SPATIAL VARIABILITY AND MAPPING OF SOME SOIL PROPERTIES FOR SITE-SPECIFIC SOIL MANAGEMENT IN SULEJA, NIGER STATE, NIGERIA.

By

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA IN PARTIAL FULLFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY IN SOIL SCIENCE AND LAND MANAGEMENT

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DECLARATION

I hereby declare that this thesis entitled: "**SPATIAL VARIABLILITY AND MAPPING OF SOME SOIL PROPERTIES FOR SITE-SPECIFIC SOIL MANAGEMENT IN SULEJA, NIGER STATE, NIGERIA**" is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or un published) has been duly acknowledged.

HASHIRU ALIYU ……..………………………………

MTech/SAAT/2018/7777 SIGNATURE & DATE

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CERTIFICATION

The thesis entitled: “**SPATIAL VARIABLILITY AND MAPPING OF SOME SOIL PROPERTIES FOR SITE-SPECIFIC SOIL MANAGEMENT IN SULEJA, NIGER STATE, NIGERIA**” by HASHIRU, Aliyu (MTech/SAAT/2018/7777) meets the regulations governing the award of the degree of Master of Technology of the Federal University Technology, Minna, and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

To my ParentsAlhaji Tiaminu and Hauwa, my wife Rahmat and entire family.

ABSTRACT

Spatial variability of soil properties has been identified as a threat to crop production, in this research, effort was made to assessed the spatial variability of soil properties in two fields Kwamba and Madalla at Suleja, Niger State, Nigeria purposely for precision farming. The two fields measuring 11.25 hectares each were divided into 300 m × 375 m grids at each grid intersection, total of 30 Soil samples were collected from 0-15 cm depth. Also recorded was geospatial information (latitudes, longitudes and elevation) with the aid of Global Positioning System devices, to allow for production of digitalized maps of soil properties. The samples were analyzed in the Laboratory for particle size distribution, pH, organic carbon (OC), total nitrogen (N), available phosphorus (P) and Potassium (K). Field and laboratory generated data were subjected to descriptive statistics to describe the spatial variability of the nutrients in the soil. Geo spatial data were transformed to maps using Arc Map 10.1 (ESRI, 2012) software. Results showed the dominant texture of the Soils in both farmlands(Kwamba and Madalla) were Loamy Sandy. Soil reaction was slightly acidic to neutral;In term of spatial variability pH had (CV = 3.1 % and 3.3 %) and Phosphorus had (CV = 35.0 % and 20.0 %), with low spatial variability while Soil organic carbon was high in all the Soils OC (CV = 35.0 % and 41.3 %),Nitrogen were also high in all the soil N (CV = 35.0 % and 20.0 %), while K was high in all the Soils.and K (CV = 42.15 % and 40.0 %) with high spatial variabilityand. Mapping could be helpful in partitioning of the farm into relatively uniform units to allow site specific management of SOC, N and K with high spatial variability.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Variations in soil results from complex geological, pedological processes and to some extent soil management practices (Bocchi *et al.*, 2000). Knowledge of the variation in soil properties within farmland use is essential in determining production constraints related to soil nutrients. It is also important to suggest different remedial measures for optimum production and appropriate land use management practices (Panday *et al.*, 2018). Sustainable land management practices are necessary to meet the changing human needs and to ensure long term productivity of farm land (Halbac *et al.*, 2019).

Land use and management practices are closely interrelated with soil quality, and the adoption of appropriate land management practices and land use planning would be helpful to both restore the degraded soil physical and chemical quality and ensure steady and sustainable productivity (Oyetola and Philip, 2014). It is important to know how these soil properties vary in different land use contexts so that best management practice options can be recommended to farmers based on the limited nutrients. Soil compaction following heavy grazing cause homogenous spatial distribution of soil properties and increase vulnerability of soil, water and soil loss, and consequently reduce available water for plants and production of rangeland.

Temporal and spatial investigation of data is essential for understanding of soil spatial variability. Furthermore, intensive agricultural production (example annual ploughing and use of agrochemicals) leads to soil degradation, decreasing its suitability for crop production (Liu *et al.*, 2006; FAO and ITPS, 2015).

Geographical distribution maps of soil properties, obtained from soil surveys, 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).

The West African savanna is one region with limited data on soil variability across different land uses of the soil resources (Idowu *et al.*, 2003), including the more widespread Ultisols. Okon and Babalola (2006) noted that soil variability could be induced even in a uniform field by erosion, runoff deposition and some other factors. This suggests that soil depth could also be a factor in soil spatial variability. Information on soil spatial variability is needed to understand the extent of reliability of soil data acquired from fields samples.

1.2 Statement of Research Problems

Notices of non-uniform growths in crops and the high cost of fertilizer are the major problems of farmers in the study areas and these lead to the decreases in quantity of yield. Spatial variability of the soil has great value for precision agriculture and site-specific farming, even though soil variables and their spatial variability need to be corrected to some degree according to Bocchi *et al.* (2000). `

1.3 Justification of the Study

Information on soil spatial variability will enhance better management decisions aimed at correcting problems and at least maintains productivity and sustainability of the soils (Ozgoz, 2009).

Precise knowledge of the physical and chemical variation in soils will also help to recover soil homogeneity. Better understanding of observations on the many processes in soils, rational interpretation of agronomic responses to soil management, and the rate of fertilizer application.

1.4 Aim and Objectives of the Study

The aim of the study was to assess and map spatial variability of some soil properties for site specific management of two locations in Suleja, Niger State, Nigeria while the specific objectives of this study were to:

(i) Evaluate the selected soil properties in the two locations.

(ii) Determine the spatial distribution of the selected soil properties.

(iii) Produce geospatial maps

CHAPTER TWO

LITERATURE REVIEW

2.1 Spatial Variability and Soil Properties

Spatial variability of soil properties either over the horizontal or vertical directions generally result from the interaction between the soil forming factors; however, some of them are due to tillage and management practices (Iqbal *et al.*, 2005). Information about the variability within soil properties is considered as one of the major fundamentals for local management in precision farming. Therefore, studying the spatial variability of both soil physical and chemical properties is very essential for understanding the soil processes and land management. Soil properties such as clay content have been found to be highly correlated with topographic position (Wang *et al.*, 2001). Depending on the location on a slope, physical and chemical properties of the soil will also vary either minimally or maximally. Physiography influences soil texture, penetration resistance (Bruand *et al.*, 2004) exchangeable basic and acidic cations (Stutter *et al.*, 2004), soil chemical properties (Chien *etal.*, 1997) and nutrient budget (Mallarino, 1996) are important in fertilizer management (Paz-gonzalez *et al.*, 2000).

Spatial variability of soil properties has been known to exist and to be taken into account every time field sampling is performed and investigation of its temporal and spatial changes is essential. Soil properties vary spatially from a field to a larger regional scale and it is affected by soil forming factors which can be termed as intensive factors and extrinsic factors such as soil management practices, fertility status and crop rotation (Cambardella and Karlen, 1999). The variation can also be as a result of a gradual change in soil properties caused by landforms, geomorphic elements, soil forming factors and soil management practices (Buol *et al.*, 1997). Spatial variability could be attributed to changes in macro and micro flora and fauna (Lal, 2001).

(Zhao*et al.*, 2007) reported that spatial variability of soil chemical and physical properties is affected by graze intensity and heavy grazing decreases soil water content and soil organic carbon (SOC) but increases bulk density (BD) and shear strength (SS). The mean gravel content is much higher for cultivated areas (Paz-Gonzalez *et al.,* 2000). Soil properties vary spatially from a field to a larger scale affected by both intrinsic (soil forming factors) and extrinsic factors (soil management practices, Fertilization, and crop rotation) (Cambardella and Karlen, 1999).

The variation of soil properties should be monitored and quantified to understand the effects of land use and management systems on soils. Soil has part of the earth crust system which controls hydrological, biological, and geochemical cycles and provides goods, resources and services to mankind (Keesstra *et al.*, 2012; Decock *et al.*, 2015; Brevik *et al.*, 2015; Berendse *et al.*, 2015). Robertson *et al.* (1997) reported that soil variability exists not only in cultivated soils and also in undisturbed soils areas because of the interactions of soil forming factors and It is a prerequisite to quantify such spatial variability of soils before designing site specific applications like variable fertilizer rates, irrigation rates, seed rates, strategies for future soil sampling, and appropriate tillage, land use and conservation measures (Schimel *et al.*, 2000; Iqbal *et al.*, 2005).

Soil properties are susceptible to changes spatially and temporally. Earlier, it is mainly depended on the intrinsic soil formation factors and some extrinsic factors (Sun *et al.,* 2003). Spatial variability of soil properties is assessed effectively by geostatistical methods (Mueller *et al.,* 2003; Pereira *et al.,* 2013) for site-specific management of nutrients through various rate of fertilizer application to avoid over and under application of nutrients (Fu *et al.*, 2010).

There have been growing interests in the study of spatial variability of soil characteristics using geostatistics since 1970 as geostatistics were well developed and successful in characterizingthe spatial variationsof soil characteristics (Liu *et al.*, 2008). These variations differed among soil properties and may reflect the impacts of plant, soil fauna, and precipitation and management practices adopted in the area, (Jafari *et al.,* 2011). Consequently, soils can exhibit a marked spatial variability at the macro scale and micro scale, (Fathi *et al.,* 2014). High variability of soil properties might be related to variability of properties of flood sediments and controlled by primarily the depositional environment where high energy systems deposit materials with high spatial variability, (Moss *et al.,* 2010). These processes and causes create pattern of nested variability or heterogeneity, this means that, soil properties may display spatial or temporal patterns only over certain distances and not others (Douaik, 2011).

Knowledge of spatial variability and relationships among properties is important for the evaluation of agricultural management practices and the variability of physical and chemical properties of soil is unavoidable (Fathi *et al.,* 2014), understanding the distribution of soil properties in the field is essential in refining agricultural management practices, (Akbas, 2014). Farm inputs can be adjusted and applied to the fields precisely and management decisions can be made accordingly, (Sivarajan *et al.,* 2013), and interpretation of these elements is a key in site specific farming, (Tuncay *et al.,* 2013). Therefore, it is important to study not only the extent of the surface spatial variability of soil properties but also the distribution of subsurface and deep soil horizons (Iqbal *et al.,* 2005). Knowledge about soil physical and chemical properties can save time and money in planning and management of soil spatial variability that, influence soil and crop management efficiencies as well as the effectiveness of soil research (Wasiullah *et al.*, 2010).

Precision farming applies principles of farming according to field variability, (Emadi *et al.*, 2008). It is noted that, spatial characterization is necessary to locate areas to be carefully managed for agricultural sustainable development (Ghanty *et al.,* 2012) and studying physical and chemical properties provide basic information of better plant growth and management of the recourses (Akhtaruzzaman *et al.,* 2014) and provide insight into understanding ecosystem processes, (Nkheloane *et al.*, 2012).

Iqbal *et al.* (2005) reported that spatial variability of soil properties in any field position is inherent in nature due to geologic and pedologic soil forming factors, but some of the variability may be induced by tillage and other management practices. Benefits from soil tillage are known as improvement of soil-air-water relations in seedbeds, control of undesired vegetation, and reduction of the mechanical impedance to root growth. Skuodiene *et al.* (2013) reported that the shallow ploughing and shallow plough less tillage treatments contained more weed seed species in the soil compared with the deep ploughing treatment. Soil tillage practices causes changes to soil structure and hydraulic properties dynamically in space and time (Mueller *et al.,* 2003 and Strudley *et al.,* 2008). The ordinary kriging is one of the most common methods in spatial interpolation of soil properties after estimating semi variogram parameters of soil properties using geostatistical tools (Goovaerts, 1998 and Zhao *et al.,* 2009).

2.1.1 Soil physical properties

Spatial variability of soil physical properties within or among agricultural fields is inherent in nature due to both geologic and pedologic factors of soil formation. However, management practices such as tillage, irrigation, and fertilizer application may also induce variability within the field and may further interact with each other across different spatial and temporal scales, and are further modified locally by erosion and deposition processes (Igbal *et al.,* 2005).

Tsegaye and Hill(1998), Studied the intensive tillage effects on spatial variability of soil physical properties such as; texture, bulk density, soil strength, mean pore size and saturated hydraulic conductivity. They reported that all soil physical properties, except saturated hydraulic conductivity, were weakly spatially dependent for the 6 to 9 cm depth of soil, and moderately spatially dependent for 27 to 30 cm soil depth. Although the major purposes of tillage are to reduce bulk density and soil strength and to control pests and diseases. Soil cultivation may lead to the formation of a hard pan below the plough layer of soil that restricts root penetration and downward movement of water, therefore zero or minimum till practices must be carried out in these areas.

Ozsoy and Aksoy (2007) reported that soils, especially having vertic soil properties, must have a good and right soil management for a long-term productivity. Inappropriate soil tilling and using unsuitable equipment firstly cannot manage healthy plant growth and cause soil degradation in long time periods. Strudley *et al.* (2008) reviewed tillage effects on soil hydraulic properties in space and time, and stated that zero tillage practices generally increase macro pore connectivity and saturated hydraulic conductivity while generating inconsistent responses in total porosity and soil bulk density compared with conventional tillage practices.

Specific management effects are often overshadowed by spatial and temporal variability, and differences in temporal variability depend on spatial locations between rows, within fields at different landscape positions, and between sites with different climates and soil types. They reported that soil hydraulic properties are influenced by most tillage practices immediately, but these effects can diminish rapidly. Hangen *et al.* (2002) watched the infiltration of dye tracer (methylene blue) on small plots of farm land in sandy and silt loams under conventional tillage and minimum tillage. They found that dye stains were much deeper under minimum tillage than conventional tillage, indicating greater vertical connectivity of the micro pore space network

2.1.1.1 soil texture

Soil texture is considered as the most important physical property, where it has major effects on the other soil properties (Zebarth *et al.*, 1999; Medinski, 2007). Soil texture is the proportions of sand, silt and clay fractions in a soil. It is generally affected by soil parent material and the predominant type of weathering either physical or chemical. Soil texture remains relatively unchangeable and is not affected by management activities, where soil weathering is a very slow process. Soil structure is the arrangement of soil particles into aggregates. Aggregation is important for increasing stability against erosion, maintaining porosity, aeration capacity and soil water movement. Fine textured soils usually have a stronger and well-defined structure than coarse textured soils mainly due to shrink/swell processes and cohesion between particles.

2.1.2 Soil chemical properties

Soil properties change in time and space continuously (Rogerio *et al.,* 2006). Despite the temporal and spatial changes of soil characteristics in small and large scales, awareness of how are these changes for increasing profitability and sustainable agriculture management, is necessary (Ayoubi and Khormali, 2008). At different spatial and time scales, vegetation cover helps in protecting the soil from harsh climatic conditions, mostly soil erosion. The presence of dense vegetation affords the soil adequate cover, thereby reducing the loss in macro and micro nutrients that are essential for plants growth and energy fluxes (Iwara *et al.,* 2011).

The evidence of possible literature shows that vegetation associations within the Guinea Savanna and tree species reflect differences in soil texture, structure and mineral content (Abdul-Ameed, 2005). Land cover changes affect also soil properties and biogeochemical processes (Ross *et al.,* 1999; Zeng *et al.,* 2009). The rainy and dry seasons of the seasonal climate of the tropical ecosystem, is characterized by a number of ecological phenomena which set up series of processes which influence the biotic and edaphic components of the ecosystem. Organic matter is one of the most indexes of soil quality, thus investigation of changes and spatial distribution of organic carbon can be useful for evaluation of soil function and understanding of soil carbon decomposition processes and determination of soil quality changes trends (Wood, 1998; Venteris *et al.,* 2004).

Most Tropical soils have low soil organic carbon, pH, CEC and are mainly composed of low activity clays and sesquioxidess (Yerima and Van-Ranst, 2005). Under such conditions, crop yield could only be increased by adequate application of fertilizers and organic manure. This will require that baseline fertility status of these soils and how they vary in space are known. In urban environments and wetlands in particular, soil management practices greatly affect soil properties (Tsaboada-Castro *et al.,* 2009). Soil reactions and the availability of different nutrient elements is also affected, Soil properties exhibit a great spatial and temporal variability (Yerima and Van-Ranst, 2005). Studies on soil variability have relevance in sampling (Tabi and Ogunkunle, 2007), in site specific soil fertility management (UNEP, 2006), in definition of land management units (Tittonell *et al.,* 2008; Salami *et al.,* 2011) and in explaining variation in crop growth and yield (Kosaki and Juo, 1989; Tittonell *et al.,* 2008).

2.1.2.1 soil reaction (pH)

Soil pH is an indicator of the acidity or alkalinity of soil, and is a reflection of important chemical properties determining soil quality (Nagy and Konya, 2007). Soil pH also has a profound impact on a number of other soil properties such as phosphorus. Extremes in acidity or alkalinity will change the nutrients availability and result in the unbalanced absorption of elements in plants (Zhao *et al.,* 2011). Spatial heterogeneity refers to the lack of homogeneity and the complexity in the distribution in space of the properties of a system (Nagy and Konya, 2007). The spatial heterogeneity of soil parameters such as pH and content of organic matter and of nitrogen, phosphorus and potassium, has an important influence on the distribution and spatial pattern of plants (Stoyan *et al.,* 2000; Augustine and Frank, 2001; Silvia and Escalante, 2016). Studying the spatial heterogeneity and the driving factors behind soil properties is significant for revealing ecosystem function and biodiversity (Augustine and Frank, 2001).

Previous research has revealed that spatial variation in soil pH controls off season NO emission in agricultural soils, however, soil properties vary in space and time across natural ecosystems (Bogunovic *et al.,* 2017; Griffiths *et al.,* 2017), and distributions of soil nutrients and related environmental factors depend on scale. Many studies have shown that soil pH is negatively correlated with many variables, such as soil organic carbon content, total nitrogen content, total phosphorus content, precipitation, temperature, and clay content (Liu *et al.,* 2013). Because the spatial distribution of soil pH has structural and stochastic characteristics, measuring it accurately has implications for crop production (Liu *et al.,* 2013). Therefore, it is important to study the spatial variability of soil pH on a regional scale together with the factors influencing it; these are important for the regulation of soil acidity and alkalinity, control of environmental pollution, and sustainable utilization and management of soil nutrients in addition to the ensemble of components of the regional ecological environment.

The change in soil structure and the removal of topsoil resulting from erosion may cause the loss of nutrients and environmental degradation, thereby inhibiting plant growth (Sheoran *et al.,* 2010). The changes in availability of soil nutrients affects not only crop production and vegetation growth, but also the structure of the ecological environment (Jin and Jiang, 2002; Zhang *et al.*, 2010).

2.1.2.2 soil organic matter

Organic matter is one of the most indexes of soil quality, thus investigation of changes and spatial distribution of organic carbon can be useful for evaluation of soil function and understanding of soil carbon decomposition processes and determination of soil quality changes trends (Wood, 1998 and Venteris *et al.,* 2004). Many studies have shown the correlation between soil characteristics like organic matter and the results were illustrated in map (Fennessy and Mitsch, 2001; Anderson *et al.,* 2005).

Zhao *et al*. (2007) reported that spatial variability of soil chemical and physical properties are affected by graze intensity and heavy grazing decreases soil water content and soil organic carbon (SOC) but increases bulk density (BD) and shear strength (SS).

Variogram of organic matter at grazing site has linear structure and does not access to threshold variance in attention to regional scale. While the spatial pattern of this variable at enclosure site has strong structure and determined threshold variance. Fennessy and Mitsch, (2001) evaluated spatial distribution of soil properties in 2 years period. They found that the spatial variability of organic matter and total nutrient of soil had decreased in this period.

The major function between soil degradation and soil fertility is played by soil organic matter content (Gajda *et al.,* 2016 and Vazquez *et al.,* 2016). The basic benefits of soil organic matter can be divided into three categories physical (increases aggregate stability and soil water capacity, and decreases crusting), chemical (increases cation exchange capacity of soil and availability of essential soil nutrients) and biological (provides habitat and food for many living organisms in soil, increases microbiological diversity and expands soil food webs) (Bot and Benites, 2005). Furthermore, Soil organic matter represents the most important sink of carbon and plays a crucial role in carbon sequestration, mitigating climate change effects (Milne *et al.*, 2007; Whitmore *et al.,* 2015).

The continuing decline of organic matter from soils in agroecosystems due to inappropriate agricultural (incineration and removal of crop residues, overgrazing, inappropriate tillage and environmental conditions (rising temperature or heat wave events, frequent floods, erosion, etc.) is the main problem for soil preservation (Loveland and Webb, 2003; Liu *et al.,* 2006 and Jug *et al.,* 2018). Therefore, it is very important to exert permanent control over soil organic matter content in soils within agricultural land (Bot and Benites, 2005). The existence of proper input data enables us to predict the status of unsampled areas and to understand problems in agricultural production (Robinson and Metternicht, 2006; Schueller, 2010; Krivoruchko, 2012; Mirzaei and Sakizadeh, 2016; Lipiec and Usowicz, 2018).

2.1.2.3 nitrogen

The heterogeneity of soil properties, especially soil nutrients such as mineral nitrogen, is considered to be a problem for the determination of soil sampling strategies and the optimization of soil management (Haberle *et al*., 2004; Piotrowska and Długosz 2010). Within one field, differences in status of properties may be induced by different soil types or variations in profile development. Additionally, external factors, e.g. soil fertilization and tillage, significantly influence the soil properties in agricultural soils. The efficiency of nitrogen use in agricultural fields varies only slightly between 40 – 50 %, which was attributed to improper nitrogen use management, imbalanced fertilization and losses through leaching, volatilization and immobilization (Parama and Munawery, 2012).

An agricultural system with site specific management should be more economically and environmentally suitable than a uniform rate application. Such site-specific nutrient management is based on the prediction of the spatial variability of crop management parameters, soil nutrients and other soil properties (Inamura *et al.,* 2004) which ensure the appropriate application of fertilizers according to the variations in the field that actually exist. As aresult it may reduce nutrient losses from production fields, which is of special economic and environmental importance (Cambouris *et al.,* 2008). There has been a growing interest in the study of the spatial variation of soil properties using geostatistics, as this technique has been used successfully in characterizing spatial variations of heavy metals (Lim *et al*., 2001), micronutrients (Liu *et al*., 2004) biological soil features, such as soil enzymatic activity (Stark *et al.,* 2004, Askin and Kizilkaya, 2006) and other soil properties (Liu *et al.,* 2008, Staugaitis and Sumkis, 2011).

2.1.2.4 phosphorus

Soil available phosphorus (P) is a major nutrient, enhancing root growth, and crop productivity. But higher fixation of soil P reduces its availability and also induces variability in P status of soil (Singh and Giand 2019). Actually, various intrinsic and extrinsic factors cause spatial variability of available P. Intrinsic factors include pedologic and geologic soil forming factors such as parent material, climate, dominant flora and fauna whereas extrinsic factors include different agronomic interventions like tillage, fertilizer application, irrigation water management etc. (Liu *et al*. 2006). Blanket P fertilizer application without considering spatial variation leads to higher economic investment, soil quality deterioration and environmental pollution like eutrophication (Bhunia *et al*. 2018). Sustainable and site-specific P management can only mitigate such problems and thereby, improving P use efficiency. Thus, spatial variability assessment of P is essential prior to its application to crop field.

Both classical and geostatistical techniques are available for assessing spatial variability of available P. But the classical statistics cannot reveal the continuous variability in the presence of spatial autocorrelation between the sampling points. However, the geostatistical techniques can quantify such spatial autocorrelation using semivariograms,

auto-correlograms etc. (Martin *et al.* 2016). Kriging is a statistical interpolation technique that can be used to map the continuous spatial variability of soil properties. Several researchers used various interpolation techniques to map soil organic carbon (SOC), soil available nitrogen (N), phosphorus (P), potassium (K) and other soil properties (Patil *et al*. 2011, Vasu *et al*. 2017).

2.1.2.5 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). The soils of arid and semiarid regions usually contain enough exchangeable potassium and K-bearing minerals which provide sufficient K to the crops. Exchangeable K concentration of soils in Central Anatolia of Turkey is considerably depleted due to the intensive crop production (Munsuz *et al*. 1996). Munsuz *et al*. (1996) stated that continued K removal in Anatolia without addition of K resulted in the destruction of K-bearing clay minerals and consequently depletion of K sources in soils. Ogaard and Krogstad (2005) showed the decline of interlayer K of micas and clay minerals with constant release of K from sources with no exchangeable K. Askegaard and Eriksen (2000)also reported that K is lost from loamy sand soils by plant uptake and leaching below the root zone. Losses of K from grasslands especially in coarse-textured soils were related to actual K input, surpluses and the level of exchangeable K (Kayser *et al*. (2012).

Improved understanding of soil K dynamics in the soil and spatial distribution pattern within a watershed are critical issues for better agronomic management (Sato *et al*. 2009). Numerous studies focused on the interaction of plant nutrients with different soil constituents to obtain an accurate description of the spatial autocorrelations of nutrients across a landscape, which is a prerequisite to predict their behavior in the watershed. Specifically, to predict the yield of major crops grown, one must account for reserve and available nutrient concentrations and interactions of the various species in the soil environment. Spatial variability of soil nutrients in arable soils is a consequence of interactions between parent materials, biology, climate, time and topography and as well as those partly created by human factors such as fertilization, tillage and cropping systems (Trangmar *et al*. 1985).

2.2 Spatial Variability and Crop Management

Crop production under variable conditions requires soil amendment. In the last two decades improve grasses have been introduced and in areas with mechanized agriculture the land use has been changed to cornand soybean crops, utilizing conventional tillage practices and blanket applications of amendments without considering the soil properties. This management is inadequate because the application of inputs and the farming practices in general do not fit the specific needs of soil and crops, leading to increased production costs, lower profits, risk of water pollution, and lower energy efficiency (Bocchi *et al.,* 2000).

Soil variability occurs due to factors acting at several spatial and temporal scales, produced by complex pedological processes (Burrough, 1993), relief and moisture regimes. However, crop management also alters soil variability (, particularly due to tillage and fertilizing practices (Kilic *et al.,* 2004). Interest in having representative information on soil spatial variability has grown, resulting in the development of models and management systems (Godwin and Miller, 2003). Although site-specific soil management is unfeasible if the cost of the required analyses is high (Bongiovanni and Lowenberg-DeBoer, 2001), determining soil properties variability allows for establishing adequate sampling distances and possible dependence among two or more variables, which may lead to reducing sampling costs.

Abreu *et al*. (2003) found high heterogeneity for different soil properties in Brazilian Oxisols and reported spatial dependence ranges and suitable zones for site-specific management. Following the same methodology on an Alfisol, Silva *et al.* (2004) obtained broader ranges, which indicate the need to perform studies on different soil orders. Furthermore, cropped soils tend to present a greater spatial dependency as depth increases, because management leads to surface homogeneity (Souza *et al.,* 2006).Unsustainable soil management practices lead to soil degradation, mainly because of loss of soil organic matter, soil erosion, changes in soil structure, degradation of the biota in the soils and soil chemical degradation (Cerda *et al.,* 2009; Mupenzi *et al.,* 2011; Novara *et al.,* 2013; Mukherjee *et al.,* 2014; Stanchi *et al.,* 2015; Seutloali and Beckedahl, 2015; Novara *et al.,* 2015). In site specific management of nutrients through variable rates of fertilizer application to avoid over and under application of nutrients to farm land (Fu *et al.,* 2010).

2.2.1 Vegetable crops

Vegetables are an important component of a healthy diet in the world. They have been hailed for their nutritional and non-nutrient bioactive ingredients (Smith and Eyzaguirre, 2007). If consumed daily in sufficient amounts, they would help prevent major diseases such as cardio-vascular diseases and certain cancers. The low intake of fruit and vegetables is responsible for about 31 % of ischemic heart diseases and 11 % of strokes (WHO, 2002). Each year, over 2.7 million lives would be saved if fruit and vegetables consumption are sufficiently increased. It has been recommended that a minimum of 400 g of fruit and vegetables should be consumed (FAO/WHO, 2003). However, the increase in soil degradation has posed a serious threat to agricultural productivity. Some of the major factors of soil degradation are the decline in soil fertility as a result of the lack of nutrient inputs, the use of urban wastes (Alloway, 1995), inappropriate land use, poor management, erosion, salinization (Bationo *et al.*, 2006) and climatic constraints.

2.3 Spatial Variability and Soil Fertility

Soils are inherently heterogeneous in nature, diverse and dynamic system (Kavianpoor *et al.*, 2012) and its properties change in time and space continuously (Maniyunda *et al.*, 2013). Heterogeneity in soil properties with depth and across landscapes can be accounted for by several interacting factors that operate with different intensities and at different scales and acting simultaneously (Serrano *et al.*, 2014). Estimating spatial variability of soil properties is important for evaluating environment (Inigo *et al.*, 2012) and provides the factors and processes controlling potential in agriculture production (Akbas, 2014). It is also an important determinant of efficiency of farm inputs and yield as well as crop management and design and effectiveness of field research trials.

The availability of soil nutrients for plant growth and yield production is a function of different parameters, including soil pH, soil organic matter and texture, and soil biological activities (Karaca, 2004). Hence, determination of such parameters is important for evaluating nutrient behavior in the soil and for suggesting appropriate methods of enhancing nutrient availability to plant. The important way to gather knowledge in this respect is to prepare maps through spatial interpolation of point-based measurements of soil properties using geostatistics. There have been growing interests in the study of spatial variation of soil properties using geo-statistics since 1970s, as geostatistics techniques were well developed and successful in characterizing the spatial variations of soil properties (Liu *et al.,* 2006). While many studies have been carried out at a small scale (Wilcke, 2000), relatively few have been done at large-scale (Qu *et al.,* 2014).

2.3.1 Topography

The spatial variation of soil properties is significantly influenced by some environmental factors such as topographic aspect induced micro climate differences, topographic positions, parent materials, and vegetation communities. Topography as a soil forming processes is affected by erosion and deposition, thus leads to differentiation in soil properties and hydrological conditions (Lawal *et al.,* 2014).

The identification of landscape features is an important tool used by pedologists in their soils mappingprocedures. The use of landscape elevation digital models has increased predictions on soil parameters from terrain attributes. Since topography parameters, defined from primary and secondary attributes, controls water and sediments distribution over the landscape, researchers have been trying to correlate landscape features (altitude, slope, shape) with physical soil attributes (Pachepsky *et al.,* 2001; Sobieraj *et al.,* 2002).

Spatial variability of soil color and texture were considered feasible to be used in models of digital soil mapping (Novaes Filho *et al.,* 2007). Many evidenced show the influences of landforms on soil physical properties. Souza *et al*. (2004) found that small variations in the landscape form defined different spatial variability in soil physical attributes. Similar results were found by Souza *et al*. (2003), which evaluate the effect of landforms on anisotropy of soil physical attributes and observed higher spatial variability of soil physical attributes in the concave landform when compared to the linear form.

2.3.2 Soil erosion

Soil erosion is a significant economic and environmental problem worldwide as a driving force affecting landscape (Zhao *et al.*, 2013). It is a very dynamic and complex process, characterized by the decline of soil quality and productivity, as it causes the loss of topsoil and increases runoff (Lal, 2001; Yang *et al.*, 2003). Furthermore, soil erosion often causes negative downstream impacts, such as the sedimentation in rivers and reservoirs decreasing their storage volume as well as lifespan (Haregeweyn *et al*., 2013). One of the main causes of soil loss intensification around the world is associated with land use change (Leh *et al.*, 2013). The relationship between different land use and soil susceptibility to erosion has attracted the interest of a variety of researchers (Yang *et al.*, 2003; Cerda and Doerr, 2007), which have shown the impact of changes on vegetation cover and agricultural practices on soil properties and therefore in overland flow. Generally, cultivated lands experience the highest erosion yield (Cerdà *et al.*, 2009; Mandal and Sharda, 2013). In the Mediterranean regions, in combination with these anthropogenic factors, the climate change has amplified the concerning about soil erosion since it is expected the increase of dry periods followed by heavy storms with concentrated rainfall (Nunes *et al.*, 2009). Land has been utilized intensively for all purposes at the expense of its suitability thereby resulting in land degradation and altering the natural ecological conservational balances in the landscape. There have been several attempts to relate soil properties to physiographic position for many landscapes (Wysock*i et al.*, 2001).

2.4. Digital Soil Mapping

Digital soil mapping (DSM) can be used as a solution for soil spatial variability studies. Digital soil mapping can estimate soil properties based on relationships between soil and environmental variable obtained from digital elevation model (DEM) and satellite imagery (Mc-Bratney *et al.*, 2003) and several studies have recently been conducted on spatial variation of soil properties using DSM method.Knowledge about soil is fundamental to its utilization, management and economy as a whole. Knowing the soil can be said to involve obtaining information about it and describing its varied features. Traditionally, describing the soil often starts with measurements and analysis by experts. Information such as, drainage, mapping units, classification type, texture, pH values, unique locations, landscape, possible uses and other characteristics features to a soil distribution is usually provided and represented as spatial features in maps and other supporting documents by a qualitative method.

Several soil maps have been produced (FDALR, 1990) using this qualitative approach, which have help in providing adequate data to support several agro-based and scientific projects, the accuracy and reliability of supporting data remains questionable. The methodology has been considered to be slow, time consuming and expensive (Lark, 2007) and the resulting soil maps often suffer from dimensional instability, with highly generalized legend, no flexibility of scale (Okeke and Nkwunonwo, 2007) and tend not to be suitable for quantitative purposes (Zhu *et al.*, 1997) Thus, the need for quick, quantitative, up to date, high resolution and more accurate soil data seems to overwhelm the qualitative soil maps.

Digital soil mapping is a task towards optimizing the usefulness of soils in many places. Several studies (Hengl *et al.*, 2003; Kempen *et al.*, 2012) have shown that such operations are effective ways of ensuring steady availability of soil data. Moreover, they tend to guarantee regular update of soil data and remove limitations in their uses. Such operations offer significant supports to solving a myriad of environmental and geographical problems (Platou *et al.,* 1989 and Jamagne *et al.,* 1995) that spread across local, national and regional levels. New sets of data often result from further analysis of data obtained by such operations (Zhu *et al.,* 1997 and Zhu *et al.,* 2001), and they tend to help overcome the limitations placed by traditional soil maps. With these benefits associated with such soil mapping technology, its implementation remains unaccomplished in many places and much environmental issues are still unresolved. Zhu *et al.,* 1997; Zhu *et al.,* 2001 proposed a digital soil model SoLIM which integrates GIS and remote sensing technologies, to overcome limitations imposed by conventional soil maps in a number of Asian countries.

Soils fulfill many functions important for agriculture, forestry and the management of soil resources and natural hazards. The functionality of soils depends on their properties; hence, Accurate and spatially highly resolved maps of basic soil properties such as texture, organic carbon content and pH for specific soil depth are needed for the sustainable management of soils (FAO and ITPS, 2015).

Geostatistical tools are useful in preparation of the maps based on limited number of samples collected from agricultural landscapes. Kriging simulation technique predicts the values at unsampled locations by spatial correlation and reduces variance of estimation error and investigation costs (Saito *et al.*, 2005 and Pereira *et al.,* 2015). In northern and southern regions, respectively, many studies and research have been carried out in order to understand soil spatial variability in the regions (Wuddivira *et al.*, 2000; Tabi and Ogunkunle, 2007; Oku *et al.*, 2010; Abu and Malgwi, 2011).

2.5 Progresses on Spatial Variability Studies in Nigeria

The studies done so far in Nigeria differed in their consideration of the inherent and the inherited attributes of soils contributing to their spatial variability. In order to enhance the usefulness of such studies in any ecological zone, locally important factors should be factored into them. The soils in the derived savanna of southeastern Nigeria are known for their structural defects. In this environment, Igwe (2001) reported differences in soil structural development due to land use options (native forest, oil palm plantation, grassland fallow, and arable cropping). Oyedele and Tijani (2010) reported the spatial variability of soil moisture content in an Alfisol in south western Nigeria.Studies on soil spatial variability help to identify soil properties with normally distributed data, with the aim of estimating their mean values at unsampled points at a predefined level of precision.

Idowu *et al.* (2003) and Tabi and Ogunkunle (2007) used this approach to arrive at the minimum number of soil samples per hectare for predicting mean properties of Alfisols in southwestern Nigeria. Works on the variability of some soil properties along quartzite and gneiss toposequences in Southwestern Nigeria, was relatively little and literature on the variability of tropical soils, particularly for the forest zone of Nigeria, compared to the vast work and readily available literature on the availability of physical and chemical properties of temperate soils.

In Nigeria, no sustainable use of land has resulted in massive land degradation and low soil fertility. Meeting the food and fibre needs of the ever increasing growing population in this period of global recession has been a major concern to the agriculturists. In practice, particularly in south western Nigeria, the use to which land is put is not often related to the land potential capacity for the use type (Senjobi, 2007). Land degradation may be partly due to the realization of the role topographic position plays in influencing runoff, soil erosion and hence soil formation (Babalola *et al.,* 2007). High degree of soil variability in the tropics has long been recognized and this had made it difficult for most tropical soils to be mapped and predict accurately their management and productive potentials (Ogunkunle, 2003).

Soil variability could either be spatial or temporal. Spatial variability is a variation in soil properties which occurs with distance, while temporal variability is a seasonal variation in certain soil properties that display continuous variation depending on the activities on them (Akinbola *et al.,* 2010). Effiom *et al.* (2010) have also reported that variability in soil properties could result in some part of a cultivated field receiving sufficient inputs with the other part receiving excess.

In the tropics, many different soil types occur as a result of a combination of pedogenic factors such as climate, topography, parent materials, disturbance history and soil forming processes like pedoturbations. Varied landscape structures arising there from characterize soil property variations both laterally and vertically in most agricultural sites in savanna ecology. Sustaining agricultural productivity and bio activity is a function of soil bio physical and chemical properties (soil quality indicators). But the inability of the soil quality indicators to perform optimally in terms of increasing productivity, especially in savanna agroecologies, has been related mostly to soil degradation. Ezeaku and Alaci,(2008) defined soil degradation by erosion processes (wind or water) as the lowering of soil physical and chemical fertility to a threshold that limits maximization of agricultural productivity.

The use of inappropriate farming practices and frequent changes in land uses (over cultivation), variation in micro climate, vegetation, parent material, and crops grown acerbate degradation, resulting to constant plummeting of soil fertility levels and productivity. Reports show that soil and crop variability are mostly observed in the fields where fertilities are low and according to Akinrinde and Obigbesan,(2000) where there is practice of more than one kind of land use within an area.

Phil-Eze (2010) specifically showed the role of vegetation cover in variability of soil properties in south eastern Nigeria. The study identified sand, organic matter, moisture content and cation exchange capacity (CEC) as explaining over 91 % of the impact of vegetation cover on variability of soil properties (Phil-Eze, 2010). In spite of their fragile nature, the Nigerian derived savanna soils support intensive agricultural activities (Igwe, 2001). Thus, the focus has been placed on variations in physical properties of the soils due to cropping systems (Amana *et al*., 2010; Asadu *et al*., 2010; Obalum and Obi, 2010), but knowledge of their spatial variability under uncultivated conditions is limited to date.

Understanding the variability of soil properties is vital for soil survey, land assessment, environmental management and most especially agricultural production (Young *et al.*, 2009). Usually, researchers use descriptive and inferential statistics to describe the distribution and variation in soil properties and the relationship that exists between them (Nielsen and Wendroth, 2003). Still viable methods, however, the results are sometimes qualitatively ambiguous (Lin *et al.*, 2005), due to lack of spatial interpretation of the phenomenon. Efficient and realistic appraisal of the variability of soil properties in a given area, nowadays, many researchers (Ogunwole *et al.*, 2014; Reza *et al.,* 2015; Bogunovic *et al.*, 2016) adopts the use of geospatial technique using field dataset and geospatial tools to illustrate the pattern of spatial variability of the soil properties. Spatial interpolation tool uses points with known values and spatial reference to estimate values and spatial reference at another point (Li and Heap, 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site Description

The study Sites were Kwamba and Madalla of Suleja Local Government Area in Niger State and Suleja is located between latitudes 09^{o} 21'107" N and longitudes 07^{o} 18'516" E and Suleja, a major satellite town close to the Federal Capital Territory is densely populated by the low income earners of about two hundred and fifteen thousand people (National Population Commission, 2007) and the coordinates of Kwamba is latitude 09^{o}10'102"N and Longitude 07^{o}12'485"E while Madalla is situated on latitude 09^{o}12'734"N and Longitude 07^{o}12'824"E and both locations are in the southern Guinea savanna zone of Nigeria.

3.1.1 Climate

The study areas had mean annual air temperature of 32 ^{o}C and annual rainfall of 1338 mm. The rainy season commences between March/April and lasts till October/November. About 74 % of the annual rainfall occurs between June and September with the peak in August (Alabi and Ibiyemi, 2000). The potential annual evapotranspiration is approximately 1,242.7 mm while the relative humidity falls between 50-70 % with a mean value of about 65 % (Okoye*et al*., 1985).

3.1.2 Geology and soils

The geology of the study areas is a basement complex which is associated with quartzite, the upland soils under the basement complex formation around the study areas are generally deep, weakly to moderately structured sand to sandy clay with gravelly and concretionary layers in the upper or beneath the surface layers (Ojanuga, 2006). Predominant and major soil types in the study areas are generally gravely red laterite developed on basement complex rocks(Lawal *et al.*, 2013).

3.1.3 Topography

The study areas has marked topographic variation with steep and very steep slopes covering about three fourth of the total area. The rest is made up of moderately steep slopes of colluvial deposits. Physical features around Kwamba and Madalla, Suleja, Niger State consist of gently undulating high plains developed on basement complex rocks. Beneath the plains, bedrock is deeply weathered and constitutes the major soil parent material (Ojanuga, 2006).

3.1.4 Vegetation and land use

The locations are belt of complex vegetation zone, being a product of centuries of trees. Natural vegetation of the study area consists of trees, bushes and savanna grasses. The trees are interspersed with shrubs and trees occurring on slopes are remnants of a once dense evergreen forest and include species such as *Nauclea latifolia, Pilliostigma thonningi and Calotropis procera*. The trees develop long tap-roots and thick backs to enable them survive the long dry season and resist bush fires (Okoye *et al.*, 1985).

3.1.5 Farming system and cropping

Agriculture is the mainstay of the economy in the study areas and is characterized by subsistence mixed crop livestock farming. Major crops in the study areas include rice, maize, vegetables, and potatoes. Livestock is closely integrated into the farming system and is used mainly for plowing, threshing, and transport. Livestock also provides food and household income. Crop residues are either removed for fuel wood or as animal feeds.

3.2 Field Study

3.2.1 Systematic grid design and soil sampling

Eleven-point twenty-five hectares (11.25 ha) farmland each in Kwamba and Madalla in Suleja respectively, were surveyed in a systematic grid design. Each grid was specified at a fixed distance of 300 x 375 meters intervals in the north to south and east to west directions and soil samples were collected at intersection points from 0 – 15 cm soil depth. The sampling point was established and maintained using a Global Positioning System (GPS) device. Soil spatial variability distribution pattern as an anisotropic medium, varying in both vertical and horizontal dimensions, the horizontal sampling techniques were considered and soil samples were collected across the soil surface. The total of 30 sampling points was selected in each farmland.

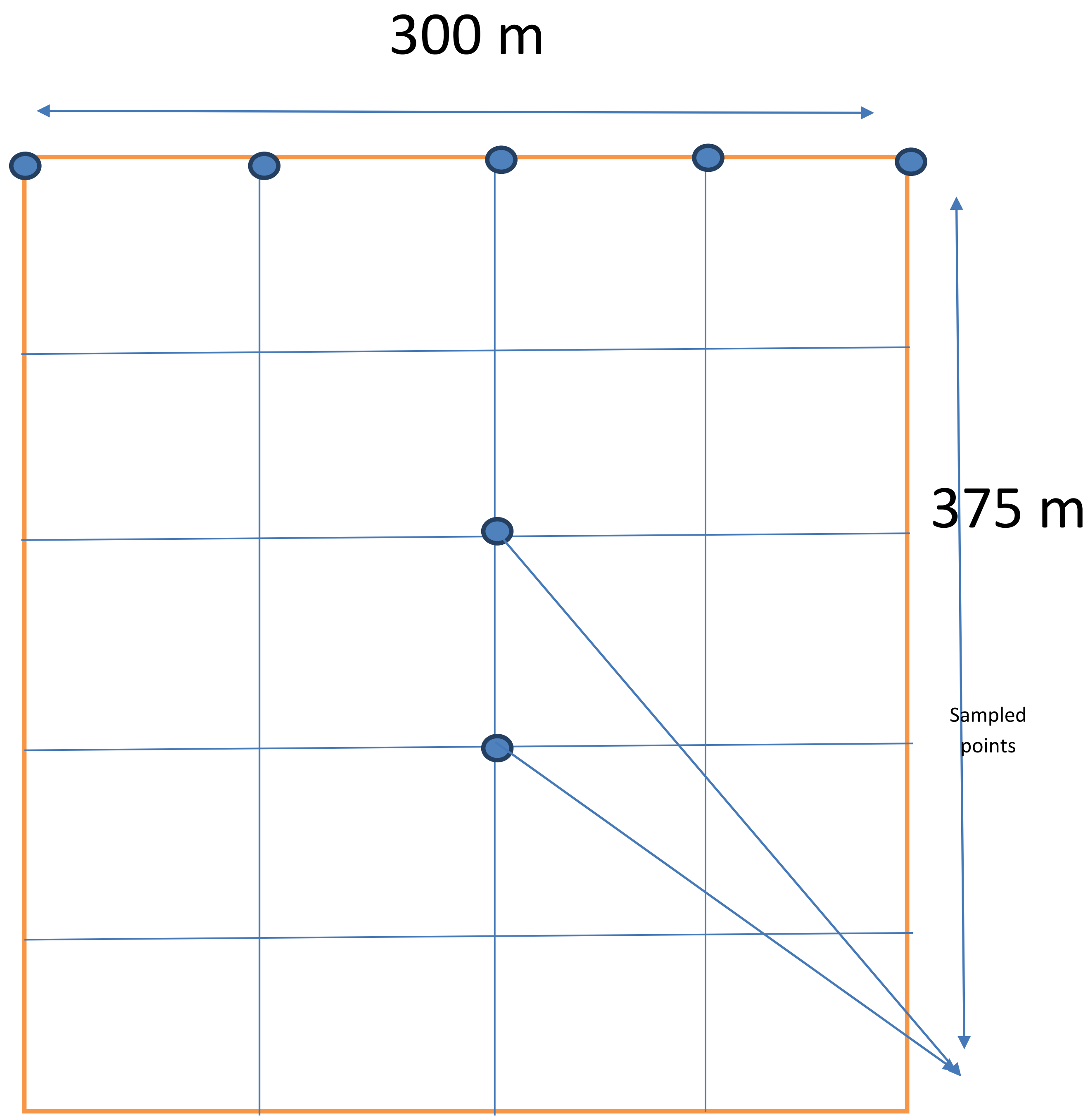

Figure 3.1: Grids design on the study locations

3.2.2 Soil sample preparation

The bulk soil samples collected from the study areas were air dried, gently crushed using porcelain pestle and mortar and passed through a 2 mm sieve to obtain fine earth separates, while some were passed through 0.5 mm sieve for total nitrogen and organic carbon determinations. The samples were properly kept for some physical and chemical properties analysis.

3.3 Laboratory Analysis

3.3.1 Determination of particle size distribution

Particles Size Distribution: The particles size distribution was determined by the Bouyoucous hydrometer method as described by Gee and Bauder (1986), by dispersing the soils samples with 5 % sodium hexametaphosphate (Na_2PO_3). The soil suspension was left on a stable surface undisturbed; hydrometer and thermometer reading were taken for both 40 seconds and 2 hours respectively. Blanks were also prepared in the same manner and hydrometer and thermometer readings were taken also at 40 seconds and 2 hours respectively. The textural classes of the soils were determined using the United States Department of Agriculture (USDA, 2004) Marshal's textural triangle.

3.3.2 Determination of soil chemical properties

3.3.2.1 soil reaction (pH): The soil pH was determined in distilled water at a 1:2.5 soil/water or solution ratio. On equilibrium, pH was read with a glass electrode on pH meter (McLean, 1982).

3.3.2.2 organic carbon: This was determined using finely ground soil samples by Walkley and Black dichromate oxidation method as described by Nelson and Sommers (1982). Concentrated sulphuric acid was used as a catalyst to activate the reaction.

3.3.2.3 total nitrogen: Nitrogen was determined using the kjeldhal distillation method as described by Bremner and Mulvaney (1982). The ammonia from the digestion were distilled with 45 % NaOH into 25 % boric acid and determined by titrating 0.05N KCl.

3.3.2.4 available phosphorus: The available P was determined by the Bray P 1 extraction method (Olsen and Sommers, 1982). The phosphorus in solution was determined calorimetrically by the modified single solution procedure using ascorbic acid (Murphy and Riley 1962).

3.3.2.5 potassium: Exchangeable Potassium was measured after extraction with ammonium acetate (Rhoades, 1996).

3.4 Statistical Analysis Method and Mapping

The data collected were subjected to descriptive statistics like mean, range, standard deviation (SD), coefficient of variation (CV). Statistical Package (SPSS,2011). was used for interpolation and mapping of the geospatial data collected from field and laboratory analysis. Spatial variability ranking was carried out as described by Wilding and Drees, (1983), in which CV values of 0-15, 16-35 and 36 % and above were classified as low, moderate and high variability, respectively.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil Physical Properties

The texture of the soils in both Kwamba and Maadalla were Loamy Sandy as presented in Table 4.1. The results show no significant difference in soil texture in the both farmlands and most of these soils are developed on basement complex, which dominated the study site with pockets of loamy sand and accounted for about 85% of the whole area.

Table 4.1 Spatial Distribution of the Soil Physical Properties

Soil Texture	**KWAMBA**					**MADALLA**				
(g kg^{-1})	Range	X	SD	CV (%)	R	Range	X	SD	CV (%)	R
Sand	734 – 864	809	32.46	4	Low	754 –864	807	31.22	4	Low
Silt	30 – 100	63	23.97	38	High	30 – 100	94	19.9	21	Medium
Clay	106 - 176	124	15.62	13	Low	96 – 156	272	15.52	6	Low

X = mean, SD = standard deviation. CV = Coefficient of variability, R= Ranking where <15% = least variable; 16-35% = moderately variable > 35% = highly variable.

4.2 Soil Chemical Properties

4.2.1 Soil pH

The soil reaction (pH) was slightly acid to neutral for both farmlands as presented in (Table 4.2). By implication, the pH of the soils falls within a favorable range of 5.5-7.0 Most plant nutrients are readily available to crop roots at pH range 5.0 to 6.0 (Adeboye *et al.,* 2009). Spatially, pH values of Kwamba range from 6.0 t0 6.81 with CV 3.10 % while Madalla range from 6.12 to 6.54 with CV of 3.3 % implying low spatial variability, this is probably due to the similar parent material in which the soils were developed and spatial distribution maps of the soil pH are graphically represented in Figures 1 and 2.

4.2.2 Organic matter (OM)

Soil organic carbon (SOC) of Kwamba ranged from 0.73 to 5.44 g kg^{-1} with CV value of 41 % while Madalla range from 1.34 to 4.53 with CV of 35 % as shown in (table 4.2 above) which was all high. Management of this farm may require measures that will ensure recycling of crop residues or other forms of soil organic matter amendments. In terms of distribution, SOC had a high CV values signifying high spatial variability. The high variation observed may likely be associated with the management practices of the farmer and which is contrary to the finding of some researchers who reported that the highest OM content is found on grasslands compared to agricultural fields (Paz-Gonzalez *et al.*, 2000) and Spatial distribution maps of the soil organic carbon are graphically represented in Figures 3 and 4 respectively.

4.2.3 Total nitrogen

Nitrogen (N) content in the Soils of Kwamba was high while Madalla is medium. This result was similarto low N content in a similar Soils as reported by (Lawal *et al.*, 2014) and (Adeboye *et al.,* 2020). Therefore, high N content observed in all sections of Kwamba farm could be as a result of application of N-rich fertilizers, such as urea, in managing the fertility of the soils by the farmer. This was a departure from findings of (Martey *et al.*, 2014) which indicated that improper fertilizer rates application by farmers contribute to the low contents of nutrients in soil. In terms of spatial distribution, N values in the soils of Kwamba ranged from 0.10 to 0.25 g kg^{-1} with CV of 34 % indicating high spatial variability and while Madalla Soils range from 0.14 to 0.28 g kg^{-1} with CV of 20 % which indicating medium spatial variability as shown in (table 4.2 above). The farm may respond to further application of N fertilizer. The high spatial variability of N will require partitioning of the farm into small uniform units for effective nutrient management and spatial distribution maps of N are graphically represented in Figures 5 and 6 respectively.

4.2.4 Available phosphorus

The values of available phosphorus (Av P) content of Kwamba was low within the range of 0.71 to 0.63 and with a CV value of 10 % while Madalla range from 0.42 to 0.31 with a CV value of 20 %as shown in (table 4.2 above) and this might be related to balanced P fertilizer application (Gao *et al.*, 2001). For areas with low soil P (<10 mg kg^{-1}), additional P fertilizer will be needed (Bruun *et al.*, 2006). Spatial distribution maps of P are graphically represented in Figures 7 and 8respectively.

4.2.5 Exchangeable potassium

Potassium (K) concentration in the soils of Kwamba range from 0.05 to 0.42 cmol kg^{-1} while Madalla range from 0.10 to 0.37 cmol kg^{-1} which was all high. Critical limits for rating K concentration in the soil was 0.15 cmol kg^{-1} for low and 0.30 cmol kg^{-1} for high fertility (Esu, 1991) and (Chude *et al.,* 2011). In terms of distribution K, Kwamba and Madalla had CV of 42.15 % and 40.01 % respectively, implying high spatial variability in the soil as shown in (Table 4.2) above.

Table 4.2 Spatial Distribution of the Soil Chemical Properties

Soil Chemical Properties	KWAMBA Range	X	SD	CV (%)	R	MADALLA Range	X	SD	CV (%)	R
Soil pH (H_2O)	6.00-6.8	6.44	0.20	3	Low	6.12-6.54	6.33	0.21	3	Low
Org C. (g kg^{-1})	0.73-5.44	2.68	0.94	35	High	1.34-4.53	2.98	1.23	41	High
Total N. (g kg^{-1})	0.10-0.25	0.84	3.62	34	High	0.14-0.28	0.20	0.04	20	Medi
Avail. P. (g kg^{-1})	0.71-0.63	0.2	0.02	10	Low	0.42-0.31	4.20	0.91	12	Low
Exc. K ($cmolkg^{-1}$)	0.05-0.42	0.16	0.11	42	High	0.10-0.37	0.20	0.08	40	High

X = mean, SD = standard deviation. CV = Coefficient of variability, R= Ranking, where <15% = least variable; 16-35% = moderately variable > 35% = highly variable**.**

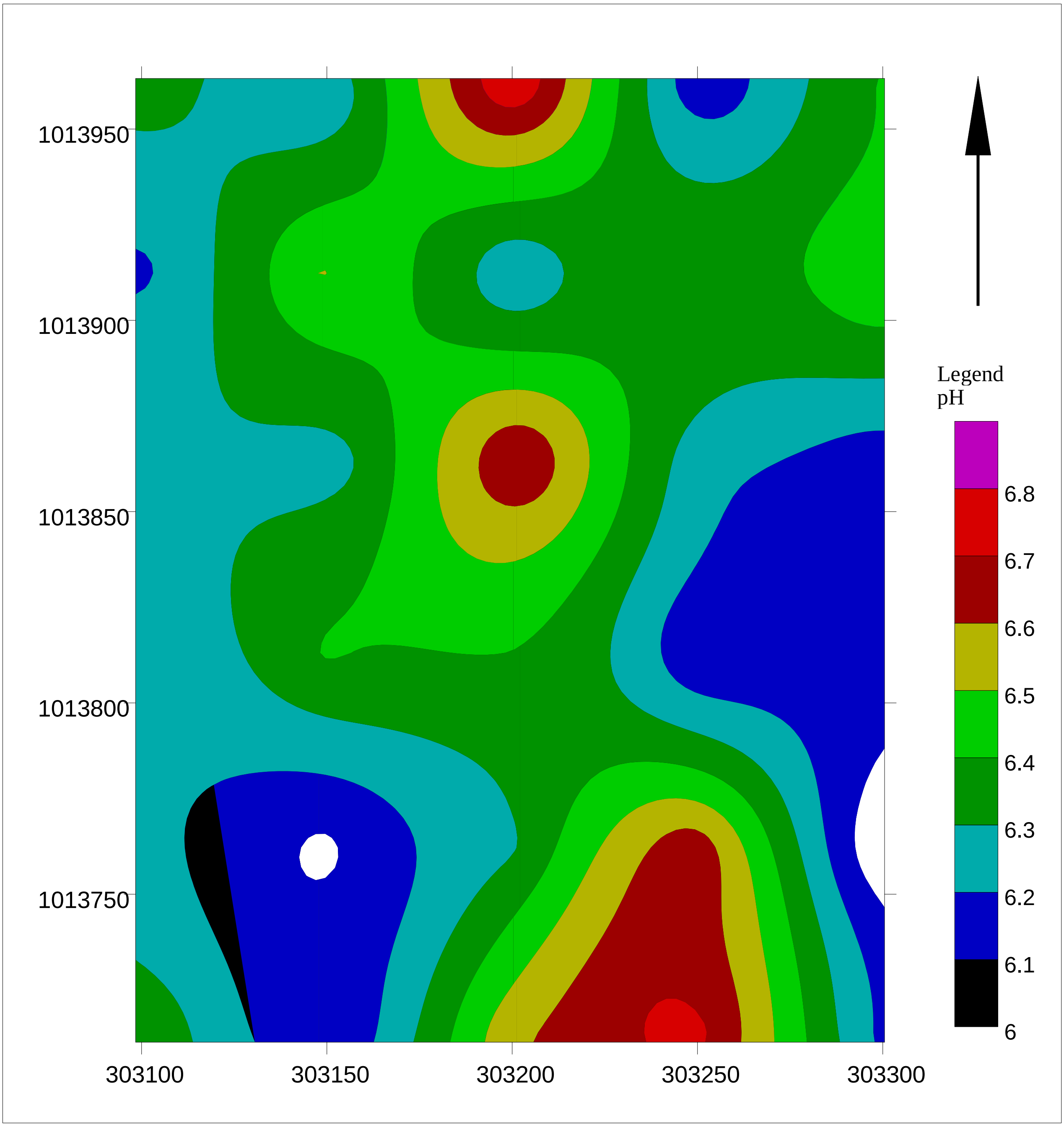

Figure 4.1: Spatial Distribution Map of Soil pH in Kwmaba

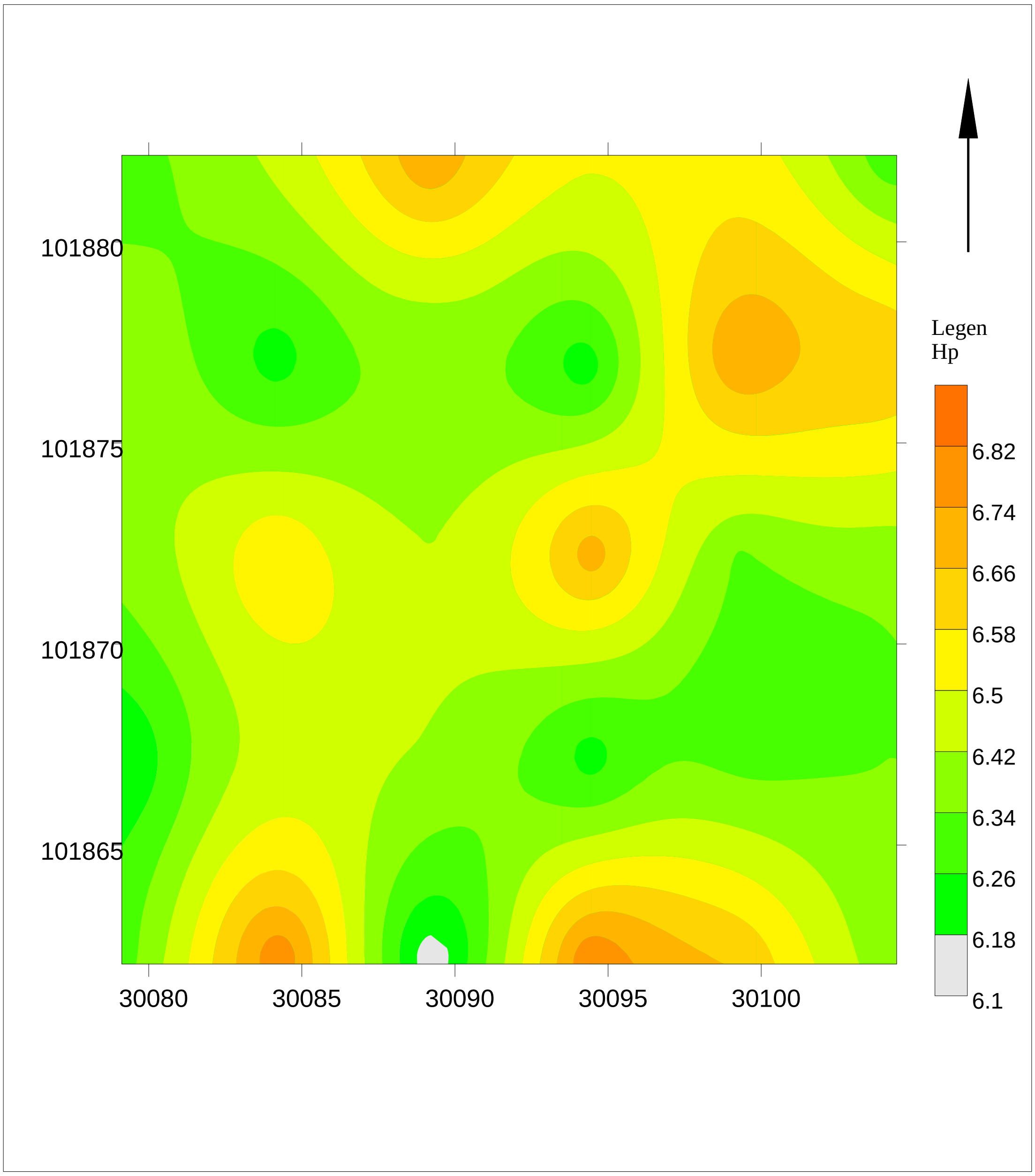

Figure 4.2: Spatial Distribution Map of Soil pH in Madalla

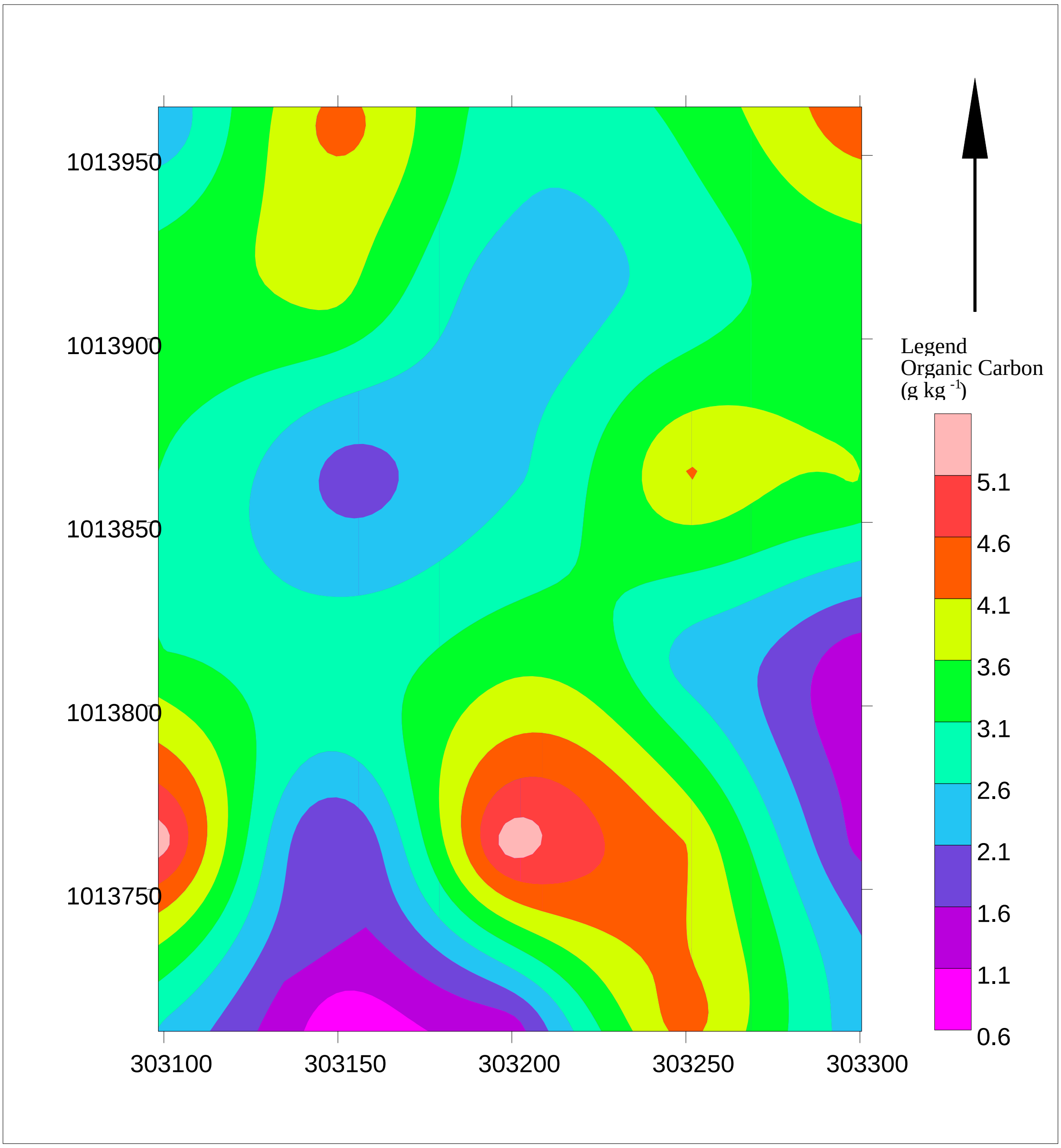

Figure 4.3: Spatial distribution Map of Soil Organic Carbon in Kwamba

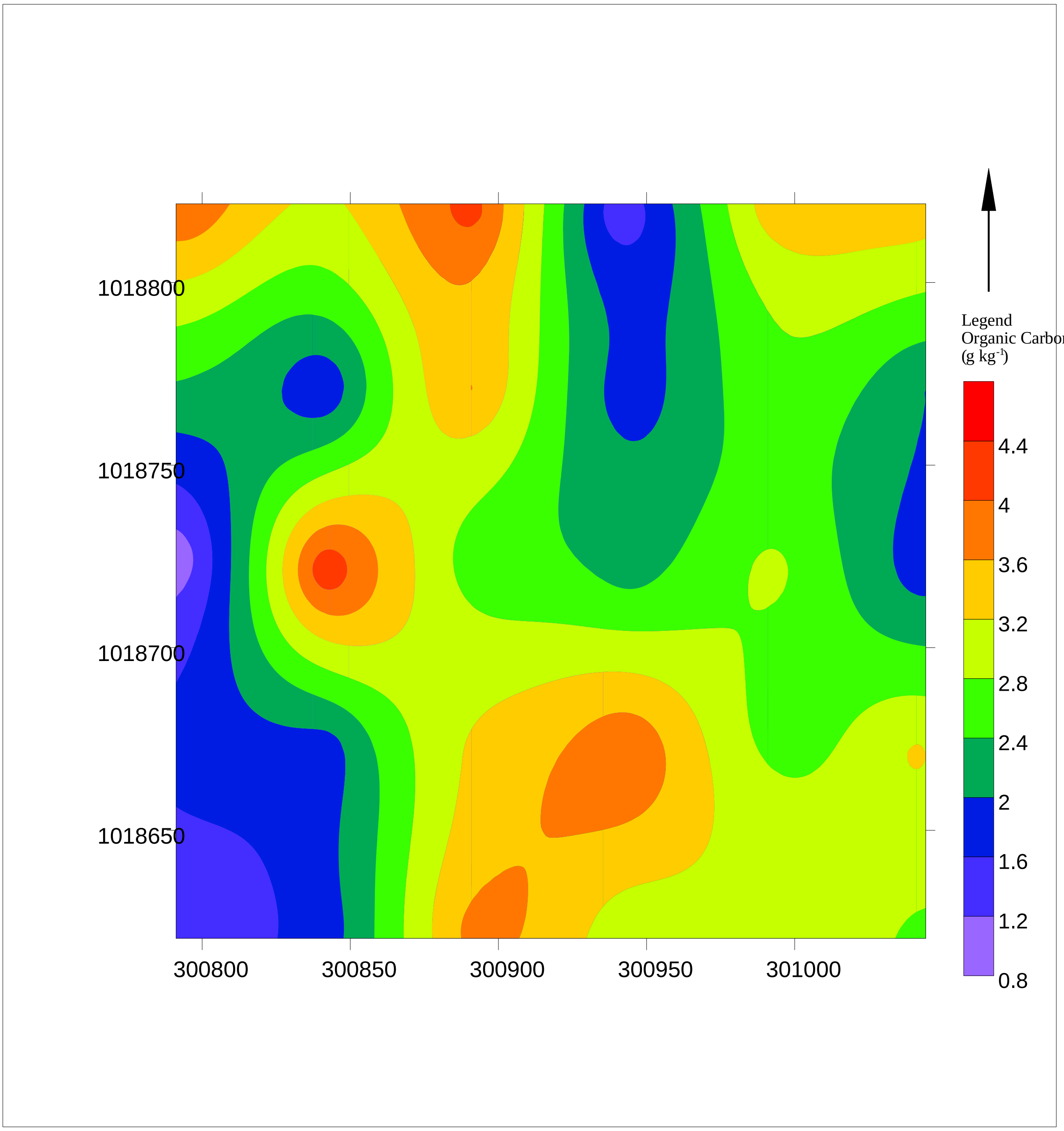

Figure 4.4: Spatial distribution Map Soil Organic Carbon in Madalla

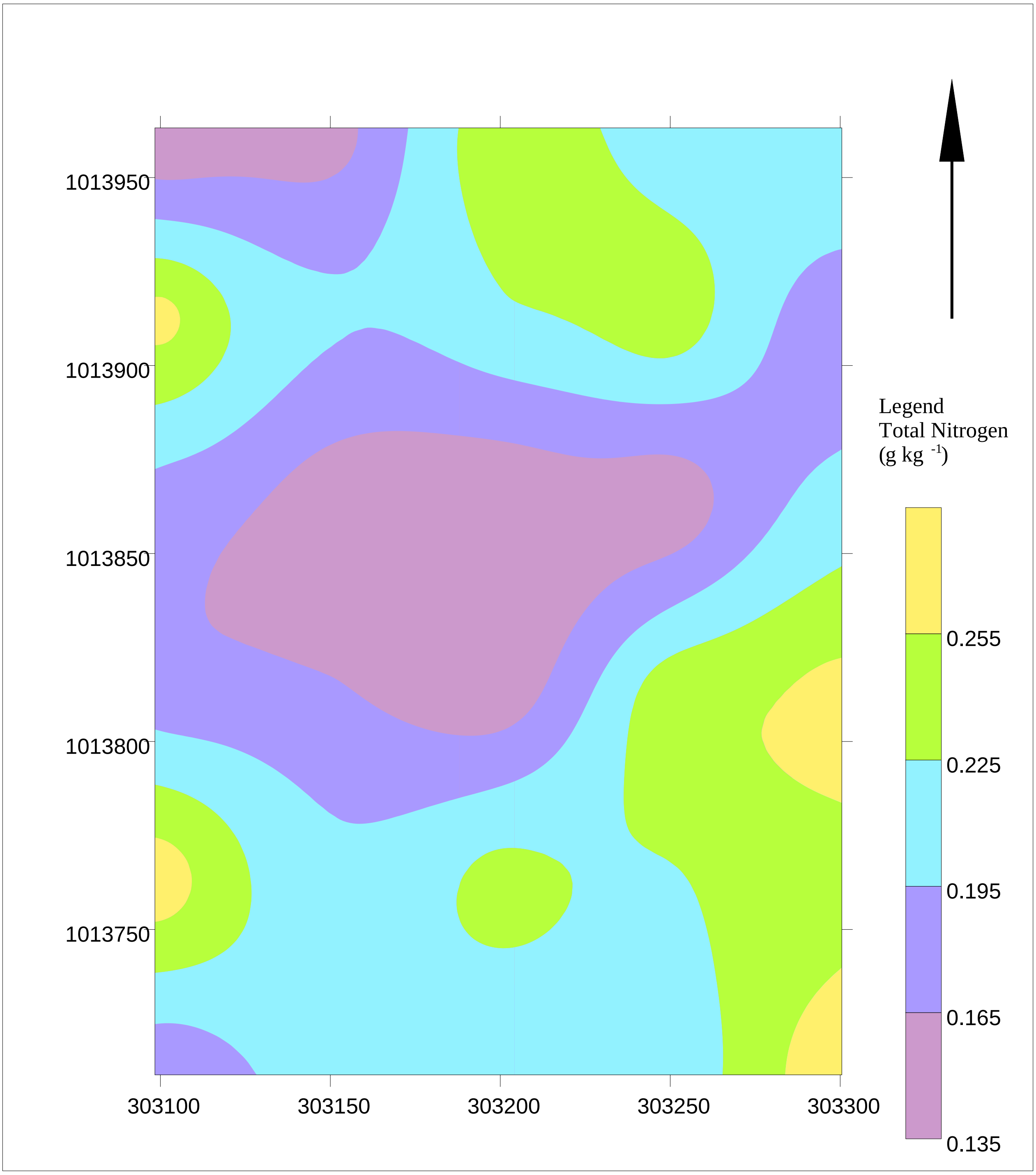

Figure 4.5: Spatial distribution Map of Nitrogen in Soils of Kwamba

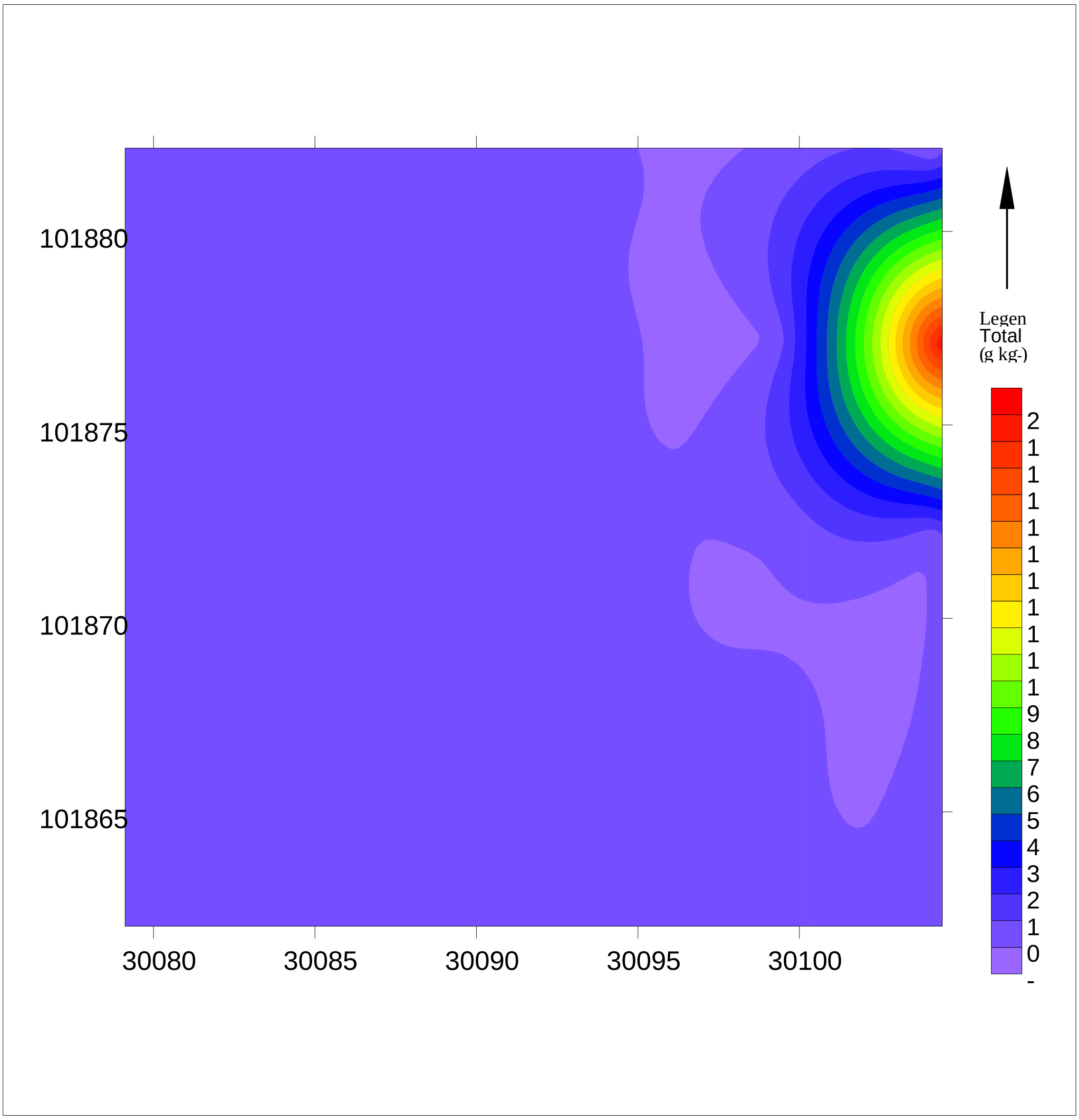

Figure 4.6: Spatial distribution Map of Nitrogen in Soils of Madalla

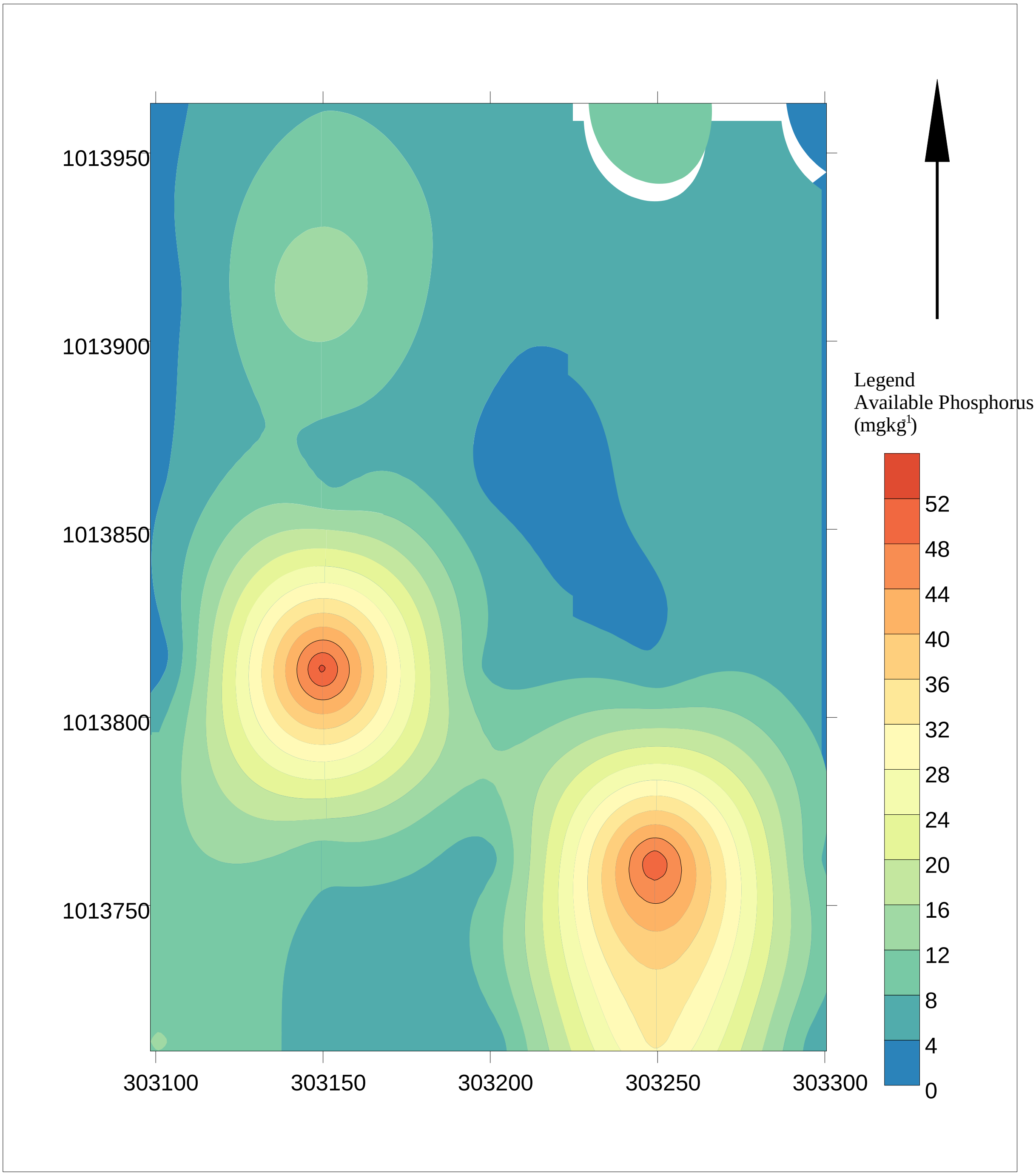

Figure 4.7:Spatial distribution Map of phosphorus in Soils of Kwamba

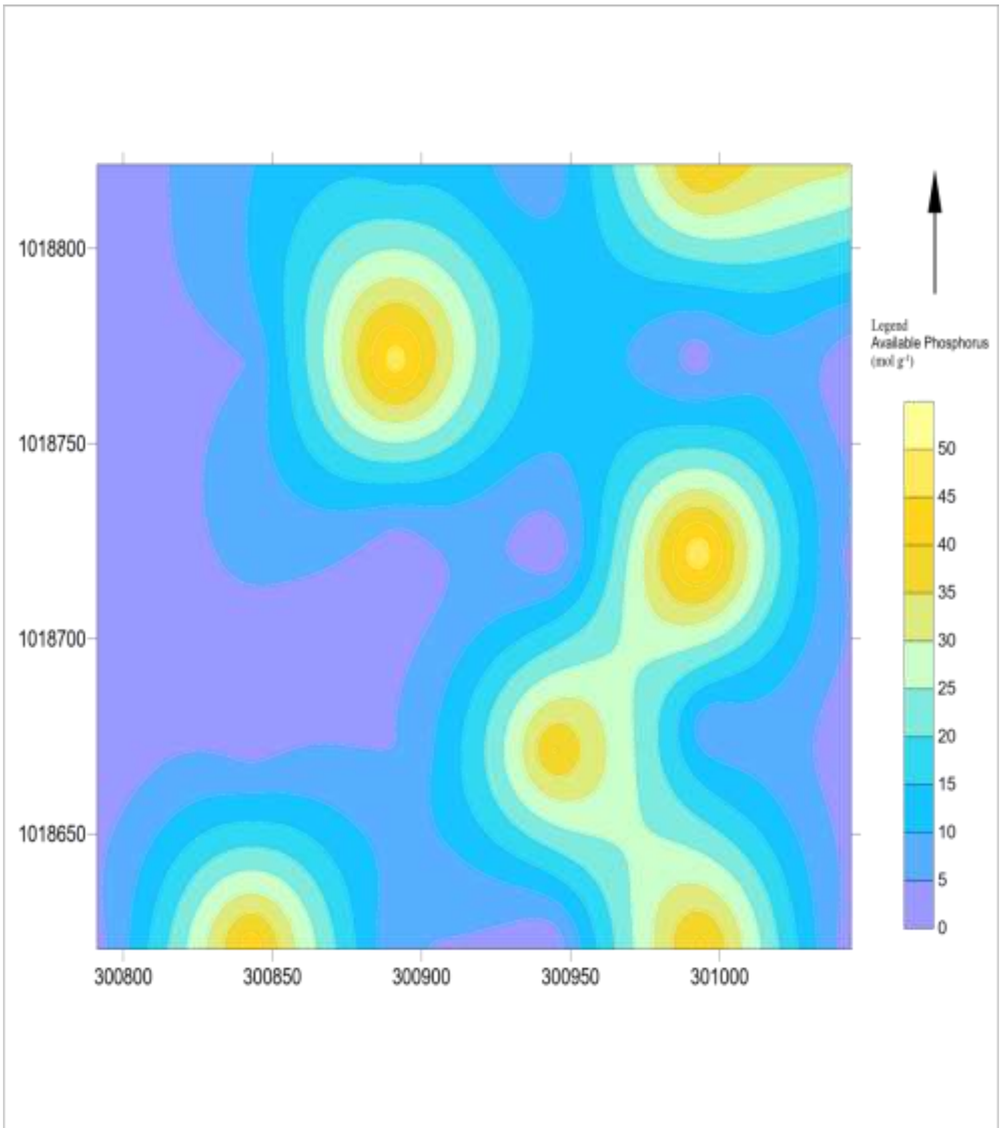

Figure 4.8: Spatial distribution Map of phosphorous in Soils of Madalla

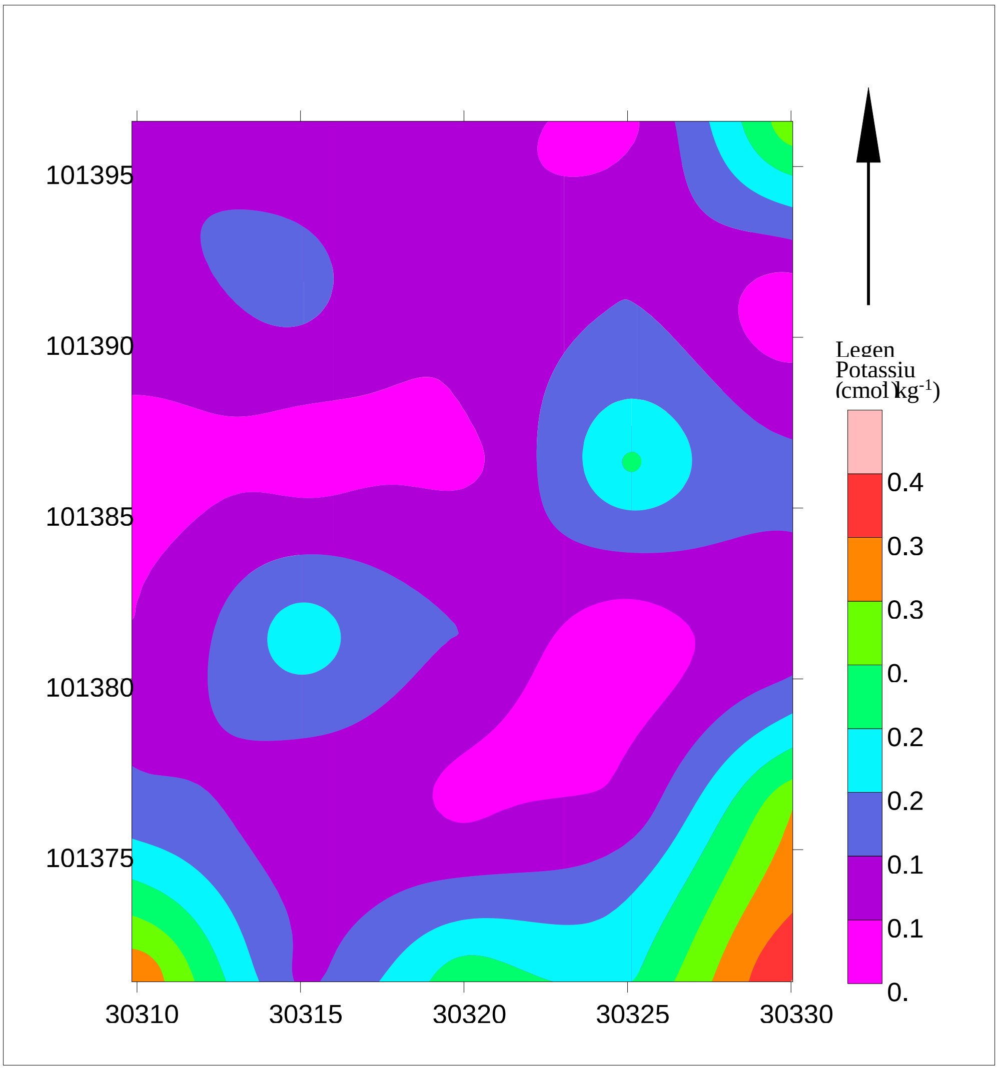

Figure 4.9: Spatial distribution Map of Potassium in Soils of Kwamba

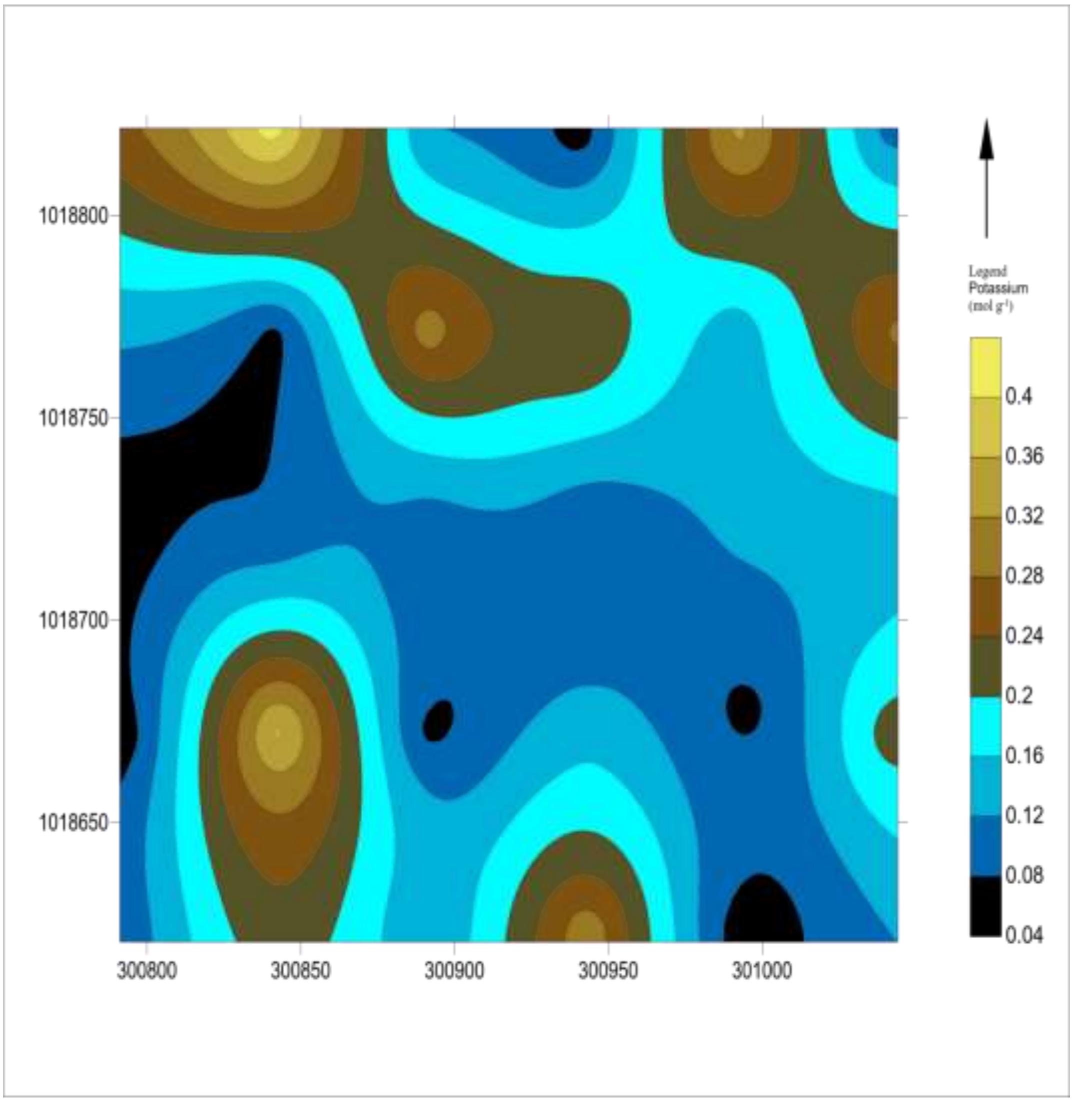

Figure 4.10:Spatial distribution Map of Potassium in Soils of Madalla

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

It could be concluded that knowledge of distribution of soil properties is important in mapping for precision management even at the level of smallholder farm. This study observed low spatial variability in sand, clay, soil pH and high spatial variability in Silt, SOC, N, P and K. Production of soil maps for site-specific management in respect of particle size distribution may not be necessary for tillage related activities and the soil may not require additional liming due to the soil acidity. spatial variability of soil properties is significant prerequisite for soil and crop management.

5.2 RECOMMENDATIONS

Soil sampling scheme and better soil management practice is recommended to farmers based on the limited nutrients and for optimum crop production, moderate application of phosphorus and potassium are required and more research should be conducted in order to understand the pattern of distribution on the studied area.The use of organic material such as cow dunk manure which is a common source and the use of mineral fertilizer are also recommended. The maps of soil spatial distribution are also recommended to the researchers or farmers to become familiar with the characteristics of the soil properties and accordingly can help to plan appropriate agricultural strategies

5.3 CONTRIBUTION TO KNOWLEDGE

This research work will help to improve sustainable agriculture and agricultural practices. Also, this research would add to the wealth of information on the soils of Suleja, Niger state, Nigeria and would provide information to land users on how toeffectively manage the soils for increased productivity.

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APPENDIX

Appendix T a b l e A:Spatial variability of the selected chemical properties of KWAMBA

Factors Sample No.	pH in H_2O	SOC (g kg^{-1})	T N (g kg^{-1})	Avail P. mg kg	Potashcmol kg
1	6.33	2.90	0.18	49.90	0.13
2	6.41	3.26	0.14	4.93	0.70
3	6.31	1.27	0.20	3.64	0.09
4	6.28	2.54	0.18	5.71	0.07
5	6.45	1.81	0.14	2.41	0.07
6	6,55	3.45	0.22	41.22	0.33
7	6.22	3.99	0.17	40.77	0.15
8	6.81	1.81	0.25	42.84	0.23
9	6,11	3.81	0.14	52.10	0.12
10	6.38	0.91	0.13	2.07	0.06
11	6.65	3.08	0.15	42.39	0,05
12	6.58	4.35	0.17	6.44	0.09
13	6.71	2.18	0.21	0.78	0.08
14	6.37	1.81	0.18	4.42	0.13
15	6.42	2.54	0.14	1.74	0.10

Source: Laboratory analysis 2021

Appendix T a b l e B: Spatial variability of the selected chemical properties of KWAMBA

Factors Sample No.	pH in H2O	SOC (g kg^{-1})	T N (g kg^{-1})	Avail P. mg kg	Potash cmol kg
1	6.18	1.81	0.24	1.34	0.06
2	6.34	3.26	0.14	2.41	0.22
3	6.65	2.00	0.20	1.34	0.29
4	6.36	2.72	0.11	2.30	0.12
5	6.81	2.90	0.18	0.73	0.31
6	6,44	3.08	0.22	9.41	0.42
7	6.31	3.99	0.25	2.13	0.27
8	6.73	4.17	0.20	13.10	0.12
9	6,28	3.45	0.18	31.19	0.10
10	6.51	1.27	0.14	5.43	0.07
11	6.22	1.63	0.10	4.87	0,07
12	6.74	2.72	0.14	2.18	0.14
13	6.41	2.36	0.17	4.20	0.13
14	6.35	3.63	0.21	48.50	0.30
15	6.21	1.81	0.17	12.49	0.24

Source: Laboratory analysis s2021

Appendix T a b l e C: spatial variability of the selected chemical properties of MADALLA

Factors Sample No.	pH in H2O	SOC (g kg^{-1})	T (g kg^{-1})	AvailP. mg kg	Potashcmol kg
1	6.33	2.18	0.14	2.69	0.18
2	6.81	2.72	0.25	5.04	0.15
3	6.41	4.53	0.22	1.74	0.33
4	6.11	3.26	0.20	10.75	0.13
5	6.23	3.08	0.17	0.78	0.14
6	6,18	3.45	0.27	1.90	0.17
7	6.30	3.08	0.18	3.25	0.12
8	6.71	2.54	0.14	2.58	0.13
9	6,48	3.08	0.17	7.78	0.10
10	6.22	4.35	0.15	8.23	0.16
11	6.51	3.81	0.20	15.90	0,20
12	6.41	2.90	0.17	53.48	0.25
13	6.38	2.72	0.25	5.38	0.18
14	6.26	1.81	0.14	6.78	0.12
15	6.19	2.36	0.28	4.70	0.42

SOURCE:Laboratory analysis 2021

Appendix T a b l e D: spatial variability of the selected chemical properties of MADALLA

Factors Sample No.	pH in H2O	SOC (g kg^{-1})	T N (g kg^{-1})	Avail P. mg kg	Potash cmol kg
1	6.00	1.45	0.24	7.06	0.34
2	6.21	2.18	0.22	4.76	0.14
3	6.08	1.27	0.20	9.18	0.15
4	6.11	2.36	0.25	4.82	0.11
5	6.28	5.44	0.24	6.05	0.13
6	6,40	3.45	0.14	6.55	0.18
7	6.13	3.63	0.21	7.78	0.19
8	6.24	4.17	0.14	5.10	0.27
9	6,38	2.54	0.17	12.26	0.37
10	6.58	1.27	0.20	4,87	0.29
11	6.68	4.17	0.22	51.63	0,15
12	6.73	4.35	0.20	32.87	0.25
13	6.23	5.44	0.28	10.25	0.19
14	6.16	1.09	0.27	5.15	0.15
15	6.10	0.73	0.21	6.66	0.17

SOURCE: Laboratory analysis 2021

Appendix T a b l e E: Particle Size Distribution of Kwamba Soils

A	Sampling Points			Particle Size Distribution (g kg^{-1})			
SN	Northing	Easting	Elevation (M)	Sand gkg^{-1}	Silt gkg^{-1}	Clay gkg^{-1}	**Textural class**
01	09^0 10.102827N	007^0 12.482185E	453	854	20	126	LOAMY SAND
02	09^0 10.103238N	007^0 12.510143E	452	844	40	116	LOAMY SAND
03	09^0 10.105294N	007^0 12.537278 E	453	844	50	106	LOAMY SAND
04	09^0 10.105705N	007^0 12.564824E	455	814	60	126	LOAMY SAND
05	09^0 10.105294N	007^0 12.591958 E	454	824	50	126	LOAMY SAND
06	09^0 10.078159N	007^0 12.482597E	454	824	60	116	LOAMY SAND
07	09^0 10.078159N	007^0 12.508909E	453	734	90	176	LOAMY SAND
08	09^0 10.077748N	007^0 12.537278E	454	804	80	116	LOAMY SAND
09	09^0 10.077748N	007^0 12.564001E	455	804	80	116	LOAMY SAND
10	09^0 10.076514N	007^0 12.591547E	452	814	30	116	LOAMY SAND
11	09^0 10.051435N	007^0 12.483008E	453	774	90	136	LOAMY SAND
12	09^0 10.051024N	007^0 12.511787E	455	824	60	116	LOAMY SAND
13	09^0 10.051435N	007^0 12.538511E	456	864	30	106	LOAMY SAND
14	09^0 10.051435N	007^0 12.565235E	455	814	70	116	LOAMY SAND
15	09^0 10.050613N	007^0 12.591547E	456	784	100	116	LOAMY SAND
16	09^0 10.051435N	007^0 12.538671E	455	774	100	126	LOAMY SAND
17	09^0 10.023889N	007^0 12.510143E	453	804	80	116	LOAMY SAND
18	09^0 10.024345N	007^0 12.537278E	450	754	90	156	LOAMY SAND
19	09^0 10.023889N	007^0 12.564824E	455	844	40	116	LOAMY SAND
20	09^0 10.022656N	007^0 12.591958E	455	834	40	126	LOAMY SAND
21	09^0 9.996754N	007^0 12.482185 E	455	774	90	136	LOAMY SAND
22	09^0 9.996754N	007^0 12.509731E	455	764	80	156	LOAMY SAND
23	09^0 9.996754N	007^0 7 12.53778E	455	804	90	116	LOAMY SAND
24	09^0 9.996343N	007^0 12.564412E	454	784	70	126	LOAMY SAND
25	09^0 9.996754N	007^0 12.59237E	455	814	70	116	LOAMY SAND
26	09^0 9.97003N	007^0 12.48383E	454	784	30	136	LOAMY SAND
27	09^0 9.968797N	007^0 12.510965E	456	854	30	116	LOAMY SAND
28	09^0 9.969208N	007^0 12.537689 E	456	834	60	106	LOAMY SAND
29	09^0 9.97003N	007^0 12.564824E	456	844	40	116	LOAMY SAND
30	09^0 9.969619N	007^0 12.591547E	456	794	80	126	LOAMY SAND
	Mean			809.33	63.33	124.0	
	Standard deviation			32.46	23.97	15.62	
	Coefficient of variation			4.0	37.8	12.6	
	Spatial variability ranking			Low	High	Low	

Appendix T a b l e F: Particle size distribution of Madalla Soils

B	**Sampling points**			**Particle Size Distribution** (g kg^{-1})			
SN	Northing	Easting	Elevation (M)	Sand	Silt	Clay	**Textural class**
01	09^0 12.734078 N	007^0 11.210381 E	449	814	70	116	LOAMY SAND
02	09^0 12.734435 N	007^0 11.235722 E	446	834	40	126	LOAMY SAND
03	09^0 12.733721 N	007^0 11.263562 E	446	784	70	146	LOAMY SAND
04	09^0 12.734078 N	007^0 11.290687 E	445	804	80	116	LOAMY SAND
05	09^0 12.734435 N	007^0 11.318527 E	445	794	70	136	LOAMY SAND
06	09^0 12.734792 N	007^0 11.345653 E	446	764	80	156	LOAMY SAND
07	09^0 12.706952 N	007^0 11.208953 E	449	844	40	116	LOAMY SAND
08	09^0 12.706952 N	007^0 11.236436 E	445	774	100	126	LOAMY SAND
09	09^0 12.707309 N	007^0 11.263562 E	446	864	40	96	LOAMY SAND
10	09^0 12.706239 N	007^0 11.291758 E	444	824	60	116	LOAMY SAND
11	09^0 12.708023 N	007^0 11.318527 E	445	754	100	146	LOAMY SAND
12	09^0 12.707666 N	007^0 11.347081E	446	854	30	116	LOAMY SAND
13	09^0 12.681611 N	007^0 11.209667 E	447	784	80	136	LOAMY SAND
14	09^0 12.680183 N	007^0 11.236436 E	444	854	50	96	LOAMY SAND
15	09^0 11.264632 N	007^0 12.680897 E	445	844	60	96	LOAMY SAND
16	09^0 12.680897 N	007^0 11.292829 E	447	774	100	126	LOAMY SAND
17	09^0 12.680897 N	007^0 11.319241 E	445	774	100	126	LOAMY SAND
18	09^0 12.680183 N	007^0 11.34601E	446	834	50	116	LOAMY SAND
19	09^0 12.6573N	007^0 11.3210 E	446	804	70	126	LOAMY SAND
20	09^0 12.653771 N	007^0 11.237506 E	444	774	80	146	LOAMY SAND
21	09^0 12.653771 N	007^0 11.263919 E	446	784	90	126	LOAMY SAND
22	09^0 12.653415 N	007^0 11.292829 E	444	794	90	116	LOAMY SAND
23	09^0 12.652701 N	007^0 11.210381 E	445	824	60	116	LOAMY SAND
24	09^0 12.653771 N	007^0 11.345653 E	444	814	70	116	LOAMY SAND
25	09^0 12.625218 N	007^0 11.210024 E	446	814	70	116	LOAMY SAND
26	09^0 12.626289 N	007^0 11.237506 E	447	834	50	116	LOAMY SAND
27	09^0 12.625932 N	007^0 11.264632 E	446	754	90	156	LOAMY SAND
28	09^0 12.626646 N	007^0 11.292472 E	445	824	60	116	LOAMY SAND
29	09^0 12.626289 N	007^0 11.319955 E	446	794	80	126	LOAMY SAND
30	09^0 12.626289 N	007^0 11.347081 E	444	834	50	116	LOAMY SAND
	Mean			807.33	94	272	
	Standard deviation			31.22	19.9	15.52	
	Coefficient of variation			3.9	21.1	5.7	
	Spatial variability ranking			Low	High	Low	

Appendix T a b l e G: Chemical properties of Kwamba Soils

A	**Sampling Points**			**CHEMICAL PROPERTIES**				
SN	Northing	Easting	Elevation (M)	pH	OC gkg^{-1}	TN gkg^{-1}	Avail. P mg kg^{-1}	K cmolkg^{-1}
01	09^{0} 10.102827N	007^{0} 12.482185E	453	6.31	3.99	0.25	2.13	0.27
02	09^{0} 10.103238N	007^{0} 12.510143E	452	6.44	3.08	0.22	9.41	0.42
03	09^{0} 10.105294N	007^{0} 12.537278 E	453	6.73	4.17	0.20	13.10	0.12
04	09^{0} 10.105705N	007^{0} 12.564824E	455	6.51	1.27	0.14	5.43	0.06
05	09^{0} 10.105294N	007^{0} 12.591958 E	454	6.55	3.45	0.22	4.22	0.33
06	09^{0} 10.078159N	007^{0} 12.482597E	454	6.28	3.45	0.18	31.19	0.10
07	09^{0} 10.078159N	007^{0} 12.508909E	453	6.41	2.36	0.17	4.20	0.13
08	09^{0} 10.077748N	007^{0} 12.537278E	454	6.22	1.63	0.10	4.87	0.07
09	09^{0} 10.077748N	007^{0} 12.564001E	455	6.35	3.63	0.21	8.50	0.30
10	09^{0} 10.076514N	007^{0} 12.591547E	452	6.21	1.81	0.17	12.49	0.24
11	09^{0} 10.051435N	007^{0} 12.483008E	453	6.74	2.72	0.14	2.18	0.14
12	09^{0} 10.051024N	007^{0} 12.511787E	455	6.65	2.00	020	1.34	0.29
13	09^{0} 10.051435N	007^{0} 12.538511E	456	6.38	0.91	0.13	2.07	0.06
14	09^{0} 10.051435N	007^{0} 12.565235E	455	6.58	4.35	0.17	6.44	0.09
15	09^{0} 10.050613N	007^{0} 12.591547E	456	6.42	2.54	0.14	1.74	0.10
16	09^{0} 10.051435N	007^{0} 12.53817E	455	6.71	2.18	0.21	0.78	0.08
17	09^{0} 10.023889N	007^{0} 12.510143E	453	6.33	2.90	0.18	4.98	0.13
18	09^{0} 10.024334N	007^{0} 12.537278E	450	6.37	1.81	0.18	4.42	0.13
19	09^{0} 10.023889N	007^{0} 12.564824E	455	6.28	2.54	0.18	5.71	0.07
20	09^{0} 10.022656N	007^{0} 12.591958E	455	6.45	1.81	0.14	2.41	0.37
21	09^{0} 9.996754N	007^{0} 12.482185 E	455	6.41	3.26	0.14	4.93	0.07
22	09^{0} 9.996754N	007^{0} 12.509731E	455	6.22	3.99	0.17	3.77	0.15
23	09^{0} 9.996754N	007^{0} 12.537278 E	455	6.18	1.81	0.24	1.34	0.06
24	09^{0} 9.996343N	007^{0} 12.564412E	454	6.34	3.26	0.14	2.41	0.22
25	09^{0} 9.996754N	007^{0} 12.59237E	455	6.31	1.27	0.20	3.64	0.09
26	09^{0} 9.970030N	007^{0} 12.48383E	454	6.81	1.81	0.25	2.84	0.23
27	09^{0} 9.968797N	007^{0} 12.510965E	456	6.11	3.81	0.14	5.21	0.12
28	09^{0} 9.969208N	007^{0} 12.537689 E	456	6.81	2.90	0.18	0.73	0.31
29	09^{0} 9.970038N	007^{0} 12.564824E	456	6.65	3.08	0.15	2.39	0.05
30	09^{0} 9.969619N	007^{0} 12.591547E	456	6.36	2.72	0.11	2.30	0.12
	Mean			6.44	2.68	0.84	0.20	0.16
	Standard deviation			0.20	0.94	3.62	0.02	0.11
	Coefficient of variation			3.10	35.0	34	10.0	42.15
	Spatial variability ranking			Low	High	High	Low	High

Appendix T a b l e H: Chemical properties of Madalla Soils

B	Sampling points			CHEMICAL PROPERTIES				
SN	Northing	Easting	Elevation (M)	pH	OC gkg^{-1}	TN gkg^{-1}	Avail. P mg kg^{-1}	Kcmol kg^{-1}
01	09^0 12.734078 N	09^0 12.734078 N	449	6.33	2.18	0.14	.69	0.18
02	09^0 12.734435 N	09^0 12.734435 N	446	6.22	4.35	0.15	8.23	0.16
03	09^0 12.733721 N	09^0 12.733721 N	446	6.81	2.72	0.25	5.04	0.15
04	09^0 12.734078 N	09^0 12.734078 N	445	6.11	3.26	0.20	10.75	0.13
05	09^0 12.734435 N	09^0 12.734435 N	445	6.41	4.53	0.22	1.74	0.33
06	09^0 12.734792 N	09^0 12.734792 N	446	6.18	3.45	0.27	1.90	0.17
07	09^0 12.706952 N	09^0 12.706952 N	449	6.51	3.81	0.20	0.90	0.20
08	09^0 12.706952 N	09^0 12.706952 N	445	6.21	2.18	0.22	4.76	0.14
09	09^0 12.707309 N	09^0 12.707309 N	446	6.38	2.72	0.25	5.38	0.18
10	09^0 12.706239 N	09^0 12.706239 N	444	6.48	3.08	0.17	7.78	0.10
11	09^0 12.708023 N	09^0 12.708023 N	445	6.30	3.08	0.18	3.25	0.12
12	09^0 12.707666 N	09^0 12.707666 N	446	6.26	1.81	0.14	6.78	0.12
13	09^0 12.681611 N	09^0 12.681611 N	447	6.71	2.54	0.14	2.58	0.13
14	09^0 12.680183 N	09^0 12.680183 N	444	6.24	4.17	0.14	5.10	0.27
15	09^0 11.264632 N	09^0 11.264632 N	445	6.13	3.63	0.21	7.78	0.19
16	09^0 12.680897 N	09^0 12.680897 N	447	6.23	3.08	0.17	0.78	0.14
17	09^0 12.680897 N	09^0 12.680897 N	445	6.41	2.90	0.17	2.41	0.25
18	09^0 12.680183 N	09^0 12.680183 N	446	6.40	3.45	0.14	0.55	0.18
19	09^0 12.657 897N	09^0 12.657346 N	446	6.11	2.36	0.25	4.82	0.11
20	09^0 12.653771 N	09^0 12.653771 N	444	6.16	1.09	0.27	5.15	0.15
21	09^0 12.653771 N	09^0 12.653771 N	446	6.23	5.44	0.28	10.25	0.19
22	09^0 12.653415 N	09^0 12.653415 N	444	6.08	1.27	0.20	9.18	0.15
23	09^0 12.652701 N	09^0 12.652701 N	445	6.28	5.44	0.24	6.05	0.13
24	09^0 12.653771 N	09^0 12.653771 N	444	6.68	4.17	0.22	0.95	0.15
25	09^0 12.625218 N	09^0 12.625218 N	446	6.00	1.45	0.24	7.06	0.34
26	09^0 12.626289 N	09^0 12.626289 N	447	6.38	2.54	0.17	0.01	0.37
27	09^0 12.625932 N	09^0 12.625932 N	446	6.10	0.73	0.21	6.66	0.17
28	09^0 12.626646 N	09^0 12.626646 N	445	6.58	1.27	0.20	4.87	0.29
29	09^0 12.626289 N	09^0 12.626289 N	446	6.73	4.35	0.20	2.07	0.25
30	09^0 12.626289 N	09^0 12.626289 N	444	6.19	2.36	0.28	4.70	0.42
	Mean			6.33	2.98	0.20	4.20	0.20
	Standard deviation			0.21	1,23	0.04	0.91	0.08
	Coefficient of variation			3.3	41.27	20.00	12	40
	Spatial variability ranking			Low	High	Medium	Low	High