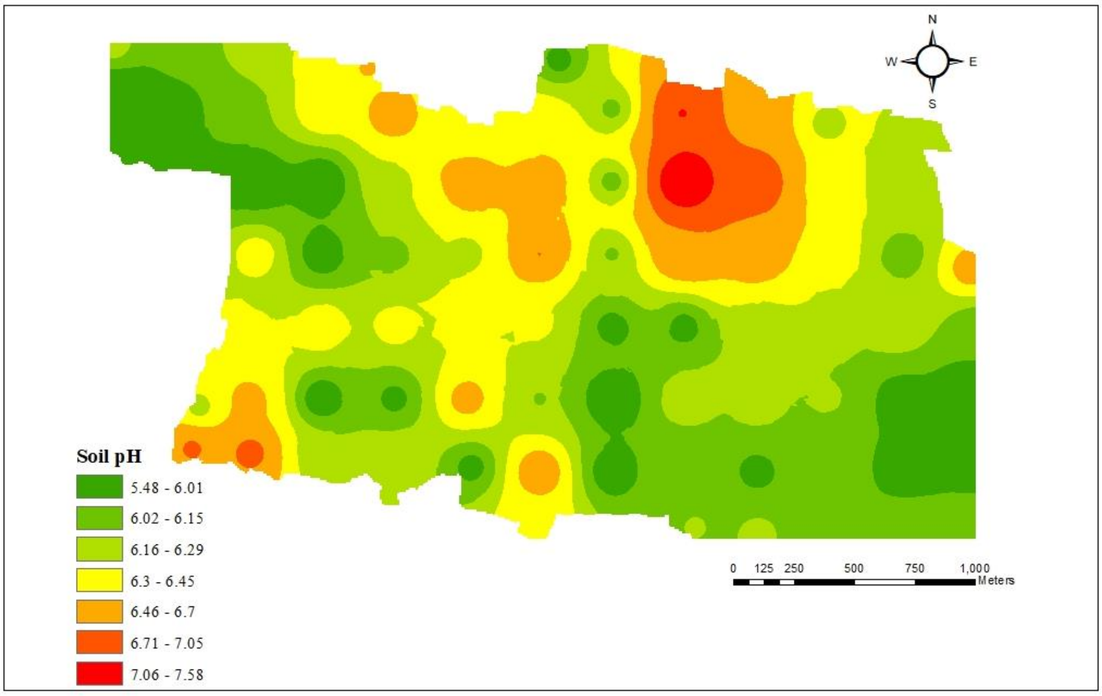


Figure 4.1 (a) Spatial distribution of soil pH

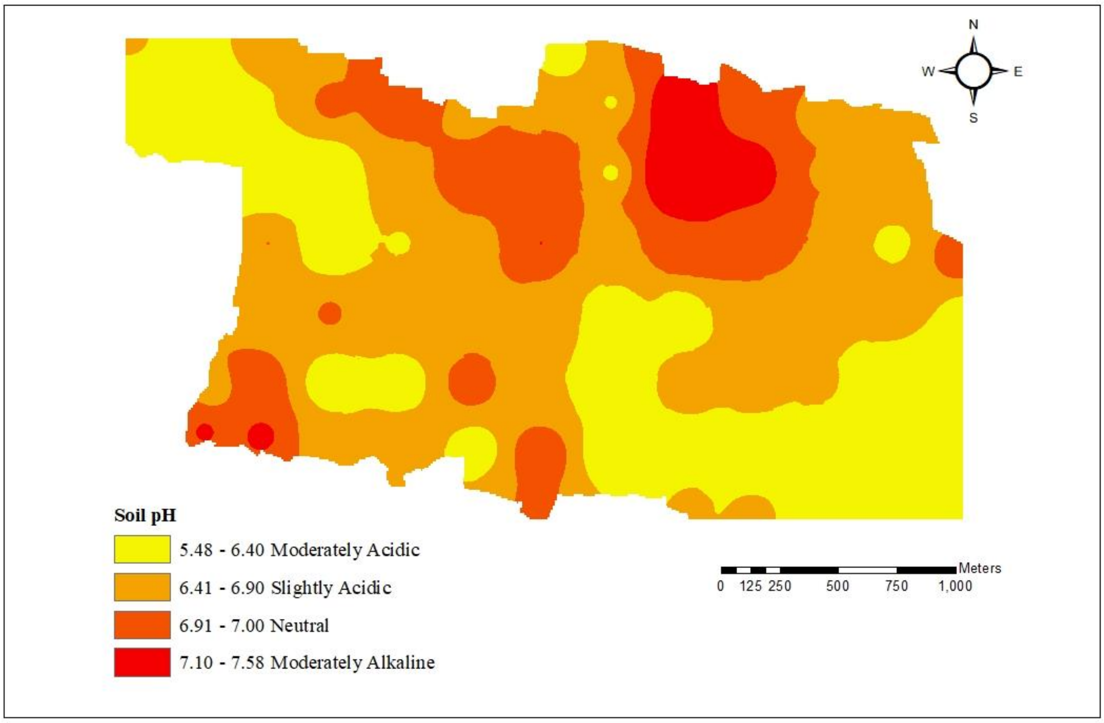


Figure 4.1 (b) Classified soil pH

The pH of soil samples was found to be 75% of sample showed moderately acidic, 21.25% of samples were slightly acidic, while 2.5% of samples were nearly neutral and only 1.25% of samples were moderately alkaline (Table 4.2). Some grid plots showed slightly acidic to moderately acidic in reaction probably due to some factors such as mineralogy of soil (i.e high iron content), sufficient amount of rainfall which promote soil acidity, and farmer's practice such as using acid-forming nitrogenous fertilizers for crop production every year (described in section 4.6.3). It was stated that most of the acidic soils were probably due to natural systems like mineralogy (soil containing high Fe, Al, etc.), climate (high annual average rainfall) and weathering, use of acid-forming nitrogen fertilizers, or removal of bases such as potassium, calcium, and magnesium (Rawal et al., 2018).

Moreover, farmers in the study area already practiced legume cultivation every year and it was stated that leguminous plants are particularly acidifying because they take-up more cations, in comparison to anions (Harter, 2007). Brady and Weil (2004) also stated that the soils are acidic and it might be as a result of the leaching of basic cations or due to incessant uptake by crops grown on the field. Another cause of rising acidity is generally related to nitrate leaching and a build-up of organic matter (Charman, 2000). Harter (2007) also explained that legumes take up little nitrate from the soil because most of their nitrogen needs are satisfied by microbial nitrogen fixation, but in non-leguminous plants, nitrate uptake partially balances base cation uptake, so less hydrogen is exchanged from the root to obtain these nutrients.

Nevertheless, Gazey and Davies (2009) stated that the pH value between 5.5 and 8.0 were considered as ideal for plant growth. Thus, the observed pH values for the entire study area may not harmful for plant growth and the availability of most of plant nutrients might not be limited within the observed pH range.

4.2.2 Soil electrical conductivity

Electrical conductivity (EC) of a soil solution can be used to estimate the salinity of an area and gives a clear idea of the soluble salts present in the soil. Generally, it can be assumed that the lesser the EC value, the salinity value of soil will be lower and vice versa. It was evidently observed that the value of EC ranged from 0.051 to 0.505 dS m^{-1} with an average of 0.095 dS m^{-1} (Table 4.3). The spatial distribution map and classified EC status generated using IDW interpolation technique for the study area were shown in Figure 4.2 (a) and (b).

Table 4.2 Measured pH of soil samples in Kyee Inn Village Tract

Sr. No.	$pH_{(1:5\ water)}$	Category	Range (No. of samples; %)
1	<5.4	strongly acidic	-
2	5.5-6.4	moderately acidic	5.48-6.37 (60; 75)
3	6.5-6.9	slightly acidic	6.41-6.79 (17; 21.25)
4	7.0-7.0	neutral	6.92-7.06 (2; 2.5)
5	7.1-7.5	slightly alkaline	-
6	7.6-8.3	moderately alkaline	7.58-7.58 (1; 1.25)
7	>8.4	strongly alkaline	-

Table 4.3 Measured EC values of soil samples in Kyee Inn Village Tract

$EC_{(1:5)}$ ($dS\ m^{-1}$)	Category	Range (No. of samples; %)
<0.5	low level	0.051-0.147 (79; 98.75)
0.5-2.0	medium level	0.505 (1; 1.25)
>2.0	high level	-

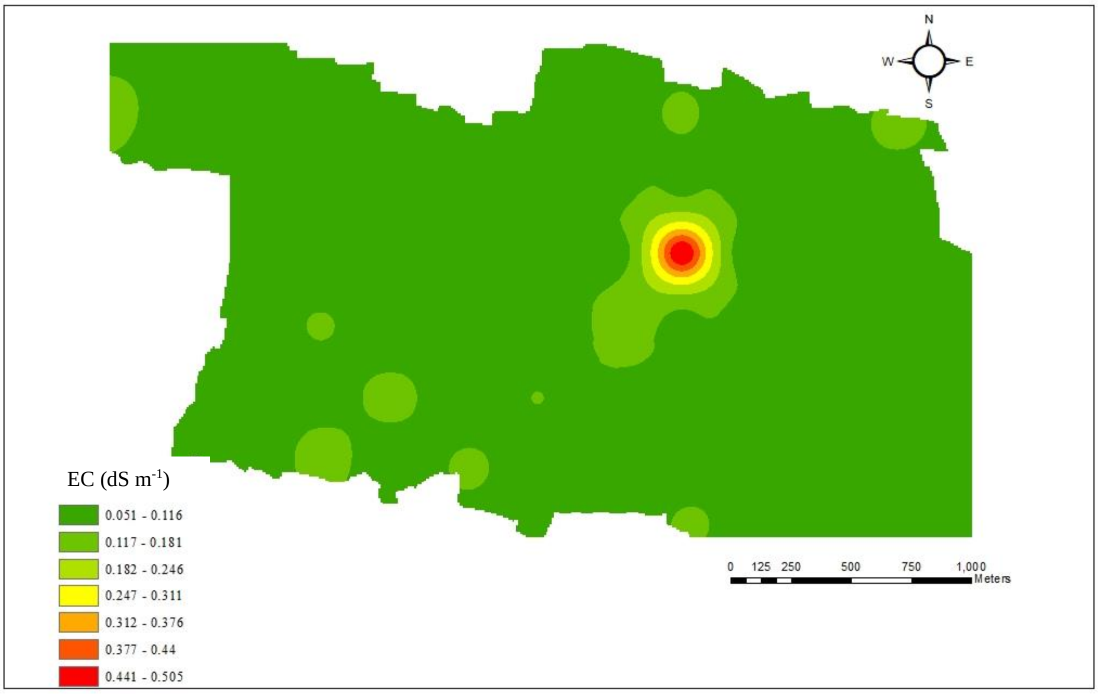


Figure 4.2 (a) Spatial distribution of soil electrical conductivity (EC)

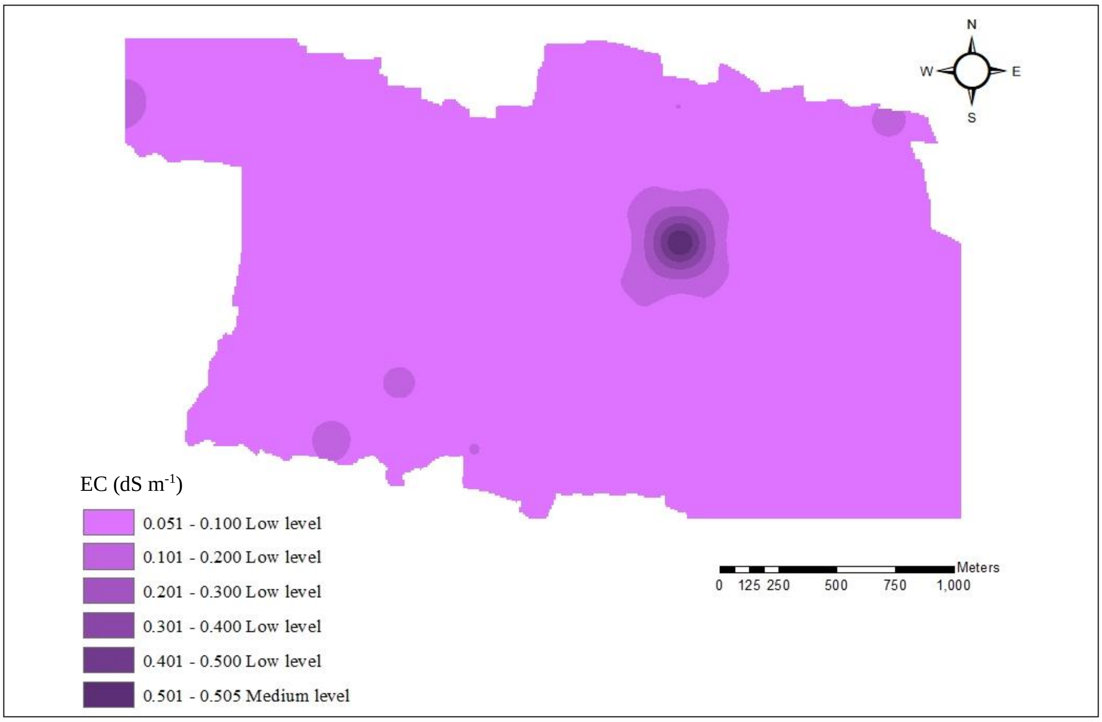


Figure 4.2 (b) Classified soil electrical conductivity (EC)

The observed mean EC value revealed the study area does not seem to have a salinity problem. Because of all EC values were noticeably lower than 1.5 dS m^{-1}, it can be considered suitable for agriculture. Saline soils are those with an EC greater than 1.5 dS m^{-1} for a 1:5 extract, therefore, the yield of most crop would not be restricted until EC is greater than 2 dS m^{-1} (Charman, 2000). According to soil guide (Moore, 2001), the observed EC values for the study area were situated between the ranges of low level of EC value 0.051 and 0.5 dS m^{-1} which can have minimum effect on plant growth. Landon (1991) reported that soils of sub-humid tropics where there was sufficient rainfall to flush out base forming cations from the root-zone, EC was found to be too low, usually being less than 4 dS m^{-1}. EC varies with the concentration of dissolved salts (Bohn, McNeal & O'Connor, 1987).

4.2.3 Cation exchange capacity

The cation exchange capacity (CEC) measurement is commonly made as part of the overall assessment of the potential fertility of a soil (Landon, 1991). The CEC ranged from 2.13 to 11.05 meq100 g^{-1} soil with the mean value of 6.22 meq100 g^{-1} soil for the whole study area. The spatial distribution map and classified CEC levels generated using IDW interpolation technique for the study area were given in Figure 4.3 (a) and (b).

According to Landon (1991), 23.75% and 76.25% of sampling grid plots can be characterized as a very low and low level in CEC, indicating that the study area has inadequate basic cations to support plant growth (Table 4.4). Ahmed, Jeb, Usman, Adamu and Mohammed (2015) stated that any CEC of < 4 meq100 g^{-1} soil indicate a degree of infertility normally unsuitable for agriculture.

The observed CEC values were relatively low level for all study area perhaps due to some factors such as lower level of organic matter content, higher bulk density, moderately acidic conditions and continuous cultivation practiced by the farmers. The variation in CEC values may be because of variation in organic matter content, type and amount of clay, and intensity of cultivation reported by Mesfin (1998).

It was reported that both clay content and organic matter considered as a source of nutrients by attracting cations and provide more exchange sites to get the cations adsorbed on it; so, soils that have a large amount of clay or organic matter have higher exchange capacities than sandy soils, which are usually low in clay content and organic matter (Chude, Malgwi, Amapu & Ano, 2011). The low values of CEC may be attributed to the effect of soil tillage that led to the reduction of soil organic matter (Paz-Gonzalez et al., 2000). Soil CEC is expected to increase through improvement in soil organic matter content (Kedir et al., 2016).

4.2.4 Soil organic matter

Soil organic matter (SOM) can be considered a pivotal component of the soil because of its role in physical, chemical and biological processes. In broad sense, it comprises all living soil organisms and all the remains of previous living organisms in their various degrees of decomposition (Rawal et al., 2018).

The organic matter content was ranged from 0.20% to 1.70% with a mean value of 0.87%. This obviously showed that the whole study area has very low level of soil organic matter content (Table 4.5). The amount of organic matter in a soil is highly dependent on a range of ecological factors (climate, soil type, vegetative growth, topography) in which it occurs as well as land use and management and tillage of the soil, intensive cropping (Rawal et al., 2018). Figure 4.4 (a) and (b) displayed the spatial distribution of the percent of organic matter showing gradually higher from the northeast portion towards the southwest portion and the highest content was obviously found in southwest portion of the area. The reason is probably due to the slightly higher elevation of the northern portion as organic matter accumulation is often favored at the lower elevation of the area. Soil organic matter and nutrient content vary in different topographic positions due to leaching, transporting and accumulation. Purdie (1998) stated that soils with organic matter content greater than 2.6% have good nutrient storage. It can be considered that the level of soil organic matter content in all sampling grid plots was very low for good nutrient storage and supply.

Based on the survey data of soil management practices (described in section 4.6.3), the spatial variability of low organic matter content may be attributed to the adopted improper agricultural management practices such as such as complete removal of crop residues, lack of addition of organic manures and unsystematic application (irregular and inadequate amount) of organic materials (rice straw, pulses residues, cow dung, etc.). After harvesting, the burning of crop residues is a usual practice of this area. To improve soil organic matter and crop yield to some extent, soil management practices such as addition of organic matter and returning of crop residues to the plots should be practiced.

Table 4.4 Determination of CEC values of soil samples in Kyee Inn Village Tract

CEC (meq100 g^{-1}soil)	Category	Range (No. of samples; %)
< 5	very low	2.13-4.94 (19; 23.75)
5-15	low	5.03-11.05 (61; 76.25)
15-25	medium	-
25-40	high	-
> 40	very high	-

Table 4.5 Determination of SOM% of soil samples in Kyee Inn Village Tract

SOM (%)	Category	Range (No. of samples; %)
< 2.0	very low	0.20-1.70 (80; 100)
2.0- 3.0	low	-
3.0 -7.0	optimum	-
7.0-8.0	high	-
>8.0	very high	-

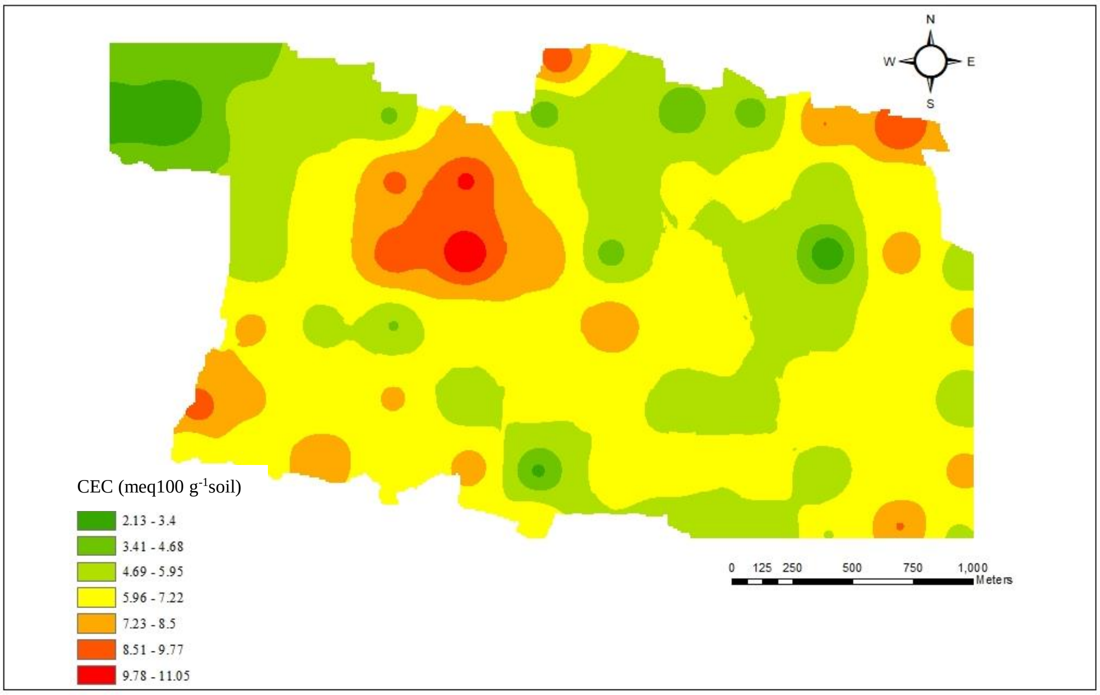


Figure 4.3 (a) Spatial distribution of soil cation exchange capacity (CEC)

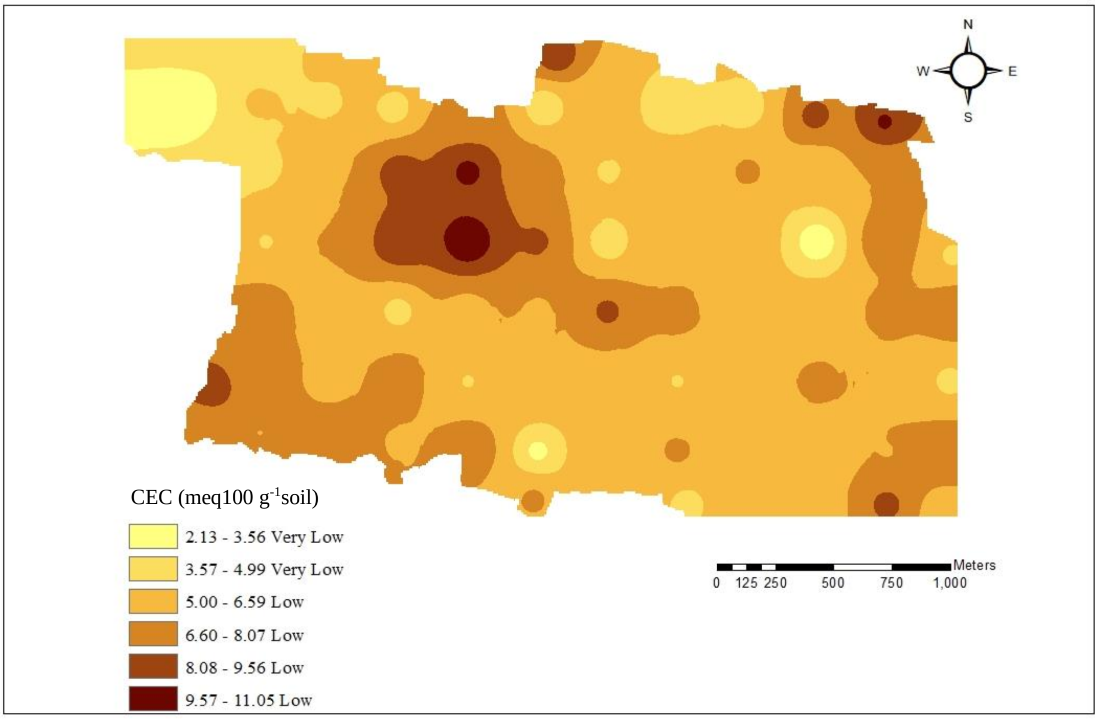


Figure 4.3 (b) Classified soil cation exchange capacity (CEC)

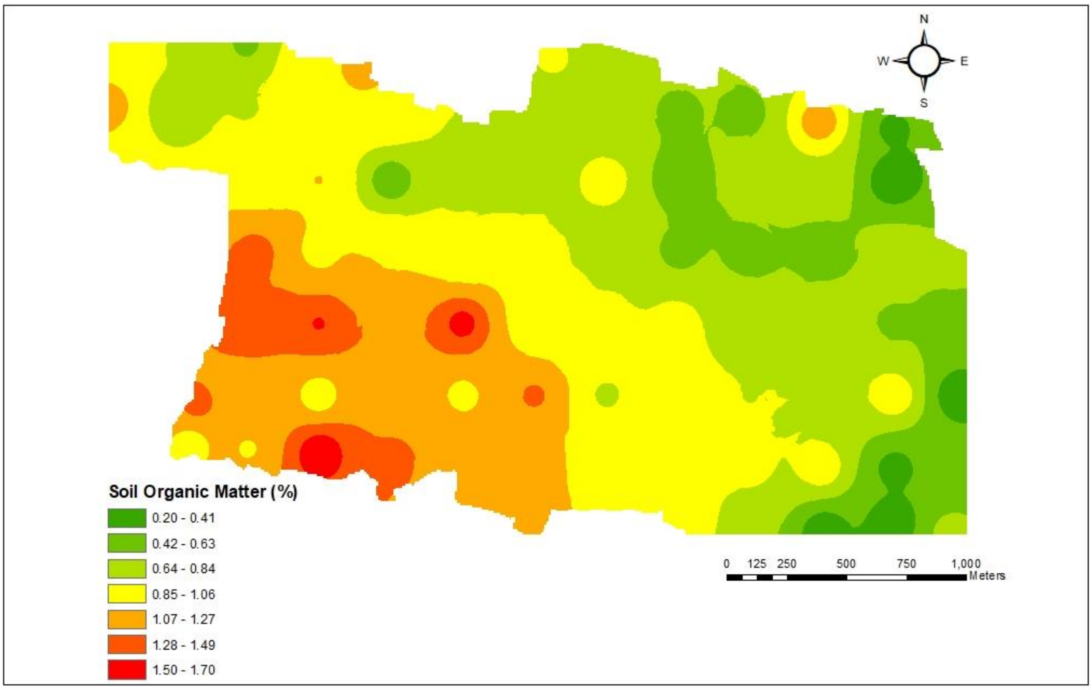


Figure 4.4 (a) Spatial distribution of soil organic matter

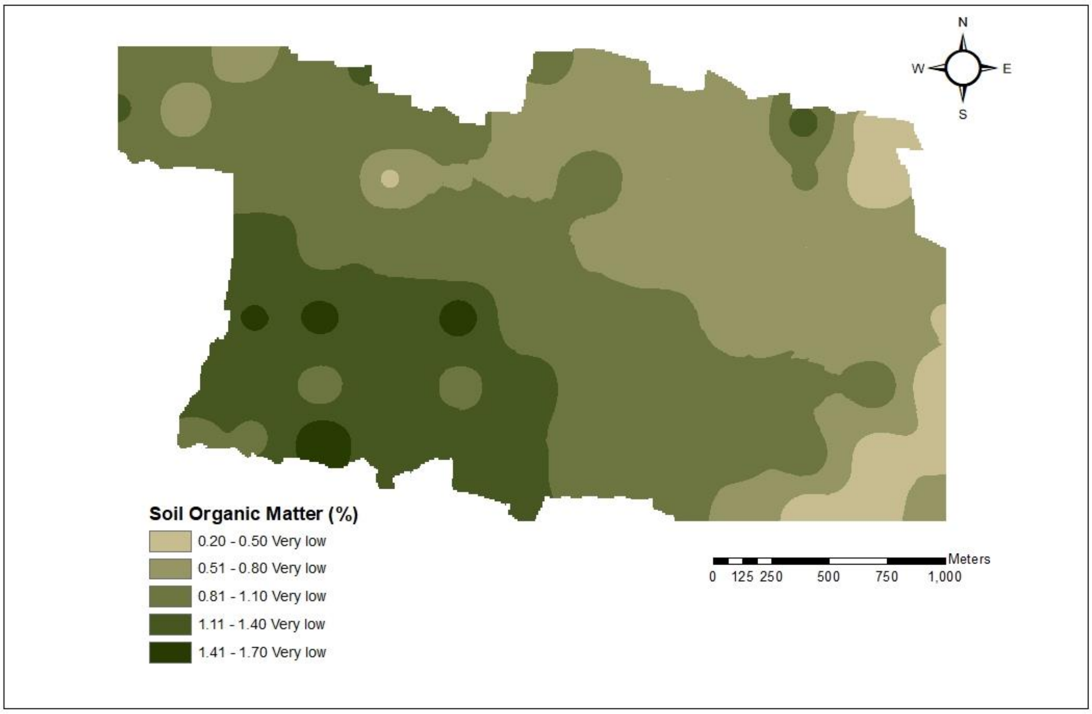


Figure 4.4 (b) Classified soil organic matter

Another possible reason might be that low level of organic matter accumulation resulted from the rapid decomposition of organic matter due to tropical climate of this region that gives high temperature (rises up to 38°C during hot season). Generally, soil organic matter content of the soils in dry zone is very low because of faster decomposition rate of organic matter than accumulation in soil. The organic matter build up in soils is related to natural vegetation, cropping history and temperature (Dudal, 1965).

Kilic, Kilic and Kocyigit (2012) described that the depletion of organic matter in the cultivated fields can be associated with the intensive tillage and the removal of plant residue. The lower organic matter content in the cultivated land units might be due to higher rate of organic matter decomposition aggravated by intensive cultivation, and also perhaps because of low rate of return of organic materials as crop residues due to a number of competing ends such as animal feed, fuel, construction, etc. (Kedir et al., 2016).

Therefore, incorporation of different organic matter adding materials, adoption of suitable crop rotation, crop residue management, mulching and tillage is important for soil organic matter improvement. Farmers in this area should be encouraged to return as much as residue as possible to soil in addition to application of manure and compost.

4.2.5 Soil bulk density

To understand the physical behavior of soils, the bulk density is more important (Kumar, 2005) and it is a measure of how dense and tightly packed a sample of soil is, which depends on the structure of the soil peds, the number of pore spaces and the composition of the soil particles (Smitha & Sobha, 2014). The spatial distribution map and classified bulk density status generated using IDW interpolation technique were shown in Figure 4.5 (a) and (b).

For distribution of bulk density values ranged from 1.31 g cm^{-3} to 1.72 g cm^{-3}. The observed mean bulk density value of 1.52 g cm^{-3} obviously showed that the higher bulk density value for crop production for the whole study area. High bulk density refers to the poor physical condition of the soil. It is generally desirable to have soil with a low bulk density (<1.5 g cm^{-3}) for optimum movement of air and water through the soil (Hunt & Gilkes, 1992).

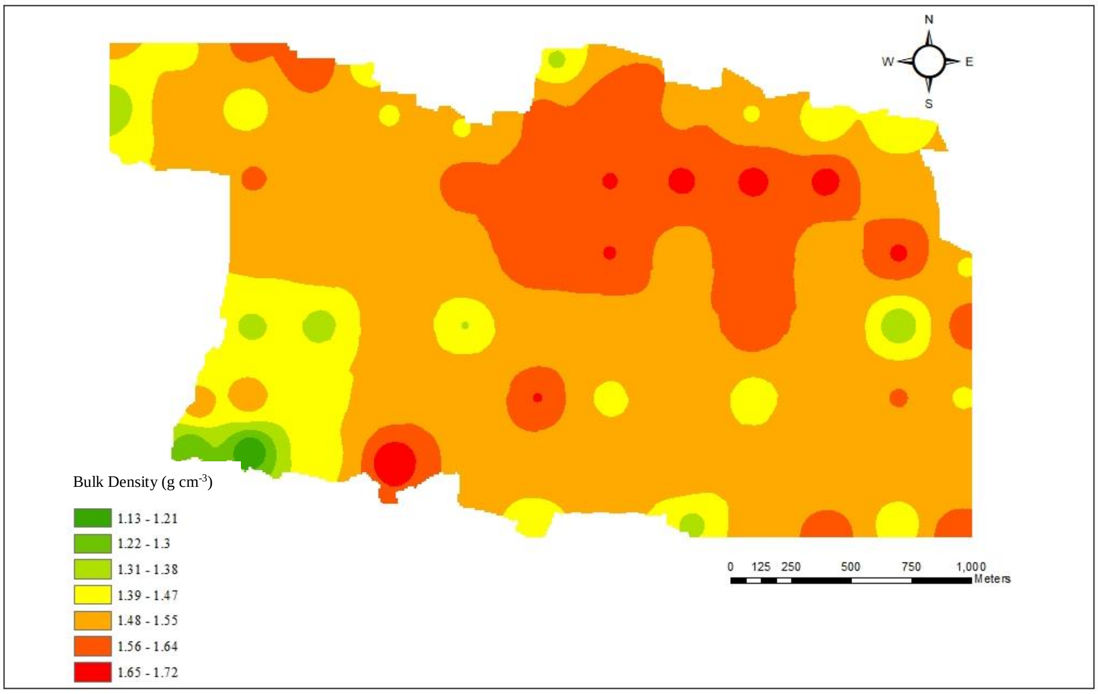


Figure 4.5 (a) Spatial distribution of soil bulk density

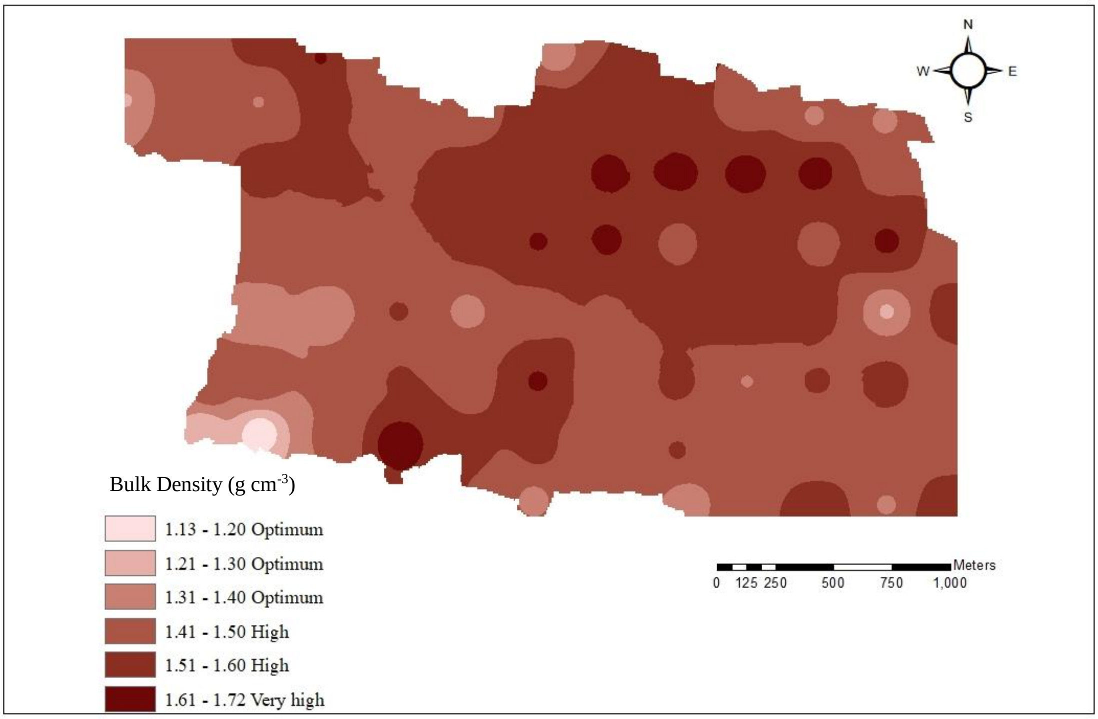


Figure 4.5 (b) Classified soil bulk density

Optimum condition of bulk density values were found in marginal sampling point in this study area like patchy distributions and the highest bulk density values were largely observed in north eastern part of the area. According to survey data of soil management practices by the farmers, some reasons for higher bulk density values may probably be as a results of cumulative traffic of machinery utilization for crop productions in the study area. All of the farmers have a practice of using machinery equipment and tractors from land preparation to harvesting processes for their crop production every year.

Blak and Hartge (1986) mentioned that a very compacted soil perhaps due to tractor compaction would have a bulk density of 1.4 to 1.6 g cm^{-3} and an open friable soil with good organic matter content will have a bulk density of <1.0 g cm^{-3}. The higher bulk density can be observed after the rice season affected by paddling caused changes in soil physical properties by breaking down soil aggregates and forming hardpans at shallow depth (Zhou, Lv, Chen, Westby & Ren, 2014).

The variation in bulk density could be attributed to variation in soil organic matter content, soil texture, and intensity of cultivation (Sharma & Anil, 2003). Bulk density is affected by factors such as water, aeration status, root penetrate, clay content, texture, land use and management (Sakin, 2012). Accordingly, the highest bulk density for north eastern portion could be due to lower soil organic matter content in this portion and also higher degree of soil compaction due to mechanized cultivation since farmers have been used farm tractors for a long period of time. Nandakumar (2004) stated that lower bulk density is due to higher organic content and higher porosity. Bulk density normally decreases, as mineral soils become finer in texture. (Miller & Donahue, 1995).

The observed bulk density range of the study area was found to be unsuitable for crop production and root growth. There is needed to take some precautions for machinery utilization in crop production to break down the hard pan of compacted soils and also farmers should be returned the crop residues and organic fertilizers into the fields for optimizing the soil bulk density.

4.2.6 Soil moisture

Spatial variability of soil moisture helps in mapping soil properties across the field and variability in irrigation requirement (Noguchi, Tsuboyama, Sidle & Kubota, 2014). The spatial distribution maps of soil moisture content generated using IDW interpolation technique for the study area were given in Figure 4.6 (a) and (b).

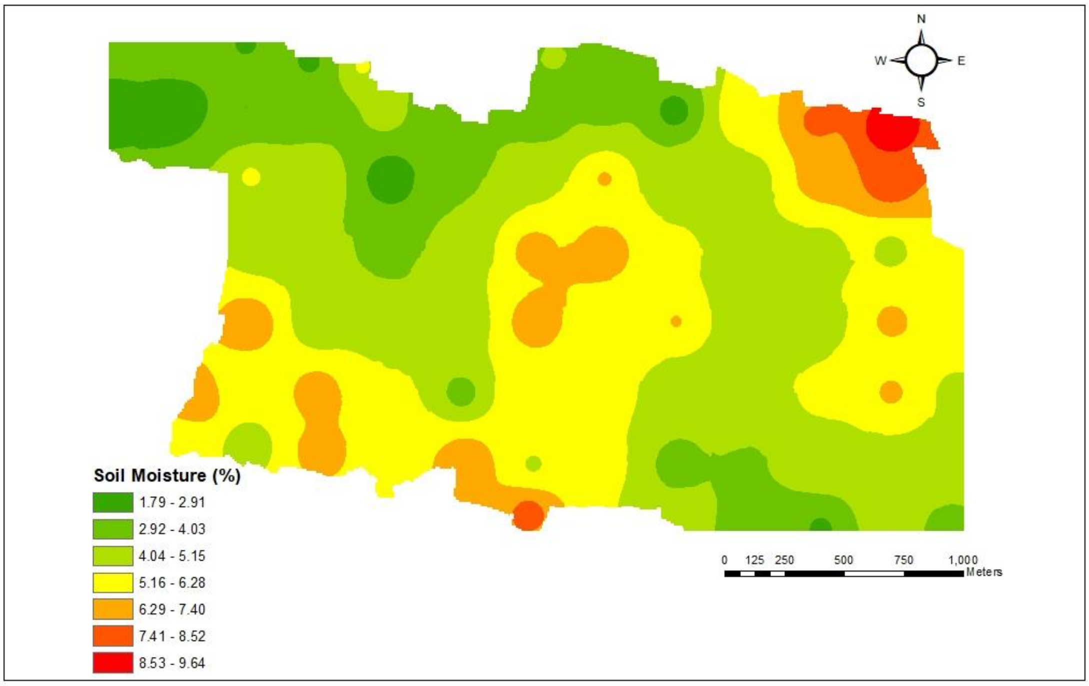


Figure 4.6 (a) Spatial distribution of soil moisture content

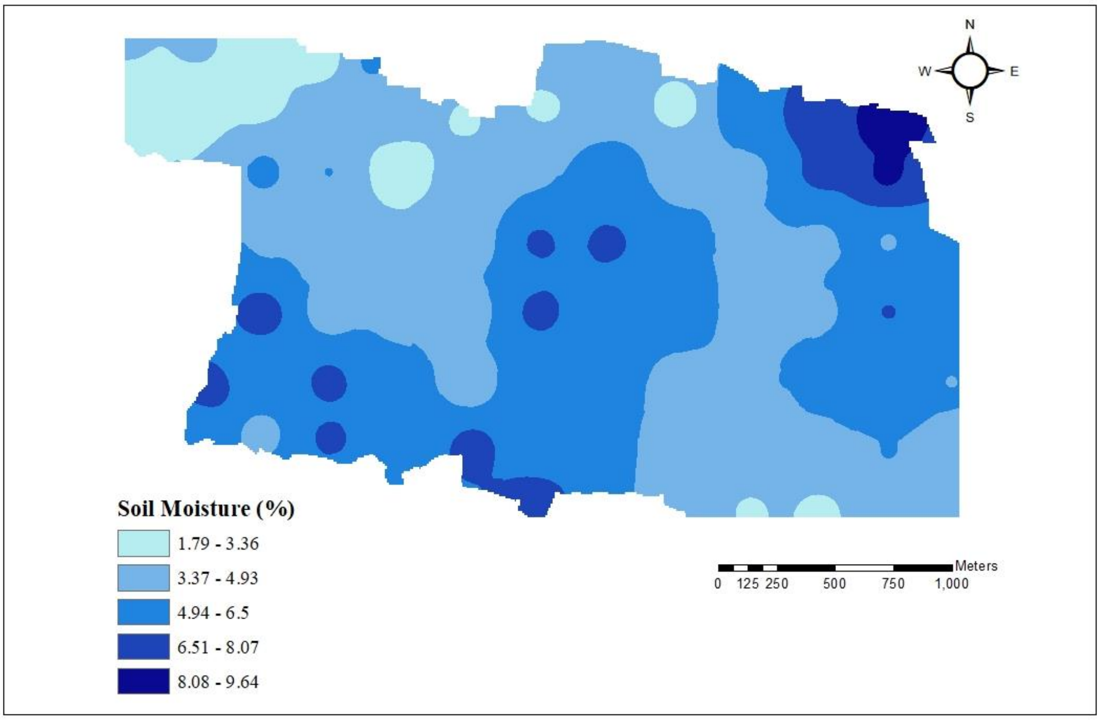


Figure 4.6 (b) Classified soil moisture content

It was observed that the average soil moisture was 4.92% and ranged from 1.79% to 9.64% in the study area. The highest moisture percentage distribution was evidently seen on the northeast portion of the area because this site has already located near-by a small stream that is flowing from the north to east direction along the margin of the study area.

The lowest soil moisture level can be observed in the northwest portion. The reason is due to the slightly higher elevation of the northwest portion than other portions of the area. Therefore, moisture percentage was visibly distributed with the topography. According to Hawley, Jackson and McCuen (1983), topography was the most important factor controlling the distribution of soil moisture.

The most important parameters influencing the spatial variability of soil moisture content are topography, soil properties, vegetation type and density, depth to water table, precipitation depth, solar radiation, and other meteorological factors (Hebrard et al., 2006). Zhao et al. (2006) stated that many soil properties have an important influence on soil moisture, (Zhang et al., 2014) such as temperature, pH, soil organic matter content, and soil bulk density and soil acidity is mainly due to humus and organic matter, and porous soil has a low soil bulk density, indicating that soils with low pH and soil bulk density have high soil moisture content and soil organic matter content. Accordingly, relatively higher moisture portions of this study area exposed lower bulk density value, higher organic matter level and also lower soil pH value of acidic condition.

4.3 Spatial Variation in Soil Nutrient Content

4.3.1 Total nitrogen in soil

Due to high variability of soils, analyzing spatial patterns of soil nitrogen, phosphorus, and potassium stocks is necessary for scientific nutrient management (Tang, Xia, Guan & Fan, 2016). Nitrogen is one of the most important plant nutrients and the most frequently deficient of all nutrients (Havlin et al., 2010). It is the basic nutrient that helps in seed formation and increases the food and feed value of crops. It usually has greater effect on crop growth, crop quality and yield (Oates, 1998).

The total nitrogen content varies from 0.01% to 0.33% with the mean value of 0.113%. Overall results showed that the total nitrogen content was very low to high level in range. The spatial distribution maps of total nitrogen content generated using IDW interpolation technique were displayed in Figure 4.7 (a) and (b).

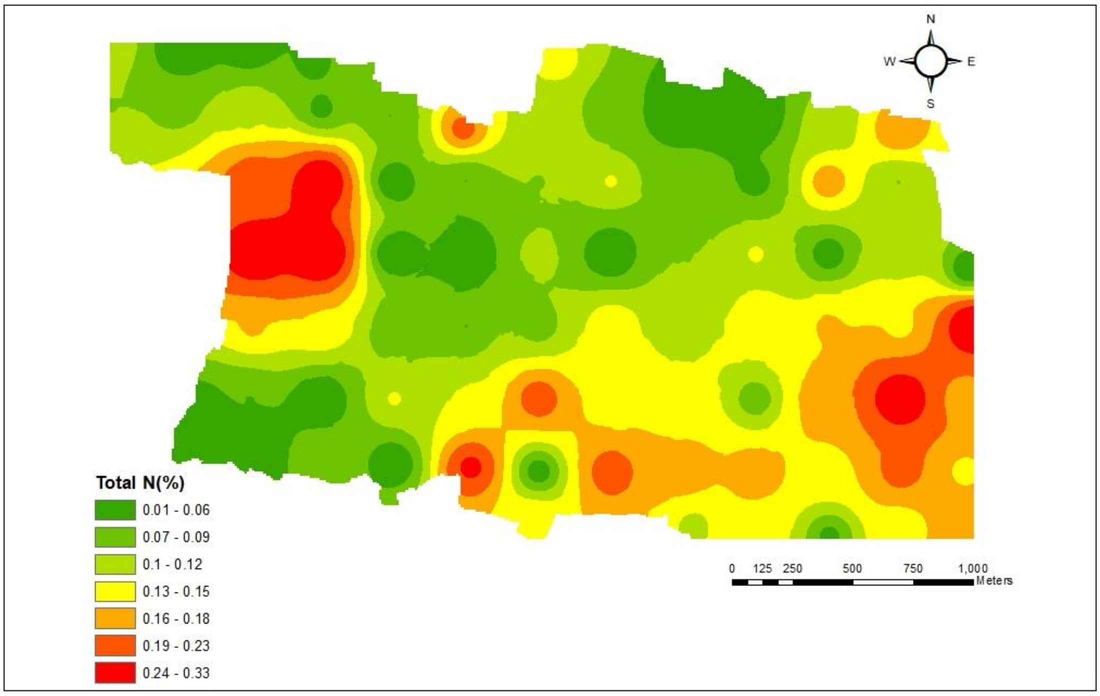


Figure 4.7 (a) Spatial distribution of total nitrogen in soil

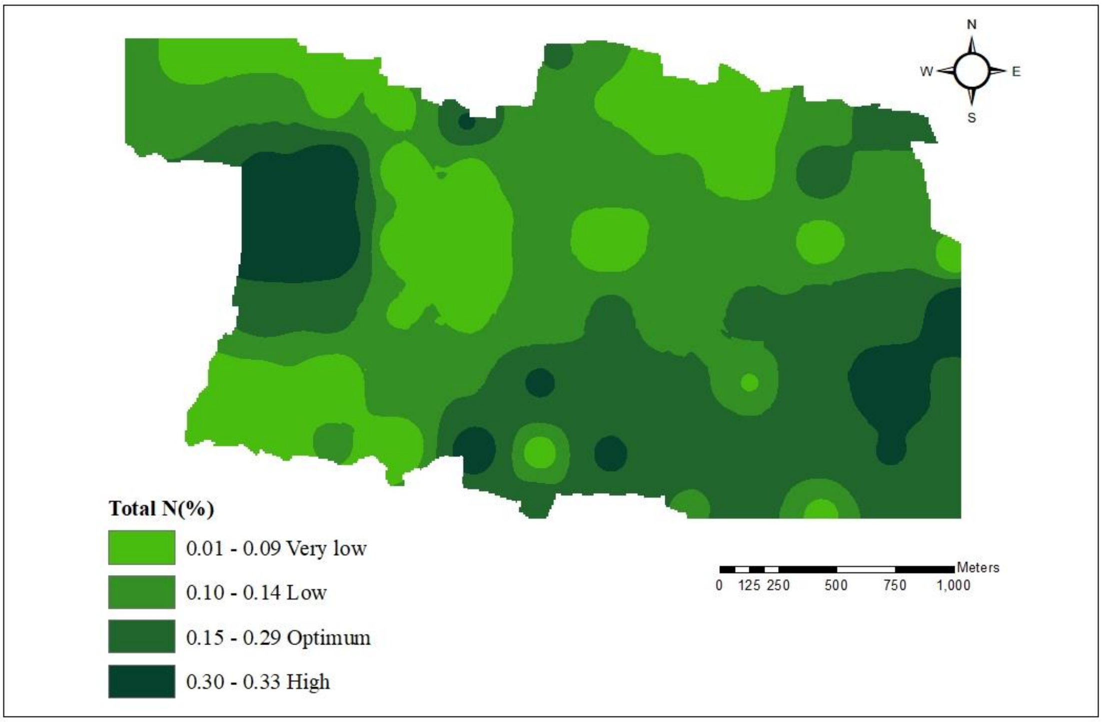


Figure 4.7 (b) Classified total nitrogen in soil

The study indicates that about 45% of the samples exhibited very low and 30% were low, while 20% samples were medium and 5% under high range of total nitrogen content. The critical value of total nitrogen in soil is 0.12% (Shah, Islam, Haque, Ishaque & Miah, 2008).

The lower total nitrogen content in this study area may be possibly due to the insufficient level of soil organic matter content, removal by crops and due to high temperature which encourages faster decomposition and removable of organic matter leading to the shortage of soil nitrogen reserve. According to survey results, medium to high level of total nitrogen may be related to the addition of organic materials in the form of plant residues, due to soil management practices possibly the use of animal dung and as a result of fixed nitrogen by the legume cultivation because sampling was done during the period of legumes harvesting in this area. The total nitrogen content in the soils is dependent on temperature, rainfall and altitude (Joseph, 1994).

Kedir et al. (2016) stated that the lower total nitrogen contents in most land units of the area could be ascribed to cereal-based continuous cropping system that could be attributed to rapid decomposition of organic matter following cultivation. Lower external nitrogen inputs (like plant residues, animal manures) and nitrogen (especially nitrate ions) leaching problem as a result of higher rainfall could also contributed to lower total nitrogen content in soils.

This finding is in agreement with that of Solomon et al. (2002) who reported that low levels of nitrogen was found in cultivated lands. It was also stated that the low content of total nitrogen might be due to high leaching loss of inorganic nitrogen from the soil. However, total nitrogen is typically slow to respond to manage changes and treatment effects, may not be easily measured within a decade (Grace, Ladd & Skjemstad, 1994).

4.3.2 Total phosphorus in soil

Phosphorus is one of the major macronutrients essential for plant growth and development. Its availability can be limiting in agricultural systems if without supply for fertilizer application (Aerts, 2000). It is essential in the production of legumes, as it increase the activity of nodule bacteria, which fix nitrogen in the soil. The spatial distribution maps of total phosphorus content generated using IDW interpolation technique were shown in Figure 4.8 (a) and (b).

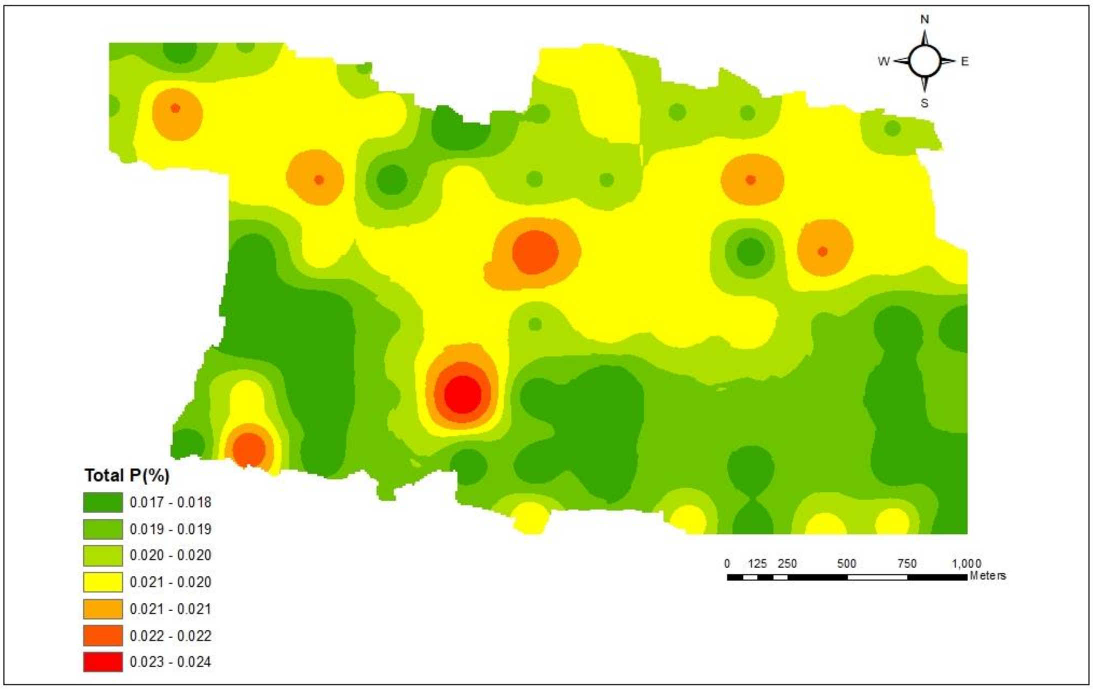


Figure 4.8 (a) Spatial distribution of total phosphorus in soil

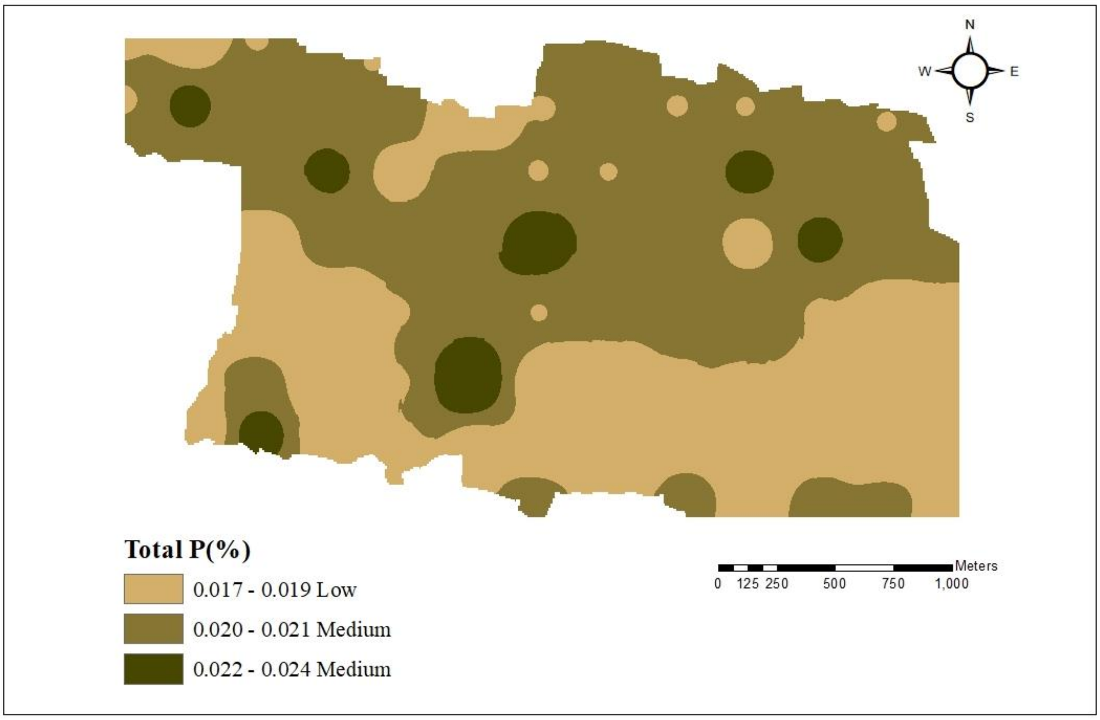


Figure 4.8 (b) Classified total phosphorus in soil

For spatial distribution of total phosphorus content, 43.75% of the sampling area was medium in range whereas 56.25% showed lower amount of phosphorus content in soil. The inadequacy of phosphorus in soil is mainly due to its retention as adsorbed phosphorus on the surface of soil particles and associated with amorphous aluminum and iron oxides (Mitran & Mani, 2017). In this study, the total phosphorus content ranged from 0.017% to 0.024% with the mean value of 0.019%. In most soils, phosphorus content is very low in the surface layer and represents less than 1% of total phosphorus and may vary widely and depend on some factors such as organic matter content, climatic conditions, parent materials and degree of fertilization (Salem et al., 2014).

According to survey data of management practices, lower level of phosphorus may be possibly due to rare application of organic and inorganic phosphorus fertilizers to the crops. Another reason for low phosphorus content in soil may be the effect of crop removal since this area usually practice the cropping pattern of monsoon rice and pulses. Havlin et al. (2014) stated that total phosphorus in surface soil decreases with increasing weathering intensity and thus, total soil phosphorus is much lower in humid and tropical region soils compared to semi-arid and arid region soils.

It was reported that phosphorus also plays a crucial role in the development of the symbiotic relationship between legumes and bacteria as a certain amount of phosphorus is required to carry out biological nitrogen fixation (BNF) (Rotaru & Sinclair, 2009). But most of the agricultural soils have inadequate amounts of phosphorus to support efficient biological nitrogen fixation (Brown, George, Barrett, Hubbard & White, 2013). Soils from cultivated fields with low to medium phosphorus content in the study areas can be improved by applying phosphorous fertilizers with the right rate as required by a particular crop.

4.3.3 Total potassium in soil

The information on distribution of potassium in agricultural soils is important because it indicates the depletion as well as accumulation pattern of potassium (Saini & Grewal, 2014). Characterizing spatial variations of soil potassium status dynamics is critical for understanding and predicting how soil resources in both natural and cultivated ecosystems (Rezapour & Samadi, 2012). The spatial distribution maps of total potassium status generated using IDW interpolation technique for the study area were given in Figure 4.9 (a) and (b).

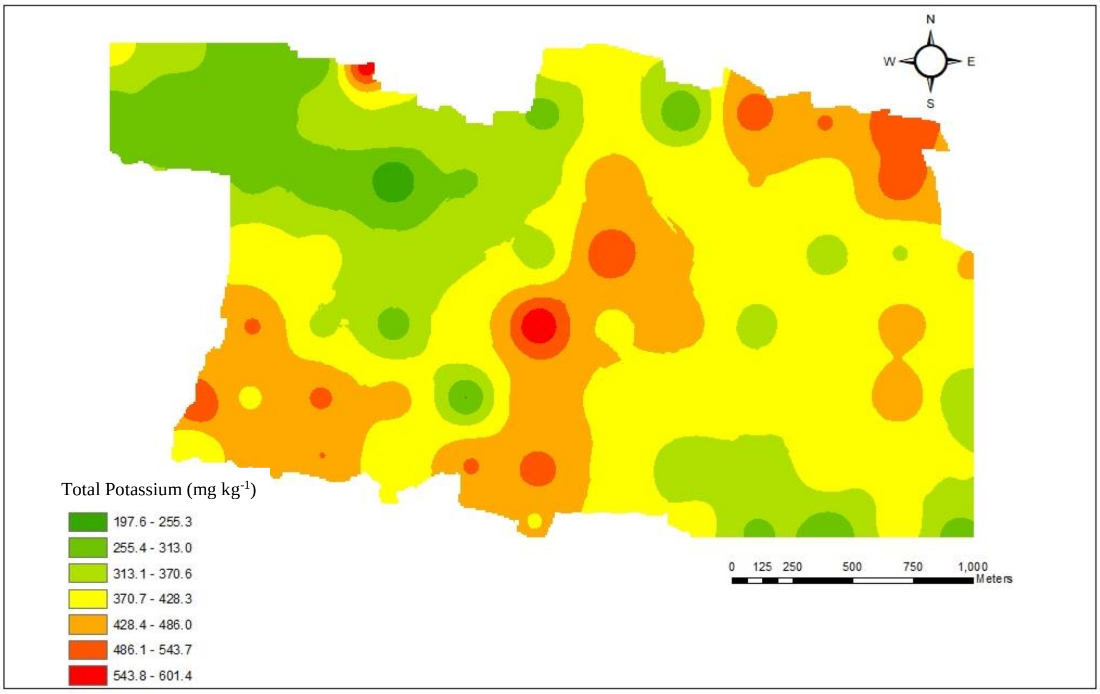


Figure 4.9 (a) Spatial distribution of total potassium in soil

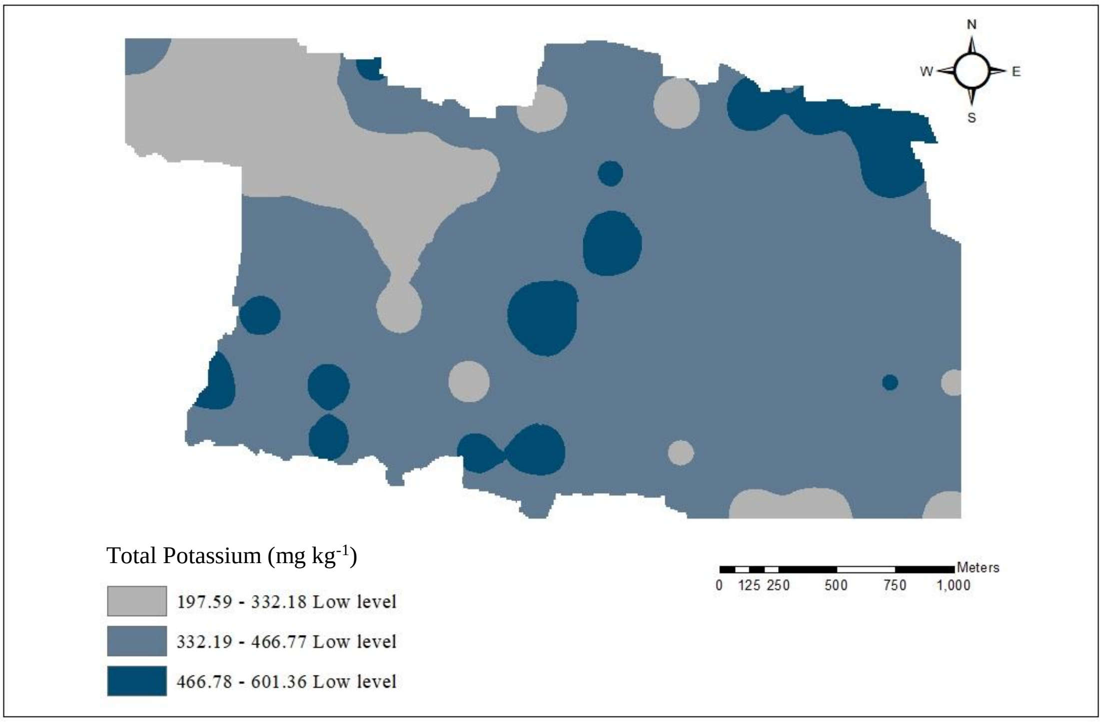


Figure 4.9 (b) Classified total potassium in soil

Reported values of potassium ranged from 197.5 mg kg^{-1} to 601.4 mg kg^{-1}. Mean value for total potassium content was found to be 391.1 mg kg^{-1} and obviously showed that relatively lower amount of total potassium content in the whole study area. Distribution of total potassium was obviously shown that the lowest concentration was found at the north western part of the area.

The reasons for this result may be some evident aspects such as minimum soil moisture content, very low level of cation exchange capacity and also insufficient amount of organic matter of this portion in the study area. Total content of potassium in soils varies within wide limits from 0.01% up to 4%, with most common values of about 1% and an average content between 1-2% (Wild, 1988).

In tropical soils, the total potassium content may be quite low because of the origin of the soils, high rainfall and high temperatures. Unlike nitrogen and phosphorus, which are immediately deficient in most tropical soils due to leaching and/or fixation, the need for potassium applications frequently arises only after a few years of cropping a virgin soil (Yawson, Kwakye, Armah & Frimpong, 2011).

According to survey data of soil management practices, there was no practice of potash straight fertilizers application by the farmers for their crop production. This is one of the reason for lower amount of total potassium content. However, the content of total potassium depends on the type of parent material, primary and secondary minerals and type of soil fraction (Dhakad et al., 2017), particle size distribution, degree of weathering and management practices (Sekhon, Brar & Rao, 1992). The potassium content of soils would vary depending on the intensity of cropping as well as leaching (Afari-Sefa et al., 2004).

And also farmers in this area have a usual practice of burning the fields and crop residues such as rice stubbles after harvesting. Although burning induces short-term increases in nutrients, losses of nutrients due to burning can occur (Kumar & Goh, 2000) as a result of the direct convective transfer of ash (Harwood & Jackson, 1975), and subsequent losses may be increased by the action of wind and water. In general, losses of nutrients due to burning decrease in the order of nitrogen > calcium >sulphur > potassium > magnesium > phosphorus > sodium (Kumar & Goh, 2000). Volatile losses of phosphorus and potassium occur at temperatures exceeding 500℃ (Raison, 1979).

4.4 Soil Nutrient Index Value

For Nutrient Index Value (NIV) developed by the Ramamoorthy and Bajaj (1969), the nutrient parameters studied for this area such as soil total nitrogen, total phosphorus and total potassium content clearly revealed the low status of nutrient index values (Table 4.6).

The nutrient index value for total nitrogen was 1.30 and situated low soil fertility class because of exploring 70% of samples were low level, 20% of samples were medium and 5% of samples showed high level only. For total phosphorus content, approximately equally amount of samples exhibited low and medium level and contributed to the nutrient index value of 1.43 and represented low status for soil fertility. And also the total potassium content for this area was indicated the lower level and explored the low status for nutrient index value of 1.00.

The data compiled on nutrient index value revealed that all the soil samples collected from studied area are rated as low status in soil fertility for these major nutrients. According to this estimation, soils of this area are expected to respond to the added of these nutrients through combined management of organic and inorganic fertilizers application with the sufficient amount for crop production. The rank of the important nutrients according to NIV was total P> total N> total K.

4.5 Relationship among Soil Parameters

Certainly, any soil properties cannot be completely independent. There exists interrelations between soil and other properties that can be described statistically (Boruvka, Donatova & Nemecek, 2002). The correlation coefficient values of soil parameters viz; soil pH, electrical conductivity, cation exchange capacity, bulk density, soil moisture, soil organic matter, total content of nitrogen, phosphorus and potassium were worked out for surface soil (0-15 cm) and are presented in Table (4.7).

The correlation coefficient revealed soil pH showed highly significant but negative correlation with total nitrogen content (r=-0.412). This suggested that pH accounted for about 16.96% of the total variability in total nitrogen (Figure 4.10). Similarly, by the increase in pH, total nitrogen decreases progressively and vice-versa. In addition to this, with the increase on soil pH by one unit, total nitrogen decreases by 0.098 unit and vice-versa.

Table 4.6 Percent sample and Nutrient Index generated using classical statistics of (N=80)

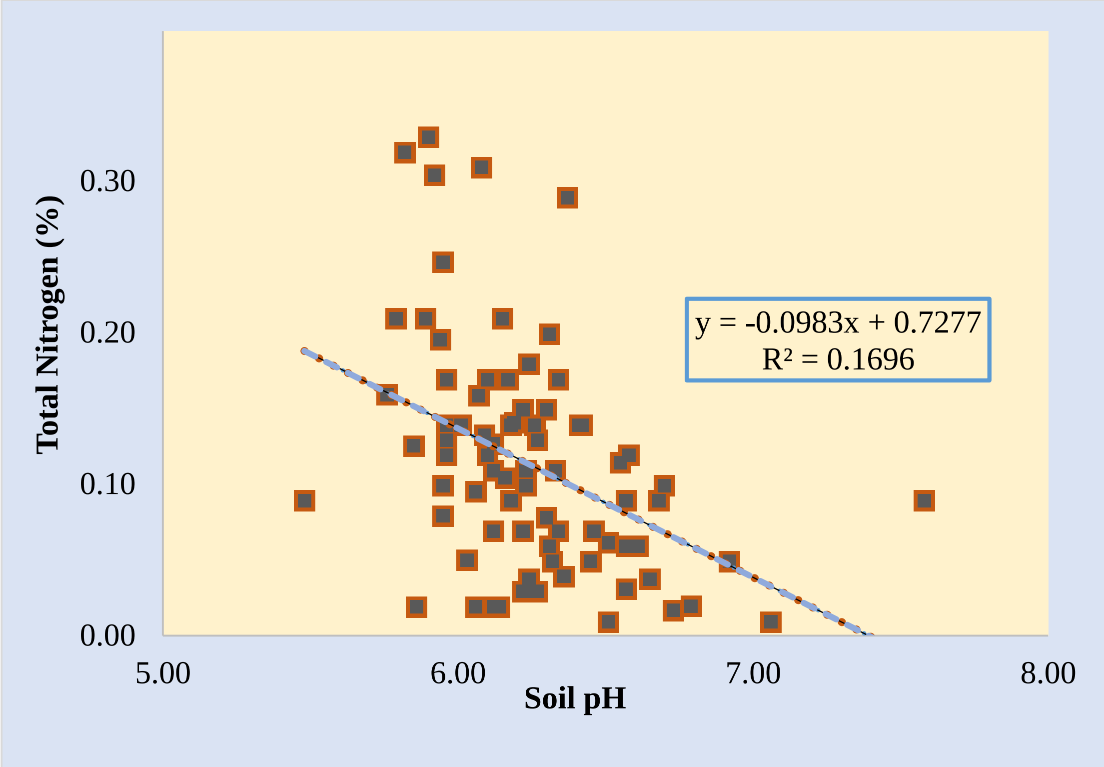
Nutrient Parameter	Percent Samples under different Categories			Nutrient Index Value (NIV)	Nutrient Index (NI) Classes
	Low	Medium	High		
Total Nitrogen	75.00	20.00	5.00	1.30	Low
Total Phosphorus	56.25	43.75	-	1.43	Low
Total Potassium	100.00	-	-	1.00	Low

Table 4.7 Correlation among the different soil parameters under study

	pH	EC	CEC	BD	SM	SOM	TN	TP	TK
pH	1								
EC	0.095	1							
CEC	0.014	0.007	1						
BD	0.052	-0.148	-0.018	1					
SM	-0.047	0.146	0.352**	-0.066	1				
SOM	-0.025	0.106	0.035	-0.191	0.162	1			
TN	-0.416**	0.028	0.145	0.092	0.182	0.058	1		
TP	0.242*	-0.064	-0.036	0.096	-0.117	-0.107	0.216	1	
TK	0.047	0.136	0.204	-0.161	0.782**	0.238*	0.045	-0.217	1

*Correlation is significant at the 0.05 level; **Correlation is significant at the 0.01 level

(EC: electrical conductivity, CEC: cation exchange capacity, BD: bulk density, SM: soil moisture, SOM: soil organic matter, TN: total nitrogen, TP: total phosphorus, TK: total potassium)



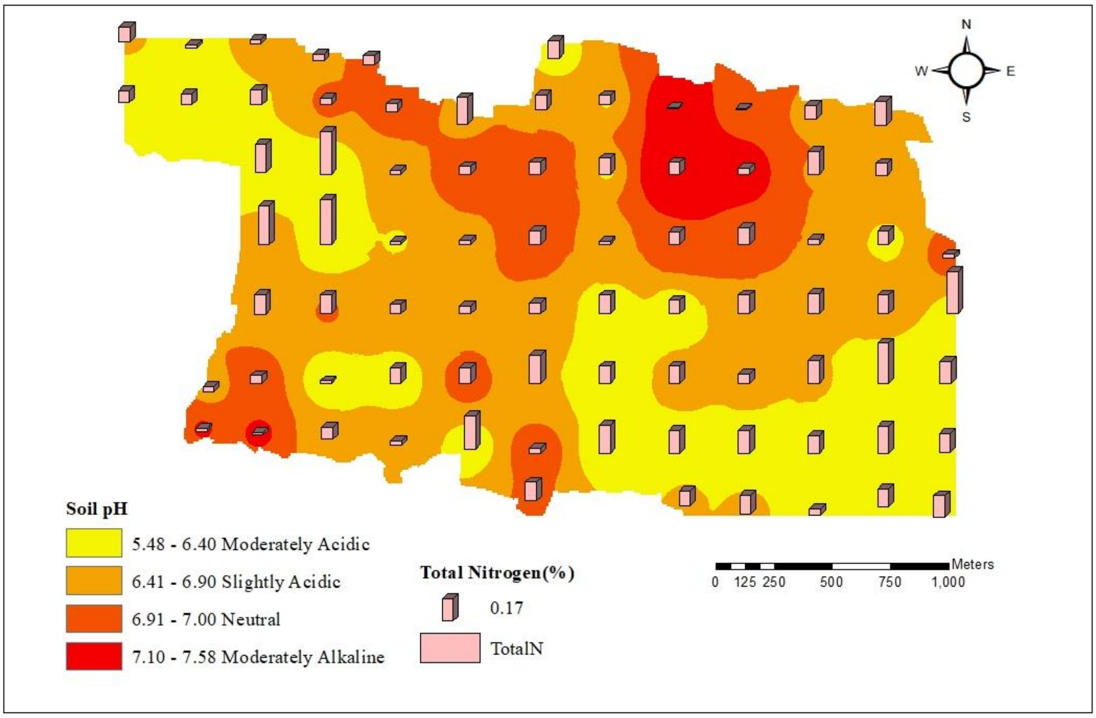


Figure 4.10 Relationship between soil pH and total nitrogen content of studied soil samples

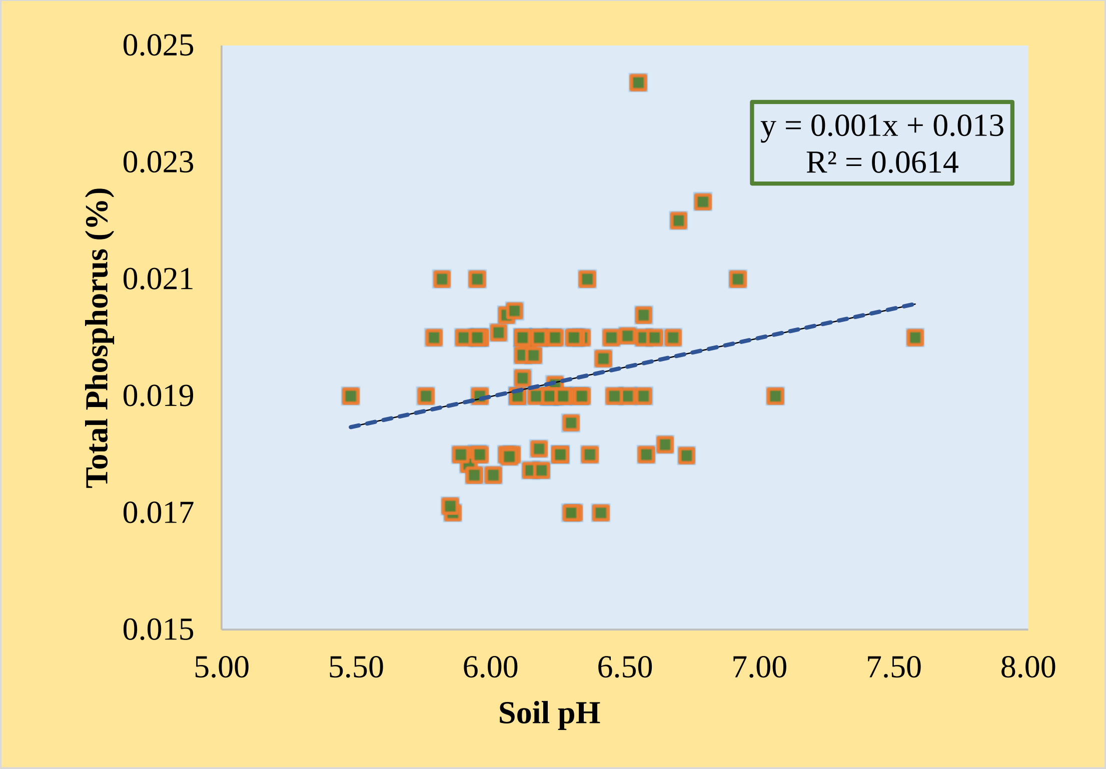
The similar result was also obtained by Singh and Mishra (2012).While, significant but positive correlation between soil pH and total nitrogen was obtained by Athokpam et al. (2013), whereas, non-significant relation was obtained by Dhamak, Meshram & Waikar (2014).

It was stated that the result relating correlation revealed the total nitrogen were significantly and negatively correlated with soil pH (Khadka et al., 2016). Xue, Cheng and An (2013) also reported that the correlation between the soil nitrogen forms and soil pH was negative. Soil pH also showed significant and positive correlation with total phosphorus (r=0.248) (Figure 4.11). The results were in harmony with the finding of Athokpam et al. (2013). But non-significant correlation between them was observed by Ogaard (1994).

According to literature, soils with inherent pH values between 6 and 7.5 are ideal condition for phosphorus availability, while pH values below 5.5 and between 7.5 and 8.5 may limit phosphorus availability to plants due to fixation by aluminum, iron, or calcium. The observed pH values of this study ranged from 5.48 to 7.58, and therefore, the soil test phosphorus content may be significant and positively correlated with this observed pH range.

Meanwhile, the total potassium content was highly significant and positively correlated with soil moisture expressed the correlation matrix of r=0.782 (Figure 4.12). The results were in conformity with those of Singh and Singh (2004) and Zeng and Brown (2000) who found a positive correlation between moisture content and potassium content in soils.

Total potassium also showed significant positive correlation with soil organic matter and significant negative correlation with total phosphorus, and non-significant positive correlation with soil pH, electrical conductivity, total nitrogen, cation exchange capacity, and negative correlation with soil bulk density. This means that total potassium content may increase with increase in pH, electrical conductivity, cation exchange capacity, soil organic matter, total nitrogen, and may decrease with increase in bulk density and total phosphorus and vice versa.



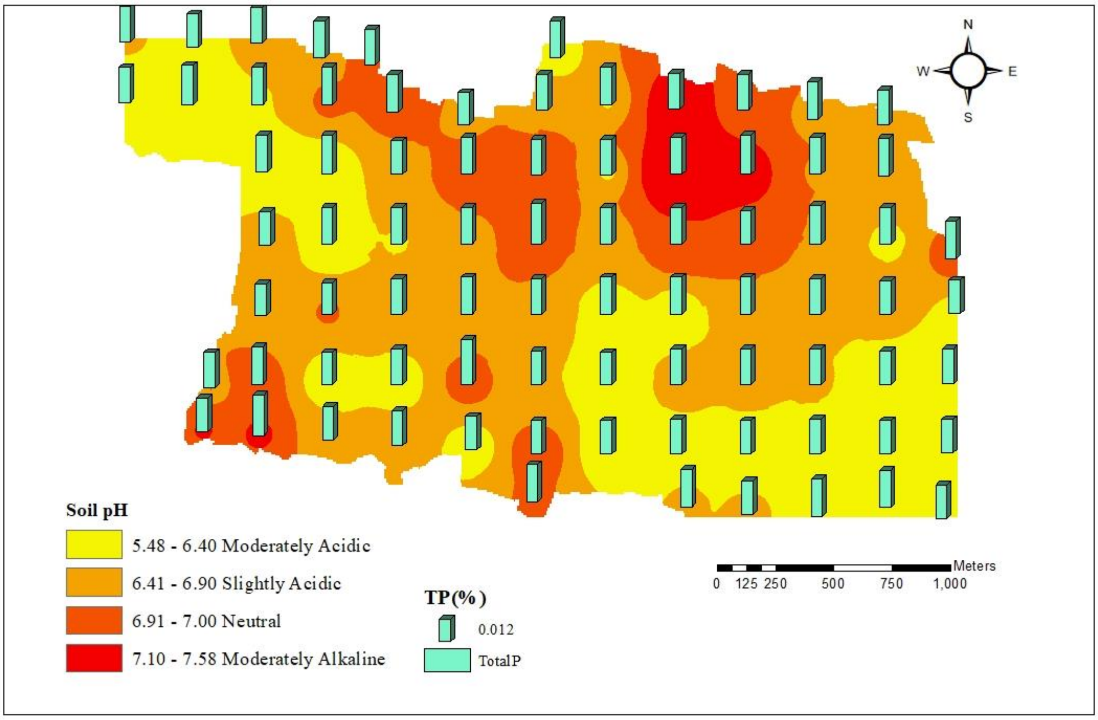
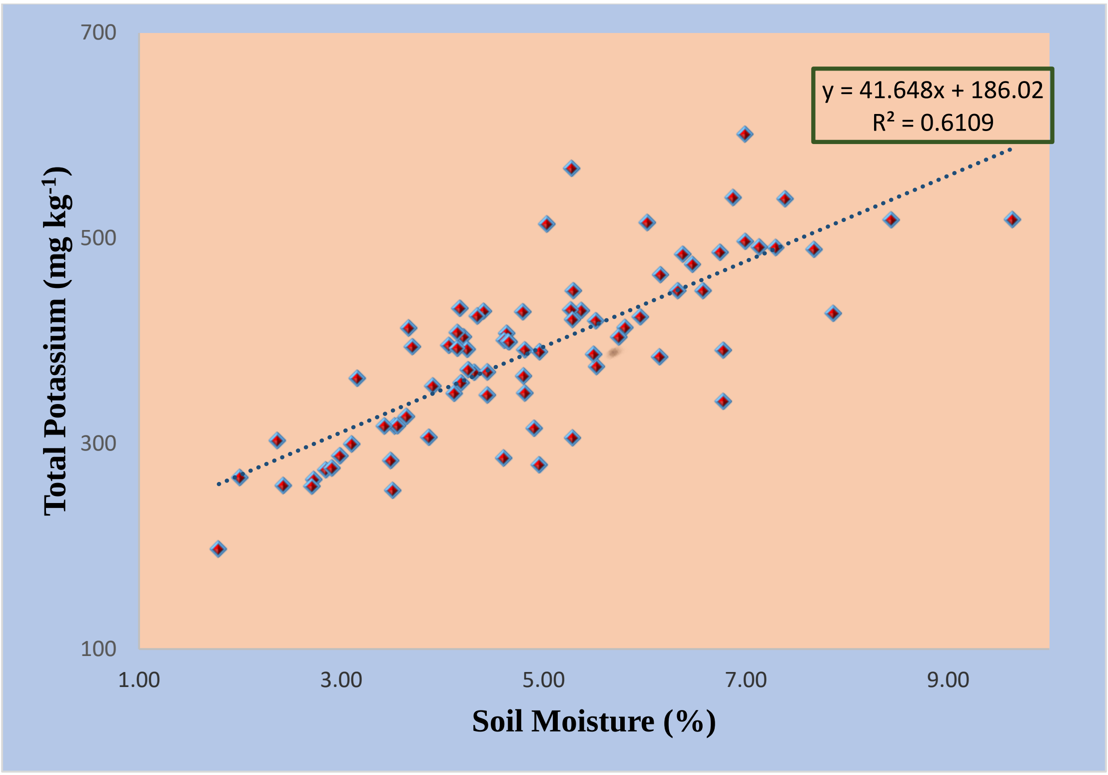


Figure 4.11 Relationship between soil pH and total phosphorus content of studied soil samples



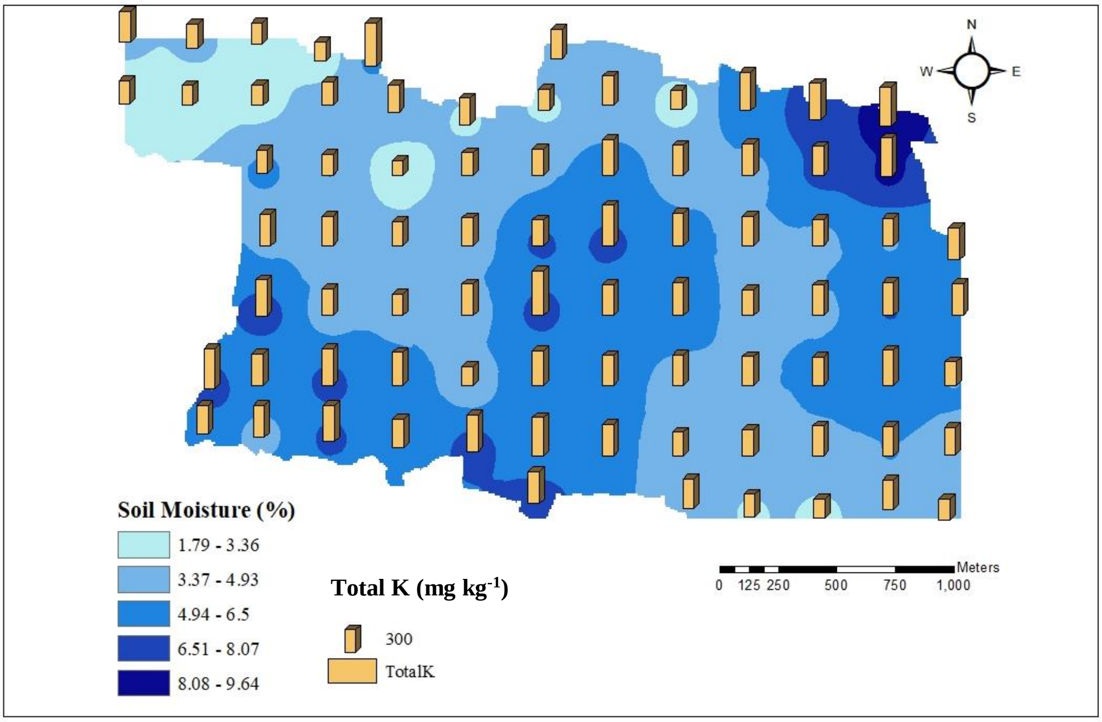


Figure 4.12 Relationship between soil moisture and total potassium content of studied soil samples

According to correlation analysis results, it was clearly detected that all soil parameters were interrelated with each other but most of the relationship showed non-significant. The relationships that commonly found among soil properties were also observed in non-significant correlation such as positive correlation of soil organic matter and total nitrogen (r=0.058), negative correlation of soil bulk density with soil organic matter(r=-0.191) and soil moisture (r=-0.066), positive correlation of cation exchange capacity with total potassium (r=0.204) and negative correlation of cation exchange capacity with bulk density (r=0.018). A significant and positively correlation between cation exchange capacity and soil moisture content (r=0.352) was also observed (Figure 4.13).

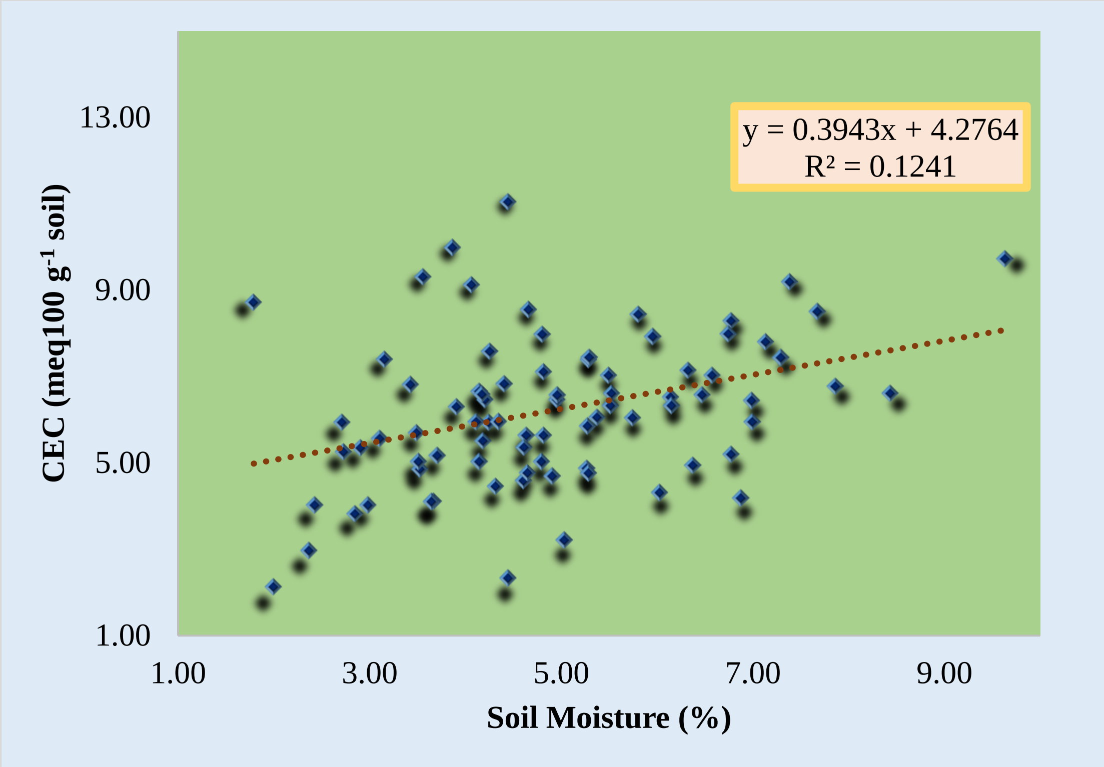
The negative correlation between bulk density and soil moisture content suggested two possibilities: that soil moisture contents declined as bulk density increased due to less storage space or that soil moisture content was sufficient for the soil to resist compaction (Carter & Shaw, 2002). This is consistent with studies that have examined bulk density and soil moisture content (Hill & Sumner, 1967; Greacen & Sands, 1980). Many researchers (Askin & Ozdemir 2003; Morisada, Ono & Kanomata, 2004; Sakin, 2012) obtained the relationship between organic matter and bulk density of soils and showed strong correlation between them. Bulk density tends to decrease as soil organic matter concentration increases (Curtis & Post, 1964).

4.6 Results of Survey Data

A survey, an interview with farmers was conducted using a set of structured questionnaire to identify the soil management practices of sampling area. There are total number of 68 farmers from the sampling area and they were interviewed individually.

4.6.1 Socioeconomic information of sampled respondents

According to the findings of the study, the respondents in survey areas possessed three groups of land-holding level ranging from <2.0 hectare to >6.0 hectare of farm size (Figure 4.14). Most of the respondent's farm holding were characterized by small size, which could be attributed to land acquisition and land fragmentation among family members.



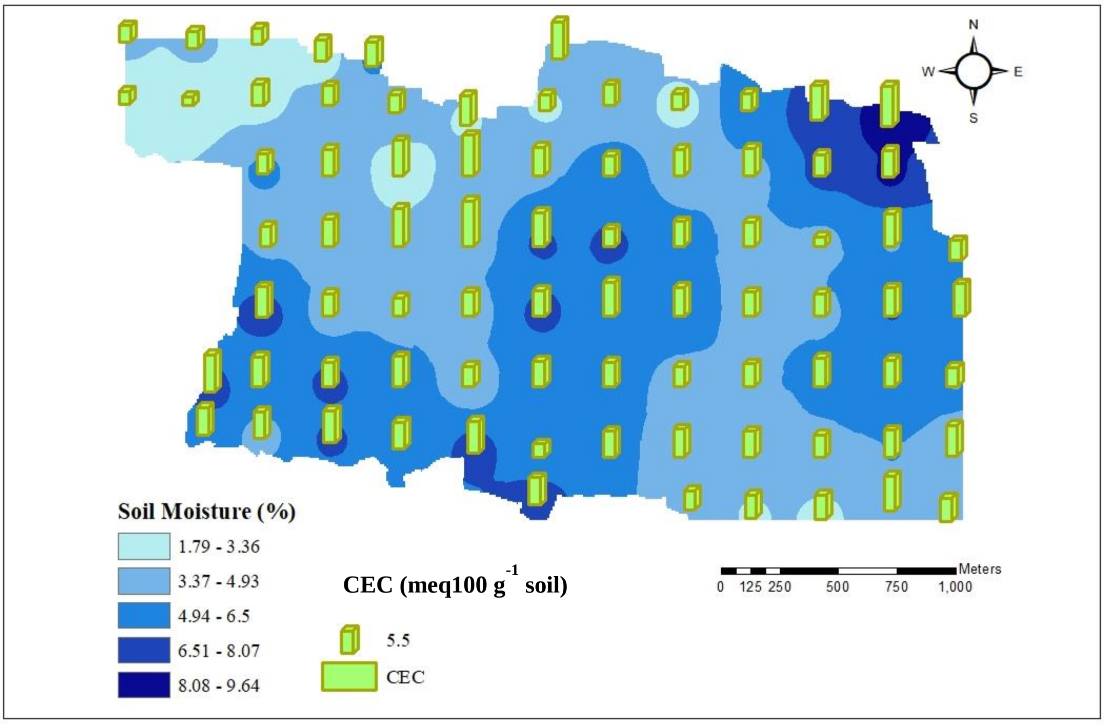


Figure 4.13 Relationship between soil moisture and cation exchange capacity of studied soil samples

Response on farming experience clearly showed five different levels of farming experiences under 5 years to above 20 years (Figure 4.15). The result showed that most of the farmers have been in the farming profession for quite some period of time and are not novices in farming activities that may enhance the better soil management practices.

The education status of the respondents in survey areas was found to be different education levels from primary education to University education status. The secondary education level was the highest and there was little graduate education status in the study area (Figure 4.16). This showed that farmers could read extensions, posters and magazines for more innovation and could communicate their experiences to illiterate farmers. The level of educational attainment is sufficient to support the adoption of technology through information sharing and distribution as entries.

4.6.2 Field and crop history information of sampled respondents

In the study area, response to opinion for soil fertility condition gave by the respondents was found to be three classes such as good soil fertility status, medium and poor soil fertility condition (Figure 4.17). Nutrients removed from the soils by harvesting of rice crop have not been replaced through the use of corresponding amounts of plant nutrients in the form of organic and inorganic fertilizers. The efficient uses of both inorganic and organic fertilizers are important to sustain or maintain proper soil fertility status.

For method of land preparation in crop growing, farmers usually use machine power which reduce dependence on labor and increased efficiency. Only 21% of respondent used machine and animal. Oxen and buffalo are the most popular animals for agricultural practices. One of the advantages of using animal is easily to get manure for crop cultivation. For cropping pattern in this area, farmers are usually practiced the rice-pulses cropping pattern on year round. They grow the monsoon rice only starting from last week of June to end of October. After rice harvesting, the next cropping season of pulses is staring from November to February. After harvesting of pluses, the fields were fallowed last for about three months. Mostly grown rice varieties is Manawthukha and major pulses growing is black gram in this area.

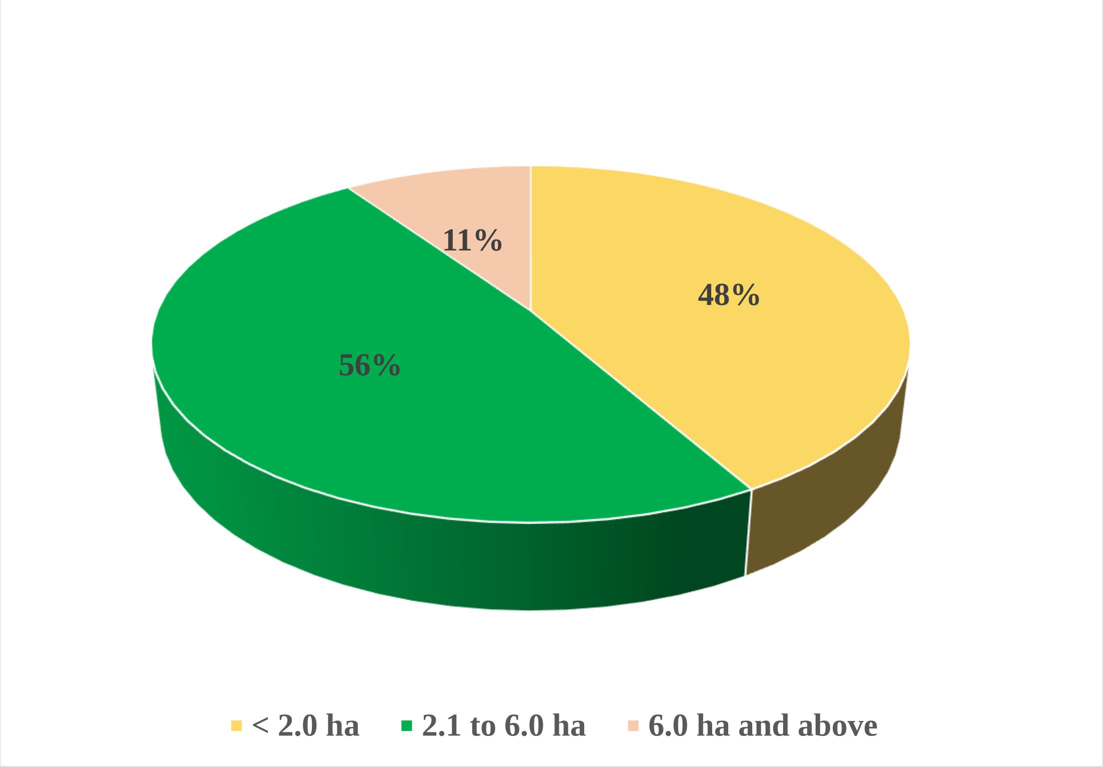


Figure 4.14 Different farm size levels of respondents

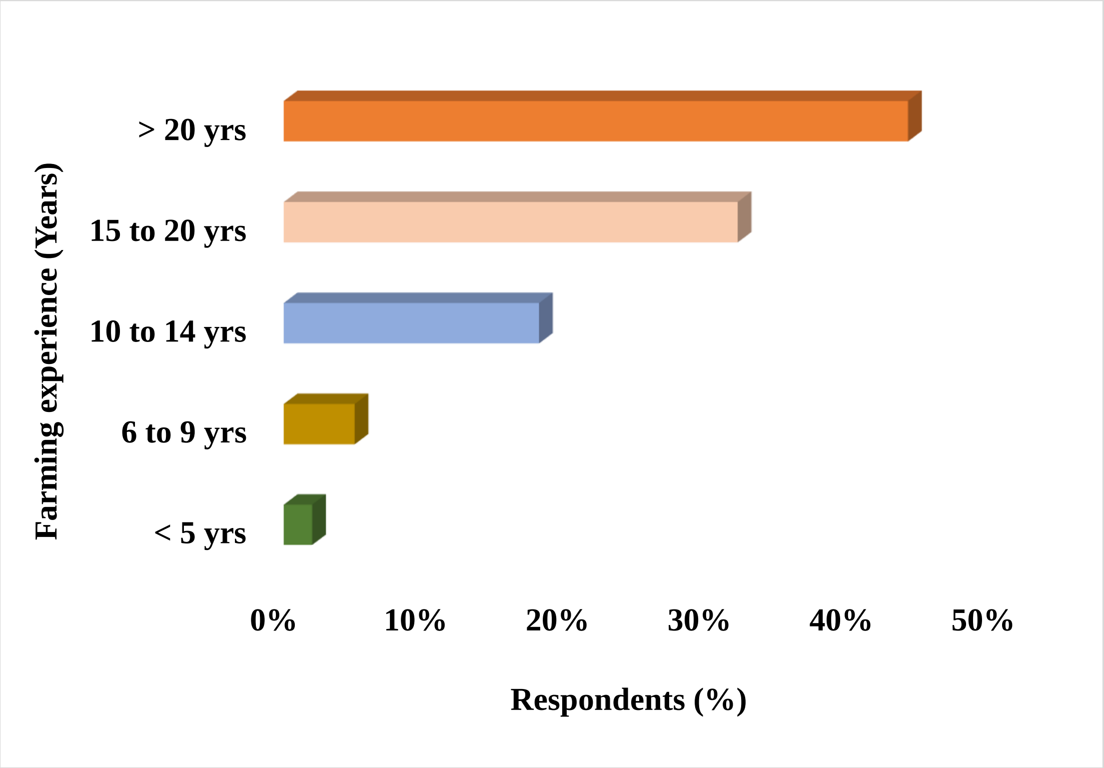


Figure 4.15 Farming experience levels of respondents

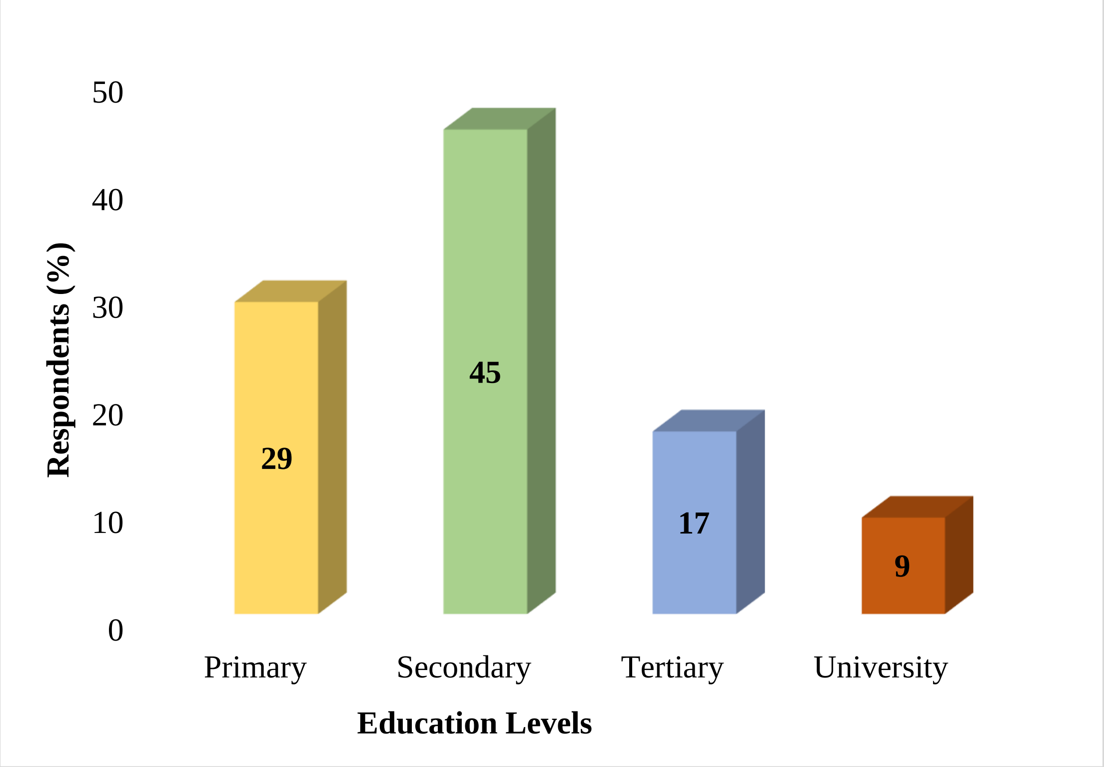


Figure 4.16 Education levels of respondents

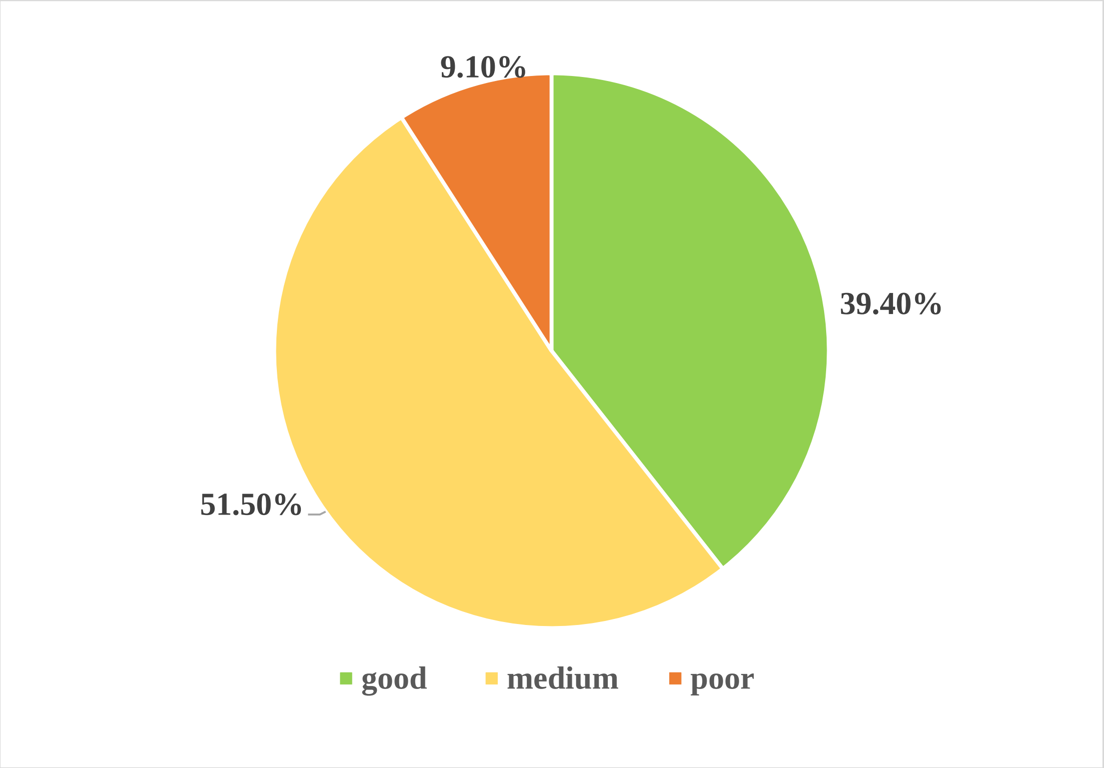


Figure 4.17 Opinion of the respondents for their soil fertility status

4.6.3 Information on soil management practices by respondents

4.6.3.1 Organic fertilizer application

About 23% of respondents used the cow-dung manure for crop cultivation, 12% of respondents applied pulses residues, because they cultivated pulses during summer time. The farmers stated that manure was not readily available when needed, and affordable. The main source of manure was from own farms. The farmers kept livestock, mainly cow. Only used manure from their animals and the quantity was not enough indicating that the farmers kept very few livestock. Consequently, the quantity of manure applied by the farmers may not be sufficient due to high transportation costs if they buy manure from other villages.

It was obviously found that farmers in this area usually practiced no application of organic fertilizers on particularly to their crop production. They piled only their pulses residues after harvest in the fields and takes any effort for replenishment into the soil systematically. There is needed to take some application practices of regular and adequate amount of organic residues into the soil after next cropping seasons in this area. Similarly, some farmers in survey area have no regular and adequate amount of cow-dung manure application to the field and they used only little amount and irregular application.

All of the farmers stored manure in the open. This raises doubt about the quality of manure used. There is necessary to train farmers on the advantages of proper manure storage in order to minimize nutrient losses during storage as well as to encourage farmers to use appropriate combinations of both mineral and organic fertilizers in order to minimize costs and build up soil organic matter.

4.6.3.2 Inorganic fertilizer application

4.6.3.2.1 Type of fertilizers

The data observed in Figure (4.18) obviously showed that the most common types of fertilizers used by the farmers were urea and compound fertilizers indicating that farmers in study area may have good perception in using these types of fertilizers which can give more yield than other types of fertilizers for their crop production. There was little accepting knowledge for using other types of fertilizers such as the phosphorus and potash fertilizers for crop production.

4.6.3.2.2 Methods and time of fertilizers applied by the respondents

According to the survey data, most of the farmers are commonly practiced in broadcasting fertilizer application methods and any of basal application method was used. The lower knowledge level of fertilizer application practices may contribute to no application of basal fertilizers and mismanagement practices of fertilizer application for crop cultivation. Another reason for using broadcasting method is the lower investment cost, since farmers were mostly faced by lack of capital for using machineries and labor in crop growing of survey areas. Regarding with time of fertilizer application for rice cultivation, the data showed that most of the respondents used the top dressing application at tillering and flowering stages (Figure 4.19).

4.6.3.2.3 Response on amount of urea application under different farm sizes and education levels

The distribution of respondents with respect to amount of urea fertilizers application at different classes of farm size in survey area was obviously found that farmers in smaller farms applied the relatively low amount of urea fertilizers than larger farms in all survey areas, indicating that larger farms were essentially needed for using higher amount of urea because of most desirable application of urea fertilizers by the farmers in survey area for expecting their crop yield will be higher (Figure 4.20).

Figure (4.21) illustrated that the distribution of respondents with respect to amount of urea fertilizers application at different level of education in survey areas. It was found that farmers has positively trend of education level and amount of urea application. University education level of farmers were applied higher amount of urea for their crop production indicating that higher education level may have high perception for using higher amount of urea fertilizers.

4.6.4 General conclusion on findings of survey

According to the results, respondents in study area had the high perception for using chemical fertilizers as they believed that it was necessary for the crop to do well and can give the yield double. But they had already known that using chemical fertilizers can increase the costs of their crop production. Farmers are usually faced many problems in their crop production, especially in input requirement under without consideration of edaphic climatic conditions.

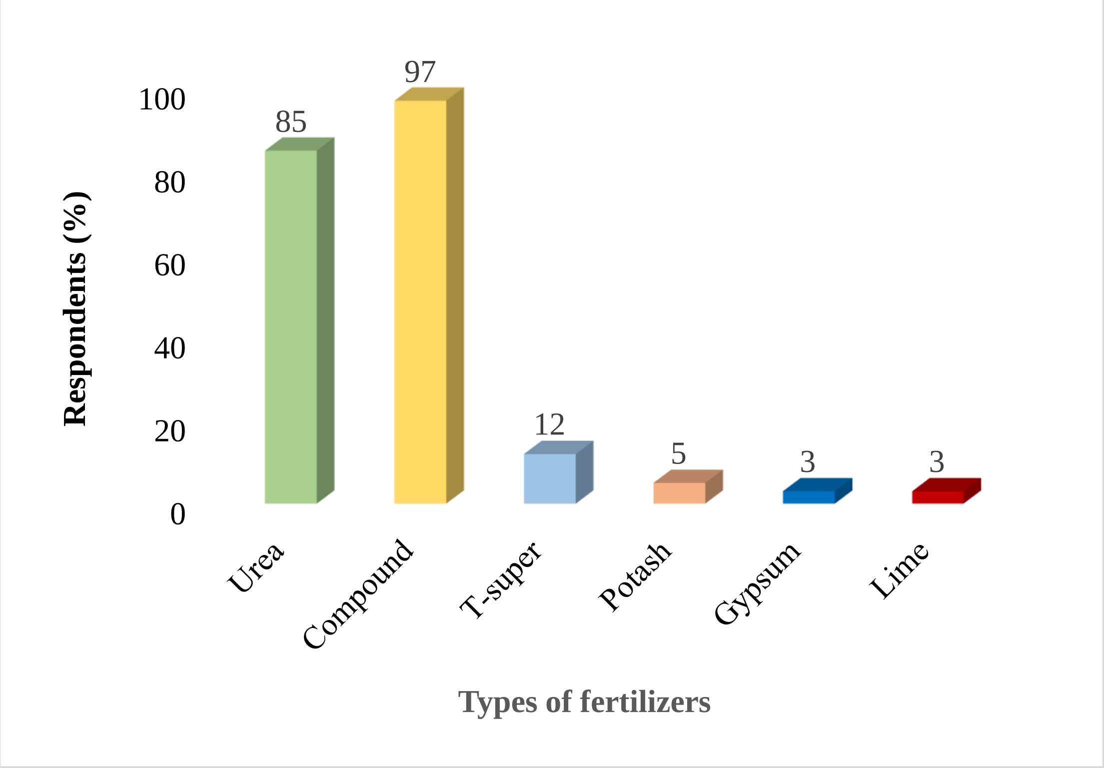


Figure 4.18 Type of fertilizers used by the respondents

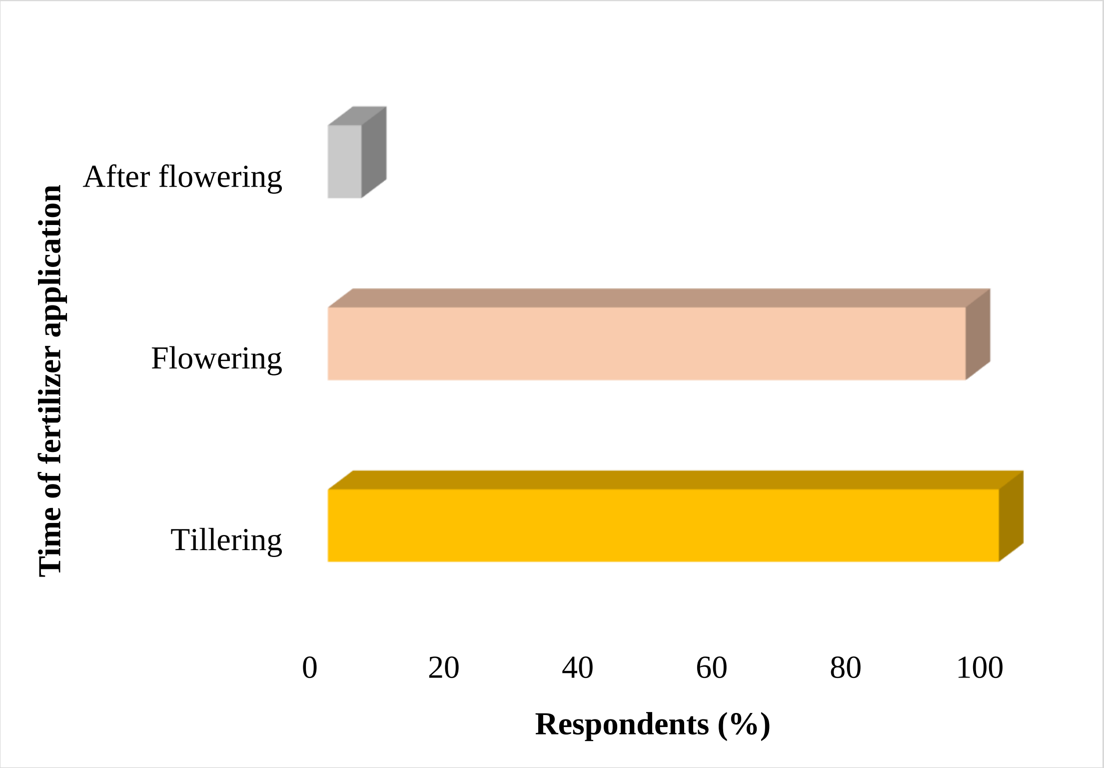


Figure 4.19 Time of fertilizer application by the respondents

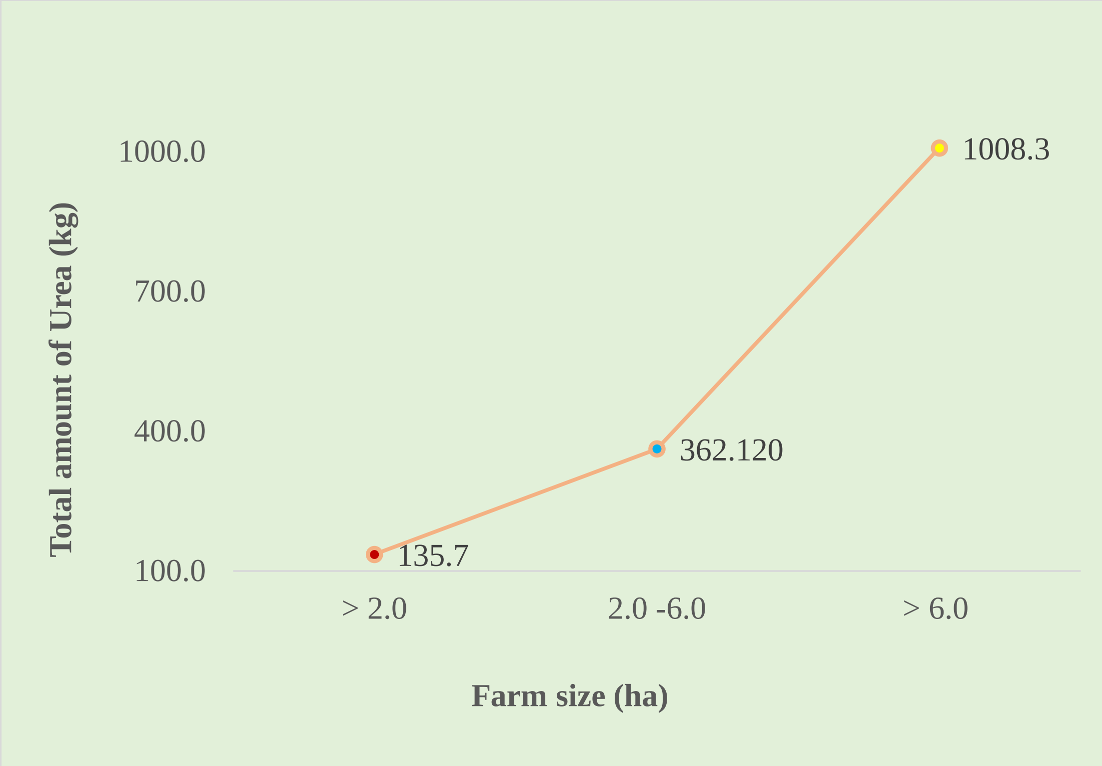


Figure 4.20 Response on amount of urea application at different farm size levels

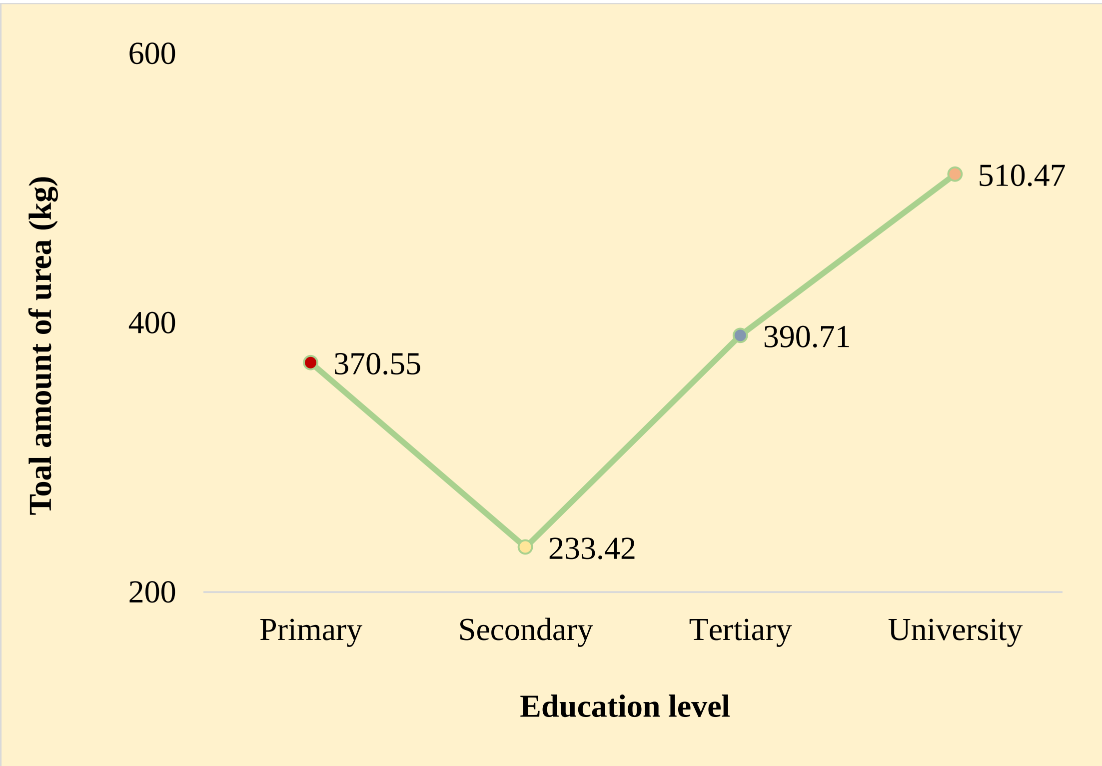


Figure 4.21 Response on amount of urea application at different education levels

The major problems faced by the farmers were insufficient water for crop growing, inadequate credit and infestation of pests and some problems caused by seed and soil factors in survey area. Farmers were commonly encountered many kind of constraints to use the fertilizers for crop production such as high cost of fertilizers, lack of capital, less in weight and poor quality of fertilizer.

Most of the farmers applied urea fertilizers as two to three times of splits to be more efficient for rice production. However, it was clearly seen that majority of farmers used below the recommend doses of urea (125.80 kg ha^{-1} for monsoon) by Land Use Division, Department of Agriculture. In addition, they incessantly used compound fertilizers which contain different ratio of nutrients from a variety of sources such as Thailand brand, China brand, and some are produced by locally. Thus, the quality of fertilizers should be considered for effective utilization. There is no practice of application of phosphorus and potash source straight fertilizers in this area for rice cultivation as well as legume production. Fertilizer application was done only for rice cultivation and no application of fertilizer was used for pulses growing in this area. Farmers used many kinds of foliar fertilizers for pulses production at weekly intervals during the whole season. There was also evidently found that any fertilizers were applied at basal time in this area.

Manure application was rare and also transportation costs were high. As a result, it was likely that the quantity of manure applied was very low due to the lack of proper storage facilities may cause poor nutrient supply. Lack of proper management of fertilizers among the farmers increases the cost of production and excessive application could have adverse effects on aquatic and terrestrial ecosystems. Intensifying education on fertilizer use and management through agricultural extension services, the media, and at the point of sales should be recommended to improve sustainable use of fertilizers for crop production in the survey area.

4.6.5 Field day at Kyee Inn village (Discussion and suggestion to farmers for soil analysis results)

After completing the research activities, the results of the soil analysis were discussed and suggested to the farmers in survey area like field day was conducted. The findings of the research were firstly presented and explained to all the farmers in sampling area and discussed with individually by the leadership of the Professor and head of Soil and Water Science department, supervisor and research candidate in combination with township manager and staffs from Department of Agriculture. Farmers were deeply interested and discussed about the current findings results of their soil status and actively reply with many questions to know what amendments are required to optimize the productivity of the soil. They also discussed to know the better soil management practices for appropriate fertilizer application methods.

CHAPTER V
CONCLUSION

The present study revealed there was wide variation in soil fertility status of soils in this research area. It might be largely due to some evident factors of soil management practices by the farmers such as inadequate application of inorganic fertilizers, lack of incorporation of organic manure and materials (rice straw, pulses residues, cow dung), burning of rice stubble after harvesting, and so on. Results of soil analysis evidently showed that the whole study area was poor in soil organic matter content, very low (75%) to high (5%) level of total nitrogen status, low (56.25%) to medium (43.75%) range of total phosphorus, very low (23.75%) to low (76.25%) level of cation exchange capacity, higher bulk density values, insufficient level of soil moisture condition, and below the desired level of total potassium content. However, soil pH and electrical conductivity ranges showed certainly not detrimental to the crop cultivation. The calculated Nutrient Index Value for all nutrient in soils of this study area was classified as low class and ranked as total P> total N> total K.

The spatial distribution maps of soil physical and chemical properties developed from this research would provide the important basic information to the farmers for proper site-specific fertilizer management in the study area. According to the prepared soil database from soil test results of this study, farmers were clearly understand how to manage their soil with suitable practices for improving the productivity of their farms. The results were also applicable for optimizing the cost of production especially in fertilizer application and for addressing nutrient deficiency. This study shows that the use of new technologies such as GIS and GPS can improve the management of fertilizer application and prevent environmental pollution in this area.

According to the findings of soil analysis results, most part of the study area showing moderately acidic soil reaction may cause some problems for the nutrient availability and microbial diversity. Therefore, amelioration of soil acidity is important for this area. Similarly, insufficient organic matter level was also major constraint, and therefore, adoption of organic matter improvement practices such as organic manure and crop residue incorporation, reduced tillage, crop rotation, green manuring, composting, and mulching, etc. is prerequisite. This may result in optimum soil conditions for crop cultivation such as increasing soil nutrient status and decreasing the higher bulk density of this area. There was also needed to avoid the burning of the fields and crop residues after harvesting.

Based on the results of nutrient status from this research, it can be suggested that farmers should know what amendments were required to improve the crop production and the optimum fertilizer doses should be applied by considering the observed nutrient status of their soils. The method of combined use of organic and chemical fertilizers was an effective technology for the accumulation of soil total nitrogen. Lower phosphorus content could be corrected by the application of phosphate fertilizers, usually single or triple superphosphate. However, this application should be carried out carefully to avoid nutrient imbalance due to the residual effect of phosphorus. Crop removal constitutes the largest avenue of loss of total potassium and therefore potash fertilizer application should be practiced with recommended dosage. Moreover, according to the information of soil management survey, farmers in this area should be encouraged to practice the application of some fertilizers at basal for land preparation such as phosphate and potash fertilizers as well as gypsum and lime applications with the correct dosage and right time.

It can be concluded that the variability of each soil characteristic existed largely due to the differences in management practices by farmers and therefore, farmers should be encouraged to return as much crops residues as possible to soil with efficient practices (sufficient and consistent) in addition to application of manure and fertilizers to improve the soil fertility level for higher crop production. Further, legume and cereal cropping pattern should also be considered consistently for long-term nutrient supply for better yield and economics of crop production. The observed various spatial variability of soil properties that affected soil fertility would provide the farmers in making crop management decisions in Kyee Inn area.

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APPENDICES

Appendix 1. Questionnaire of the soil management practices survey

Code No. ---------------------------

Questionnaire for interview to farmers for Soil management practices in Kyee Inn Village, Pyinmana Township, Naypyitaw

Date of interview ---

Interviewer ---

1. Respondent Name ---

2. Age ---

3. Education

☐ Graduate ☐ High School ☐ Middle School ☐ Primary ☐ Read/Write

4. Land holding (ha)

☐ Irrigated ( ) ac ☐ Rainfed ( ) ac

5. Family member

☐ Male ( ) ☐ Female ( )

6. Labor

☐ Hired ☐ Family labor

7. Experience of farming ( ) yrs

8. Soil fertility status

☐ good ☐ poor ☐ medium

9. GPS/GIS/Drone mapping technology awareness of the respondents

- Do you know GPS instrument?

☐ Yes ☐ No

- Do you know GIS technology?

☐ Yes ☐ No

- Do you know Drone mapping?

☐ Yes ☐ No

10. Method of land preparation

☐ Animal power ☐ Machine power

11. Cropping pattern

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12. Fertilizer application

☐ Organic ☐ Inorganic ☐ Foliar ☐ None

If organic,

- Name ---------------------------------------
- Rate ---------------------------------------
- Cost ---------------------------------------

If Inorganic,

☐ Nitrogen (N)

- Type ---------------------------------------
- Rate ---------------------------------------
- Time of application

☐ Basal ☐ Top dressing

- No. of application -----------------------
- Cost ---------------------------------------

☐ Phosphorus (P)

- Type ---------------------------------------
- Rate ---------------------------------------
- Time of application

☐ Basal ☐ Top dressing

- No. of application -----------------------
- Cost ---------------------------------------

☐ Potassium (K)

- Type ---------------------------------------
- Rate ---------------------------------------
- Time of application

☐ Basal ☐ Top dressing

- No. of application -------------------------------
- Cost ---------------------------------------

☐ Foliar

- Rate --
- Time of application

  ☐ Flowering ☐ Others

- No. of application ------------------------
- Cost --

13. No. of years for Fertilizer application

  ----

14. Weed management

  Herbicide

  ☐ Preplant

  - Name --
  - Rate --

  ☐ Postemergence

  - Name --
  - Rate --
  - No. of application ---------------------------

15. Method of harvest

  ☐ Manual ☐ Machine

16. Practices of incorporating straw

  ☐ Yes ☐ No

17. Yield (bsk/ac) ---------------------------