USING GEOSPATIAL ANALYSIS TO MONITOR IMPACT OF INTEGRATED SOIL FERTILITY MANAGEMENT INTERVENTIONS ON MAJOR SOIL NUTRIENTS IN SELECTED DISTRICTS OF NORTHERN REGION, GHANA

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SOIL SCIENCE

BY

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DEDICATION

To my family and all those who in diverse ways have added value to my life.

CERTIFICATION

I hereby declare that this submission is my own work toward the obtainment of the PhD award and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement and recognition have been made in the text.

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ABSTRACT

Amendment of soils that are low in fertility is necessary for increased productivity under predominant smallholder farming systems in Ghana. Fertilizer recommendations that have been made to amend the soils are often blanket over entire geographic areas resulting in low efficiencies of some applied nutrients. For best results, identification of site - specific fertilizer requirement needs to be made. This study aims at (i) applying geospatial analyses to map the distribution of nutrient contents in 80 maize farm locations in the Northern region of Ghana, (ii) assessing nutrient needs of Districts based on the nutrient content and the maximum maize grain yields removed and (iii) evaluating the practices of nutrient fertilizer input by farmers and researchers and relating them to their corresponding yields to establish the appropriateness of the practices in 13 Districts within the study area. Soil samples were collected from the 80 locations and analysed for Nitrogen (N), Phosphorus (P) and Potassium (K) contents. The nutrient contents were taken through geostatistical and spatial analysis, which generated spatial models to map the distribution of the N, P and K contents across the region. Topographic elevation, soil pH and average amount of fertilizer used by smallholder farmers in the Districts were assessed in order to study their association with the soil N, P and K contents. The amount of N, P and K fertilizer input in the Districts and associated maize grain yields by farmers and researchers were calculated and compared using two-sample t-test. The amount of N, P and K nutrients removed through harvested maize produce were also evaluated in order to calculate the amount of nutrients needed to replenish the soil. Results of the study indicated that, 95% of the study area were deficient in N, 77% were deficient in P and 11% were deficient in K. The spatial dependence within the N, P and K contents distribution was moderate which implied that locations that are closer to each other may not necessarily have similar N, P and K contents and must be managed differently. The association between amount of fertilizer used by farmers and soil N, P and K contents resulted in negative coefficients (N, -0.0003; P, -0.0023; and K, -0.001); an indication that where even small amount of fertilizer input was made, there was increase in N, P and K contents in the soil. The t-test results indicated that average amount of fertilizer input by researchers was significantly ($p < 0.05$) higher than the average amount of fertilizer input by the smallholder farmers, but the high fertilizer input did not significantly ($p = 0.80$) increase researchers' maize yields more than the smallholders' in 13 Districts of the study area. On the average, five Districts applied low fertilizer and recorded low yields. But when researchers increased quantities of fertilizer applied in these five Districts, yield significantly ($p < 0.05$) increased. The outcome showed that smallholder farmers in such Districts could increase maize yields by 36% in the region should they adopt the maize production strategy by the researchers. The study therefore confirms that N, P and K contents were deficient in the study area and fertilizer application provided the needed nutrients to enhance the nutrient status to support maize yields. However, the needed input that increased maize yields was based on the nutrient status and availability of organic resources in a location. This study could enable better implementation of site - specific nutrient recommendation in the Northern Region of Ghana.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of study

Integrated Soil Fertility Management (ISFM) approaches and technologies have been developed by a number of researchers to help smallholder farmers manage their soils and ensure efficient nutrient use towards sustained crop productivity (Bationo, 2004; Vanlauwe *et al.*, 2010). In order to manage these soils and ensure sustained productivity, smallholder farmers will require adequate and affordable inputs during farming. One major input required by farmers in order to obtain better crop yields continuously is to apply fertilizers to the soils. Hence, one important aspect of ISFM technologies is to promote fertilizer application to the soil in order to supplement soil nutrient needs. However, one setback of the ISFM approach, as practised in Ghana, is that the same experiments are conducted at different districts in different communities, making it difficult to associate a particular ISFM technology to a particular location in order to monitor the impacts. Therefore, it is appropriate to document results from these experiments at the different locations and compare with indigenous farmers' approaches in order to properly promote and disseminate ISFM products; and also monitor the impact on the soil nutrients status at the different locations. Furthermore, in order to ensure that the appropriate fertilizer recommendation is proposed in a technology, it is essential to study the spatial distribution of the soil nutrients so that the nutrient needs of the locations could be considered during fertilizer recommendations. Properly dissemination and monitoring of ISFM technologies require an advancement in ISFM practices. One way proposed by Sanginga and Woomer (2009) to advance ISFM practices in Africa is to make use of appropriate tools to cautiously evaluate and validate nutrient recommendations. To make such advances in soil science therefore necessitates scientific and technological innovations that aim at improving soil fertility management (Verchot *et al.*, 2007). Technological innovations in soils would also require the use of technological decision support systems that help in soil problem diagnosis and also target better interventions.

In order to properly assess ISFM technological impacts, there is the need for thorough investigations of the different experiments that have been conducted. These investigations need to be made to collect data on locations where these practices have been implemented as well as what informs the choice of a technology in a particular locality. The investigations should require studies on the spatial distribution of ISFM technologies leading to a well-established database covering the distribution of those technologies. Spatial distribution of technologies will assist researchers to identify similar locations that could benefit from such technologies; and also enable farmers wishing to make use of these technologies to make informed choices. Ultimately, this will aid the improvement of productivity of soil services and management as intimated by Staal *et al.* (2003). In their report, Staal *et al.* (2003) proposed that evaluating crop production using a particular technology demanded accurate predictions and planning strategies, and must be formulated with the participation of stakeholders in accordance with approved regulations. They defined soil fertility management practices as means by which soil services are managed in order to increase the quality and durability of such services. The soil management practices need to be an integrated approach that will lead to the development of technologies, which will be accepted economically and socially (Verchot *et al.*, 2007). This integrated approach necessitates the need to find ways to identify technologies and to ensure proper monitoring of which technology is used where, why and how it is contributing to increased crop production in those localities (Reetz and Rund, 2004). Identification and monitoring of technologies can be done using Remote Sensing (RS) and Geographical Information System (GIS) tools such as spatial and geostatistical analytic tools which have been introduced in the study of soil science (Goovaerts, 1999).

Geographic information system and other technological decision support tools are making advances in Agriculture to improve soil vegetation cover, soil moisture and nutrient management systems (Reetz, 1998; Tsirulev, 2010). According to these researchers, GIS can be used to map soil survey data, yield data and other soil management information to reveal spatial variations that exist in fields for site specific management. The information that GIS provides can also be used to make decisions which will have positive effect on the choice of the best agricultural practices that need to be encouraged in order to promote food security.

Geostatistical analysis, which is a GIS tool provides this needed information. The use of this new tool ensures that soil nutrients are properly mapped and validated to produce reliable soil nutrient maps. With regards to the use of geostatistical methods, one aspect of the soil properties that has not been exploited much in Ghana is the mapping of the status of soil nutrient contents and their relationship to crop yield outcomes. Generally, the inability to properly put in place site-specific measures is because there is no proper site characterization to delineate management zones (Buresh and Witt, 2007). The site-specific measures that would be provided by the soil maps through a management zoning strategy will address specific issues such as not characterizing chemical properties of a location and blanket fertilizer application rates. Other decision support tools such as the Decision Support System for Agrotechnological Transfer (DSSAT) and Agricultural Production System Simulator (APSIM) have been combined with other technologies by a number of researchers in the field of Agriculture to make predictions on crop yields in Sub-Saharan Africa (SSA) (Waireji, 2011), but combining such decision support tools with GIS analysis to evaluate ISFM technologies has not been widely implemented. Technological innovations, according to Bontkes and Wopereis (2003), if combined with GIS may influence the choice of sites that need monitoring as well as areas that need modifications of such technological development. It is therefore appropriate to exploit these GIS tools to predict nutrient requirements and crop yield. This study therefore seeks to focus on the use of scientific research methods and GIS tools such as spatial and geostatistical methods to map soil nutrient contents within the study area and analyse the spatial relationship within them in order to propose District (site) specific ISFM strategies that meet the conditions at the specific locations and produce better maize yields. The analysed nutrient contents would be mapped to depict their spatial distribution. The distribution of the nutrient contents would then be used as a base map to propose ISFM practices that have been implemented in the study area and have resulted in better maize yields than farmers' practices.

The study was conducted in the Northern region of Ghana where ISFM practices are dominant and is regarded as one of the "breadbasket" regions in Ghana (Adesina, 2009). The understanding of spatial distribution of soil nutrients in ISFM dominated area, according to African Soil Health Consortium, will help refine agricultural management practices, improve sustainable land use, and provide basis for future soil nutrient recommendations at specific locations (Wairegi, 2011). These refined benefits are expected to result in the intensification of ISFM practices in the region. In addition, outputs from this study will include appropriate nutrient management practices within ISFM options that result in high crop yields proposed for the Districts based on the identified ISFM strategy; and availability of nutrient models that will help generate major soil nutrients information in the study area.

1.2 Knowledge gaps

Studies done by Desbiez *et al.* (2004) revealed that farmers have recognised soil variations within their fields and needed technological interventions to manage these variations more effectively. Verchot *et al.* (2007) explain that variation in soil fertility is one of the major constraints to crop production in smallholder farms in SSA. To resolve this constraint, the kind of variation that exists in every field should be categorised and dealt with accordingly. And one way to resolve this issue, as proposed by these researchers, is to combine the use of scientific methods such as field research analysis on soil nutrient contents and technological innovations such as RS and GIS to improve soil fertility. The use of RS and GIS is important because, as explained by Brus and De Gruijter (1997), classical statistics previously used to make predictions for soil maps have failed as a tool to develop soil nutrient maps because they treated the nutrient contents as identically and independently distributed. Therefore, it has become necessary to use model-based approaches that can map these soil nutrients appropriately.

However, in SSA, one major challenge in agriculture research capacity is the advancement of the application of the new GIS innovation and its integration into soil fertility research in national research institutions and universities even though these institutions play major role in soil fertility research (Verchot *et al.*, 2007). In addition, assessment of spatial variation in soil quality and soil degradation has been subjected to individual research procedures leading to little or no objectivity in the research results matter (Wang *et al.*, 2003). The differences in the perception of soil degradation are major constraints to solving soil degradation problems and managing soil fertility on a large scale, and even on smallholder farms. Furthermore, the extent and severity of soil nutrient degradation have normally been based on expert opinion and therefore lack scientific validity to allow for comparisons and monitoring over space and time (Verchot *et al.*, 2007).

But the use of developed approaches by spatial analysts and ecologists using RS and GIS tools have led to major breakthroughs in soil science, elsewhere. The approach has proven to be instrumental in problem identification, leading to the formulation of required interventions. Unfortunately, in Ghana, much research has not been done using spatial and geostatistical analyses to map soil properties. In Ghana, GIS and RS applications in the field of soil science have been focused mainly on mapping Land Use and Land Cover (Frimpong, 2011). Other studies in Ghana also used the approach to locate and map suitable areas for rice cultivation (Boateng, 2005) and to map fertilizer recommendations for cocoa production (Snoeck *et al.*, 2010). Because geostatistical approaches have not been explored to identify nutrient distribution in Ghana, this study was designed to include focus on the use of the approach to map soil nutrients distribution. This study seeks to fill the gap on the use of geostatistics to map soil nutrients distribution in the Northern Region of Ghana. The expectation is that spatial distribution would reveal the variations in the soil nutrients and their influence on maize crop yields in the study area. The results will lead to proposals on appropriate nutrient recommendations to enhance soil fertility management and maize yields.

1.3 Problem Statement

The soil which is a natural resource is considered as semi-renewable in the short term or sometimes a non-renewable resource (Haghdar *et al.*, 2012) because of the slow processes involved in its formation. It forms the basis for plant development and sustains animal as well as food production. The soil, however, has seen severe degradation in recent years due to factors including nutrient losses, continuous application of blanket fertilizers, moisture stress, and loss of biodiversity (Montello, 2001).

This situation has led to diminishing soil fertility and accompanying declining crop production. The situation by extension has led to increase in food production cost, severe environmental damage and incorrect application of fertilizers and poor fertilizer use (Halcomb, 1990) . These problems combined with inadequate agricultural policies could have provoked the introduction of soil fertility management procedures such as ISFM practices as a way of increasing soil fertility to sustain crop production. ISFM options can be grouped as adding organic and inorganic fertilizer, reducing nutrient losses, managing available resources properly and improving input use efficiency as outlined by Africa Soil Health Consortium (Fairhurst, 2012).

The main problem associated with the practice is that the approach has not been used to spatially target the distribution of agricultural properties by considering inherent soil characteristics and the spatial differences in soil fertility. In the Northern Region of Ghana, the use of geospatial tools would provide strategic site-selection criteria for site-specific nutrient recommendation for application and documentation.

1.4 General Research Objective

To use biophysical and GIS methods to map the spatial variation of major soil nutrient contents across the Northern region of Ghana for effective monitoring of the nutrients and enhanced maize productivity in selected Districts.

1.4.1 Specific Objectives

The specific objectives addressed in the study were to:

i. map the spatial distribution of major soil nutrients; nitrogen (N), phosphorus (P) and potassium (K) in the Northern Region.

ii. evaluate the spatial relationship between N, P and K and factors (topography, soil pH and quantity of N, P and K fertilizer used) associated with their distribution patterns.

iii. assess N, P and K nutrient management options within range of ISFM approaches and propose appropriate site-specific option(s) for the Districts under study.

iv. create a spatial database containing N, P and K status and nutrient recommendations for Districts within the study area to enable proper update of a soil fertility management base technology.

1.5 Research Hypotheses

The above research objectives were formulated based on the hypotheses that:

i. Spatial and external soil factors influence the distribution pattern of N, P and K contents in different locations. ii. High NPK fertilizer rates application by researchers produces high maize yields at specific smallholder farms.

iii. Availability of soil spatial database enables easy update of scientific technologies and visualisation of nutrients distributions using GIS-based analytical procedures.

1.6 Central Research Question

How can the GIS approach be used to reveal the spatial variation in major soil nutrient contents across the Northern Region of Ghana and how do researchers manage soil nutrients within ISFM options in selected Districts within the Region?

1.6.1 Sub-Research Questions

1. What is the spatial distribution pattern of major soil nutrients across the Northern Region?

2. Do spatial factors such as topography of landscape, soil pH and quantity of fertilizer used in a location influence distribution pattern of the N, P and K?
3. Will the application of different amounts of fertilizer produce the same maize yields regardless of location and farmer or researcher management?
4. How must ISFM technologies be stored, evaluated, monitored and updated for improved localised soil fertility management and crop yields?

1.7 Justification and significance of the study

There is a need to establish the basis for disseminating ISFM technologies. The use of GIS as a decision-making tool will allow proper analysis of factors that influence soil fertility problems and how solutions to these problems can be harnessed using tools related to their analysis. The study will allow for: (1) generation of appropriate soil nutrient models that will provide parameters for mapping soil nutrients distribution pattern; (2) mapping of selected smallholder farm locations including areas where ISFM technologies are practised and development of associated database that will allow for retrieval and update of soil information about the Districts; (3) identification and proposition of suitable ISFM technologies for the Districts. In addition, the research findings will provide policy makers with soil N, P and K information on smallholder maize farms to assist in effective site-specific fertilizer management.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil fertility degradation in SSA

One major constraint to food security in SSA has been the continuous degradation of the soil fertility (Verchot *et al.*, 2007). The authors attributed decline in soil fertility to factors ranging from soil physical and biological degradation, inappropriate agronomic practices, persistent pests and disease invasion to decline in soil nutrients. In addition, issues pertaining to this degradation are linked to institutional failures, inadequate policies, absence of decision support tools that will help make informed decisions, and inadequate motivation to tackle these issues. Soil fertility degradation has grave consequences on agricultural production in SSA because the poor soils can no longer support crop production. It is therefore necessary that the factors causing the degradation be addressed and the appropriate interventions made to restore or enhance soil fertility. The decline in soil fertility can be assessed through expert knowledge by farmers and researchers, spatial and temporal monitoring of soil chemical properties at different locations and through studies on nutrient balance (Hartemink, 2006) as related to this study.

2.1.1 Soil nutrients decline

Nutrients in the soil are essential to ensure that crop production results in desired crop yields. These nutrients are required in right amounts to support production and keep the environment in harmonised conditions. The most important major soil nutrients needed for crops to grow are N, P and K. When these major nutrients are inadequate, plant growth becomes stagnant. The decline in soil nutrients has also been attributed to farming systems that are unfavourable and does not permit the soil to regain its fertility for short periods of fallow. But it can be difficult to assess significance in nutrient decline because the processes involved in the changes of soil chemical properties are slow and need a long term research agenda to monitor. Unfortunately, according to Hartemink (2006), research in soil nutrient decline has not received similar attention as other soil related studies like soil erosion studies (Pimentel, 2006) due to the probable difficulty in its assessment spatially and temporally. Therefore spatial analysis of soil nutrients must be intensified to ensure that the status of nutrients availability in the soil is timely monitored. This will ensure that adequate nutrients are recommended for application to support the current food demand.

2.1.2 Factors that lead to soil nutrient decline

Soil nutrient decline has been described as one of the root causes that lead to soil fertility problems. The decline of the nutrients is caused by a number of factors which include unsustainable farming practices and increasing population pressure. Unsustainable farming practices include continuous cropping on the same piece of land all year round with little fallow periods, and soil loss through erosion due to improper agronomic practices. Because of inadequate agricultural lands, smallholder farmers have limited options of leaving previously cropped lands to fallow for some time before farming on them again. These farmers have also intensified cultivation of crops on these lands, sometimes extending onto marginal lands (Braimoh and Vlek, 2004). This means that the soils in such farms have to continuously supply the needed plant nutrients to support the continuous cropping. Furthermore, when the soil is made loose because of continuous tillage and harrowing, some of the nutrients leach out and render the soil poorer. The loose soil may also be exposed to wind or water erosion which also contribute to nutrient loss (Drechsel *et al.*, 2001). In addition, improper application of some N fertilizer inputs may cause the applied N to leave the soil through gaseous losses into the environment.

Population increment also increases land subdivision in communities where lands are shared among family members. Continuous land subdivision would result in smaller parcels of land, with some of the lands being changed from agricultural lands to other land uses, which will result in decrease in agricultural lands that would have been used to produce food for the growing population. To increase food production in such smaller agricultural lands therefore implies intensification of crop production per unit area. In such situation, the nutrients in the soil are mined continuously with no or little nutrient additions which are inadequate to restore the removed nutrients (Rijpma, 2003). Other factors include decline in soil pH or increase in exchangeable Al, organic matter losses from the soil and increases in toxic elements in the soil (Hartemink, 2006) that reduce the availability of some plant nutrients in the soil. Therefore activities of smallholder farmers should be streamlined to prevent soil fertility decline.

2.1.3 Consequences of soil nutrient decline

Continuous loss of nutrients in the soil, as discussed above, is the main cause of low crop productivity that threatens food security in SSA (Bationo, 2004). Nutrient mining due to continuous cropping and poor soil management cause decline in the nutrient stock in the soil. This will prevent smallholder farmers from achieving desired crop yield goals, subsequently resulting in inadequate food production to feed the increasing population and decrease in farmers' income that deprive them of a sound livelihoods (Majule, 2010).

2.2 Fertilizer recommendations and soil fertility restoration in Ghana

The soil nutrient decline needs to be replenished in order to ensure proper food security in SSA. Animal manure and crop residues have been used by smallholder farmers to replenish the lost nutrients but these have proved inadequate (Herman, 2011). The use of inorganic fertilizers therefore became necessary to supplement these organic materials. Research studies have resulted in various fertilizer recommendations and promotion. One aspect of the promotion is the blanket fertilizer recommendation to wide geographical locations without considering variations that exist in different locations. To the researchers involved in these kinds of studies, once a project resulted in an expected outcome at a specific location, they hoped it would produce the same outcome anywhere, regardless of what pertains in the different localities. However, with time, this assumption of a proposed blanket adoption and dissemination of soil management practices became an issue as recommendations did not give expected results everywhere. In response, researchers became more interested in studying variations in soil properties at different locations so that they could consider such variations when conducting research on soil resources including replenishing soil nutrient losses through fertilizer recommendations (Mowo *et al*., 2006).

Recent times have, however, seen an advanced change in agricultural systems around the world. This may be attributed to the efforts taken to restore fertility of soils at specific locations due to the continuous till of land and different changes that occur in soils as the land is tilled to produce food (Ping *et al.*, 2009). One of these changes in agriculture is the precise addition of inorganic fertilizer to the soil in a given location. Precise fertilizer formulation and recommendation as input into the soil are important because, it is necessary that the right amount is used at the right place to prevent misuse and misapplication of the nutrient fertilizers (Zhang *et al.*, 2010). The added fertilizer is necessary to ensure that the soil is fertile enough to sustain crop production.

2.2.1 Fertilizer use and maize production in Ghana

Fertilizer input must meet nutrient demands of crops to obtain enough yields. In Ghana, fertilizer application to maize fields adopted from the blanket fertilizer recommendation is insufficient (FAO, 2005). The response of maize crops to input fertilizer is also relatively high. To increase maize production in Ghana therefore implies that maize production and fertilizer application should be closely related (Atakora, 2011). The use of inorganic fertilizers and improved ways of applying these fertilizers become essential in attaining better maize production. This is important especially in locations where smallholder farmers do not have access to other organic fertilizer resources to supplement low inorganic fertilizer input. To attain yield increment on the same farmland annually therefore will require strategies that will ensure that the soil nutrient sources are adequate at specified locations. Low fertilizer input will have to be either increased to their right and required amounts at specified places or supplemented with other organic fertilizer resources where available, in required quantities, in order to meet the nutrient needs of the maize for the expected yields. The use of organic resources will improve the nutrient storage capacity of the soil and enhance maize production with low quantities of inorganic fertilizers (Chivenge *et al.*, 2011). The improvement and enhancement of production, however, depend on the quality of the added organic resource.

This assertion on the use of fertilizers therefore means fertilizer use must be adapted to situations pertaining to different locations. To achieve judicious use of these fertilizers, fertilizer recommendation should be targeted at places where they are needed with regards to amount and quality of organic resources available at such places (Reetz and Rund, 2004; Tsirulev, 2010). In this regard, fertilizer use on maize fields should be increased from the current low input to meet required amount thereby approaching the recommendation target set by the Heads of States at the African

Fertilizer Summit conducted in Abuja, Nigeria (African Fertilizer Summit, 2006). This summit was aimed at increasing fertilizer use in SSA from 8 to 50 kg ha^{-1} by 2015 (Sanginga and Woomer, 2009) in order to increase crop production.

2.3 Integrated soil fertility management (ISFM)

Integrated soil fertility management is defined as 'a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity' (Vanlauwe *et al*., 2010). It involves a number of steps aimed at improving the fertility of a soil. The processes include putting in better agronomic practices up to the use of improved seedlings and germplasm. It promotes appropriate interventions that need to be made during soil management procedures, fertilizer use and crop agronomy which result in increased yields and productivity. These interventions are affected by government policies and driven by market demands, and hence should be strategized to meet all policies to be successful. The impact of these strategies when appropriately applied are expected to lead to sustainable improvement of food security, less agricultural land use and more yield outcome, increased farm incomes and lower food prices (Fairhurst, 2012).

2.3.1 Nutrient management within ISFM

The ISFM strategy also advocates combined use of mineral fertilizers and organic fertilizers. But in situations where organic fertilizers are in less quantities, the focus has been shifted from seeking organic input from other locations to applying the requisite mineral fertilizer in order to generate enough crop residues for subsequent usage. This is because the availability of organic resources is necessary in implementing ISFM strategies (Sanginga and Woomer, 2009). The use of mineral fertilizers is to supplement the added crop residues or animal manures. The mineral fertilizers are used as supplements because they are concentrated sources of required soil nutrients that come in a form that is readily available for plants. In the implementation of ISFM strategies, emphasis is placed more on the use of fertilizers on farmers' fields where the effect will be greatest and beneficial. The beneficial effect of the use of inorganic fertilizers was illustrated by Herman (2011) where the use of inorganic N fertilizer (recommended rate of 50 kg ha^{-1}) alone produced maize grain yield which was 68% more than the use of an equivalent dry-weight of N from cattle manure, even though the yield produced from the inorganic fertilizer was still low. Since neither the use of organic resources alone nor the recommended inorganic fertilizer rate alone can meet the yield goals of maize, it is essential to advance ISFM practices to increase maize production (Tittonell *et al.*, 2008) through mapping of spatial variability of soil properties.

2.4 Technological advancement in soil science

A number of researchers have proposed different scientific and technological ways to ensure efficient use and management of soil resources (Verchot *et al.*, 2007; Killham, 2010; Wairegi, 2011). To contribute to solving the issues of food security, these scientific researchers have developed new technologies that would complement fertilizer recommendations, different ways of fertilizer applications that promote nutrient uptake by plants and different ways to control soil loss which cause nutrient depletion. The most recent ones include various models and decision support tools that ensure that proper decisions regarding the soils are made in order not to further degrade the soil, which is the primary medium that supports agriculture.

These models are used to depict the nature or state of the soil at different locations to assist in making timely interventions. They are also used in making projections and predictions of possible changes that can occur in time and space. With these innovations, there is the constant awareness creation of what is happening with the soil that supports crop growth. The opportunities presented by these new technologies that exist in soil science have, however, not been widely exploited to study the variations of soil nutrient distribution in Ghana. Since soil nutrient decline has been described as a root cause of soil fertility depletion, it will be appropriate to make use of these decision support tools to identify nutrient distribution on a geographical location and delineate management zones for prompt decision making.

2.4.1 Decision support systems (DSS)

Decision support systems are computer based programs that analyse input data in a way that will assist and influence decision making by scientists and policy makers (Keen, 1987; Shim *et al.*, 2002). The system operations are the mainstream of information system analysis. It deals with processing and analysing data to provide needed information. The information that DSS provide is managed in a database that is used for monitoring a given phenomenon. It uses simulations to model phenomena in space and in time and can be altered to mimic future situations using the same dataset (Guisan and Zimmermann, 2000).

2.4.1.1 Relevance of DSS in soil science

Before the introduction of DSS in soil science, statistical methods were used to determine how significantly different one application of soil resource was from another based on the soil properties. Even before the introduction of these statistical methods, the differences in soil resource management were based on traditional assumptions and expert opinions. However, these methods could not provide localised georeferenced information about the soil resources and soil properties with these statistical methods. Therefore, decision making by policy makers became difficult because they had to deal with assumptions. Krasilnikov *et al.* (2008) noted that engineers had made an effort to predict values of soil properties from sample data by combining classical statistics with soil classification. These engineers made soil maps on which there was a more accurate representation of random sample of soil classes.

Then, they computed data for targeted soil properties from the mean values of the data for the soil classes and used those mean values to predict the classes of soil properties of interest. In addition, they measured uncertainty within the soil maps that they made by computing the variances of the associated prediction. The degree of uncertainty thus gave a measure of validity or reliability of the soil maps produced. According to these researchers, although the classical statistics method worked for several soil engineering properties such as the Atterberg limits and the particle size fractions, it failed to work for the plant nutrients in the soil (Stewart, 2011). This was because the nutrients in the soil are strongly affected by farm management. Furthermore, the results depended on the skills and preferences of individual soil surveyors who made the maps. Some other approach was therefore needed and which led to the use of DSS.

The DSS approach has proven to be a useful tool in helping to allocate and optimise resources to specific locations without any intensive and laborious field work (Recio *et al.*, 2003), or resorting to trial and error methods of conducting research. Furthermore, the DSS integrates human expertise and the power of computer innovations in such a way that improves the effectiveness in decision making without any imposition (Keen, 1987; McCown, 2002). In spite of the difficulty in assessing the variations in soil properties within a location, the DSS has proven to be reliable in identifying soil nutrient variations at different land scales for decision making purposes.

2.4.1.2 Quantitative evaluation of fertility of tropical soils (QUEFTS)

The QUEFTS is a model that describes the quantitative evaluation of the indigenous fertility of tropical soil by using calculated yields of unfertilised maize fields as a measure (Janssen *et al.*, 1990). The model is used to evaluate the fertilizer demands of soil to produce an estimated potential yield (Liu *et al.*, 2006b). All other growth conditions are considered optimal, with the exception of fertilizer application which is considered in the model to affect the fertility of the soil (Janssen *et al.*, 1990). According to the researchers, soil fertility in this regard is interpreted as the capacity of a soil to provide plants with adequate nitrogen, phosphorus and potassium, although other nutrients are required to facilitate these nutrients provision.

The characteristics of the soil dataset required for the model to operate successfully is a well-drained, deep soil with a pH (H_2O) ranging between 4.5 and 7.0, organic carbon content of less than 70 g kg^{-1}, P-Olsen below 30 mg kg^{-1}, and exchangeable potassium below 30 mmol kg^{-1}. The chemical properties should be analysed for a soil of depth 020 cm (Smaling and Janssen, 1993). The model employs four successive steps to model the nutrients requirements and estimate yields (Das *et al.*, 2009).

The first step involves the assessment of potential indigenous supply of N, P and K nutrients by establishing the relationship between soil chemical properties and the maximum quantity of those nutrients that can be taken up by maize, if no other nutrients or other growth factors are yield limiting. The second step involves the estimation of the actual uptake of each nutrient from the soil by maize as a function of the potential supply of that nutrient by considering the potential supplies of the other two nutrients as follows:

Uptake and supply of N = Supply of P × Supply of K

Uptake and supply of P = Supply of N × Supply of K

Uptake and supply of K = Supply of N × Supply of P

The nutrients are then compared in pairs in the third step, and three yield ranges as functions of actual uptake of N, P and K respectively are designated and the lower of the two resulted estimates is considered more realistic in conformity with the law of the minimum (Smaling and Janssen, 1993). The final step is the calculation of the yield estimate by combining the yield ranges for nutrients in pairs and accounting for their interactions and averaged to obtain the ultimate yield estimate.

2.5 Heterogeneity in soil

Farmers have knowledge about variation in the soil and have considered managing the variation through their own means (Krasilnikov *et al.*, 2008). These variations have been identified to be very large sometimes even within the same field of land. Heterogeneity in soils results from dynamic processes between natural environmental factors that interact across a geographical space and time which inherently depend on the extent of a geographical location (Okeyo *et al.*, 2006). These variations affect soil management since locations exhibit different characteristics especially in their (soil) nutrient contents (Wang *et al.*, 2009). It is therefore important that these variations are studied and taken into consideration before soil management processes are put in place.

2.5.1 Soil nutrient variability assessment

Farmers have recognised variations in their soil and have therefore divided their land into fields within which the soil is treated as if it were uniform. These farmers have accepted that the cultivated fields were not uniform and had a substantial variation within them (Desbiez *et al.*, 2004; Tittonell *et al.*, 2005). However, the farmers have realised that with modern technologies, crop yields could be increased and better use of fertilizers and other agrochemicals could be made by taking soil variation into account in their management. This realization has led to the current interest in precision agriculture and the need to map the variations. In a similar way, people and their governments, at least in the developed world, have become more concerned about soil pollution and natural toxins (whether salts or trace elements) found in the soil. Maps of individual soil properties have been produced which in some instances show locations of the pollutants and their concentrations. These governments and the precision farmers want quantitative information on the substances of interest in order to strategize management procedures (Ben-Dor, 2002), hence it becomes essential that quantitative information regarding the soil properties are mapped and analysed scientifically so that the approach could be linked to the development of management practices that deal with the soil fertility issues. The mapping of soil properties is necessary for the provision of thematic information on soil properties of interest so that the right strategies would be developed for adoption to maintain or enhance soil fertility. Furthermore, Behrens and Scholten (2006) explained that when spatial distribution of soil nutrients are mapped, it avoids the use of time consuming and expensive conventional survey methods that are no longer affordable, to generate soil information systems. Soil information system generated for site-specific locations could be one sure way to progress and advance in site-specific nutrient management which could promote soil fertility in SSA.

2.5.2 Importance of assessing factors that influence soil nutrient variability

Soil properties exhibit spatial dependency, a situation whereby soil samples collected close to each other in a geographic location tend to be more correlated than those collected far apart. The spatial dependency is related to the variation in the soil arising out of a complexity of factors. Hence it is important to study the dependency that exists within the variation to identify delineated areas that can be treated and managed the same way. Nutrient management requirements for each delineated area would then be applied by considering patterns within the variation.

Crop production services from the United States Environmental protection Agency (USEPA, 2012) explained that many factors contribute to soil nutrient variations and consequently affect crop growth and yields (Letey, 1985; Lobell *et al.*, 2009). The variations exist because development of soils is over a geologic time, and is influenced by the parent material, from which they are formed, as well as climate, biota and topography (Birkeland, 1984; Jenny, 1994; Effland and Pouyat, 1997). In addition to that, soil texture, colour, and strength that are physical characteristics of the soil cannot be easily modified (Isbell, 2002) over a geographic location.

Environmental factors such as topography and slope gradient can affect the accumulation or otherwise of the nutrients in the soil. High topographic areas with high slope gradients can cause erosion to be severe in these areas resulting in loss of soil which carries nutrients away (Ferguson *et al.*, 2012). On the other hand, low elevated areas with low or uniform gradients can cause the areas to receive deposited soils and nutrients, thereby enriching these areas with nutrients. In addition, soil type of a location can affect the soil chemical properties. All soil types have their own characteristics including their capacity to store and retain nutrients.

Human activities that influence soil nutrient variability include their fertility management practices and agronomic practices (Omotesho *et al.*, 2012). For example, some smallholder farmers apply soil amendments to increase soil nutrients availability to plants while other farmers do not practice any amendment strategies and therefore accelerate nutrient mining. Farm management practices such as harrowing, burrowing, mulching, fertilizer placement, and water retention methods can also affect soil variability.

In essence, farm management practices have limited effect on altering the structure and permeability of soil (Dobermann, 2007) because of the impact that these characteristics have on the soil properties. Also, these management practices cannot easily modify cation exchange capacity, which is a soil chemical property and other chemical properties. However, management practices such as cropping patterns, history of fertilization and irrigation practices may influence residual nutrient contents, pH, and salinity when soluble salts are dissolved and concentrated in irrigation water (Wallender and Tanji, 2011). Each of the above factors may contribute to the variability in crop growth, crop yields and nutrient contents that exist in the field. In order to appreciate this variability in soil nutrients and other chemical properties and potential effects on crop productivity, they need to be properly defined at the locations and across the scope where the variations exist. This analysis and definition will enable the identification and mapping (Delve *et al.*, 2007) of the variation that exists since these factors affect the variability differently at different locations.

It therefore becomes relevant to assess how these factors influence the soil variability in a given geographical location so that better management strategies could be applied.

2.6 Global positioning system (GPS)

A GPS is a satellite system used to determine three-dimensional (3-D) position (Farrell, 2008). The system requires an appropriate receiving equipment known as GPS device to provide accurate, continuous, world-wide 3-D position information to users (Kaplan and Hegarty, 2005). The device receives satellite information from space to record the latitude, longitude, and altitude (elevation/height) data of a localised position. Latitude and longitude, also known as geographical coordinates, specified by a GPS device permit a location to be mapped using GIS software. Appropriate mapping of a location requires that the geographical coordinates be georeferenced with the appropriate geographical coordinate system (GCS) so that correct positions would be specified and integrated into the world grid system (WGS). The WGS used for GPS data differs from country to country. Ghana uses WGS 1984

(WGS (84) in short) to georeference GPS data. The local grid system is the AccraGhana grid. Therefore, the GPS device records the position in WGS (84) and when the data is imported in a GIS software, a coordinate transformation is made between WGS

(84) and Accra-Ghana grid system for accurate data georeferencing and mapping. Georeferencing GPS data will also allow relocalisation of soil sample sites in case resampling becomes necessary. The third dimension recorded by the GPS device, called altitude or elevation, is derived from data points that can be analysed spatially in a GIS software to create surfaces representing the topography of the geographical area.

2.7 Geographical information system (GIS)

Geographic Information System has been a major tool that has emerged to help solve problems and improve decisions on soil resource management in the past two and a half decades. It has been widely used in agriculture (Peterson *et al.*, 1995) and natural resources management (Delve *et al.*, 2007). During this era, precision agriculture became widely promoted (Hernandez and Yuxin, 2008) using GIS tools. As a DSS, GIS requires a system of hardware, software, procedure and personnel that facilitate the management, manipulation, analysis, modelling, representation and display of georeferenced data to solve complex problems regarding planning and management of resources (NCGIA, 1990; Wieczorek and Delmerico, 2009). With the introduction of GIS in soil science, researchers have used the tool to study and map the spatial distribution of various soil nutrients within an agricultural field (Newman *et al.*, 1997;

Liu *et al.*, 2004; Liu *et al.*, 2006b; Mallarino and Wittry, 2006). In this way, they are able to recognise the heterogeneity that exists in the field so as to take necessary measures and decisions on soil nutrient application as well as planting. Some have also been able to identify particular areas that are suitable for planting particular crops due to the inherent properties of soil that have been analysed with GIS tools (Delve *et al.*, 2007). The advantages of using this tool has been summarized by Peterson *et al.* (1995) as (i) scientific data integration and management improvement (ii) spatial and temporal variability assessment and handling (iii) soil - landscape relations modelling (iv) knowledge advancement and (v) managing landscapes as ecosystems. Hernandez and Yuxin (2008) have made it clear that GIS alone provides the ability to manage and store geographic information as well as analyse patterns, relationships and trends to help make better decisions and that some problems would remain unsolved if GIS and its related technologies were not used.

Wairegi (2011) emphasized that problems and opportunities that exist in agricultural systems can be diagnosed using decision support tools, of which GIS is one. He believed that such diagnosis could help in making alternative choices in agricultural management, experimental analysis as well as diffusion of technologies. In using GIS as a decision support tool for assessing land suitability in Ghana, Boateng (2005) established spatial inventory of land resource database to assess potential areas suitable for rice production in Ghana. He based his land suitability analysis on the methodology developed by FAO/IIASA/AEZ for Africa, which was applied in Kenya (FAO/IIASA, 1993). Lee (2009) expected this to help decision and policy makers to facilitate the identification of areas that have the potential to produce rice in the country. Studies by Snoeck *et al.* (2010) also used soil diagnostic model and GIS tools to map fertilizer recommendations in Ghana. Their study focused on converting the previous blanket fertilizer recommendation (0 N - 165 P_2O_5 - 200 K_2O kg ha^{-1}) into a more precise recommendation accounting for local land resource and the actual nutrient requirements of cocoa. These studies that have been done in Ghana have confirmed the potential usefulness of GIS tools to help solve agricultural and soil related problems. Although the tool has not yet been used to explore and model the soil nutrients in smallholder farms in Ghana, it could prove to be essential in mapping spatial distribution of soil properties for decision making purposes.

In the study of spatial distribution of agricultural systems, various researches have been done elsewhere including modelling of the spatial distribution of agricultural land use at the regional level (Rounsevell *et al.*, 2003). The researchers identified models that best represented aggregated land use at the regional level, as well as representing spatial trends in land use patterns for agriculture. In essence, spatial distribution of soil properties allow for in-depth understanding into how certain crop species do well in certain areas, why they are adopted in such locations and what contributes to their adaptation at such locations. In a related study by Liu *et al.* (2006a) in which the spatial distribution of soil organic carbon was mapped and the related factors were analysed, it was found that, locations of lower soil organic carbon was associated with larger gradients. Furthermore, this pattern was consistent with the topography and land use type which meant topography influenced the distribution of soil carbon (Tian *et al.*, 2006). In addition, the researchers investigated the storage and spatial distribution of N in China to assess the pattern of soil N distribution. They were able to establish that the total N storage in China was 5.9% – 8.7% of the total global N storage which was slightly above its average share in the global N storage, even though large areas of China were covered with low N content.

According to Staal *et al.* (2003), to avoid primitive means in the analysis of measures of location related to market access, GIS-derived variables must be integrated into household decision models through their spatial distribution. In their study, they analysed soil fertility management practices spatially based on GIS data and discovered that integrating the GIS-derived variables estimated the effects of fertility management on location much better than the usual measures employed before and offers scope for wider technology adoption in soil fertility management. Mallarino and Wittry (2006) explained that improvement in soil fertility management can be done using precision agriculture. They went on further to state that GPS and GIS tools can improve greatly soil testing techniques when they are used to better describe nutrient concentrations across a field. These technologies enhance benefits derived from fertilizer application since they are mainly for site-specific soil management practices. As computer technology continues to advance, these spatial tools, GIS and GPS, which store and analyse spatial data to make better decisions will continue to enhance agriculture and other related soil matters. These tools are powerful and complement each other for spatial analysis in agricultural sciences (Burrough, 2001). That is the reason why researchers and students in the North Carolina University used RS and GIS technologies to optimize N fertilizer management for wheat and corn in order to protect water quality. In this way GIS becomes a crucial element in the understanding and management of soils. For example, in precision agriculture, farmers use GPS, GIS, yield monitors and variable rate technology (VRT) in applying appropriate amounts of inputs in different parts of the field, as reported by North Carolina University, Department of Soil Sciences (NCSU, 2012).

2.7.1 GIS assessment of soil nutrient variability

Soil nutrient variability on the field is one of the major factors that contributes to crop yield variability (Millar, 2007; Lobell *et al.*, 2009). The spatial location of a specific plot of land has several important aspects (Staal *et al*., 2003) on its soil nutrient variability. Since the nutrient variability on the field is related to inherent properties of each location, (McBratney and Pringle, 1997) in a study of soil nutrient availability indicated that precision farming system which is implemented with GIS tools, be adopted to manage the variations. The precision farming system would integrate land resource characteristics variability (inherent properties) and crop nutrient requirements by the agronomic practices due to variation at every location in order to derive the required soil nutrients management strategy. There have been a number of different methods used to determine the soil variability within a field. The most common methods consist of one or more of the following tools: 1) Crop yield maps; 2) United States Department of Agriculture (USDA) soil survey maps; 3) Aerial photography; 4) Satellite imagery; 5) Soil electrical conductivity mapping (Veris); and 6) Detailed topographic maps from the Natural Resources Conservation Services (NRCS) under the USDA (Shanahan *et al.*, 2008). But each of these methods has its own setback (Millar, 2007).

Nevertheless, to efficiently use these methods will require a good GIS database. This database will become increasingly important as farmers work to focus their management decision skills as well as the details of using site-specific information to improve crop production practices (McBratney *et al.*, 2005). This is illustrated in the study done by (Syam, 2009) on spatial variability of nutrient content related to rice field where spatial and Geostatistical tools were used to analyse GIS data on rice to show the response of rice to nutrients (so that the nutrient applied which gave the best response in terms of yield obtained could be identified).

The use of GIS tools to assess fertility of locations before management decisions are taken is a way of implementing precision agriculture, where properties of soil are tested at different farmlands and are treated differently according to their needs and capabilities to support plant growth. Farmlands that had better and adequate soil properties were deemed fertile and managed differently from those whose properties were determined to be inadequate to support plant growth. Such lands were either adapted to suit particular crops which do not need so much nutrients in their cultivation or their nutrient requirement needs were recommended for their cultivation. This practice brought about the study of the suitability of a particular farmland to support a particular crop growth. The advanced option in precision agriculture is variable rate technology (Bullock and Lowenberg_DeBoer, 2007), where the same field is divided into different sections and managed differently. Each portion is treated differently in terms of fertilizer application according to the already existing nutrient in those locations and is mostly practiced on large acres of lands. Gradually, the mapped variations of soil nutrients enabled researchers to identify suitable areas for their research with ease and aided decision makers to allocate farming resources appropriately.

2.7.2 Application of GIS in ISFM

Fairhurst (2012) further explained that in conducting such farming systems analysis, there is a need for soil maps and other items like a Global Positioning device that will provide means for georeferencing and mapping data points. All these can be done with the use of GPS and GIS.

Various maps can be created using GIS to ensure proper soil fertility management. In terms of yield response to a particular ISFM practice, Kleinjan *et al.* (2007) explains that maps from multiple years of yield monitoring can be used to determine yield goals and fertilizer recommendations, while standard deviation maps can be used to identify areas that require corrective management. Soil maps of various types provide vital information to farmers by identifying critical sites for the implementation of precision farming practices (Cassel, 2007), such as variable seeding and fertilizer or amendment applications. But Ramisch (2008) indicated that because ISFM is complicated in nature, it must contend with certain obstacles in order to take it to higher levels. One of the obstacles in his report is that in developing ISFM principles, there should be innovation and experimentation that create opportunities and nurture the good fortunes of sudden research outcomes in order to adjust into common management principles to different local conditions (Misiko and Ramisch, 2007). To capitalize on this innovation and to create opportunities, the application of GIS in soil science should be the focus on soil science advancement. This is because one of the key significant advances that have been made over the past decade in both the science and practice of soil fertility management in Africa include the use of RS and GIS which objectively assessed the spatial variation in soil quality and soil degradation (Verchot *et al.*, 2007). In addition, they contended that this area of research would be instrumental in the diagnosis of soil problems and also better target appropriate interventions.

Application of GIS to promote ISFM strategies would be better appreciated if GIS procedures were used to identify and map ISFM strategies and relate them to the results of implementing those strategies (i.e., crop yield outcomes). In this way, ISFM strategies that need revision and those to be adopted from different demonstrations could be identified. Moreover, factors that might contribute to the implementation of the ISFM strategies could be studied and analysed to evaluate their effects to help the monitoring of their implementation.

2.7.2.1 Application of Geostaitistics in soil science

Krasilnikov et al. (2008) reported that Geostatistics have been applied in pedometrics (the application of mathematics and statistical methods for the study of the distribution and genesis of soils), as well as digital soil mapping, which Lagacherie *et al.* (2006) defined as "the creation and the population of geographically referenced soil databases generated at a given spatial resolution by using field and laboratory observation methods coupled with environmental data through quantitative relationships".

Geostatistics are also used in classical soil mapping since they allow for recovery of data knowledge hidden in traditional soil maps.

Spatio-temporal variation of soil properties have also been examined using geostatistical methods which are considered as a random process dependent on both time and space (Goovaerts, 1999). The application of geostatistical methods have also been focused on studying spatial variability of soil properties with different kriging methods over small to large spatial scales in the last two decades (Lark, 2002; Gallardo, 2003; Nayanaka, 2010). For example, Gallardo (2003) used a co-kriging method with a pseudo-cross variogram to estimate temporal changes of spatially autocorrelated soil properties. Before then, there had been an increased concern about how to estimate temporal changes of spatially varying soil attributes (Papritz and Webster, 1995; Heuvelink and Webster, 2001). Sun *et al.* (2003) also used

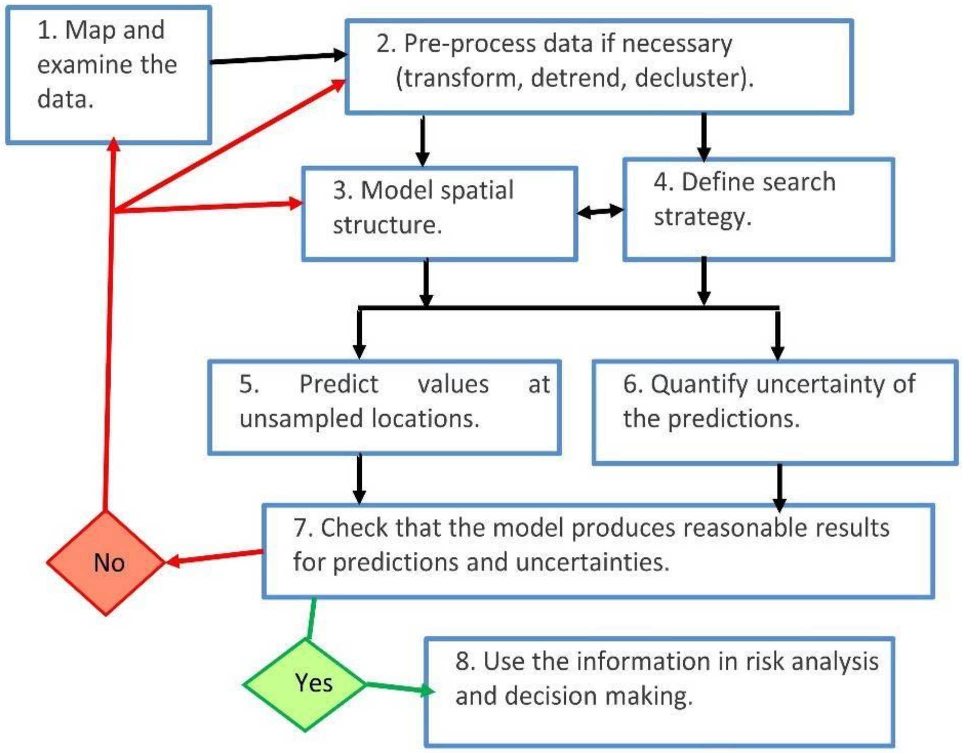
geostatistical methods to evaluate the spatial and temporal change of soil quality whilst (Liu *et al.*, 2006a) used the same methods to study the spatial distribution of soil organic carbon and analysed factors such as topography of the land that might influence the distribution of the carbon in a cropland.

Similar research activities have also been conducted where geostatistical methods were used to map specific soil horizons (Sidorova, 2008), study spatial variation of the soil floor (Solomatova and Sidorova, 2008), and to characterize changes in the spatial structure of soils (Sidorova and Fyodorov, 2008).

2.7.2.2 Geostatistical analysis of soil nutrients

Geostatistics is a class of statistics used for studying and predicting the spatial structure of georeferenced variables (Goovaerts, 1999; Krasilnikov *et al.*, 2008) that are associated with spatial or spatio-temporal phenomena (ESRI, 2010). Theses authors reported that, geostatistical tools have mainly been applied in soil science only for the past two and a half decades; with hundreds of geostatistical papers published on soil science issues in recent times. One of the specificity of geostatistical outputs is the assessment of the spatial accuracy associated with the spatial prediction of the targeted variable (Goovaerts, 1999).

In analysing soil nutrients, geostatistics employ a number of processes to generate models that can be used for the analysis and production of the final output. The processes have been described by ESRI (2010) and is presented in Figure 2.1.



Source: ArcGIS Geostatistics (ESRI, 2010)

Figure 2.1: The geostatistical model used to map spatial distribution nutrient contents.

Mapping and examining soil data points

The data set to be modelled needs to be closely examined before proceeding with the prediction and modelling. But before the examination is done on the data, they need to be mapped first to allow clear visualisation of any characteristics the dataset may present. It is important to visually check whether or not there is a pattern in how the data is mapped; that is, if lower or higher values within the data are accumulated at one particular location. In addition, it is important to note the direction in which the values are spread in order to assess the trend within the data; whether values increase from South to North or vice versa. The visualisation of the characteristics in the dataset would then give an idea of the kind of examination that will be needed to assess the data.

The dataset would then be examined based on the type of modelling to be done. Conditions are set for the different types of modelling to make predictions of variables in the dataset, for example, kriging and simulation models require that the data to be modelled follow a normal distribution. In this way, the data will be examined to evaluate if they conform to those conditions, and if they do not, the necessary actions that need to make them conform to the conditions would be taken. Furthermore, it is important to verify the necessity to subject the data to any trend removal or declustering procedures before proceeding with the modelling.

Pre-processing of soil data points

For a dataset to be modelled correctly, they need to meet assumptions of that model. Therefore if the data do not meet those assumptions after exploration, then data preprocessing become essential in order to make them meet the assumptions. Data preprocessing is done by applying appropriate transformation models to transform them so that they will follow a normal distribution (Osbourne, 2002). Transformation models used in GIS include logarithm (base 10), ArcSine and normal score. In addition, it is necessary to remove any trend that exists in the data by using a trend removal approach (constant order, 1st order or 2nd order of trend removal) so that they do not affect the results in any way. A declustering can also be applied to ensure a uniform spread of the dataset for a proper analysis to be done (Tosun, 2007).

Modelling the spatial structure of soil data points

The spatial structure allows investigation into the dataset to check if spatial autocorrelation exists. The autocorrelation will show the spatial dependency within the dataset. If there is no autocorrelation between the dataset, then interpolating the data to make predictions would produce unreliable results. Therefore, it is important to establish that autoccorelation exists in the data before proceeding with the modelling.

Defining search strategy

The search strategy defines the number of points that are used to predict a value at an unsampled location. It can also define the relationship of one location with respect to another and the unsampled location. The choice of a spatial strategy influences the interpolation procedures and hence, it must be selected in such a way that the uncertainty that will be associated with the prediction value will be minimum (Madigan and Raftery, 1994).

Predicting values at unsampled locations

The prediction is used to generate values for all unsampled locations within the area of interest. The output of the prediction is mostly a map showing values of the variable that has been modelled. Any prediction requires a prediction model, for example, kriging; and the choice of a prediction model will depend on the expected output for the phenomena.

Quantifying uncertainty of predictions

It is not enough to produce maps showing predictions of variables of interest; therefore the uncertainties associated with such predictions should be indicated (Minasny *et al.*, 2008). These uncertainties measure the accuracy of the modelling output. They allow the identification of any inadequacies in the modelling of variables, identification of variables that need improvement as well as indicating the confidence and reliability of the final maps (Dehghan and Ghassemian, 2006). Uncertainties associated with kriging models should be very small, preferably very close to zero (ESRI, 2010). Hence, it is important to verify if the interpolated values and associated uncertainties are expected or reasonable.

Validating the model

Finally, the model needs to be validated to generate report that produces summary statistics of the modelling processes. The validation should comprise the model used, any pre-processing method applied, the spatial structure model, the prediction equation for the unsampled locations, and the uncertainty associated with the predictions (Hengl *et al.*, 2010). When all these processes give satisfactory outcome, then the model is said to be validated.

2.7.3 Statistical analysis of soil nutrients

Statistics deals with the use of scientific methods to analyse measured properties of natural phenomena in order to make inferences based on the measured data. Soil chemical properties are regarded as natural phenomena which are affected by natural processes. Hence, these properties could be statistically analysed to obtain information about their patterns in the soil. In order to make a rational statistical inference based on measured soil chemical properties, the analysis must consider the objective of the investigation by involving a broad perspective of the task from the initial stage of problem definition, through to the stages of planning and data collection up to the stages of analysis and conclusion.

Concepts employed during statistical analysis may differ in some aspects based on the approach that needs to be taken during the procedure. But it is always necessary to inspect sample data values before undertaking any in-depth data analysis. This is because, data inspection may reveal shortcomings within the dataset such as duplication of values, missing data, null/zero values, and any unexpected values or outliers. These shortcomings may affect the overall analysis of the data and therefore makes it essential to go through the inspection. Some descriptive statistics that may be used to inspect the dataset and measure the distribution of the data in order to produce summary results for further actions are the four central moment measures: mean, variance, skewness and kurtosis.

2.7.3.1 The mean

The mean value obtained from measured chemical properties provides a general overview of the summary measure of samples representing a population. It provides an estimate of the nutrient contents levels in a location based on the measured contents by summing the values of variables measured and dividing by the number of the variables. The moment is usually taken about the mean and hence it represent the first central moment of a distribution (Weisstein, 2015a). For a given set of values, $x_i, \ldots, x_n$, the mean is given as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad \text{(Crump, 1998)} \qquad (2.1)$$

where n is the sample size and x_i is the measured variable.

2.7.3.2 The variance

The variance within soil chemical properties represents the second central moment of the distribution of the chemical properties (Weisstein, 2015b). It measures the spread of a distribution. If a calculated variance value is high, then it implies that the chemical properties being studied are spread out from the mean, and hence from each other (Pellissier, 2007). On the other hand, small variance values suggest that the data is close to the mean and therefore close to each other. Since the sample variance may not rightly represent the population variance when calculated, it is advisable to use the corrected sample variance from a population to estimate the variance in sample distribution. The unbiased (corrected) sample variance is calculated as:

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2 \qquad \text{(Hozo } et\ al.\text{, 2005)} \qquad (2.2)$$

The coefficient of variation (CV) is used to assess the variation and it is derived from the variance as

$$CV = \frac{s}{m} \qquad \text{(Abdi, 2010)} \qquad (2.3)$$

where s is the standard deviation and m is the mean of the N, P and K contents variables.

A given CV, which is more than about 30% might be indicative of problems within the measured variable. Such variable might need further processing to correct the inconsistencies within the variable; or the dispersion within such variable could be wide and uncontrolled (Brown, 1998). Lower CV percentages indicate better precision and consistencies. But sometimes, at very low concentration values, means of variable may be high and present high CV percentages signifying high dispersion within such variable (Lovie, 2005).

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[1] *.7.3.3 Skewness*

For a data to be considered symmetrical about its mean, the frequency distribution must be unimodal and not be skewed, that is skewness value must be zero. Skewness measures the degree of asymmetry in the distribution of a data (Weisstein, 2002). A left skewed unimodal distribution with a long tail tilted to the right is said to have positive skewness (value > 0). If the skewness values are more than zero, then it suggests that the distribution is skewed to the right with a long tail tilted to the left

(Motoyoshi *et al.*, 2007). It is generally calculated as a function of the 3rd moment about the mean. Given a set of data values, with known population mean and variance, the summation for moment of coefficient of skewness for a sample data is:

$$\text{sample skewness: } G_1 = g_1 \frac{\sqrt{n(n-1)}}{n-2} \quad (2.4)$$

g_1, the population skewness is given as: $g_1 = \frac{m_3}{m_2^{3/2}}$, $m_3 = \frac{\sum (x - \bar{x})^3}{n}$ and $m_2 = \frac{\sum (x - \bar{x})^2}{n}$ (Joanes and Gill, 1998) (2.5)

where $\bar{x}$ is the mean and n is the sample size. m_3 is the third moment of the dataset and m_2 is the variance.

2.7.3.4 Kurtosis

Kurtosis is a measure of the height and sharpness of the peak of a frequency distribution (Weisstein, 2002). High kurtosis values indicate that the distribution has a central peak higher and sharper with longer and flatter tails. A distribution with a central lower and broader peak with shorter and thinner tails suggests lower kurtosis. Kurtosis is a function of the fourth moment about the mean and can be better explained when the sample size is large enough (more than 50 for example) (Borne, 2014). A standard normal distribution has a kurtosis of 3 (excess kurtosis = 0; i.e. kurtosis - 3). For a given set of data values, $\{x_i\}$ with known population mean and variance, the moment coefficient kurtosis of a sample data is given as: sample excess kurtosis:

$$G_2 = \frac{n-1}{(n-2)(n-3)}\left[(n+1)g_2 + 6\right] \quad (2.6)$$

g_2, the population kurtosis: $a_4 = \frac{m_4}{m_2^2}$, excess kurtosis: $g_2 = a_4 - 3$ (2.7)

$m_4 = \frac{\sum (x - \bar{x})^4}{n}$ and $m_2 = \frac{\sum (x - \bar{x})^2}{n}$ (Joanes and Gill, 1998)

where $\bar{x}$ is the mean and n is the sample size. m_4 is the fourth moment of the data and m_2 is the variance.

2.7.4 The Geostatistical analyst

Geostatistical analyst is one of the GIS tools used to perform geostatistical analysis of soil properties. The analyst allows spatial prediction of geographic data and mapping of results. Krasilnikov *et al*. (2008) explained that it is used to predict soil contamination in industrial areas, to predict nutrient concentrations to build agrochemical maps in the field level, or to predict physical and chemical soil properties due to its diverse and extensive use in soil science. Geostatistics is regarded as one of the three branches of spatial statistics, with spatial analysis and spatial point processes being the other branches (Diggle and Ribeiro, 2007; Cressie, 2015). According to Webster (2008), geostatistics treat the soil properties as random processes and characterize their variations using variograms. It describes the variation in terms of spatial dependence. The variogram (also known as semi-variogram) has different parts and each part plays a role in modelling the spatial phenomena.

2.7.4.1 The semi-variogram

The semi-variogram analysis that is performed in geostatistics determines the structure and magnitude of spatial patterns of various measured soil properties (Goovaerts, 1999). He reported that the tool characterizes the spatial pattern of continuous and categorical soil attributes.

The semi-variance $\gamma(h)$, as a function of separation distance (lag h) is expressed as:

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [Z(X_i) - Z(X_i + h)]^2 \qquad (2.8)$$

where n is the number of samples separated by a distance h, and z represents the measured value for a soil property.

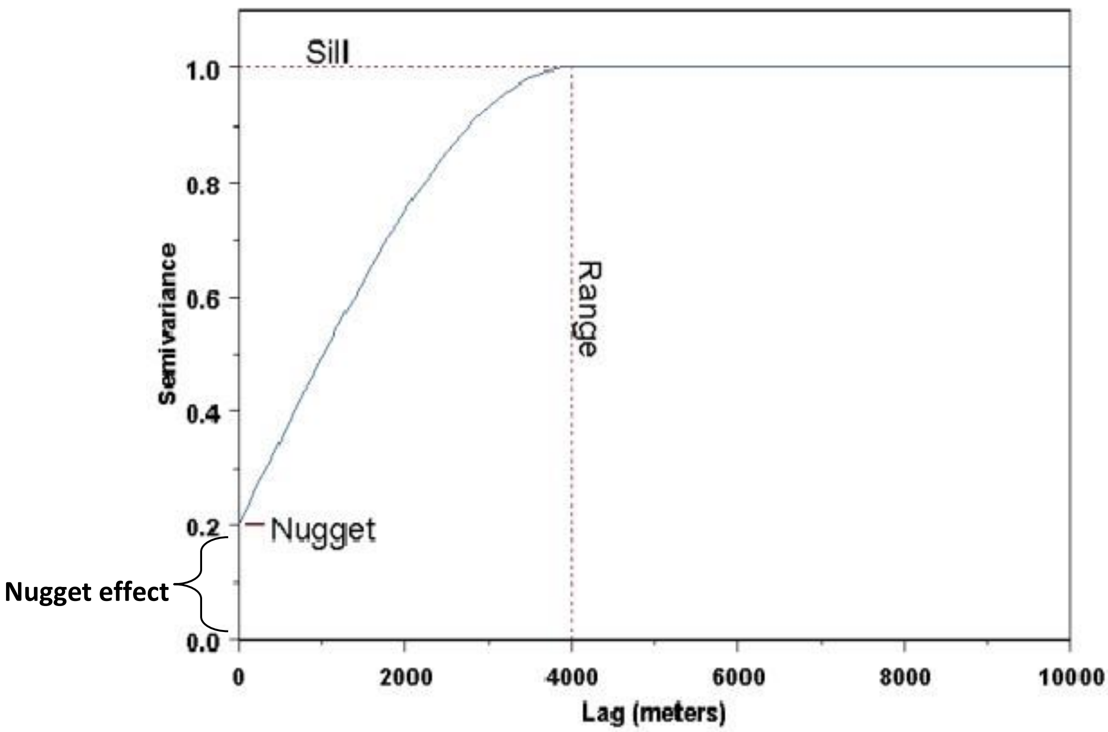
A semi-variogram (Figure 2.2) measures the strength of statistical correlation as a function of the distance and a way to measure the autocorrelation in the data variables. It has three characteristics; the sill, the nugget and the range.

The sill

The sill refers to the value of the semi-variogram at which the variogram model first levels out. It is the value that the model attains at the distance from where the model flattens off on the y-axis.

The range

The range is the distance (lag) where the model levels off. It is obtained at the point the model reaches the sill value, and at this point autocorrelation is assumed to be zero (Bohling, 2005). Sample locations are considered to be spatially autocorrelated when the distances of separation are closer than the range, and those that are far apart are considered to be less spatially autocorrelated (Tobler, 2004).



Source: (Bohling, 2005)

Figure 2. 2: Characteristics of a semi-variogram

The nugget

It is the value that the model attains at the y-axis at distance zero. This is where the semi-variogram intercepts the y-axis. In theory, the nugget value must be zero. However, at very small separation distances, the semi-variogram exhibits nugget effect. This nugget effect may arise from variability at distances smaller than the typical sampling interval or measurement error. When the nugget is deducted from the sill value, the value obtained is called the partial.

2.7.4.2 Kriging

Dealing with variation of quantities requires the use an interpolation procedure which provides the best unbiased linear estimates for such quantities (Liu *et al.*, 2004). The kriging method uses optimal, unbiased estimates of regionalized variables to predict values at locations where samples were not taken by using the structural properties of the semi-variogram and the initial set of measured data (Diodato, 2005). Simple kriging and simulations are used to model soil data by producing several realisations of the phenomena (ESRI, 2010). Kriging assumes that the data to be modelled is normally distributed. A dataset therefore need to be subjected to exploratory spatial data analysis to ensure that they meet this assumption before kriging, so that, appropriate models and parameters could be generated to map their distribution.

2.7.4.3 Stochastic simulation of point dataset

Stochastic simulation generates multiple realisations of input variables (Buttafuoco *et al.*, 2012). It is a simulation process that traces variable evolutions that have certain probabilities of changing randomly (Shalizi, 2013). Realisations are created based on a set of random values to record output of the realisation. The steps are repeated with a new set of random values of the variables, and the distribution of the output that shows the most probable estimates and expectations with respect to the ranges within which the values of the variables are more or likely to lie within (Goovaerts, 2000).

2.7.5 Contribution of geostatistics to the advancement of soil science

Geostatistics provide quantitative measures of spatial variation in the soil (Webster, 2008). Goovaerts (1999) makes it clear that the geostatistics application to soil science has primarily been the estimation and mapping of soil attributes at unsampled locations. In this way, their values can be predicted. To progress in geospatial technology, research has been intensified in the study of soil spatial variability, precision agriculture and remote sensing as what pertains in researches done in some American Universities (NCSU, 2012). The interest in the study of spatial variability and its analysis is driven by the fact that soil chemical and physical properties that vary spatially, can sometimes be very severe within the same field (Cambardella *et al.*, 1994; Jin and Jiang, 2002; Okeyo *et al.*, 2006).

In essence, through the application of geostatistical methods, most of these variations that exist in soils could be mapped to allow the appropriate interventions to be taken to address some of the issues. In addition, areas that are highly fertile in the production of particular crop have also been identified and targeted for the cultivation of such crops through mapping of their soil properties. Those that were found to be less fertile were adapted to the production of crops that could do well in less fertile soils or soil fertility interventions were put in place to remedy such situations.

2.8 Spatial analysis

Spatial analysis is a branch of GIS that explores more on the surface analytical capabilities of GIS. It describes the patterns and relationship that exist in geographic data (Fotheringham and Rogerson, 2013). Spatial analysis performed in GIS uses the spatial analyst tool which contains surface generation tools to create surface patterns. It permits the creation of useful information from a data source by deriving distances from points, polylines, or polygons. The spatial analyst tool is also used to calculate population within measured quantity and reclassify existing data into suitable classes. In addition, the tool is used to create and visualise a terrain landform. Patterns such as contours, steepest downslope direction (aspect), slope, hill shade output and view shed can be quantified to generate a surface. The surface provided can then be used for the interpretation of the analysed pattern (ESRI, 2010).

2.8.1 Models of spatial analysis

Spatial models represent real situations of modelled phenomena. They are simple, manageable and help to understand, predict or describe real world situations. These spatial models have two groups: representation and process models. Representation models depict landscape patterns and process models simulate interactions and processes in the landscape. For example, contour surface spatial analyst tool is used to depict landscape topography from elevation data while fuzzy overlay spatial analyst tool is used to overlay simulated soil properties to analyse their interactions in the landscape. Fuzzy overlay tool is used for optimal site selection or for site suitability modelling. The technique applies a common scale of values to different variables in order to obtain an integrated analysis.

2.9 Spatial statistics

Spatial statistics is a study discipline that involves using statistical and quantitative analyses to mathematically model spatial data and spatial relationships such as distance, area, length and other spatial characteristics of data (ESRI, 2015). Spatial statistics are used for different types of analyses, including pattern analysis, surface modelling, spatial regression and statistical modelling and prediction of interactions. The interest in the statistical analysis of geographic data ha increased due to the accessibility of GIS systems and geospatial data.

2.9.1 Analysing patterns within soil properties distribution

Pattern analysis within soil properties describe levels of distribution of variables in a geographic location. The pattern analysis is performed to identify the trend in the distribution of variable of interest. Spatial autocorrelation analysis is one of the tools used to analyse patterns within geographic data. It uses the Global Moran's *I* Index to measure the correlation among neighbouring features and their associated data values in a pattern that depicts their levels of spatial clustering i.e., positive spatial autocorrelation (Anselin and Getis, 2010) or their levels of spatial dispersion (negative spatial autocorrelation) (ESRI, 2015). The spatial autocorrelation tool returns five values: the Moran's Index, expected index, variance, z-score, and p-value. However, the analysis is done using the Global Moran's *I* Index and both the z-score and the pvalue to evaluate the significance of the calculated index. The Global Moran's Index (*I*) statistic is calculated as:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \quad \text{(Moran, 1948; Badu, 2010)} \quad (2.9)$$

where Z_i is the deviation of an attribute for feature *I* from its mean (x_i – X), $w_{i,j}$ is the spatial weight between feature *i* and *j*, *n* is equal to the total number of features, and S_o is the aggregate of all spatial weights which is given by:

$$S_0 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j} \quad \text{(Moran, 1948; Badu, 2010)} \quad (2.10)$$

The z- score for the statistic is computed as:

$$z_I = \frac{I - E[I]}{\sqrt{V[I]}} \quad \text{(Moran, 1948; Badu, 2010)} \quad (2.11)$$

where:

E[I] = -1/(n – 1)

V[I] = $E[I^2] – E[I]^2$

2.9.2 The strength and weaknesses of the Moran I index

Spatial autocorrelation based on Moran's Index has been applied to many fields resulting in interesting findings due to its ability to generalise the Pearson's correlation coefficient (Moran, 1948) so that a spatial sample data better represents the population from which the sample was taken. Although spatial autocorrelation from Moran's

Index is significant to spatial analysis, the procedure has not been linked to scaling laws even though correlation in geographic systems require scaling procedures (Chen and Jiang, 2010). In addition, the formula for calculating the Moran's Index is complicated, especially the spatial weights which cannot be determined objectively, and there are several problems which remain unsolved (Chen, 2012). Experts in spatial analysis are therefore conducting research to construct a framework for the theory and propose new ways to express and estimate the Moran's Index (Chen, 2013). However, since spatial weights could be generated using a GIS software, its effects is minimised on the outcome of results that expresses the significance of the spatial autocorrelation. Some studies have also shown that outcomes of some newly calculated correlation coefficients are highly correlated with the Moran's Index (Song *et al.*, 2011) and therefore could be used in spatial analysis.

2.10 Soil spatial database management systems

Accurate development of soil spatial database provides scientific basis for strategic and sustainable land use, monitoring of soil properties and land cover in order to conserve soil for its intended use (Shoba *et al.*, 2010). Spatial database are built based upon the spatial component of the data and the attributes. The database is used for storage, processing and retrieval of data.

In building a database, the spatial component should represent the exact location so that the location can be provided with its morphological description. A spatial database can be developed with an active GIS software that embeds programming in its functions to create relational databases. One of these software is the MapWindow GIS.

2.10.1 The MapWindow GIS

The MapWindow is a GIS project software for providing interface for building a spatial database. It is a free and opensource desktop GIS that has an extensible plugin architecture, an Active X control for GIS applications and a GIS programmer library to provide codes for building the database. It provides mapping functionality to user written windows forms application. The codes for operating in the MapWindow are mostly written in visual basic (VB) 6, VB.NET or C# (Ames, 2015).

Summary

Soil nutrient decline has been identified to be a major constraint to food security in SSA. Ghana, as a developing country in SSA, is faced with similar challenges in food security. Technological innovations based on the application of DSS such as GIS tools combined with other models such as DSSAT, APSIM and QUEFTS have been employed to address some of the issues on nutrient decline based on ISFM technologies in order to raise food production in other countries. Unfortunately, such technological innovations have not been widely promoted in Ghana, especially in the breadbasket regions of which Northern Region is one. Since a dynamic GIS based on spatial properties of soil is important for research, an analysis that combines both spatial and quantitative measures to address soil related problems could make up for deficiencies within ISFM strategies. Therefore combination of GIS tools (to map spatial distribution of soil nutrients in order to identify their variations in the region) and QUEFTS model (to calculate nutrient requirement based on the variations in nutrient status) is deemed appropriate and in the right direction. ISFM strategies that meet requirements of the model and produces increased production could therefore be recommended for specific Districts so that food security issues in Ghana could be managed.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The Study Area

Integrated Soil Fertility Management practices are done intensively in the three Northern regions of Ghana namely Northern, Upper East and Upper West, which are classified as the "breadbaskets" of the country (Adesina, 2009). This study was conducted in the Northern Region of Ghana which has a territorial land area of about 70, 384 km^2 (Figure 3.1).

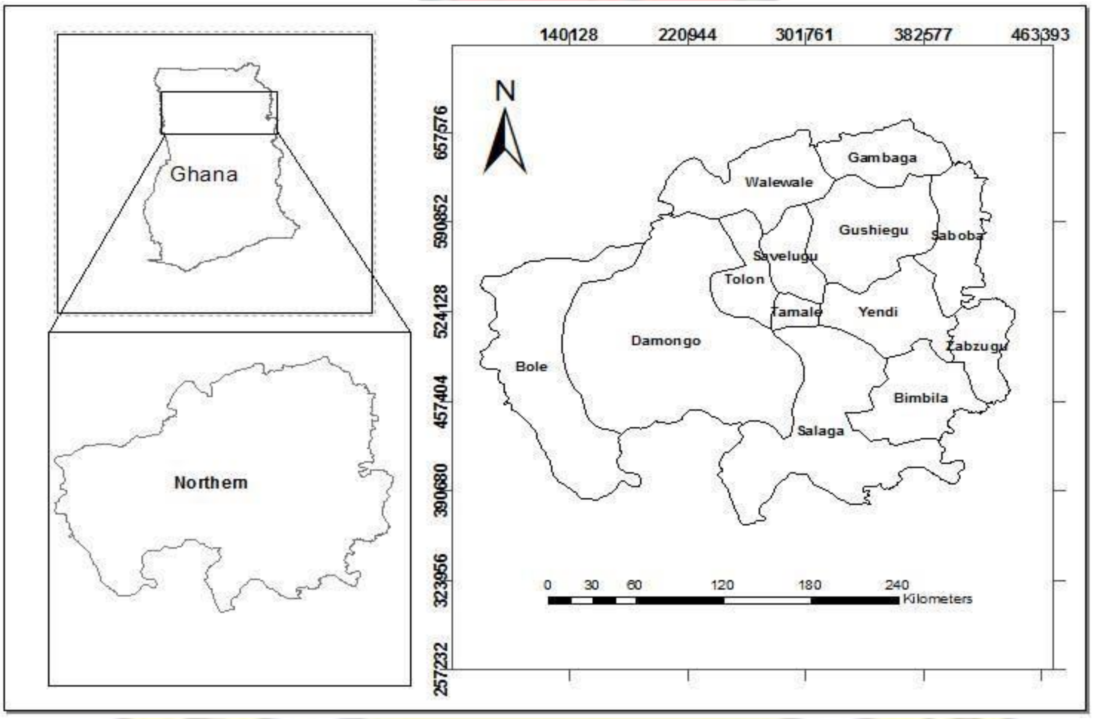


Figure 3.1: Map of study area.

It is located geographically within latitudes N9º 30' and N10º 00'and longitudes W0º 51'and W1º 00' with a mean elevation of 149 m above mean sea level (Getamap, 2006). The mean annual rainfall of the region is between 750 mm and 1050 mm and is be located in the Guinea - Savanna agro-ecological zone (Agyare, 2004). About 80% of the land area is used for agriculture (Karbo and Agyare, 2002), while the 20% is used for industry and other activities. The average temperature of the region is about 28 ºC but can be as low as 14 ºC during the night in December/January and as high as 40 ºC in February/March during the day (GoG, 2015). The major soils of the region are lixisols, luvisols, acrisols and gleysols (Dedzoe *et al.*, 2001). Most of the major food crops in Ghana are cultivated in this region and they include maize, rice, millet, sorghum, yam and cowpea. However, only maize croplands were targeted in this study because it is anticipated that maize will remain one of the central crops in the "food security equation" in case the agricultural economy is modified (Sauer *et al.*, 2007). Some properties availability status indicators of the soils in the study area are presented in Table 3.1.

Table 3.1: Average soil chemical properties in the Northern Region of Ghana

Soil property	Status
Total Nitrogen (%)	0.02 – 0.05
Organic Matter (%)	0.6 – 2.0
Available Phosphorus (mg kg^{-1} soil)	2.5 – 10.1
Exchangeable Calcium (mg kg^{-1} soil)	45 – 90
Soil pH	4.5 – 6.7

Sources: AQUASTAT data from Soil Research Institute-Council for Scientific Research Institute, Kumasi (2005), FAO/NRMED (2005); modernghana.com (2005) on 22/10/2013

3.2 Data sources

Topographical map of the study area was obtained from the Department of Geomatic Engineering, KNUST, and was used as a base map for the study. Farm practice data regarding the use of fertilizers from farmers and other stakeholders involved in the ISFM project were obtained from the Savanna Agriculture Research Institute (SARI), Tamale in the Northern region. Crop yield data collected from both farmers and researchers were also obtained from SARI and used to assess the differences in crop yield that informed further analysis. Field location data points obtained with the GPS provided the coordinates of locations of farmers' fields. Soil samples from five farm locations within each District were used to assess the variation in concentrations of major soil nutrients - N, P and K.

3.3 Materials

Materials used in collecting soil samples from the study area were soil auger, mallet, bucket, and plain polyethylene bags. The Garmin geographical positioning system (GPS), with error margin of +/-5 m, was used to collect coordinates of farm locations where soil samples were taken. The GPS was also used to collect approximate elevation points of farm locations. Software programmes that were used for analyses of data were ArcGIS 10th edition (2010), SPSS 16th edition, Genstat statistical package 12th edition (2012), StatsDirect (version 2.8.0) statistical software (2013), QUEFTS model (2011) and MapWindow® GIS software (2012).

3.4 Methodology

3.4.1 Generation of point dataset for geospatial analysis

An in-depth study to collect and identify areas under ISFM technologies was done, using database obtained from SARI. Field reconnaissance was initially done in the study area to gather information from smallholder maize farmers to gain knowledge on which farms to use as representatives in the Districts. Then collection of data from farmers was done through distribution of questionnaires to farmers pertaining to the type of fertilizers they used, the amount they applied to their farm areas and the crop yields they were able to obtain. In addition, fertilizer application as well as crop yield data from ISFM trials in the various Districts were obtained from SARI. The Garmin GPS device was also used to obtain these farm locations as point data which were plotted on the base map of the study area. In all, five farmlands were localised from each of the 16 Districts where the study was done, giving a total of 80 locations that were used in the study between May, 2012 and March, 2013.

The localised 80 farmers' fields were downloaded from the Garmin GPS into Expert GPS software where the points were converted from GPS exchange format (.gpx) into shapefile format (.shp), which was a readable format for ArcGIS/ ArcInfo software used for the analysis.

3.4.2 Processing of topographic base map

The digitized topographic map of the study area was obtained from the Geomatic Engineering Department of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. The obtained digitized map was already in a shapefile format and did not require any exchange format. This digitized map was used as the base map on which data points were superimposed in order to conduct other analysis within the study area. The base map was imported into the ArcInfo software and was projected onto the Accra Ghana geographic coordinate system (GCS) with reference from the World Geographic System 1984 (WGS 84) coordinate system. This referencing allowed for accurate georeferencing of the data points in order to obtain precise location of points in the real world system so that accurate thematic maps could be derived. The digitized map has a flexible scale adjustment to allow for viewing of details at different scales. Database was generated based on the choice of a particular ISFM practice in a chosen location and it comprised type of land use, maize cultivation based on soil NPK content level and the soil nutrient requirement (Figure 3.2).

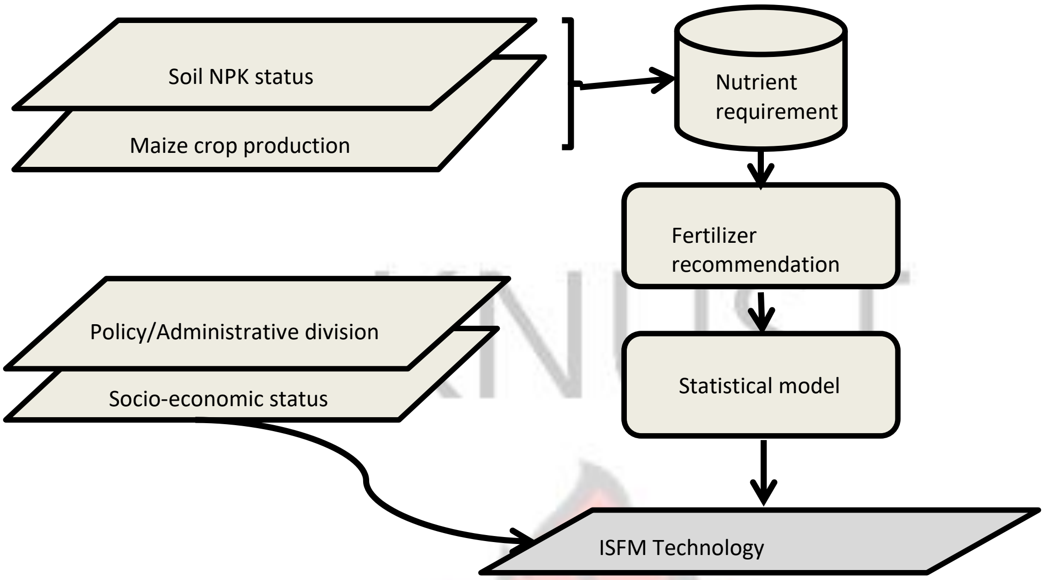


Figure 3.2: Structure of the database analytical model (adopted from Boateng (2005)).

3.4.3 Soil sampling and laboratory analyses

Soil samples were taken from all the 80 locations of the smallholder maize farms across the Districts in the region where the study was carried out. The criteria on which the five farms from each District were chosen were: (1) the smallholder farmer was available and ready to give information about his/her farm practices; (2) there was no land issue disputes associated with such land area and that such farm was available for the soil samples to be collected; (3) Farmland was previously cropped to maize and was used for maize cultivation as at the time of sampling; (4) the smallholder farmer had knowledge about the crop yields for at least two years; (5) the farms chosen were as far apart as possible from each other to ensure that they were fairly and evenly distributed within a District to allow for proper interpolation to be done.

The method of sampling was based on management zone sampling as proposed by Ferguson and Hergert (2009) where the sampling area is not divided into grids. Soil samples were collected in an indefinite zigzag manner to evenly cover the whole field.

In this study, 20 cores of soil samples, to a depth of 0-20 centimetres, were collected from within each smallholder farmer's field for laboratory analysis. The core samples were then mixed thoroughly in a bucket into one uniform sample and a composite sample was taken and put in plain polyethylene bag and labelled appropriately. Samples were localised and georeferenced with a GPS receiver to allow for mapping of sampling locations and resampling when necessary. The well packaged and labelled composite soil samples were then sent to the Department of Crop and Soil Sciences laboratory at the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, for chemical analyses.

Analysis of total N was done using the Kjeldahl method (Bremner and Mulvaney, 1982), available P was determined by Bray I method (Bray and Kurtz, 1945), and exchangeable K by Ammonium Acetate (NH_4OAc) extraction (Matula, 2009). Smallholder farms that were localised with the Garmin GPS where soil samples were taken are shown in Figure 3.3.

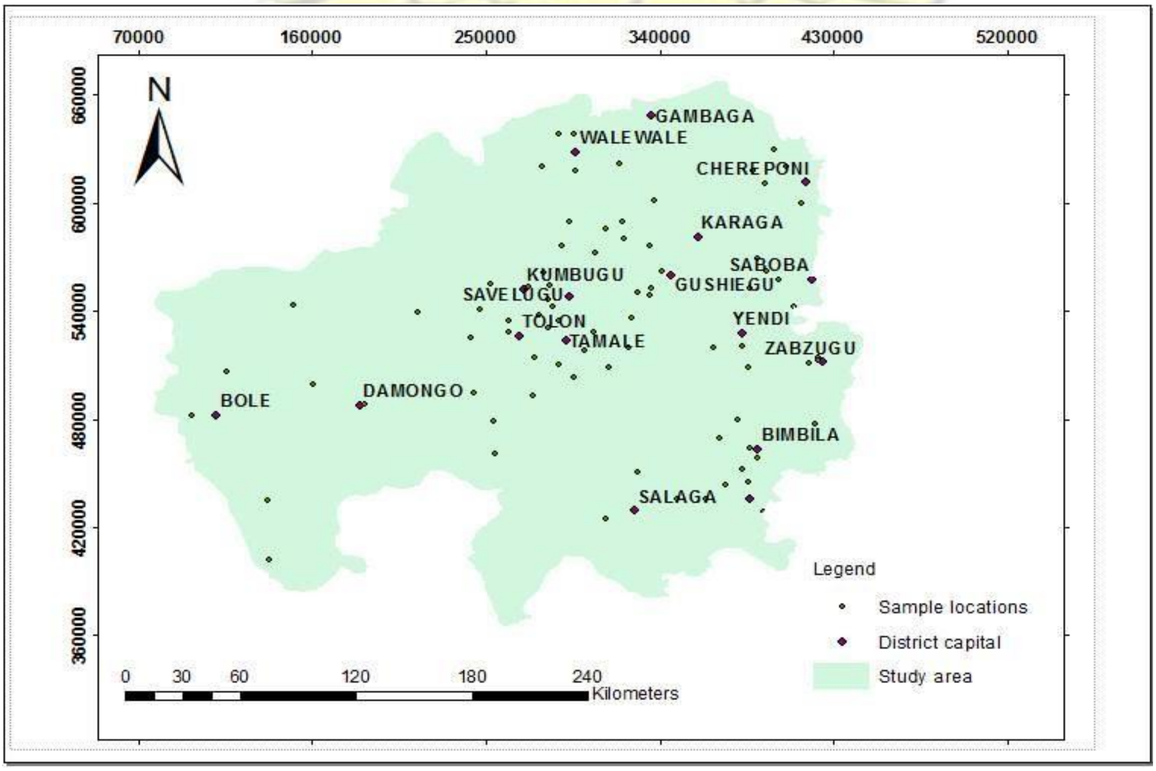


Figure 3.3: Map of soil sampling locations.

3.4.4 Preparation of soil samples for laboratory chemical analysis

The collected soil samples in plain polyethylene bags were emptied onto a shallow tray, each of the 80 samples on its own tray and were appropriately labelled. The soil samples were air-dried by placing them in an open, well-ventilated, dry area under shade for three days, whilst stirring them from time to time to ensure thorough drying. After they were dried, the samples were sieved through the 2 mm mesh sieve to remove gravels, roots, and any crop residues for only the fine particles to remain. The samples were prepared and kept to be processed for laboratory chemical analysis.

3.4.5 Soil chemical analysis procedures

3.4.5.1 Determination of total nitrogen

Determination of total nitrogen was done using Kjeldahl digestion and distillation method described by (Bremner and Mulvaney, 1982). Ten (10) grams of soil was weighed into a 500 ml Kjeldahl digestion flask. Thirty (30) ml portion of concentrated H_2SO_4 was then added to the preparation. The suspension was strongly heated to digest the soil preparation to a permanent clear green colour. Afterwards, the digest was cooled and transferred into a 100 ml volumetric flask. Distilled water was gradually added to the contents to make up the volume to the 100 ml mark. A 10 ml aliquot of the digest was transferred into a Tecator distillation flask and 20 ml of 40% NaOH solution was subsequently added. Steam from a Foss Tecator apparatus was allowed to flow into the flask. The distilled ammonium was then collected into a 250 ml flask which contained 15 ml of 4 % boric acid with mixed bromocresol green and methyl red indicators. The distillate was titrated with 0.1 N HCl solution. Finally, a blank digestion, distillation and titration as described by

Ryan *et al.* (2007) were performed without soil as a check against traces of nitrogen in the reagents and distilled water used. The percentage of total nitrogen was then calculated as:

$$\%N = \frac{(a - b) \times 1.4 \times N \times V}{s \times t} \qquad (3.1)$$

where: a = ml HCl used for sample titration b = ml HCl used for blank titration

$1.4 = 14 \times 10^{-3} \times 100$ % (14 = atomic weight of N)

N = normality of HCl V = total volume of digest s = mass of air dry soil sample taken for digestion in grams (10.0 g) t = volume of aliquot taken for distillation (10.0 ml)

3.4.5.2 Determination of Available Phosphorus

This was determined using the Bray 1 method described by Bray and Kurtz (1945). The method involves the use of Bray 1 extractant, 1.0 N HCl ammonium molybdate, ascorbic acid prepared freshly each day, stock standard A and working stock standard B. A 5.0 g of the prepared soil sample was weighed into a centrifuge tubes and 30 ml of Bray 1 solution was added. The mixture was placed in a mechanical shaker and shaken for five minutes. Afterwards, it was removed from the shaker and allowed to stand for five minutes. After allowing it to stand for five minutes, it was placed in a centrifuge for five minutes at a speed of 3000 rpm. An one ml portion of the clear supernatant solution was pipetted into a clean centrifuge tube. Six (6) ml of distilled water was added to the solution and mixed well, and then 2 ml of colour reagent was also added and mixed well. Finally, 1 ml of ascorbic acid solution was added and the mixture was thoroughly mixed again. It was left to stand for 6 minutes and after that, the color of the mixture was measured at 650 nm on a Jenway 6051 colorimeter (England, United Kingdom). Absorbance was plotted against concentration of P (ppm) and the value of unknown sample was obtained through interpolation on the plotted graph. The contents of the phosphorus were obtained as:

$$P = \frac{\text{Graph reading} \times 30}{5} \quad (3.2)$$

where:

5 = sample weight in grams

30 = ml extracting solution

3.4.5.3 Determination of exchangeable potassium

Exchangeable soil potassium (K^+) was determined by using the flame photometer. Standard solutions of 0, 2, 4, 6, 8 and 10 ppm K^+ were prepared by diluting appropriate volumes of 100 ppm K^+ solution to 100 mL in volumetric flask using distilled water. Photometer readings for the standard solutions were determined and a standard curve constructed. Potassium conentrations were read from the standard curve and the concentration of K was determined as:

$$\text{Exchangeable } K^+ \ (cmol_c \ kg^{-1} \text{ soil}) = \frac{\text{Graph reading} \times 100}{39.1 \times w \times 10} \quad (3.3)$$

where:

w = air-dried sample weight of soil in grams

39.1 = atomic weight of potassium

3.4.6 Statistical description of major soil nutrients

In order to describe the distribution of the N, P and K contents, the contents were scrutinised through data inspection so that any undesirable value or inconsistencies within the measured values might be revealed. The inspection was necessary because, any outlier within the data could be detected in order to re-measure the value to clear doubts about human errors that could be easily corrected. The descriptive statistics that were used to inspect the data distribution in order to detect any unusual expectations were the mean, coefficient of variation, skewness and kurtosis.

The mean of the nutrient distributions were calculated for each of the N, P and K contents of the 80 collected samples using equation (2.1). The skewness and kurtosis were also computed using equations (2.5) and (2.6), respectively. The coefficient of variation (CV), which measured the extent of variability within the N, P and K contents (Abdi, 2010) was calculated based on equation (2.3).

The standard deviation (S_d) was derived from the equation for variance determination (equation (2.2)) as:

$$S_d = \sqrt{s^2} \qquad (3.4)$$

where s^2 denotes the variance of the distribution of the NPK contents.

3.4.7 Soil nutrients surface modelling and generation

Geostatistical analysis was performed on the results of the contents of major soil nutrients (NPK) from the laboratory analysis. The objective of this analysis was to make predictions of the soil nutrients status at locations where samples were not taken using known sample location values. The number of known sample point values used for this analysis was 80. The minimum required data points was 10 (ESRI, 2010). The processes involved in the modelling and generation of the N, P and K distributions were based on the geostatistical model described in Figure 2.1. The best model that fitted the nutrients contents distribution was chosen during the modelling process.

The processes, as described in the model were to take the nutrient contents through exploratory data analysis to ensure that they met the requirements to be modelled. The process was to ascertain that the nutrient content distribution was a representative of what pertains to the study area, since the model was for decision making and support purposes.

The geostatistical procedures followed in modelling the soil nutrient contents were as follows:

3.4.7.1 Mapping and examining the N, P and K nutrient contents

The geographic coordinates of the localised 80 farmers' fields in a shapefile format was uploaded from the Expert GPS software into the ArcGIS software. The coordinates were then georeferenced through transformation from WGS (84) and Accra-Ghana grid projected coordinate system. The geographic projection of the data points allowed for accurate and precise measurement of distances between data points on the map. After georeferencing, they were superimposed on the georeferenced topographic base map of the study area so that their right locations would be established since they were now in the same GCS. In this way, the farm locations were mapped. The nutrient contents were then assigned to each farm location accordingly as an attribute data of the map.

In order to proceed with the modelling, the nutrient contents were examined through statistical analysis to check for normality of the nutrient contents distribution. The levels were to meet the conditions of normal distribution to be considered as appropriate. The levels were therefore subjected to Genstat (12^{th} edition) statistical descriptive analysis. This descriptive analysis provided measures that were used to ascertain whether the levels met conditions under which they could be modelled and mapped or it was necessary for the values for nutrient contents to be transformed. The measured parameters that were used to examine the data were skewness and kurtosis of the nutrient contents.

In order to confirm the output of the nutrient contents from Genstat (12^{th} edition) statistical software, further normality tests were done in SPSS (16^{th} edition) statistical package. The tests that were carried out were the Kolmogorov-Smirnova (K-S) test, Shapiro-Wilk (S-W) test, the frequency histogram plot of the nutrient contents distribution and their quantile-quantile (Q-Q) plot distribution. The QQ-plot showed the concentration cumulative proportions of the nutrient contents (quantile) against the standard normal distribution values. It was used to determine how the nutrient distribution corresponded to the standard normal distribution. These parameters were used because they were the most appropriate measures that could be used to check normality (Jondeau and Rockinger, 2003) in the soil nutrients as well as being manageable in the ArcGIS software in situation where the nutrient contents were found not to meet the conditions (ESRI, 2010).

3.4.7.2 Pre-processing of NPK nutrient contents

The NPK contents were explored and examined to ascertain whether they met the normality assumption of the geostatistics model. After data exploration, the data deviated from normal distribution and hence, a logarithm (base 10) transformation model was applied to render them fit for modelling and mapping. After the logarithm transformation, N and K contents were rendered normal, but the P contents could not be normalised with the logarithm transformation.

A normal score transformation, which renders every data normal (Harter, 1961; Royston, 1982; ESRI, 2010) was therefore applied to the P contents dataset in order to make them meet the conditions for which they could be modelled appropriately. After the transformations were done, the nutrient contents were deemed clean and appropriate to undergo the spatial modelling.

After the transformations were applied, variations in the transformed nutrient contents across the study area were assessed. This assessment was done by calculating the percentage of locations that had low N, P and K contents as well as percentage of locations that were within moderate to good concentration levels. The nutrient contents in each location were compared to standard acceptable nutrient contents that were considered as low, moderate or good concentrations before the evaluations were done.

3.4.7.3 Modelling the spatial structure of soil major nutrients

The transformed nutrient contents were recorded as attribute data and assigned to each of the 80 farm locations in the ESRI ArcGIS (10^{th} edition) software. A semi-variogram was then generated to measure the strength of statistical correlation between each of the transformed nutrient contents by plotting the transformed nutrient contents against distances between the coordinate points (Matheron, 1963; Liu *et al.*, 2006a). Models that were used for specifying the semi-variogram was iteratively performed to fit the semi-variogram; and a model was then chosen. The chosen model determined the optimal distance within which spatial correlation between the contents were evident for modelling the semi-variogram (Okeyo *et al.*, 2006). Furthermore, the model that accurately fitted the nutrient level phenomena and provided a better goodness of fit (least RMSE) compared to the other models was chosen. This generated semivariogram then provided the necessary input parameters for spatial interpolation of kriging (Krige, 1951). The parameters that were obtained from the semi-variogram were the *sill, nugget* and *range.*

The range was the value obtained from the plot of transformed nutrient contents against the distances, and at the distance from where the model first flattened out. The sill was the value obtained on the y-axis that corresponded to the range and the nugget was the value obtained at where the semivariogram intercepted the y-axis. The spatial dependency within each of the nutrient contents was calculated as:

$$\text{Spatial dependency} = \frac{nugget}{sill} \qquad (3.6)$$

3.4.7.4 Defining interpolation search strategy for N, P and K nutrient contents The search strategy for the spatial interpolation procedure was based on the maximum and minimum neighbouring known sample values to predict values at unsampled site. The procedure for the search strategy was also based on the fact that it was appropriate and objective in selecting neighbouring samples to be included in the estimation of the values at an unsampled location (Ledoux and Gold, 2005). This means that all data points that were far from the point of prediction were eliminated from calculating the values from the unsampled locations. The search neighbourhood specified for the predictions in this study was the standard neighbourhood (ESRI, 2010). The maximum and the minimum neighbours of sample values that were included in the prediction as well as other criteria were specified as follows:

Maximum neighbourhood = 5

Minimum neighbourhood = 2

Coordinates of test points (x = 259805.6, y = 519811.7)

Search strategy: circle with 4 quadrants with 45° offset.

Radius for total N = 22034.57 m; predicted value at test location: 0.048 %

Radius for available P = 22796.3 m; predicted value at test location: 3.759 mg kg^{-1}

Radius for exchangeable K = 66738.97 m; predicted value at test location: 0.141 $cmol_c$ kg^{-1}.

3.4.7.5 Predicting N, P and K content values at unsampled locations

After the necessary input parameters for the spatial interpolation were obtained, the simple kriging method was used to specifically model the nutrient contents; and it expresses the model as:

$$Z(s) = \mu + \varepsilon(s) \qquad (3.7)$$

where $Z(s)$ = the predicted value at the prediction location

μ = a known constant

$\varepsilon(s)$ = estimated error

Kriging which is a geostatistical technique was used because it provided the best unbiased linear estimates to deal with the variation in the nutrient contents. The weighted sum of adjacent concentrations of the nutrient contents were calculated and this resulted in the estimated quantities of the nutrient contents (Liu *et al.*, 2004). This means that if the nutrient contents seemed to be extremely continuous in space, more weights were assigned to the points that were closer to each other than those that were far apart (Cressie, 1990).

3.4.7.6 Quantifying uncertainty in predicting the NPK nutrient contents

Uncertainties that were contained in the predicted nutrient contents were quantified in order to ascertain the reliability of the generated surface map in decision making. As stated by Minasny *et al.* (2008), estimates of associated predictions were quantified to allow for producing reliable maps. In using ESRI ArcGIS to assess uncertainty in the prediction, the root-mean-squared (RMS) prediction error, which measures how closely the model predicts the measured value, was compared to the average standard error (ASE) of the prediction which assesses the variability in the prediction (Chai and Draxler, 2014). According to ESRI (2010), when the RMS error is close to ASE, then one can be assured that the prediction standard errors are appropriate. The prediction standard errors indicated the uncertainty associated with the prediction of values for locations where samples were not taken. The root-mean-square error was calculated as:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x}_i)^2}$$ (Chai and Draxler, 2014) (3.8)

where N is the sample size, x_i is the observed value and $\bar{x}_i$ is the mean value for the observed sample values.

3.4.7.7 Model validation

The prediction model for the soil nutrients was finally validated to measure the accuracy of the prediction map generated showing the distribution of the nutrients. The model calculated the average standard errors in predicting the nutrient contents. The minimum calculated average standard error, preferably close to zero, (i.e. which fits the distribution more accurately) was considered to be simulated and mapped. This is because such prediction model was considered reliable. In addition, the standardised root mean square was evaluated to verify that the obtained standard error was acceptable. This value must also be close to one, because when it is more than one, the model might be underestimating the variability in the predictions and if it is less than one, it will be overestimating the predictions.

3.4.8 Surface generation for N, P and K levels

The model was validated after the necessary input gave reliable and appropriate parameters for its generation. The simple krigged model produced a smoothed surface of the soil properties phenomena. The regression functions generated to produce the surfaces were:

Nitrogen prediction at unsampled locations = 0.19 x□0.05

Phosphorus prediction at unsampled locations = 0.012 x□4.03

Potassium prediction at unsample locations = 0.18 x□0.16 where

x is the known measured value for the soil nutrient.

In order to produce a map that represented the stochastic model of nutrients in the study area, the real situation of N, P and K distribution across the region was of great importance, hence simulations were used. A simulation is defined by Lantuéjoul (2002) as “any realisation of a model”; thus it is a process of replicating the reality of a (stochastic) model (ESRI, 2010; Lantuéjoul, 2013). The random function generated has the same statistical features as the sample data that was used in its generation. This according to Brown (1998) results in a distribution function with the mean, variance and confidence limits being same as the sample data. This confirmed the stationarity assumption used by the simulation model, i.e. the mean, variance and semi-variogram remaining the same over the spatial domain of the data. Appropriateness of the stochastic model to fit the N, P and K distribution gave a more accurate result, as has been pointed out by Brown (1998).

3.5 Modelling the spatial relationship of major soil nutrient concentrations and factors that may be associated with their distribution

In order to determine whether external factors have a relationship with the spatial distribution of the nutrient contents in the study area, factors such as landscape topography, soil pH and amount of fertilizer input were regressed on the N, P and K concentration levels. The study restricted the external factors to the above three (landscape topography, soil pH and amount of fertilizer applied) for the purposes of availability of the needed data. Ordinary Least Squares (OLS) regression model was used to model the relationship between N, P and K concentrations that were obtained from the laboratory analysis and the landscape topography, soil pH and amount of fertilizer input. These N, P and K contents were used as the dependent variables, while the factors that were deemed to influence the N, P and K concentration levels were used as the explanatory variables.

Soil pH in water (1:2.5) was determined with the pH meter (Laslett *et al.*, 1987) in the laboratory for each of the 80 soil samples collected from the 16 Districts in the study location (i.e. five samples from each District). The average soil pH value of the five samples was taken as the pH of the soil for each of the 16 Districts.

The landscape topography of the study area was determined from the elevation data points. These elevation points were collected and georeferenced together with the geographic coordinates from the 80 locations. Spatial analyst tool within ArcGIS 10^{th} edition software was then used to generate surface contours from the elevation point data at 50 m intervals. The elevation data was selected as an attributed data of the sample points in the ArcGIS software and run in the surface contour generation interface found in the spatial analyst tool. Due to the relatively flat nature of the landscape in the Northern region (Modernghana, 2005), the elevation values were relatively close to each other. Therefore to distinguish between areas of low elevation and areas of high elevation, the elevation data values were grouped into two categories. The groupings were made up of values of elevation points more than 150 m high and those that were less or equal to 150 m high. The choice of the height level for the groupings was related to the mean height of the study area which is 149 m above mean sea level (Getamap, 2006). Elevation of topography that were above 150 m were considered to be relatively high elevated lands and those that were equal or less than 150 m were considered to be low elevated lands, for the purpose of this study.

Data on fertilizer input by smallholder farmers on the farmlands were obtained from SARI in May, 2012. This data from SARI consisted of 150 farmers from the various Districts, except two Districts (Damongo and Bole), who had their farming activities captured in SARI's database. In March 2013, survey questionnaires were distributed in all the selected Districts to collect another data set from smallholder farmers on field activities including the use of inorganic fertilizer on their farms. The information retrieved after processing the survey questionnaire (sample found in Appendix 6) included 60 more farmers in the study. The amount of fertilizer applied by farmers in each District was averaged because an aggregate value was needed to represent the average amount of fertilizer applied in each District selected for the study.

The OLS model in spatial statistics within ArcGIS 10^{th} edition was required to produce reliable results to ensure that a useful model was being used to establish the relationship between N, P and K contents and the associated variables. To verify the reliability of the model, a diagnostic test was performed to assess the overall model significance using the Joint F-statistic, Joint Wald statistic and the Koenker's studentized Bruesch-Pagan (Koenker (BP)) statistic (Cui and Jones, 2002). Joint Fstatistic and Joint Wald tests were used because the model involved multiple variables (Blackwell, 2008) as explanatory variables. Koenker (BP) statistic test was done to check how consistent the associated variables were to the N, P and K content variables. The test that gave a statistically significant p-value indicated that the data was not stable for a 95% confidence level. In this instance, the robust coefficient standard errors for the individual associated variables were used to assess the model performance. Furthermore, a Jacque-Bera diagnostic test was performed to ensure that the residuals from the model follow a normal distribution, in order to avoid bias in the data. Jacque-Bera test was used because it ensured that residuals from the OLS model were not one sided (skewed) so that the model was prevented from being biased in the distribution of the phenomenon (ESRI, 2010; Sheehan *et al.*, 2013). Finally, a variance inflation factor (VIF) which determined whether or not factors used as variables that relate to the N, P and K contents were different from each other, according to Cui and Jones (2002), was used to establish that there was no redundancy in the associated variables used. This check implied that no two factors of the associated variables were telling the same story about the N, P and K content variables.

For the associated variables to be considered as redundant, the VIF must be more than 7.5 (Cui and Jones, 2002). Also, for the model to be significant, both Joint F-statistic and Joint Wald statistic should have significant probabilities while Koenker (BP) statistic should have non-significant probability (Matkan *et al.*, 2010). Where this criteria failed robust coefficient test was used to confirm this significance. The robust coefficient standard errors and their probabilities for the individual associated variables (topography, amount of fertilizer applied and soil pH) on the N, P and K content variables were used to assess effectiveness and significance of each one of associated variables.

3.5.1 Spatial autocorrelation analyses of N, P and K contents

In this study, spatial autocorrelation statistic was used to measure the correlation within N contents, P contents and K contents levels. The assumption for this pattern analysis was that N, P and K contents are randomly distributed in the study area. The spatial autocorrelation therefore was performed to assess whether they were indeed randomised, and if not, to show whether or not they were clustered or dispersed. The Global Moran's Index, I, was used to evaluate the correlation and was calculated for N, P and K as follows:

$$I_N = \frac{n_{(loc)}}{S_0} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} (N_{(content\ i)} - \overline{N}_{(content)}) * loc_{ij} * (N_{(content\ j)} - \overline{N}_{(content)})}{\sum_{i=1}^{n} (N_{(content\ i)} - \overline{N}_{(content)})^2} \quad (3.9)$$

$$I_P = \frac{n_{(loc)}}{S_0} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} (P_{(content\ i)} - \overline{P}_{(content)}) * loc_{ij} * (P_{(content\ j)} - \overline{P}_{(content)})}{\sum_{i=1}^{n} (P_{(content\ i)} - \overline{P}_{(content)})^2} \quad (3.10)$$

$$I_K = \frac{n_{(loc)}}{S_0} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} (K_{(content\ i)} - \overline{K}_{(content)}) * loc_{ij} * (K_{(content\ j)} - \overline{K}_{(content)})}{\sum_{i=1}^{n} (K_{(content\ i)} - \overline{K}_{(content)})^2} \quad (3.11)$$

where $n(loc)$ is the number of farm locations where soil samples were taken, loc_{ij} is the element in the spatial weights matrix corresponding to the pairs of locations $i\ j$,

;

and $N_{(content\ i)}, P_{(content\ i)}, K_{(content\ i)}$ and $N_{(content\ j)}, P_{(content\ j)}, K_{(content\ j)}$ are nutrient contents in location i , j respectively, and $\bar{N}_{(content)}, \bar{P}_{(content)}, \bar{K}_{(content)}$ are the mean nutrient content values for N, P and K respectively.

However, the first step used in the spatial autocorrelation analysis was to generate spatial weights matrix that contained information on the neighbourhood structure for each location. The spatial weight matrix was generated for each of the nutrient contents and denoted by

$$S_o = \sum_{i=1}^{n}\sum_{j=1}^{n} loc_{ij} \;. \qquad (3.12) \quad i \neq j$$

where loc_{ij} collectively defined the neighbourhood structure over the entire study location. The z-score value for each of the nutrient contents and the I obtained from the spatial autocorrelation analysis were then used to specify the pattern of distribution that existed within the N, P and K contents. The probability value obtained was then used to assess the significance of the distribution, whether dispersed, clustered or of a random nature.

3.6 Creating models for site-classification

Classification of the sites to determine locations of relatively low overlaid N, P and K contents to relatively high overlaid N, P and K contents was performed using fuzzy overlay spatial analysis (ESRI, 2010). The interest for this analysis was to generate a model which identified locations that were within limited levels and needed interventions for decision making purposes. The input layers for the overlay analysis were derived from the means of the simulated N, P and K contents. These layers were in a raster format and the overlay analysis was modelled based on the output layer generated by the input layers. This analysis was performed with the ArcGIS ArcInfo software (ESRI, 2010) .

3.7 Evaluation of the relationship between amount of fertilizer input by farmers and their corresponding yield

The relationship that existed between quantities of fertilizer input by farmers and their corresponding yield was evaluated. This relationship was to determine whether the blanket recommendation had any significant increase on farmers' yields, regardless of the location of the farms in the Districts. All other variables that contribute to yield outcomes such as climatic conditions and sowing dates were held constant due to data constraints, and were not included in the data analysis. The assumption developed for this analysis was that, if fertilizer input by farmers was exceeded from the blanket recommended rate, it would have a significant impact on the maize yield if all other conditions were favourable. That implied that time of planting would not be included in the recommendations.

3.7.1 Processing of farmers' data to study the variation within different N, P and K nutrient application

Hundred and fifty (150) farmers' data were acquired from SARI to be used for studies. After thorough scrutiny of the selected farmers' data, 89 were chosen to be used studying the use of fertilizer under three categories. The selection of the 89 farmers was due to the fact that the study was interested in gathering appropriate information on farmers who had both their amount of fertilizer input and corresponding yield available in the database provided by SARI. Farmers who did not have both the quantity of their fertilizer input and corresponding maize yields were excluded. No data from the survey questionnaire were added in this analysis because focus on this study was to assess the use of fertilizer and maize yield in one cropping season. And the SARI database provided enough farmers' data to be considered for the study compared to the farmers' data obtained from the survey questionnaire which was obtained in another cropping season. The data were then grouped into three categories of application of both NPK 15:15:15 and SoA (Sulfate of Ammonia) as follows: (1) farmers whose fertilizer input on the field was less than the blanket recommendation (i.e. < 375 kg ha^{-1}); (2) farmers who used the blanket recommendation (i.e. 375 kg ha^{1}) and (3) farmers whose fertilizer input exceeded the blanket recommendation (i.e. > 375 kg ha^{-1}). The data were then subjected to SPSS (16th edition) regression analysis to analyse the variability that existed between and within these three groups, with their corresponding yields. The input independent categorical variable was the amount of fertilizer applied, and the dependent variable was the corresponding maize yield.

3.7.2 Homogeneity test of variance between farmers' fertilizer input

Test of homogeneity of variance was performed on the three categories of farmers to determine how comparable the quantities of fertilizer inputs were. The homogeneity test assumed that samples used were from populations of equal variances, meaning variability of scores for each of the groups was similar. Therefore, Levene's test of equality was performed at significance level of $p < 0.05$ for equality of variances in the farmers' maize yields as part of the analysis of variance.

3.7.3 Analysis of Variance of farmers' fertilizer input and corresponding maize yield

After the test of homogeneity of variance, a one-way analysis of variance (ANOVA) between and within groups was conducted to explore the varied impact of amount of fertilizer applied on the maize yield outcome. Subsequently, the effect size, which is given as eta squared, and expressed as the amount of associated variation that was accounted for by the effect of fertilizer application on maize yield and error obtained (Brown, 2008) in ANOVA, was determined. The effect size was determined as:

$$eta^2 = \frac{\textit{sum of squares between categories}}{\textit{Total sum of squares}}$$

(Brown, 2008) (3.13)

The effect size which does not over rely on statistical significance to draw conclusions (Cohen, 1992) determined whether the obtained means of grain yields within the categories in the analysis of variances were large or small. Cohen (1992), classified effect size of 0.01 as small effect, 0.06 as medium effect and 0.14 as large effect.

3.8 Evaluation of amount of fertilizer input within farmers' and researchers' practices and recommendation of site-specific practices from researchers' demonstrations

Data from field demonstration trials that researchers had made, as well as practices of farmers on their farms with regards to fertilizer application that were collected were categorised for comparison in order to select the best practice for each District under study. One hundred and twenty three (123) smallholder maize farmers' data were used for this study. Eighty nine (89) of them were selected from SARI's database, and 34 were selected from the results of the survey conducted in the various Districts because those were the data that contained particulars of farmers who had both their maize yields and fertilizer input available. These farmers' data represented 13 Districts out of the 16 Districts in the study area, and consisted of data from two to three years cropping seasons. Thirteen (13) Districts were chosen because in 3 of the Districts, data from the researchers' field trials were unavailable. The trials either failed or were not demonstrated at all and so they were omitted from the study as at the time of collecting the data in March 2014. The categorisation consisted of the amount of fertilizer that farmers were using on their farms and the resulting corresponding yield. It also included research trials on ISFM practices targeted at inorganic fertilizer application. The processes through which the categorisation and comparisons were done have been illustrated in the following subsections.

3.8.1 Processing of fertilizer input and maize yield data by smallholder farmers

The collected data on farmers' quantity of fertilizer application as well as corresponding maize yields were grouped and averaged for each District. The groupings were done in Microsoft Excel by selecting all farmers who had their activities recorded in SARI's database within communities in each District under study. Amount of fertilizer input by the farmers in communities as well as the corresponding yields were assigned to the District in which it is located and grouped accordingly. The sorting was done to properly identify the year in which the farming was done, the various amounts of fertilizer applied on individual farms and the associated maize yield for each of the 13 Districts. The N, P and K contents within the amount of inorganic fertilizer applied was calculated using the amount of N, P and K contained in 100 kg of NPK 15:15:15 and SoA as a guide to obtain the amount of N, P and K that were used averagely by smallholder farmers in the Districts. 100 kg of NPK 15:15:15 contains 15 kg N, 15 kg P_2O_5 and 15 kg K_2O and 100 kg of SoA contains 21 kg N while 100 kg of cattle manure contain 0.7 kg N, 0.5 kg P_2O_5 and 0.6 kg K_2O (Yeboah *et al.*, 2013).

3.8.2 Processing of fertilizer input and maize yield output in researchers' demonstration plots

The various field trials that had been demonstrated to the farmers by the researchers were also grouped and sorted for each of the 13 Districts by assigning maize yield output to each treatment in the demonstrations. The groupings were categorised for a 3 – year period from 2011 to 2013 cropping seasons. From the acquired data, four treatments within four demonstration plots were identified for the 13 Districts. The maize yield obtained from each treatment in the demonstration plot was assigned to each District, accordingly.

The treatment which gave high yields from the trial demonstrations in the various Districts for at least 2 years within the 3 – year period (i.e. after evaluation of treatments and maize yields) was then selected to represent that District so that it could be compared to the farmers' maize yields in the District. The trials from ISFM research demonstrations made use of fertilizer application with improved maize seeds and other amendments such as use of fertisoil and organic manure. The use of these resources were set up in four demonstration plots for the cultivation of maize. In all, there were four maize demonstration plots within four different communities in each District. There were four different treatments within each of the demonstration plots. Since the focus of this study was on the application of fertilizer, only the quantities of the fertilizer per hectare of land in the demonstrations were considered and they were; (1) no fertilizer use, (2) 2½ bags of NPK 15:15:15 + 1¼ bags of SoA, (3) the recommended rate (5 bags of NPK 15:15:15 + 2½ bags of SoA), (4) 5 bags of NPK 15:15:15 + 3¾ bags of SoA, (5) fertisoil (3 t ha^{-1}) + 6¾ bags of SoA, (6) manure (2.5 ha^{-1}) + ½ NPK recommended rate and 7) only NPK recommended rate (5 bags of NPK 15:15:15). The rest of the ISFM package has been tabulated in Appendix 1.

The percentage increase in the crop yields were also calculated to assess how much crop yields would be gained if such specific measures were to be adopted by the smallholder farmers within the Districts.

3.8.3 Assessment of soil N, P and K contents and estimation of nutrient requirements and yield for maize production

The aggregate N, P and K content values obtained from the five selected communities within each of the chosen Districts of study was used to represent the NPK contents in the Districts. The nutrient variability in the chosen 13 out of the 16 Districts were then classified under very low, low, adequate (moderate) and high (good) contents. The amount of N, P and K nutrient contents removed from the soil through harvest of maize grains were then computed to determine the amounts of nutrients needed to be replaced. The N, P and K uptake by the maize crops were determined as follows:

$$Uptake = (Grain\ yield\ kg\ ha^{-1}) \times Nu\ kg\ kg^{-1}\ \text{in grain} + (stover\ yield\ kg\ ha^{-1}) \times Nu\ kg\ kg^{-1}\ \text{in stover}$$

(Opoku, 2011) (3.14)

The nutrients in percentages were expressed in kg kg^{-1} in order to assess the amount of N, P and K uptake in kg ha^{-1} from the field. Data obtained from omission plots (NP, NK, and PK plots) from the model was used to obtain parameters that were used to calibrate the model. The potential nutrient supply from the soil, denoted by the recovery efficiency (RE) was estimated with the QUEFTS model; and it was expressed as:

$$RE = \frac{Uptake\ of\ Nu\ from\ Nu\ fertilised\ soil - Nu\ Uptake\ from\ Nu\ unfertilised\ soil}{Amount\ of\ Nu\ applied\ or\ available}$$

(Liu *et al.*, 2006b) (3.15) where *Nu* is the nutrient (N, P, or K) of interest.

The values of the internal efficiencies (IE), from which the maximum accumulation (a) or minimum nutrient use efficiency (the lowest IE value obtained from the calculations) and maximum dilution (d) or maximum nutrient use efficiency of nutrients in the soil (the highest IE value obtained) were calculated as:

$$IE(Nu) = \frac{Grain\ yield}{Uptake\ (Nu)} \qquad \text{(Witt } et\ al.\text{, 1999)} \quad (3.16)$$

The IE were obtained using data from demonstration trials from five Districts. Four demonstrations were taken from each of the five Districts, making a total of twenty different trials, and this data was used to calibrate the QUEFTS model (Maiti *et al.*, 2006). In calibrating the model, the maximum yield (Y max) was set to 10000 kg ha^{1}, while the potential grain yield for the area was set to 60% of the maximum yield. These values for potential yield of maize grain were considered appropriate based on the potential yield of maize in Ghana, which according to Sallah *et al.* (1997) is about 6 t ha^{-1} in the Guinea Savannah zone where this study was situated. Total P of the study area was estimated as 155 mg kg^{-1}, which was the general phosphorus status of the study area (Owusu-Bennoah *et al.*, 1995). The available P within the study area was analysed using Bray 1 method. The requirement for soil P analysis to be used in the QUEFTS model was P-Olsen method. According to Mowo *et al.* (2006), P Bray 1 is about 0.75 to 2.5 times P-Olsen. Therefore the values of the two extremes were both used in the calculation of P-Olsen in the study area, and the average value was used in order to meet the requirement of the maximum P-Olsen value that can be used in the model and pertains to the available P in the study area.

Three sets of constants were generated for ‘a’ and ‘d’ to test the sensitivity of the model after calibration. The first, second, and third sets were taken from the 5th, 7.5th, and 10th percentile of the smallest generated IE from the twenty trials to obtain ‘a’ while the 95th , 92.5th and 90th percentile of the maximum IE was used to obtain ‘d’. The first set was used for the model, and the 5th and 95th percentiles were excluded in order to remove outliers from the data (Das *et al.*, 2009).

The model was validated by running it with data from ten previous research demonstration trials in selected locations of the study area using the established parameters obtained from the calibration. The predicted maize yield was based on the grain yield and the nutrient uptake. The predicted yields by the QUEFTS model were then compared with the measured yield output from these selected locations to assess the accuracy of the predicted yield outcomes using U- Theil statistic. Theil's U statistic is a relative measure of accuracy that compares predicted results with measured results of minimal historical data (Makridakis, 1993). It is given as:

$$U = \frac{\sqrt{\frac{1}{T}\sum_{t=1}^{T}(Y_t^s - Y_t^a)^2}}{\sqrt{\frac{1}{T}\sum_{t=1}^{T}(Y_t^s)^2} + \sqrt{\frac{1}{T}\sum_{t=1}^{T}(Y_t^a)^2}} \qquad \text{(Wijayanto and Prastyanto, 2011)} \quad (3.17)$$

where T = the number of samples, Y_t^s is the predicted value of the model, Y_t^a is the measured value. When U is less than 1 or close to zero, the model is said to be better in prediction, and when it more than 1, the model is said to be poor in prediction (Wijayanto and Prastyanto, 2011).

3.8.4 Comparison of farmer' and researcher' practices

A two sample t-test (unpaired) analysis was performed in Genstat (12th edition) statistical software to compare the means of the amount of fertilizer input by researchers and farmers as well as the mean yields in the region at 95% confidence interval. The comparison was based on the following hypotheses: (i) average amount of fertilizer applied by researchers is equal to average amount of fertilizer applied by farmers and (ii) average yield of researchers in the region is equal to average yield of farmers. After comparison, the average amount of fertilizer applied in a District, either by farmers or researchers, which led to significantly high maize (grain) yields was selected and proposed to be adopted by smallholder farmers in the Districts.

3.8.5 Processing of the vegetation base map and mapping of proposed researchers' strategy

The vegetation cover base map was downloaded from ESRI website and projected onto the Accra Ghana Grid coordinate system using the project tool within ArcGIS (10.0) software package. The projection transformed the spatial reference of the map which was in WGS (84) coordinate system to correspond to the Ghana Grid coordinate system for better representation and to provide a better surface for mapping (Maling, 2013). Four points of known coordinates were marked at the edges of the topographic base map, and transferred onto the vegetation base map for geo-referencing. The coordinates of the Districts of study were then superimposed on the base map to show the locations of the Districts on the base map. The identified appropriate site-specific practice was assigned to the Districts under study and displayed on the vegetation cover base map.

3.8.6 Evaluation of the profitability of proposed ISFM strategy and farmer practice

The identified researchers' intervention was assessed in terms of cost of inputs and prices of maize grains to obtain the benefits that could be derived by smallholder farmers should they adopt the strategy. The current prices of fertilizers, maize seeds, and fertisoil were obtained from agro-dealers and confirmed with the farmers and researchers. The cost of inputs for each District were then used as cost for inputs for both the farmers and researchers. The existing sale prices for 50 kg bag of maize grains at farm gate were also obtained from farmers through survey interview and used to estimate the price of the maize yield output by farmers and researchers. The cost of input variables per hectare for producing the highest yields obtained from the demonstrations were calculated by adding the prices of each input variable. The price of the grain produced per hectare was also obtained by multiplying the maize grain yields by the price of 50 kg of maize grains. The variable cost of inputs was then deducted from the sale price of maize grains produced to obtain the benefit or contribution. Contribution is the reserve which comprised of fixed cost like labour cost or price of insecticide (which could be unique for both farmers and researchers) and profit. A profit volume ratio (P/V), which is a relationship between contribution or benefit and sales of products (Kumar, 2011) was calculated to compare the profitability of farmer and researcher practices. The P/V ratio was calculated as:

$$P/V = \frac{Contribution}{Sale}$$ (Kumar, 2011) (3.18)

Microsoft excel software was then used to derive a comparison plot of the benefits from both practices in order to properly advice an intervention.

3.9 Generation of spatial database management system of farming practices in the Northern region of Ghana

An interactive spatial database was generated using Mapwindow® GIS software program. The program used Microsoft visual basic (VB) programming language to develop the interface. The inbuilt script was uploaded into the program by inserting the names of maps and images into the right codes that upload these features. The code for displaying data shapefile layers on the map was given as:

```
var sf = new Shapefile();  if
(sf.Open(filename, null)) {
    int layerHandle = axMap1.AddLayer(sf, true);
```

```
 }
else {
     Debug.WriteLine("Failed to open shapefile: " +
sf.get_ErrorMsg(sf.LastErrorCode));
 }
```

(MapWindowGIS, 2015).

The required data used to build the database were the District map of the study area, a georeferenced jpeg image file of an overlay N, P and K nutrient status raster map of 500 dots per inch (dpi) pixel resolution, an AGRA logo in honour of the AGRA project for sponsorship, five images of maize farms and people. The code used for making the projections of the images onto the georeferenced map was given as:

```
new GlobalSettings()   var sf
= new Shapefile();  if
(sf.Open(filename, null))
 {
     //sf.GenerateLabels(0, tkLabelPositioning.lpCentroid); // don't
call it here as labels may be lost      int layerHandle =
axMap1.AddLayer(sf, true);
     sf = axMap1.get_Shapefile(layerHandle);                // grab
the reprojected version of shapefile
     sf.GenerateLabels(0, tkLabelPositioning.lpCentroid);   // now
it's ok to generate labels
 }
```

(MapWindowGIS, 2015). The associated attribute data to be displayed were the average values of N content (%), P content (mg kg^{-1}), K content ($cmol_c$ kg^{-1}), soil pH, maize yields (kg ha^{-1}), the maize production strategy that returns maximum yield for 13 Districts as at the year 2014.

CHAPTER FOUR

4.0 RESULTS

The results obtained from this study have been presented and discussed in this section to reflect the specific objectives. The soil chemical properties of interest in this study were N, P, K concentrations and soil pH. The external factors considered to have impacted on the distribution pattern of the chemical properties were landscape topography, soil pH and amount of fertilizer applied. The study as well focused on the impact of fertilizer application on maize yields as practised by farmers and researchers in demonstration trials.

4.1 Chemical description of soil samples at the various sampling sites

Laboratory chemical analysis was performed to characterize the chemical properties of the soil that are of interest to this study in order to describe and map the variation within them. In general, the soils had similar properties and did not differ much in terms of their chemical characteristics. The values from the laboratory chemical analysis obtained for each of the 80 locations sampled are shown in Appendix 5.

4.1.1 Description of soil nutrient contents

The nutrient contents obtained from the chemical analysis were described statistically to establish the extent of variation within each of them. The parameters that were used to obtain information on the variation within each of the nutrient contents (N, P, or K), as well as the mean value for the nutrient contents at the study area are presented in Table 4.1. Total N contents ranged from 0.03% to 0.13%, available P contents ranged from 1.24 mg kg^{-1} to 11.29 mg kg^{-1} and exchangeable K contents ranged from 0.06 $cmol_c$ kg^{-1} to 0.73 $cmol_c$ kg^{-1}. The differences between the ranges (minimum and maximum values) were high and this was confirmed by the high values of coefficient of variation (CV) obtained for each of the nutrient contents (N = 35.22%, P = 67.89%, and K = 63.04%).

The extent of skewness (0.88, 0.98, and 1.96) and kurtosis (3.43, 2.93, and 7.50) described the distribution of the soil N, P and K contents, respectively, in the study area, and indicated that the distribution did not follow a normal distribution. Skewness values obtained for the N and P contents were close to 1, and K contents were more than 1; kurtosis values for N and P were less than to 3 and that of K was more than 3.

Table 4.1: Statistical descriptive parameters of major soil nutrient contents (n = 80)

Parameter	Variable		
	Total N (%)	Available P (mg kg^{-1})	Exchangeable K ($cmol_c$ kg^{-1})
Mean	0.06	4.22	0.20
Median	0.06	3.44	0.50
Minimum	0.03	1.24	0.06
Maximum	0.13	11.29	0.73
S.D.	0.02	2.86	0.12
C.V. (%)	35.22	67.89	63.04
Skewness	0.88	0.98	1.96
Kurtosis	3.43	2.93	7.50

S.D. – standard deviation; C. V. – coefficient of variation

4.1.2.1 Confirmation of normality within nutrient contents levels

The K-S test and the S-W tests (Table 4.2) performed on the nutrient contents confirmed that the levels were indeed non-normal and the non-normality was significant ($p < 0.05$) for N, P and K contents. The illustrated histograms (Figure 4.1) obtained also confirmed the distribution by revealing the direction of the skewnesss within the nutrient contents. In addition, the spread of the distribution that indicated high variations was also illustrated by the Q-Q plots (Figure 4.2). The output from these tests and illustrations therefore depicted that the soil N, P and K nutrient contents in the study area deviated from normal distribution.

Table 4.2: Test of normality for untransformed soil major nutrients ($P < 0.05$)

Test of Normality[a]

Nutrient	Kolmogorov-Smirnova (K-S)		Shapiro-Wilk (S-W)	
	df	Significance (P)	df	Significance (P)

Nitrogen (%)	79	0.009	79	0.001
Phosphorus (mg kg^{-1})	79	< 0.001	79	< 0.001
Potassium (cmolc kg^{-1})	79	< 0.001	79	< 0.00

[1a] The data would not be considered to be normally distributed if both K-S and S-W tests are significant (pvalue < 0.05).

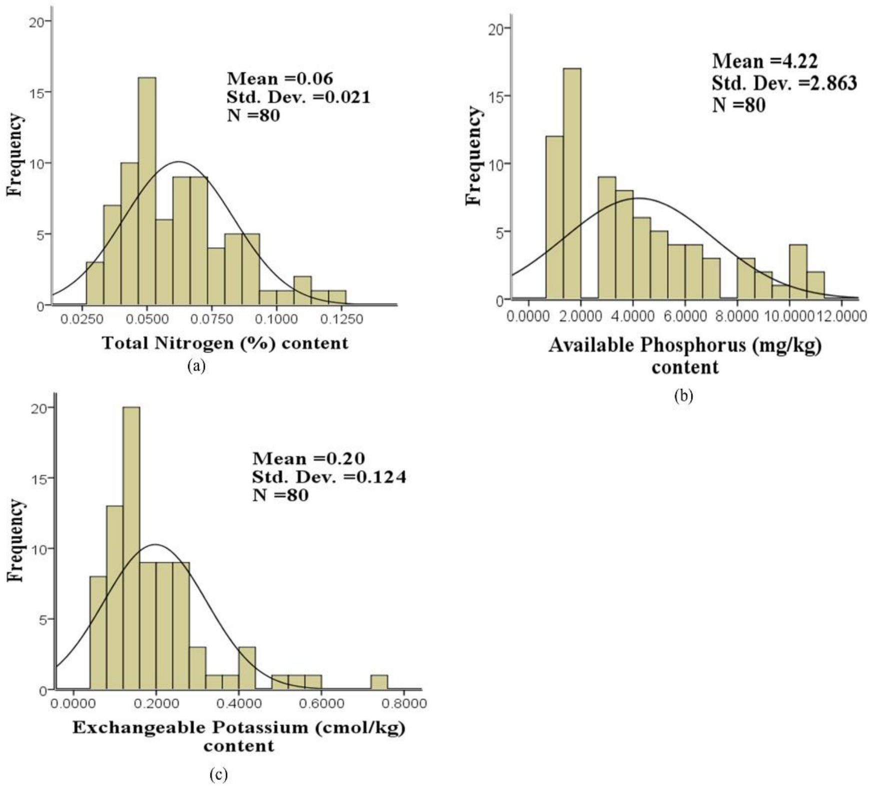


Figure 4.1: Distributions of untransformed major soil nutrient contents.

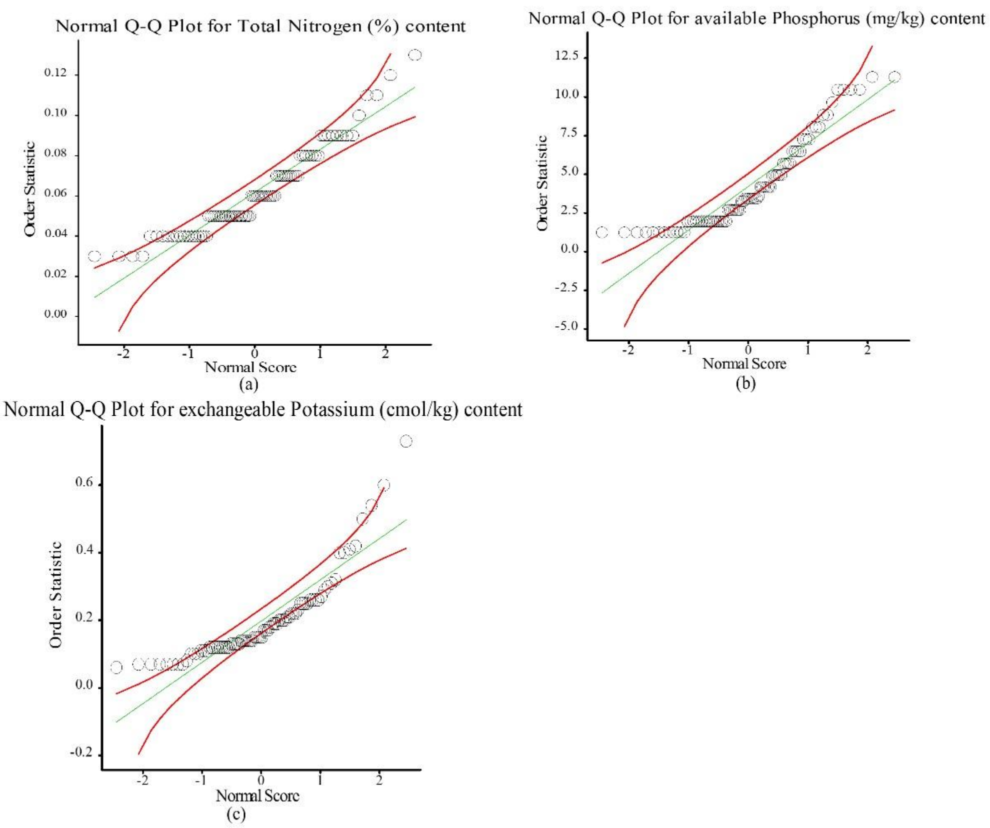


Figure 4.2: Normal QQ-plots of untransformed (a) N, (b) P and (c) K contents illustrating the spread of their distribution.

4.1.2.2 Statistical transformation of the major soil nutrients in the study area

The logarithm (base 10) transformation was applied to the dataset, which rendered the N and K contents normally distributed in order to meet the normality assumption used by the model (skewness values of 0.15 and 0.37, respectively with near normal peaks of 2.44 and 2.97 respectively, (Figure 4.3)).

Only N and K nutrient contents approached normality in their distribution (Table 4.3) as shown in the results after the log transformation. Since P contents did not follow a log-normal distribution (Figure 4.4), the normal score transformation was applied to normalise the P nutrient contents distribution and render them useful for modelling.

Table 4.3: Test of normality for log-transformed soil major nutrients (P < 0.05)

Test of Normality[a]				
Nutrient	Kolmogorov-Smirnova (K-S)		Shapiro-Wilk (S-W)	
	df	Significance (P)	df	Significance (P)
Nitrogen (%)	79	0.200	79	0.545
Phosphorus (mg kg^{-1})	79	0.148	79	0.002
Potassium (cmolc kg^{-1})	79	0.200	79	0.124

[a] The data would not be considered to be normally distributed if both K-S and S-W tests are significant (pvalue < 0.05).

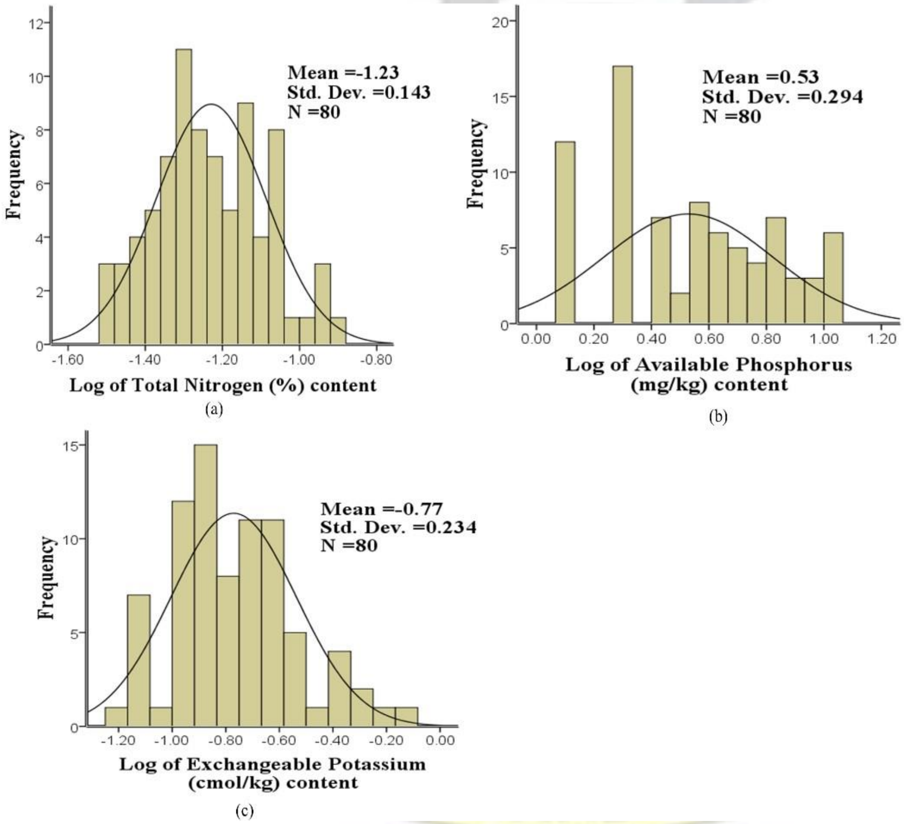


Figure 4.3: Distributions of log transformed major soil nutrient contents.

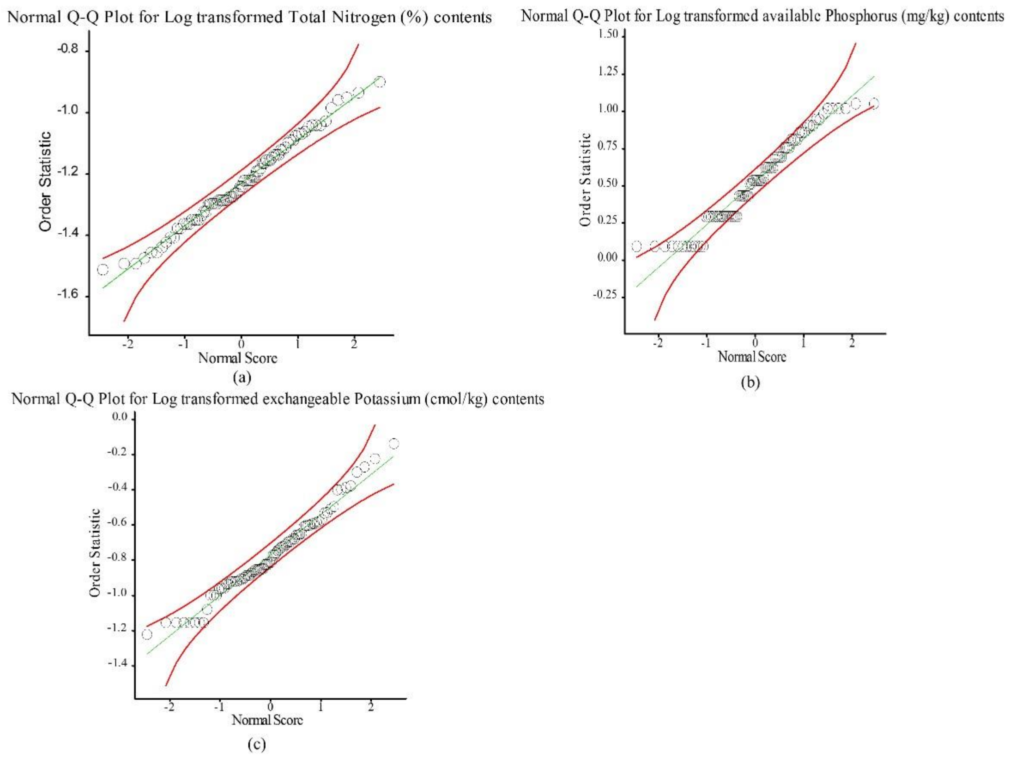


Figure 4.4: Normal QQ-plots of transformed (a) N, (b) P and (c) K contents illustrating the spread of distribution within the nutrients.

4.1.2 Variations in major soil nutrient contents in the study area

The mean values (0.06 %, 4.22 mg kg^{-1}, and 0.20 $cmol_c$ kg^{-1}) for the major soil nutrient contents in the study were low for N, P and K contents, respectively (Table 4.1). In addition, the measured N, P and K contents in the study location when compared with standard nutrient contents values in a soil fertility status context (i.e., Table 4.4) presented by Wopereis *et al.* (2009), revealed that only 5% of the locations fell within good N concentration levels in the soil leaving about 95% of the locations having N concentration in the soil below recommended average for maize production. Twenty three percent (23%) of the locations studied had levels of P within average concentration whilst 77% of the locations had P concentrations below average. Twenty one percent (21%) of the located areas had good K concentrations, 68% were within average while 11% of the locations had K concentrations below average.

Table 4.4: Concentrations of total N, available P and exchangeable K in the soil indicating fertility status at a depth of 0-20 cm

Nutrient level	Total N (%)	Available P (mg kg^{-1})	Exchangeable K (cmol$_c$ kg^{-1})
Good	> 0.10	> 25	> 0.25
Adequate	NA	6 – 25	0.10 – 0.25
Low	0.05 – 0.1	3 – 6	0.05 – 0.10
Very low	< 0.05	< 3	< 0.05

Source: (Wopereis *et al.*, 2009); NA; not available

4.1.3 Models of the spatial dependency of major soil nutrients

The parameters derived from the semi-variogram based on the model with the least RMSE as a measure of uncertainty in the modelling are shown in Table 4.5. The semivariogram models that were used to derive parameters that helped to explain the spatial dependence within the soil N, P and K nutrient contents levels are presented in Figure

4.5.

Table 4.5: Parameters for variogram model for transformed major soil nutrients (N, P and K)

Major soil nutrient contents	Model	RMSE*	Nugget	Partial sill	Range (m)
Total N (kg ha^{-1})	Spherical	0.0033	-[a]	-	-
	Exponential	0.0026	0.013	0.009	50000
	Gaussian	0.0030	-	-	-
	Linear with sill	0.0032	-	-	-
Available P (kg ha^{-1})	Spherical	0.1511	-	-	-
	Exponential	0.1533	-	-	-
	Gaussian	0.1514	-	-	-
	Linear with sill	0.1509	0.3666	0.5821	7415

Exchangeable K (kg ha^{-1})	Spherical	0.0108	0.0316	0.0195	33216
	Exponential	0.0108	-	-	-
	Gaussian	0.0108	-	-	-
	Linear with sill	0.0108	-	-	-

*RMSE (root mean square error); [a] values that were not considered in the model

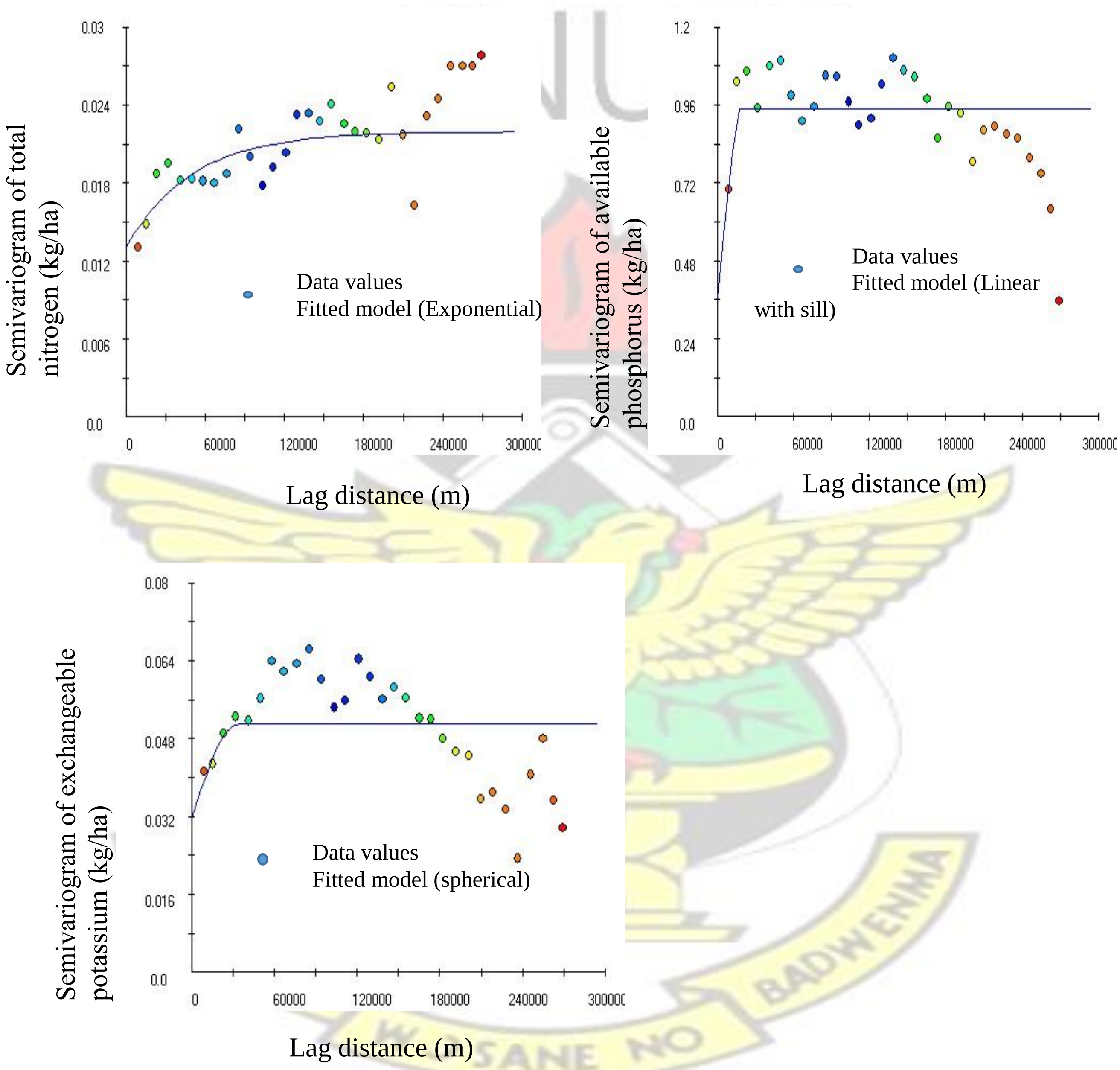


Figure 4.5: Fitted semi-variograms illustrating the strength of statistical correlation between major soil nutrients; (a) Nitrogen, (b) Phosphorus, and (c) Potassium in selected Districts in the Northern Region of Ghana.

These parameters classified the spatial dependence within the N, P and K nutrient contents in the study area. In general, nutrient contents that have a nugget-to-sill ratio less than 0.25 were regarded to have strong spatial dependence (i.e. spatial relationship that exists in variable pattern). The spatial dependence was considered moderate if the ratio is between 0.25 and 0.75 and weak if it was more than 0.75. The nugget-to-sill ratio for N, P and K contents were 0.59, 0.39 and 0.62, respectively (Table 4.5), an indication that their spatial dependencies were moderate.

The uncertainty for the prediction of the nutrient contents generated through the cross validation of the model were N = 0.02%, P = 0.95 mg kg^{-1} and K = 0.11$cmol_c$ kg^{-1} (Table 4.6). These uncertainty values were small (less than 1) and suggested that the predictions could be made. The values provided for the root mean square standardised were also close to one for N, P and K content variables suggesting that none of the variables were under-estimating or over-estimating the predictions.

Table 4.6: Measure of uncertainties in the prediction estimates of N, P and K contents variables in 16 Districts of the Northern region of Ghana

Transformed major soil nutrient	Average standard error	Root mean square standardised
Total nitrogen (kg ha^{-1})	0.02	0.97
Available phosphorus (kg ha^{-1}))	0.98	0.97
Exchangeable potassium (kg ha^{-1})	0.11	0.99

4.1.4 Spatial distribution and autocorrelation of major soil nutrients

The simulated maps from the mean values of the nutrient contents (generated from 10 realisations from different statistical parameters, i.e. mean, median, standard deviation, upper value, lower value, 1st and 2nd quartiles, minimum and maximum values and the percentile) are presented in Figures 4.6, 4.7, and 4.8 for N, P and K, respectively. The means were presented because according to simulation concepts by ESRI (2010), the means do not change over the spatial domain of the data, which fitted into the domain of distribution for this study. In addition, the mean has a Gaussian distribution around the true value, as stated by the central limit theorem (Engblom *et al.*, 2009) and will therefore provide a better representation of the distributions. The generated contours also showed how the elevation of the topography in the study area influence the variation in the N, P and K contents over the topography of the terrain.

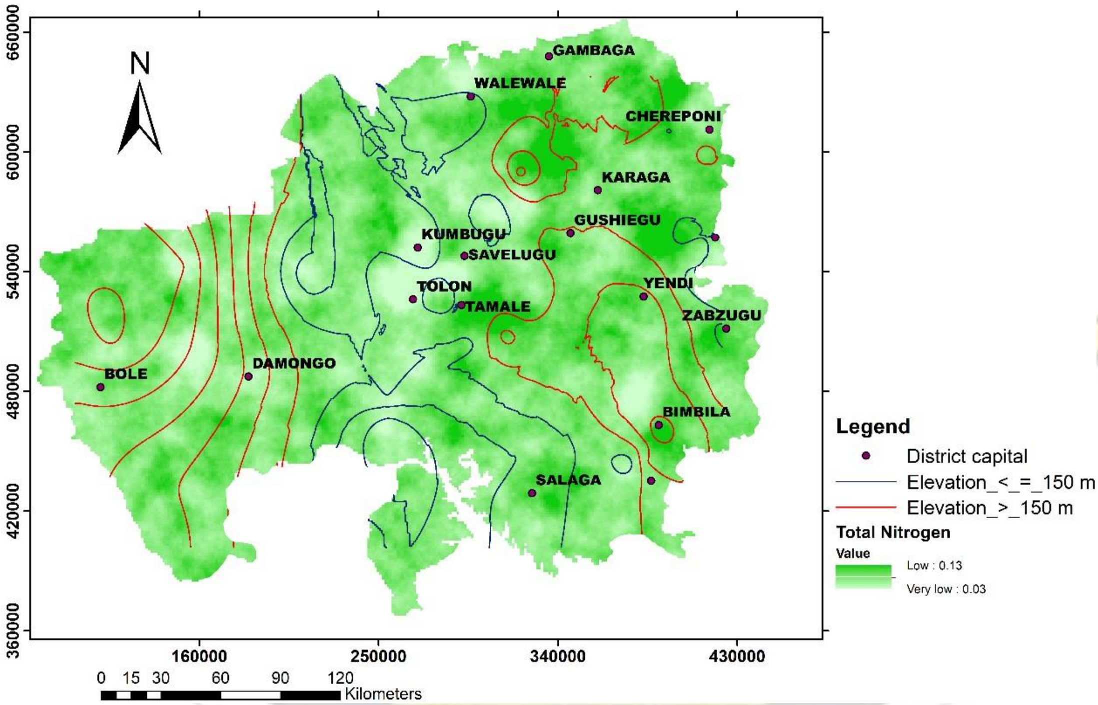


Figure 4.6: Spatial distribution of nitrogen concentration across the topography of Districts within the Northern Region of Ghana.

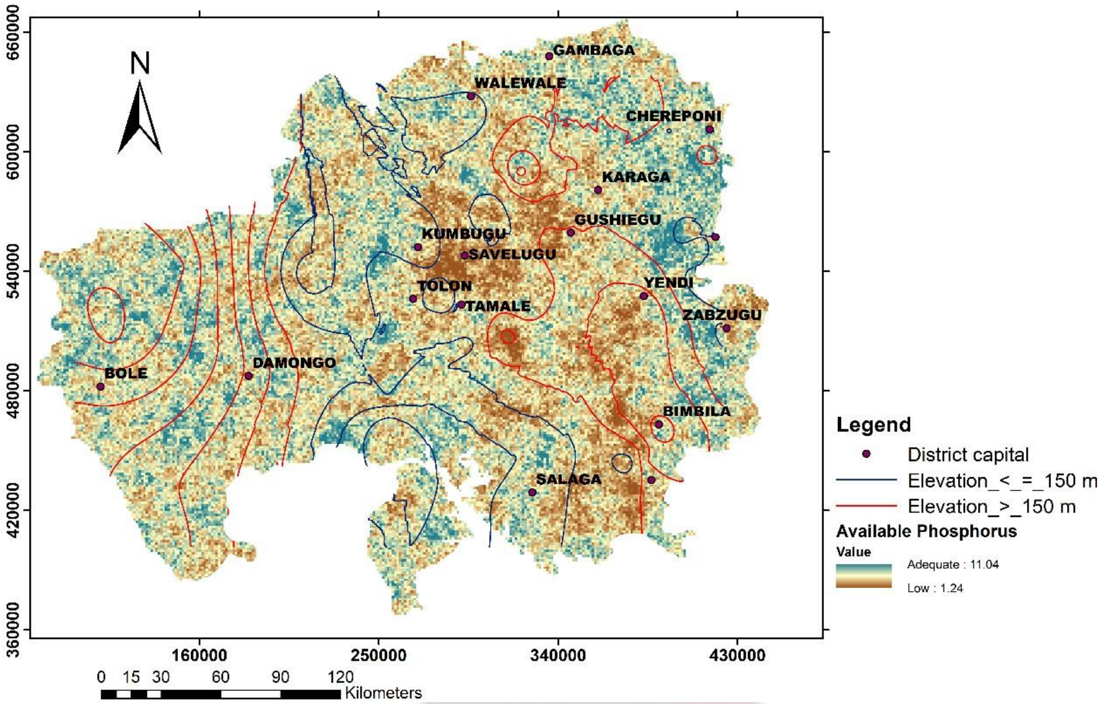


Figure 4.7: Spatial distibution of phosphorus concentration across the topography of Districts within the Northern Region of Ghana.

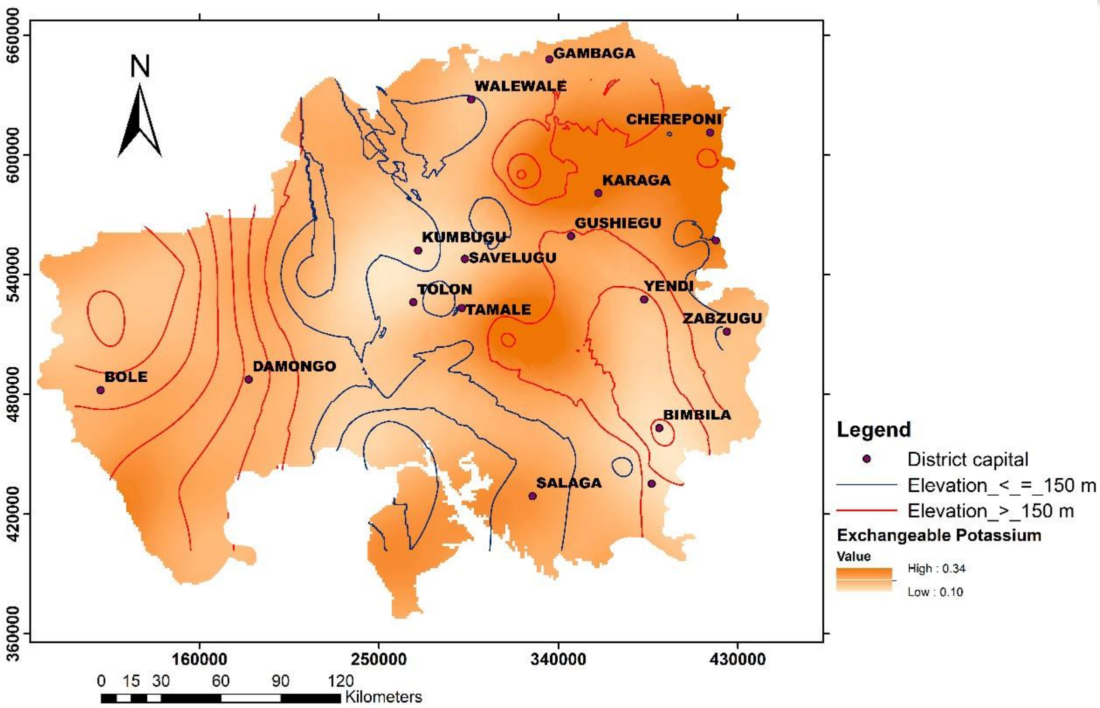


Figure 4.8: Spatial distribution of potassium concentration across the topography of Districts within the Northern Region of Ghana.

The spatial autocorrelation test that was performed to test the significance of the pattern in the distribution of the soil major nutrient concentrations over the topography are presented in Table 4.7.

Table 4.7: Test of significance of pattern analysis for soil nutrient concentration; ($P < 0.05$) and ($1.96 < z < -1.96$)

	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Moran's Index	0.25	0.05	0.17
Expected Index	-0.01	-0.01	-0.01
Variance	0.01	0.01	0.01
z-score	3.59	0.89	2.48
p-value	0.0003	0.38	0.01

The resulting contours that were generated from the elevation point data showed that the topography of the study area was generally flat (contour with values less than 150 m). Few areas recorded contour values less than or equal to 150 m, which were regarded as low elevated lands in this study. The nutrients contents across the topography were relatively low and those that were within average values were found on both flat and low elevated areas.

4.1.5 Spatial relationship between major soil nutrients and factors that might be related to the distribution of the nutrient concentration levels

Major soil nutrient contents in the study area were seen to be distributed in different patterns from the spatial distribution study analysis. These patterns are assumed to be associated with external factors and hence the relationship between these external factors and distribution pattern of the N, P and K contents have been presented in Table 4.10.

The reliability, strength and appropriateness of topography, soil pH and the amount of inorganic fertilizer input were stable for N and K nutrient contents for the first diagnostic test (Table 4.8). Phosphorus contents also stabilised after applying the second robust diagnostic test (Table 4.9).

The observed relationship between these factors and the major soil nutrients (see Table 4.10) was that some factors were strongly associated with the nutrient contents than others and the results have been expanded in the following sub-sections.

4.1.5.1 Stability modelling of factors that might influence N, P and K nutrient concentrations in the study area.

The results of the general reliability check for the OLS model are presented in Table 4.8. The different variables used as associated variables were consistent with each of the transformed nutrient variables (N, P and K contents) as determined by the Koenker (BP) significance ($p < 0.05$) statistic for N and K contents and the Robust coefficient significance values ($p < 0.05$) for the P contents (Table 4.9). The robust coefficient diagnostic test showed that the associated factors and P contents were stable. Results from the Jacque-Bera test ($p < 0.05$) also showed that the residuals from the OLS model used to assess the association between the considered factors and the N, P and K contents were normally distributed. The VIF values (< 7.5 for N, P and K contents) also suggest that the associated variables were unique and that their associations with the N, P and K contents were different from each other. Finally, the results for Wald statistic and Joint F statistic tests indicated that the model was significant ($p < 0.05$) for all the variables (N, P and K contents) and the confirmation was obtained by comparing the Wald statistic and Joint F statistic tests with the Koenker (BP) statistic test (Table 4.8).

Table 4.8: Ordinary Least Square diagnostic test that determined the significance and reliability of association between external factors and N, P and K contents in 16 Districts of the Northern Region of Ghana

Dependent variable	Explanatory variable	VIF	JacqueBera test (P < 0.05)	Joint Fstatistic (P < 0.05)	Joint Wald statistic (P < 0.05)	Koenker (BP) statistic (P < 0.05)
Log N	Elevation	1.1				
	Soil pH	1.0	0.17	4.69	9.11	4.07
	Fertilizer applied	1.0	(0.91)*	(0.004)**	(0.03)**	(0.25)**
Normal Score P		1.1				
	Elevation	1.0	4.49	2.54	11.26	8.60
	Soil pH	1.0	(0.11)*	(0.06)**	(0.01)**	(0.04)**
	Fertilizer applied					
Log K	Elevation	1.1				
	Soil pH	1.0	5.70	5.29 (< 0.001)**	19.53	2.11
	Fertilizer applied	1.0	(0.06)*		(< 0.001**)	(0.54)**

*Probability (> chi-squared), (2) degrees of freedom, statistically significant at the 0.05 level; **Probability (> chi-squared), (3) degrees of freedom, statistically significant at the 0.05 level; VIF, variance inflation factor.

Table 4.9: Ordinary Least Squares diagnostic test results on the effectiveness of each of the associated variables on the phosphorus content in the soil

Dependent variable	Explanatory variable	Robust standard error	Robust probability (p < 0.05)
	Elevation	< 0.001	0.71
P	Fertilizer applied	0.001	0.17
	Soil pH	0.19	0.77

P was transformed using the normal score transformation.

4.1.6.2 Relationship between topography, amount of inorganic fertilizer input, soil pH and transformed N, P and K in the study area

The relationship between topography, amount of fertilizer that smallholder farmers used on their farms and soil pH values at the study area are presented in Table 4.10.

Table 4.10: Relationship between soil N, P and K nutrient contents and factors that might be associated with the spatial distribution of the nutrient contents in 16 Districts of the Northern region of Ghana

Soil nutrient variable	**Associated factor**	**Coefficient**	**Probabilities**	**Coefficient of determination (R^2)**	**Model Error ($p < 0.05$)**
N (logtransformed)	Intercept	-3.7259	< 0.001*	0.12	0.96
	Elevation	-0.0002	0.30		
	Average amount of fertilizer use	-0.0003	0.13		
	Soil pH	0.2067	< 0.001*		
P (normal score transformed)	Intercept	0.4152	0.70	0.09	0.62
	Elevation	0.0003	0.73		
	Average fertilizer use	-0.0023	0.01*		
	Soil pH	-0.0199	0.91		
K (logtransformed)	Intercept	-1.9873	0.01*	0.17	0.90
	Elevation	-0.0004	0.36		
	Average fertilizer use	-0.001	< 0.001*		
	Soil pH	0.1406	0.15		

*significant at 0.05 probability level

Elevation

The results of the OLS model generated for the relationship between factors that may be associated with the major soil nutrients contents is presented in Table 4.9. The relationships between the elevation of the topography and P contents was positive (coefficient value = 0.0003) and negative (coefficient values = -0.0002 and -0.0004) for N and K contents respectively.

Average amount of fertilizer used in the Districts

The relationship between average amount of fertilizer application and that of all the major soil nutrients was negative (N = -0.0003, K = -0.0023 and K = -0.001; Table 4.9). The average amount of fertilizers used by the farmers in sixteen Districts of the study area has also been presented in Figure 4.9. The District that applied the lowest amount of fertilizer (100 kg ha^{-1}) was Tamale Metropolitan and the District that applied the highest amount (402 kg ha^{-1}) was Nanumba North.

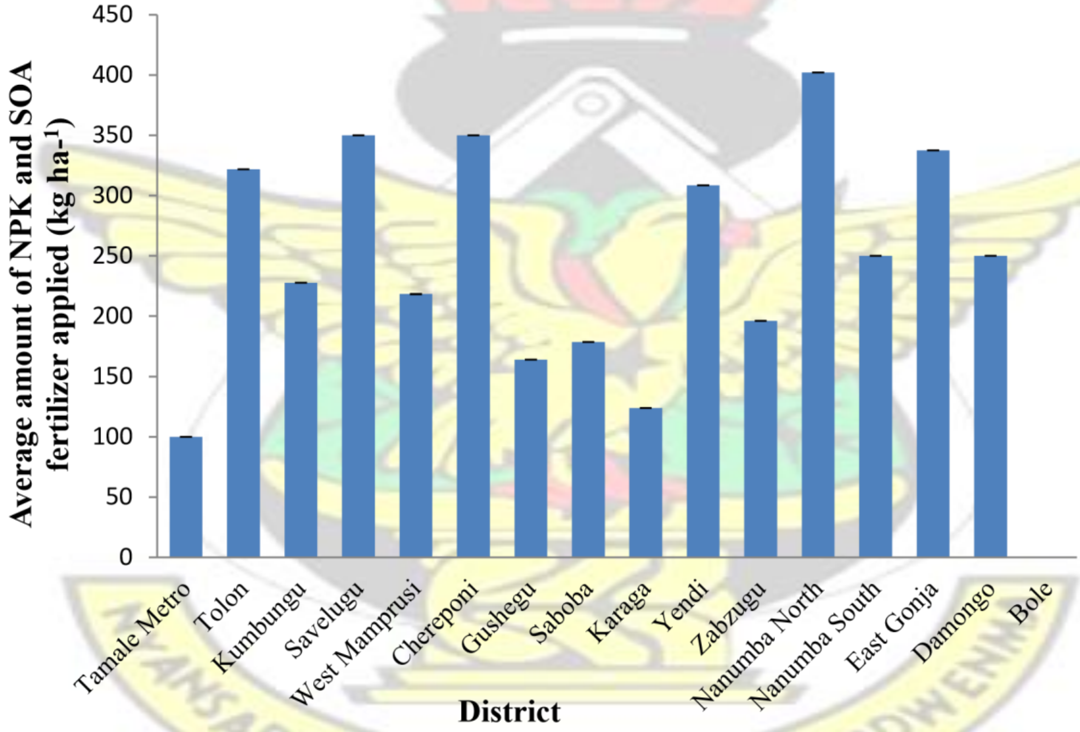


Figure 4.9: Average amount of fertilizer used by smallholder farmers in 16 Districts of the Northern Region of Ghana.

Soil pH

The average soil pH values measured for the various Districts within the study area are shown in Figure 4.10. The results of the OLS model presented in Table 4.8 suggests that, soil pH across the region influenced the N, P and K contents differently. There was a positive relationship for N and K, and negative relationship for P. However, it was only N contents that showed a significant positive relationship ($p = 0.001$) with soil pH. In general, the positive significant relationship between soil pH and N indicated that total N contents decreased in the soil at location where soil pH was relatively lower than the average or N contents increased in the soil where soil pH was relatively higher than the average. The highest soil pH (6.21) was obtained in Tamale Metropolitan and the lowest (5.08) was obtained in Zabzugu District.

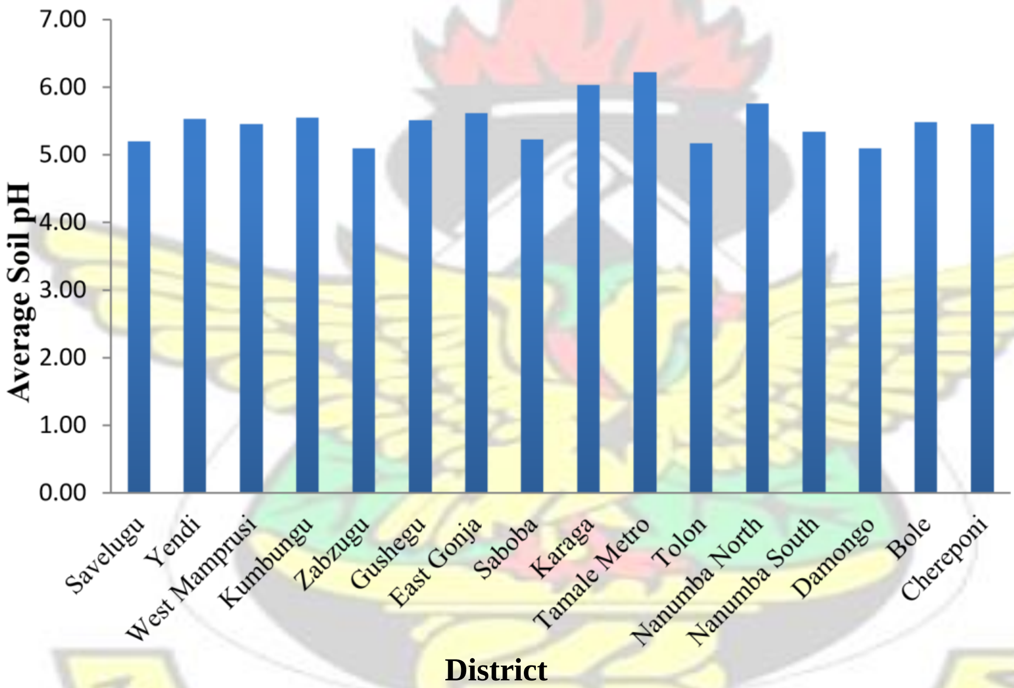


Figure 4.10: Soil pH levels in 16 Districts of the Northern Region of Ghana.

4.2 Model for site classification for combined N, P and K nutrient contents

The result for the simulation overlay analysis is a raster surface of 500 dpi resolution and is presented in Figure 4.11. The raster surface shows levels of overlaid N, P and K contents distributions from relatively low to relatively high levels across the study area. Locations having inadequate combined N, P and K contents have been represented in red pixel colours, moderate concentrations are represented in yellow pixel colours whilst adequate concentrations are in green pixel colours.

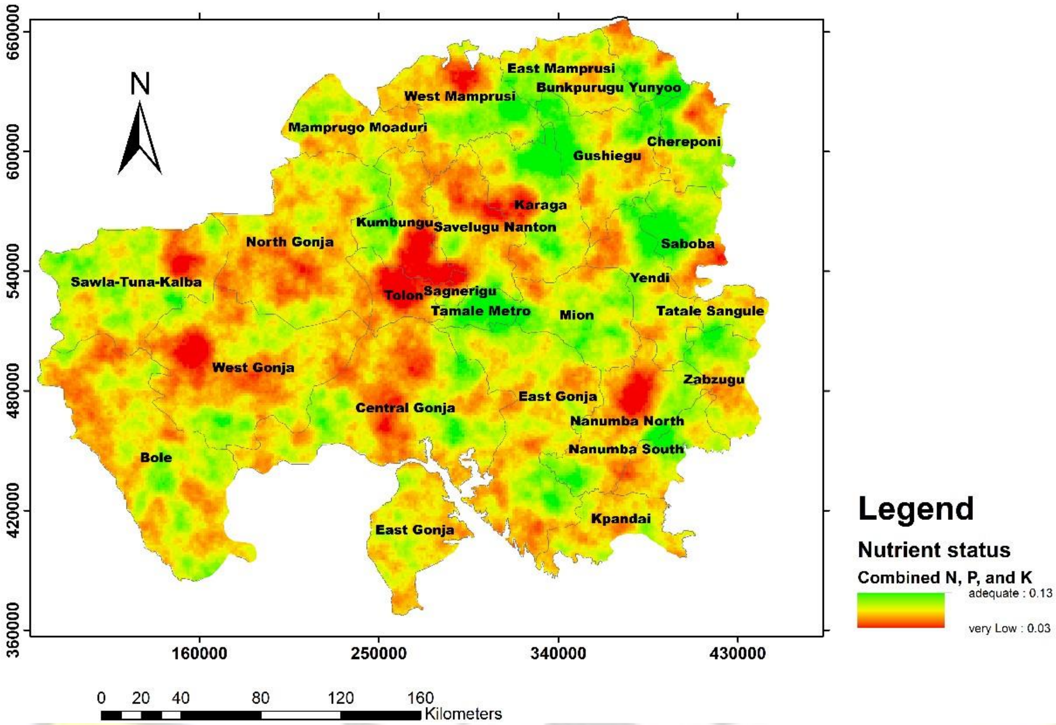


Figure 4.11: Fuzzy overlay analysis of major soil nutrients and average amount of fertilizer used.

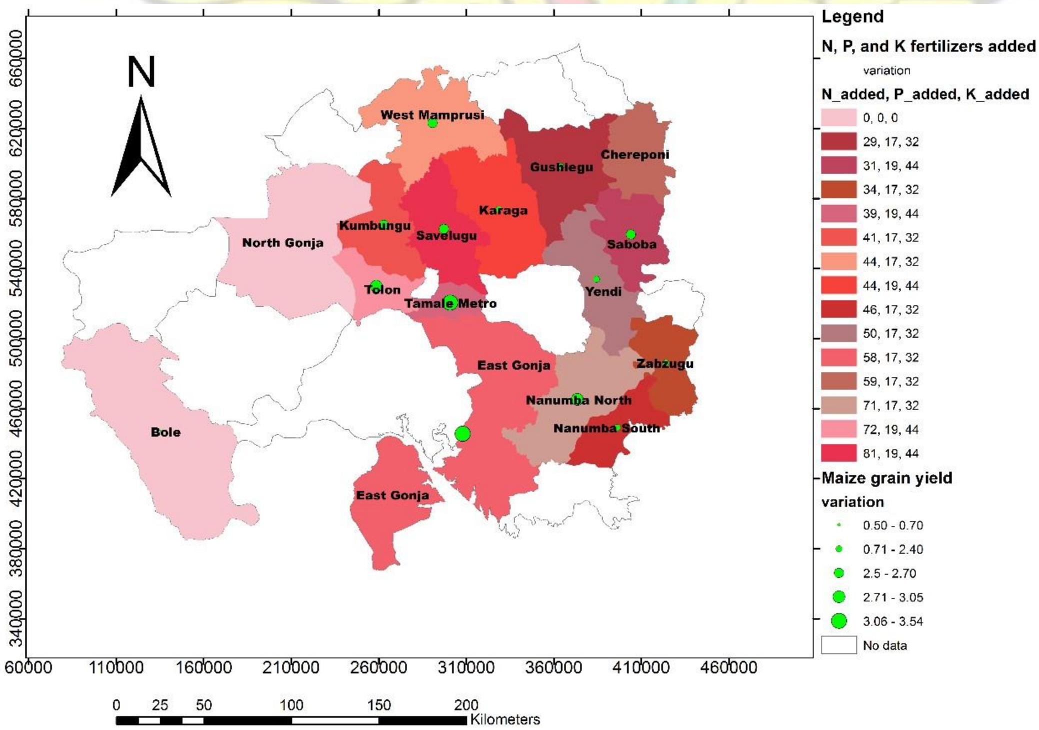


Figure 4.12: Amount of N, P and K nutrients (kg ha^{-1}) added by smallholder farmers and the corresponding maize yields in 16 Districts of the Northern Region

4.3 Assessment of N, P and K nutrient management and appropriate site-specific options

Evaluation of fertilizer input by farmers and maize yield in the study area

The fertilizer input practices mainly done by smallholder farmers differed among them and affect their maize grain yields differently as well. The variability existing in the use of fertilizer by 89 smallholder farmers from different Districts under the three categories of fertilizer input (< 375 kg ha^{-1}, = 375 kg ha^{-1}, and > 375 kg ha^{-1}) was not directly related to their maize grain yields.

Levene's test of equality of variances within the maize grain yields obtained by the smallholder farmers showed that, the amount of fertilizer used within the three categories by the farmers did not significantly ($p = 0.90$) relate to variations in their maize yields. Further analysis revealed that, even though the variances in maize yields were not significant ($p = 0.90$), the differences between the means of maize yields for the categories of fertilizer used were large; i.e. mean maize yields between farmers who applied less than 375 kg ha^{-1} and those who applied 375 kg ha^{-1} (recommended) was 344 kg ha^{-1}, that of farmers who applied 375 kg ha^{-1} and those who applied more than 375 kg ha^{-1} was 427 kg ha^{-1} and the difference between those that applied less than 375 kg ha^{-1} and those that applied more than 375 kg ha^{-1} was 771 kg ha-1 (Table 4.11). The variances of maize grain yield within the categories and between the categories (mean square value of 2445122) are presented in Table 4.12. The results showed that large differences existed between the categories and even within the categories, even though the differences within each of them did not show any significance ($p = 0.08$).

Table 4. 11: Statistical description of yield (kg ha^{-1}) as given by amount of fertilizer applied (kg ha^{-1})

Amount of NPK (15:15:15) and SoA fertilizers applied (kg ha^{-1})	N	Mean maize yield	Std. Error maize yield	95% Confidence Interval for Mean		Minimum Maize yield	Maximum
				Lower Bound	Upper Bound		
<375	49	2608	178.11	2249.42	2965.67	1024	6144
375(Blanket)	23	2952	248.14	2437.18	3466.41	1024	5376
>375	17	3379	288.43	2767.74	3990.66	1152	6144
Total	89	2844	131.91	2581.76	3106.05	1024	6144
Levene's test of variance ($p < 0.05$)						0.90	

Table 4.12: Analysis of variance in maize grain yield as influenced by amount of inorganic fertilizer applied by smallholder farmers

	Maze yield					
	Sum of Squares	df	Mean Square	F	Effect size	Probability ($P < 0.05$)
Between categories	7876386.05	2	3938193.03	2.638	0.06	0.08
Within categories	128404089.59	86	1493070.81			
Total	136280475.64	88				

Significance of variations within mean grain yields

The effect size, which was estimated by eta^2, measured the significance of the means of the variance in the maize grain yields, and gave the value of 0.06 as obtained from equation (3.13) (Table 4.12).

The relationship between different amounts of fertilizer input and maize yield The mean grain yields of smallholder farmers who applied fertilizer below the average of 375 kg ha^{-1} was lower (2608 kg ha^{-1}) while the mean grain yields of smallholder farmers who applied above 375 kg ha^{-1} was higher (3379 kg ha^{-1}) as shown in Table 4.11.

However, the results on the use of fertilizer under the three categories of fertilizer input by smallholder farmers led to different responses of maize yields to N applied in the study area (Figure 4.13). The relationship was negative for the first coefficient (x^2) and positive for the second coefficient (x) with an r value of 0.70. The established quadratic polynomial function explains how a decrease or an increase in N application impacts the maize grain yields. In the first instance of coefficient (x), as N is increased, maize grain yield increased. In the second instance of coefficient of x^2, increase in N application rate did not continuously increase the maize grain yields.

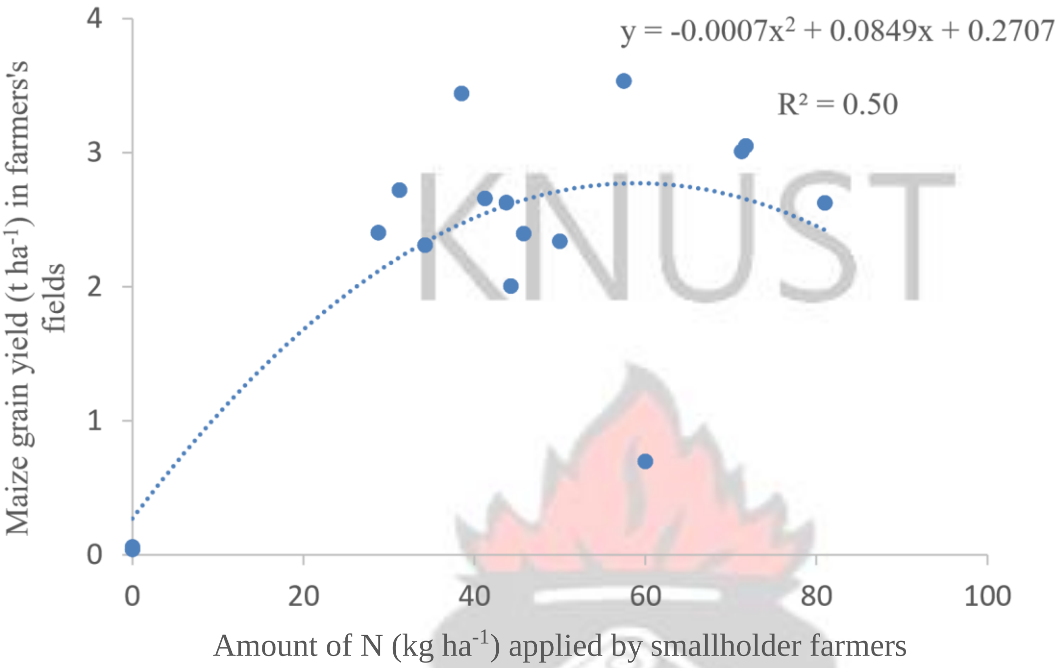


Figure 4.13: Relationship between N fertilizer application and smallholder farmers' maize grain yields in the Northern Region of Ghana.

The relationship as illustrated on the graph (Figure 4.13) shows that a further increase in the amount of N fertilizer application of 65 kg ha^{-1} resulted in a decline of maize yields. Nitrogen application in the study area explainGrd 50% of the variation of maize grain yields in the study area. Phosphorus and K did not explain much of the variations in the amount of maize grain yields in the study area (Appendices 3 and 4).

4.3.1 Evaluation of fertilizer input and maize yield from farmers' fields and researchers' demonstration plots

The amount of inorganic fertilizer used by about 55% of the farmers in the 16 Districts were lower than 375 kg ha^{-1}across the study region. The smallholder farmers relied mostly on quantity of fertilizers available as at the time of application and do not consider much what the national recommendations for maize production are.

Basically, the common practice in terms of fertilizer input by the farmers was the blanket recommendation of 5 bags of NPK 15:15:15 and 2.5 bags of Sulfate of Ammonia (SoA) for each hectare of land being cultivated. Nevertheless, some farmers used either less or more than the recommended as dictated by availability of fertilizer to farmers at the time of application. Farmers who had other sources of organic input such as animal manure and crop residues applied them to their fields in addition to the compound fertilizers.

4.3.2 Comparison between farmer and researcher fertilizer use and maize yield in the study area

Compilation and evaluation of different treatments imposed by researchers in the study area revealed that certain treatments produced higher yields consistently in 13 out of the 16 Districts in the study area for a period of 3 years; the lowest mean yield was obtained in Karaga District (1719 kg ha^{-1}) and the highest was obtained in Karaga District (4103 kg ha^{-1}) as shown in Table 4.13. The fertilizer input and the mean grain yields from selected representative smallholder farmers' fields for each of the 13 Districts are shown in Table 4.14.

The results showed that the average fertilizer used by the researchers was significantly ($p < 0.05$) higher than the average fertilizer input by the smallholder farmers. Regardless of the higher fertilizer input, the mean maize grain yield obtained from the researcher demonstration trials was not significantly ($p = 0.74$) higher than the smallholder farmers' grain yields in the 13 Districts (Table 4.15).

However, results from the t-test that compared the maize grain yields from the demonstration plots and the farmers' fields in five Districts where ISFM strategy caused increase in maize yields showed that these yields were significantly higher ($p = 0.03$) than the farmers' mean grain yields (Table 4.16).

Table 4.13: Researcher demonstrations trials producing consistent increase in maize grain yields for a 3-year period

District	Site-specific trial	Maize Grain yield (kg ha^{-1})			
		2011	2012	2013	Mean
Savelugu	Maize + Manure (2.5 tonnes ha^{-1}) + ½ NPK recommended rate	1636	1444	2229	1770
Yendi	Maize + 2 bags NPK 15:15:15 + 1½ bag SA	2728	2772	N/A*	2750
West Mamprusi	Maize + NPK recommended rate	1263	1587	N/A	1425
Kumbungu	Hybrid (Pannar 53) maize variety + recommended rate	2000	4379	5929	4103
Zabzugu	Maize + Fertisoil 3t/ha + 2½ bags/ha SA	3603	2453	5244	3767
Gushegu	Hybrid (Pannar 53) maize variety + recommended rate	2320	3083	N/A	2701
Saboba	Maize + 2 bags NPK 15:15:15 + 1½ bag SA	2221	1954	3724	2633
Karaga	Maize + 2 bags NPK 15:15:15 + 1½ bag SA	1314	2124	N/A	1719
Tamale Metro	Hybrid (Pannar 53) maize variety + recommended rate	2017	3902	4181	3367
East Gonja	Omankwa (DTMA maize variety) + recommended fertilizer rate	2453	1497	N/A	1975
Tolon	Maize + 2 bags NPK 15:15:15 + 1 bag SA	1367	2273	3646	2429
Nanumba South	Hybrid (Pannar 53) maize variety + recommended rate	2187	4125	N/A	3156

Nanumba North	Maize + 2 bags NPK 15:15:15 + 1½ bag SA	1816	2620	N/A	2218

*N/A: data not available

Table 4.14: Test of significance of average amount of fertilizer input by researchers on demonstration plots and smallholder farmers in the study area (n = 13)

Sample	Mean fertilizer input (kg ha^{-1})	Variance	F pr.
Demonstration plots	370	6811	0.001
Farmers' fields	244	8537	

Table 4.15: Test of significance of average grain yield fields in the study area (n = 13) ›n demonstratio 'armers'

Sample	Mean Grain yield (t ha^{-1})	Variance	F pr.
Demonstration plots	2.62	0.66	0.74
Farmers' fields	2.70	0.20	

Table 4.16: Test of significance of average grain yield on demonstration and farmers' fields in Districts within the study area where researchers' maize yields were higher than farmers' (n = 5)

Sample	Mean Grain yield (t ha^{-1})	Variance	F pr.
Demonstration plots	3.30	0.39	0.03

Farmers' fields	2.42	0.02

4.3.3 Comparison between farmers' practice and researchers' demonstration trials in 13 Districts in the study area

The result of the statistical test led to further investigation to compare fertilizer application by smallholder farmers to those used in the researcher demonstrations trials District by District. The average amount of N, P and K fertilizer inputs by farmers and researchers and their corresponding maize grain yields in each District under the study area are shown in Figures 4.14, 4.15, and 4.16, respectively. Figure 4.14 compares the amount of N input made by farmers to the amount of N input by researchers and shows that in 11 out of the 13 Districts, the amount of N input by researchers was more than the farmers' N input. However, the maize yields of researchers differed from District to District when compared in these 11 Districts. Figure 4.15 compares the average amount of P input by researchers to average amount of P input by farmers. The results indicated that the amount did not differ much from each other in the Districts, except in Zabzugu where P application by researchers was exceedingly more than the farmers (about twice). The same observation was made for K application and the results are presented in Figure 4.16.

In general, farmers added about 3 t ha^{-1} of cattle manure or more depending on availability at the time of application to their maize fields as organic amendment. Smallholder farmers in Districts where the use of cattle manure was prominent (Karaga and Tamale Metropolitan) either used no or very small quantities (less than 375 kg ha^{1}) of inorganic fertilizer to supplement the manure application. Six Districts

(Tamale Metropolitan, West Mamprusi, East Gonja, Karaga, Saboba and Nanumba North) had inputs of N fertilizer lower than what was used by the researchers in the demonstration trials but recorded relatively higher yields (Figure 4.14). The only Districts where smallholder farmers used relatively more N, P and K fertilizer inputs than what was used by the researchers and recorded relatively higher maize yields were Savelugu and Tolon (Figures 4.14, 4.15 and 4.16).

On the contrarily, Zabzugu, Gushegu, Kumbungu, Nanumba South and Yendi Districts used N fertilizer inputs lower than those used by the researchers and recorded relatively lower yields.

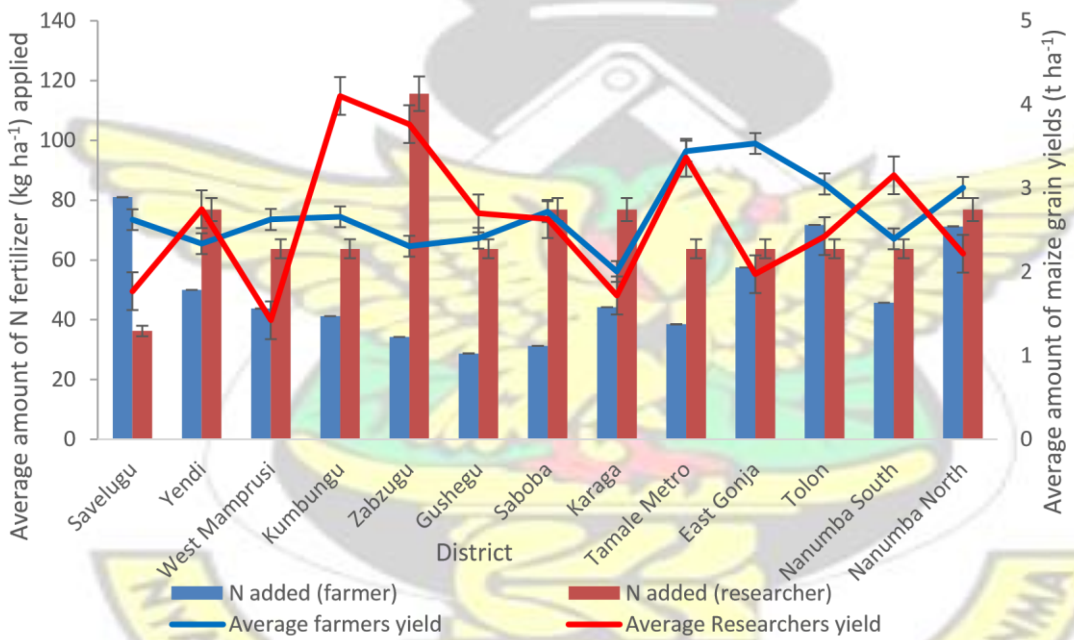


Figure 4.14: Average amount of N nutrients applied to the soil and the corresponding maize yields by smallholder farmers and researchers in the 13 Districts of the Northern Region of Ghana.

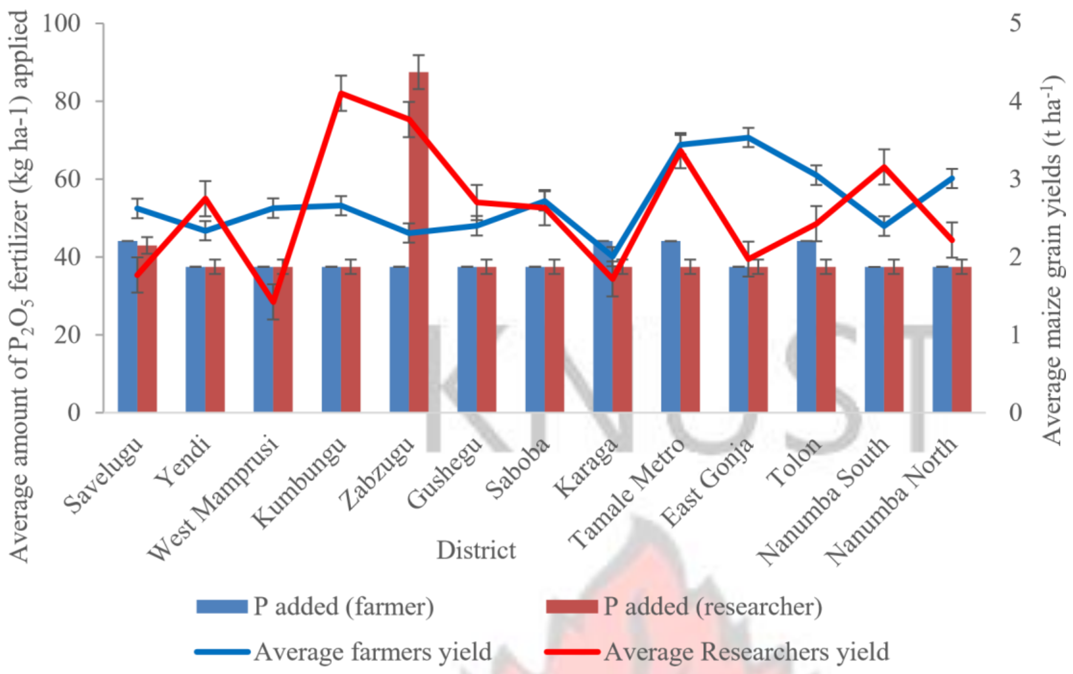


Figure 4.15: Average amount of P nutrients added to the soil and the corresponding maize yields by smallholder farmers and researchers in the 13 Districts of the Northern Region of Ghana.

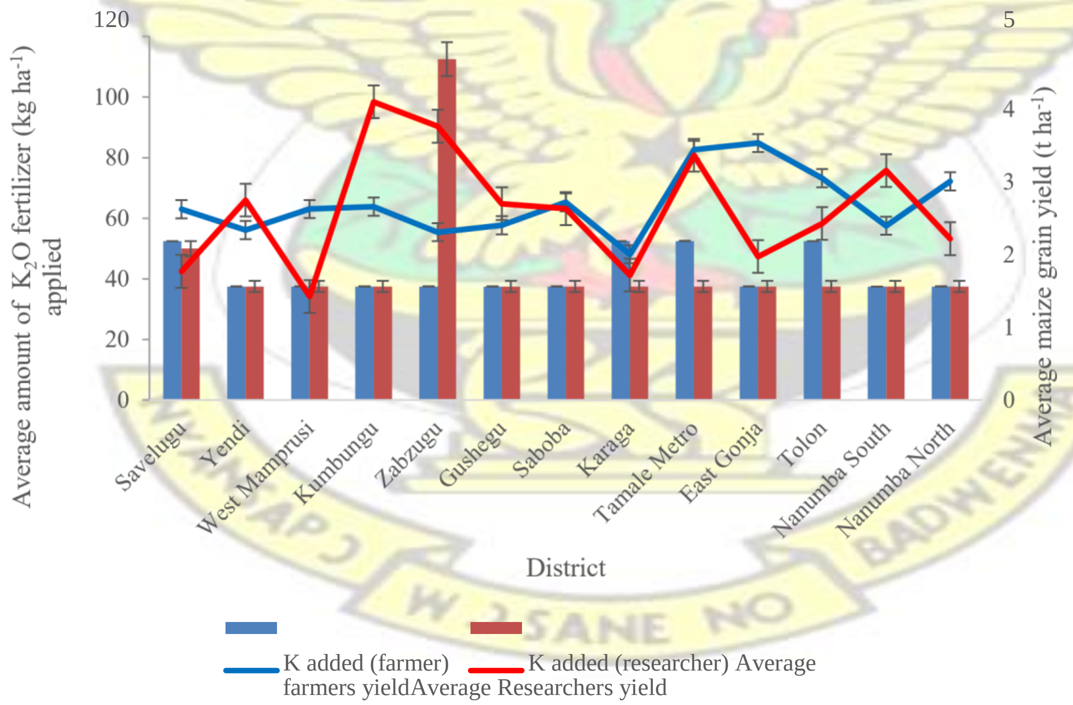


Figure 4.16: Average amount of K nutrients added to the soil and the corresponding maize yields by smallholder farmers and researchers in the 13 Districts of the Northern Region of Ghana.

4.3.3.1 Nitrogen, P and K nutrient losses through harvested produce for 13 Districts within the study area and implications for soil nutrient management and estimated potential maize grain yields

The results of the amount of N, P and K nutrient contents lost through maximum harvested maize crops (Figures 4.14, 4.15, and 4.16) calculated for 13 Districts are shown in Table 4.17. Generally, the amount of nutrients removed from the Districts were high (above 30 kg ha^{-1}). The highest removed nutrients (N = 57 kg ha^{-1}, P_2O_5 = 25 kg ha^{-1}, and K_2O = 21 kg ha^{-1}) were recorded in Kumbungu District and the lowest (N = 28 kg ha^{-1}, P_2O_5 = 12 kg ha^{-1}, and K_2O = 10 kg ha^{-1}) recorded in Karaga District. The calculated requirements of the N, P and K nutrients to replace the removed nutrients and the estimated yields have been presented in Table 4.21. The highest N, P and K nutrients to be replaced was 63, 9, and 82 kg ha^{-1}, respectively for Yendi District and the lowest calculated N, P and K nutrients to be replaced was 47, 9, and 49 kg ha^{-1}, respectively for West Mamprusi District.

Table 4.17: Nitrogen, P and K nutrients removed through harvest of highest maize grain yield

District	kg ha^{-1} removed		
	N	P_2O_5	K_2O
Savelugu	37	16	13
Yendi	39	17	14
West Mamprusi	37	16	13
Kumbungu	57	25	21
Zabzugu	53	23	19
Gushegu	38	16	13
Saboba	38	16	14
Karaga	28	12	10
Tamale Metropolitan	48	21	17
East Gonja	48	21	18
Tolon	43	13	15
Nanumba North	31	13	11
Nanumba South	44	19	16

Calibration and sensitivity test of the QUEFTS model to different values of maximum accumulation (a) and maximum dilution (d)

The RE and the IE parameters obtained from the twenty trials used to calibrate the QUEFTS model have been presented in Tables 4.18 and 4.19. The average RE (kg kg^{1}) used to calibrate the model were for N = 0.49, P = 0.33 and K = 0.67. The three sets of values for 'a' and 'd' used for the sensitivity test are shown in Table 4.19. These three sets represent different extremes of internal efficiencies which excluded outliers to test the sensitivity of the model. All three sets provided similar nutrient requirements for maize, with the exception of yield levels close to the potential. Set 1of ‘a’ and ‘d’ with values 35 kg N kg^{-1} and 77 kg N kg^{-1}, 145 kg P kg^{-1} and 509 kg P kg^{-1}, and 32 kg K kg^{-1} and 114 kg K kg^{-1} was therefore used in the standard version of the QUEFTS model, as this set of values included the maximum range of variability in the data. The relationship established between uptake of nutrients and maize grain yield are presented in Figure 4.17. The relationship for determining maize grain yields based on uptake of nutrients is also presented in Table 4.20.

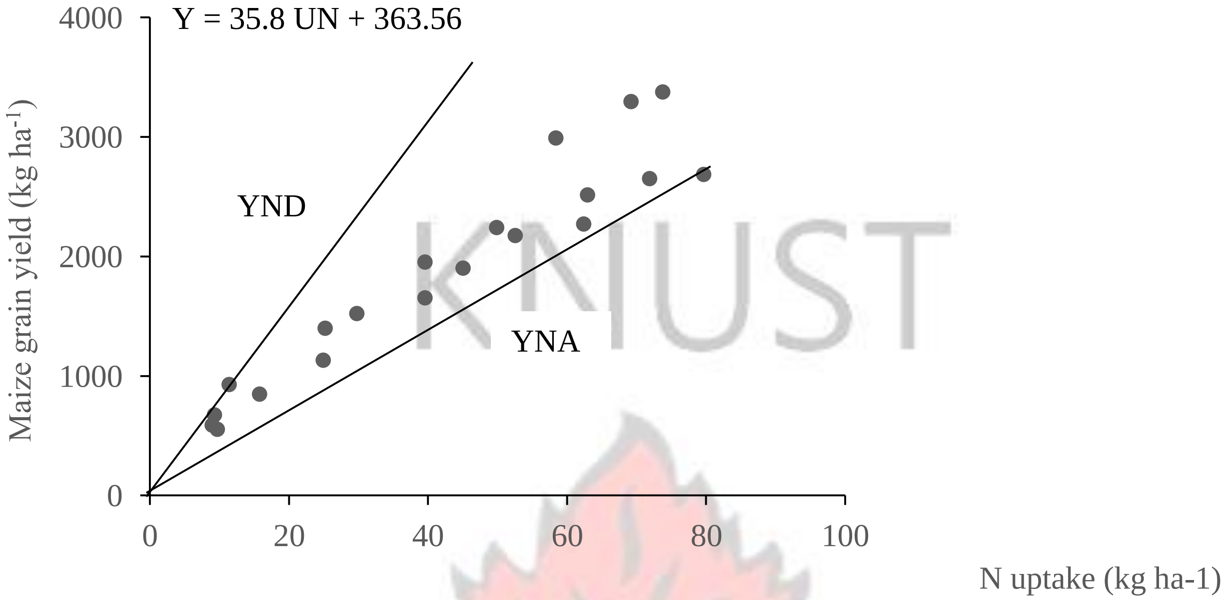
Table 4.18: Recovery efficiency obtained from the calculations from nutrient omission plots with the QUEFT model

Partition	Recovery efficiency (kg kg^{-1})		
	N	P	K
No NPK	-	-	-
NPK	0.65	0.41	0.84
NP	0.38	0.39	-
NK	0.44	-	0.62
PK	-	0.20	0.56
	0.49	0.33	0.67

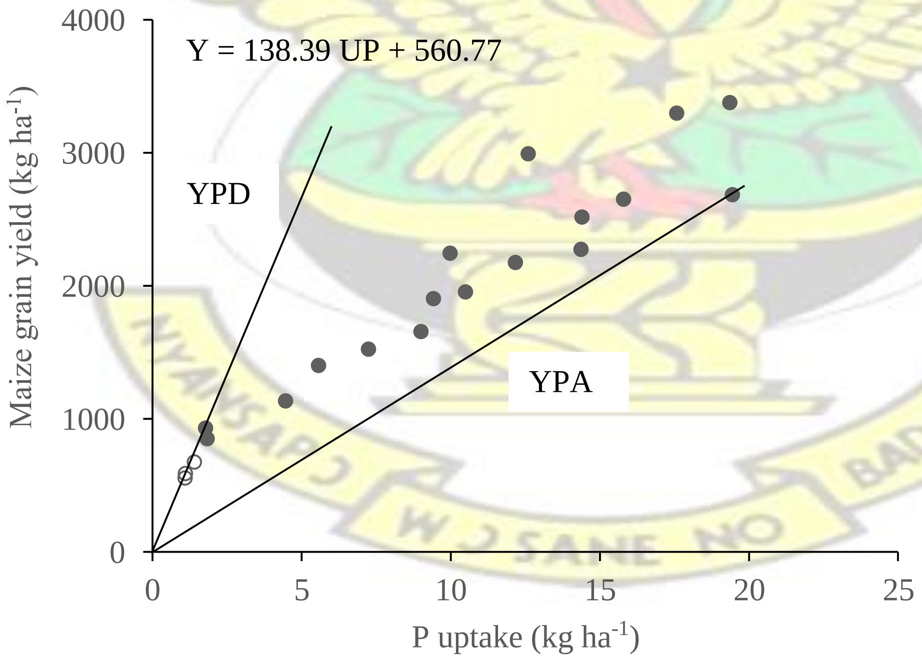
Table 4.19: Sets of constants ‘a’ (maximum accumulation) and ‘d’ (maximum dilution) obtained as related to maize grain yields and uptake of N, P and K nutrients.

Nutrient	Set I kg kg^{-1}		Set II kg kg^{-1}	
	5^{th} percentile a	95^{th} percentile d	7.5^{th} percentile a	92.5^{th} percentile d
N	35	77	36	75
P	145	509	148	496
K	32	114	33	111

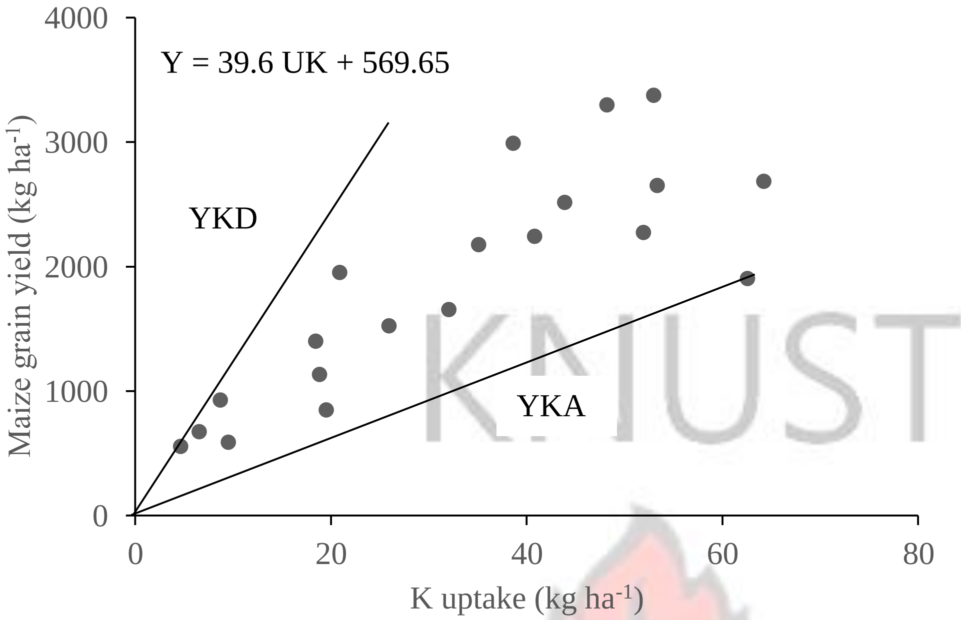
	Set III kg kg^{-1}	
	10^{th} percentile a	90^{th} percentile d
N	37	73
P	152	482
K	34	104


Y = 35.8 UN + 363.56
YND
YNA
Maize grain yield (kg ha-1)
N uptake (kg ha-1)
0
1000
2000
3000
4000
0
20
40
60
80
100

(a)


Y = 138.39 UP + 560.77
YPD
YPA
Maize grain yield (kg ha-1)
P uptake (kg ha-1)
0
1000
2000
3000
4000
0
5
10
15
20
25

(b)



(c)

Figure 4.17: Relationship between grain yield of maize and nutrient uptake of (a) N, (b) P and (c) K. The upper (YND, YPD, and YKD) and lower (YNA, YPA, and YKA) lines indicate yields of maximum dilution and maximum accumulation respectively. Data are based on research trials from Savanna Agricultural Research Institute, Tamale covering 20 demonstration sites from five Districts in Northern Region of Ghana.

Table 4.20: Relationship between nutrient supply of N (UN), P (UP), and K (UK) and maize grain yields in the Northern region of Ghana

Nutrient uptake (supply) versus maize grain yield	R^2
Yield of N = 35.8 UN + 363.56	0.92**
Yield of P = 138.4 UP + 560.77	0.92**
Yield of K = 39.6 UK + 569.65	0.71**

**Significant at 0.01 probability level

The validated model gave an accuracy of 0.18, based on U-Theil calculation of accuracy (equation 3.17). The nutrients applied within the fertilizer application methods on farmers' fields, with its observed yield and the calculated actual uptake of nutrient to be applied with the estimated maize grain yields have been presented in

Table 4.21.

Table 4.21: Average yields and fertilizer rates at farmers' fields versus simulated yields and fertilizer rates by the quantitative evaluation of fertility of tropical soils (QUEFTS) model based on soil chemical test

District	Observed (ha^{-1})[a]				Calculated (kg ha^{-1})[b]			
	Yield	N	P	K	Yield	N	P	K
Savelugu	2624	81	19	43	2979	47	9	103
Yendi	2750	77	17	31	3499	63	9	82
West Mamprusi	2627	44	17	31	2636	47	9	49
Kumbugu	4102	64	17	31	3366	55	9	97
Zabzugu	3767	116	39	93	3410	57	11	71
Gushegu	2701	64	17	31	3316	60	10.1	69
Saboba	2721	31	17	31	2934	47	10	77
Karaga	2005	44	19	44	2793	49	7	85
Tamale Metropolitan	3442	39	19	44	3018	52	10	62
East Gonja	3535	58	17	31	3286	52	9	98
Tolon	3052	72	19	44	2975	47	11	78
Nanumba South	3156	64	17	31	2932	51	9	68
Nanumba North	3010	71	17	31	3300	63	11	57

[a] Average yields and fertilizer rates at farmers' fields; [b] simulated yields and fertilizer rates by the QUEFTS model

The simulated maize yields for Kumbugu, Zabzugu, East Gonja, Tolon and Nanumba South Districts were lower than the observed/measured maize yields even though the predicted N, P and K rates were lower than the observed N, P and K rates. Districts like Savelugu, Yendi, West Mamprusi, Gushegu and Nanumba North obtained higher maize yield estimates even though the predicted N, P and K fertilizer rates were lower than the observed. However, Districts like Saboba and Karaga obtained higher maize yield estimates with higher N, P and K fertilizer rates, except Tamale Metropolitan where the N, P and K fertilizer rates were higher but the estimated maize yields were lower than the observed.

4.3.3.2 Proposition of nutrient management and maize production option from ISFM demonstration strategies mapped on the vegetation base map of the study area

The trials demonstrated by the researchers increased maize grain yields in some Districts whilst smallholder farmers' practice on fertilizer input also produced better yields than the researchers' in other Districts. In locations where researcher trials produced better yields (i.e., increase of researchers yield over farmers yield), the overall yield increment for the study area was 36% ; with the highest increase being 63% for Yendi District and the lowest being 11% for Gushegu District (Table 4.22). These demonstration trials differed from one District to another (Figure 4.18; Appendix 1), and hence the demonstration trials that produced increases in grain yields compared to those from other demonstration trials in each of those Districts were recommended to be implemented in such Districts.

Table 4.22: Percentage increase in maize grain yield of researchers over farmers yield in five Districts within the study area

District	Yield (t ha^{-1})		% increment
	Farmers	Research	
Zabzugu	2.31	3.77	63
Gushegu	2.40	2.70	11
Kumbungu	2.66	4.10	54
Nanumba South	2.40	3.16	32
Yendi	2.34	2.75	18

NB: Overall yield increment was 36% on the average

For example, in Yendi District, 2 bags of NPK 15:15:15 and 1½ bags of SoA used in the demonstration trials produced the highest maize yields and was therefore recommended in the District. The vegetation cover showed areas of dense to less dense vegetation, with the mapped proposed trials for the five Districts. Where the vegetation shows deep green cover, it suggests that the vegetation around those places are thicker with some forest cover and less farming activities. On the contrary, where the cover shows faded green cover, it suggests that the natural vegetation representing forest lands have been removed and replaced with farming activities (Figure 4.18). The extent of removal of the vegetation that has affected the loss of N, P and K nutrients and maize yields in the Districts showed high faded vegetation. The identified ISFM strategies for the five Districts indicate the specific remedy for each of the five Districts.

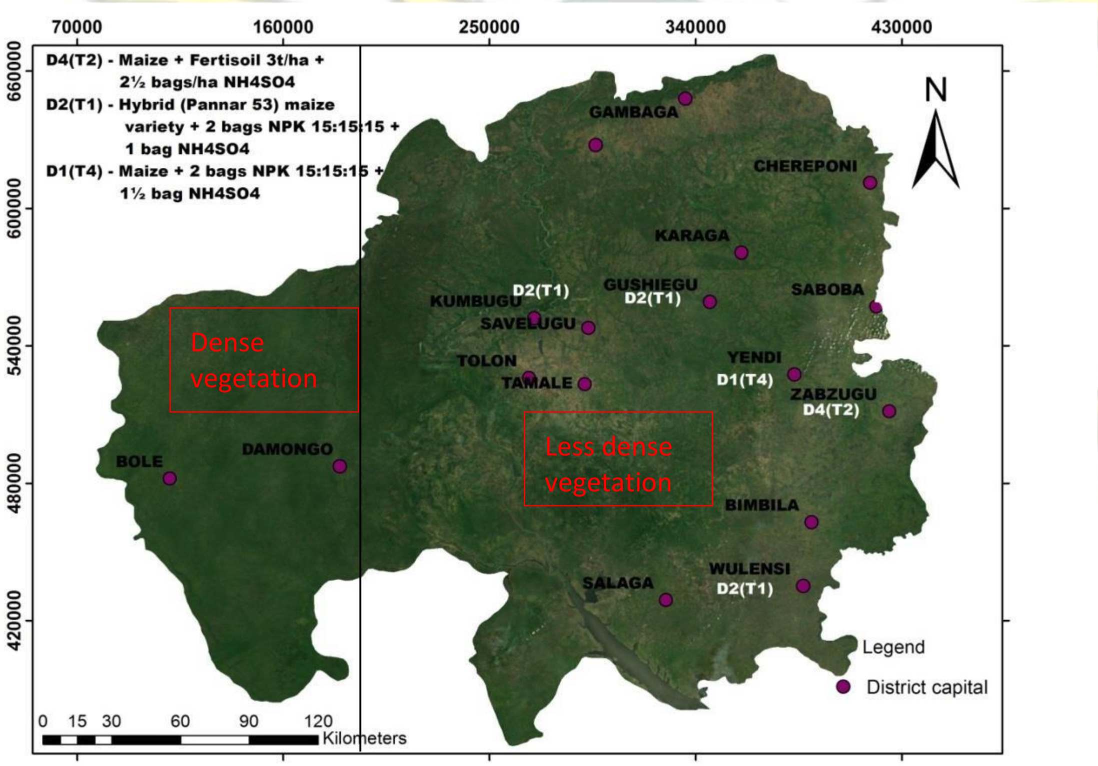


Figure 4.18: Proposed site specific nutrient recommendation strategies for five Districts across the vegetated topography in study area, D1 (T4) – maize + 5 bags of NPK (15:15:15) + 3¾ bags of SoA, D2 (T1) – Hybrid (Pannar 53) maize variety + 5 bags NPK (15:15:15) + 2½ bags of SoA and D4 (T2) – maize + fertisoil + 6¼ bags of SoA per each hectare of land.

4.3.4 Comparative profitability assessment of farmers' practice and proposed ISFM interventions

The cost involved in the production of maize within farmers' practices and proposed ISFM strategies are presented in Tables 4.23 and 4.24. The results present the cost involved in the purchase of fertilizers and maize seeds; and hence other input cost for the production of maize were regarded as same for both researchers and farmers. The P/V ratios for the five Districts were high for both farmers and researchers (i.e. above 0.5). But, the P/V values for Zabzugu and Gushegu Districts were higher for the farmers (0.8 and 0.9, respectively) than the researchers (0.7 and 0.8, respectively), and same for farmers and researchers in Kumbugu, Nanumba South and Yendi Districts (Tables 4.23 and 4.24). However, the profit margins were higher for researchers in Zabzugu, Kumbugu, Nanumba South and Yendi Districts but lower in Gushegu District (Figure 4.19).

Table 4.23: Profitability of farmers' practices in maize production in five Districts of the Northern Region of Ghana where demonstration trials produced higher maize grain yields

District	Input variable (ha^{-1})	Input variable cost (GH₵ ha^{-1})	Maize yields kg ha^{-1}	Selling price of maize (GH₵)	Benefit (GH₵)	P/V ratio
Zabzugu	Maize + 2½ bags NPK 15:15:15 + 2½ bags SoA	440.00	2337.18	2800.00	2350.00	0.8
Gushegu	Maize + 2½ bags NPK 15:15:15 + 1¼ bags SoA	330.00	2434.73	2925.00	2600.00	0.9
Kumbugu	Maize + 2½ bags NPK 15:15:15 + 2½ bags SoA	440.00	2691.85	3225.00	2775.00	0.9
Nanumba South	Maize + 2½ bags NPK 15:15:15 + 2½ bags SoA	440.00	2426.98	2913.00	2475.00	0.8
Yendi	Maize + 3¾ bags NPK 15:15:15 + 2½ bags SoA	550.00	2366.53	2838.00	2288.00	0.8

Price of maize seeds (per kg) = GH₵ 2.00, price of 1 bag (50 kg) of NPK 15:15:15 fertilizer = GH₵ 89.00, price of 1 bag (50 kg) of SoA = GH₵ 85.00, price of 100 kg bag of maize at farm gate = GH₵ 120.00. All other input variables and practices were regarded as constant and remained same for smallholder farmers and researchers.

Table 4.24: Profitability of researchers' practices in maize production in five Districts of the Northern Region of Ghana where demonstration trials produced higher maize grain yields

District	Input variable (ha^{-1})	Input variable cost (GH₵ ha^{-1})	Maize yield kg ha^{-1}	Selling price of maize (GH₵)	Benefit (GH₵)	P/V ratio
Zabzugu	Maize + Fertisoil 3 t/ha + 6¼ bags SoA	1286.00	3812.30	4575.00	3300.00	0.7
Gushegu	5 bags NPK 15:15:15 + 2½ bags SoA + Hybrid Pannar 53 maize variety	678.00	2734.15	3250.00	2575.00	0.8
Kumbugu	5 bags NPK 15:15:15 + 2½ bags SoA + Hybrid Pannar 53 maize variety	678.00	4152.53	5000.00	4475.00	0.9
Nanumba South	5 bags NPK 15:15:15 + 2½ bag SoA + Hybrid Pannar 53 maize variety	678.00	3194.68	3825.00	3150.00	0.8
Yendi	Maize + 5 bags NPK 15:15:15 + 3¾ bags SoA	769.00	2783.40	3350.00	2575.00	0.8

Price of maize seeds (per kg) = GH₵ 2.00, price of 1 bag of NPK 15:15:15 fertilizer = GH₵ 89.00, price of 1 bag (50 kg) of SoA = GH₵ 85.00, price of 100 kg bag of maize at farm gate = GH₵ 120.00, price of Hybrid Pannar 53 maize seeds (per kg) = GH₵ 8.00, price of 1 tonne of fertisoil = GH₵ 300.00 Source of fertilizer prices and maize prices at farm gate for 2015: survey interview with farmers and agro-dealers (2015)
Source of seed prices: (Ragasa *et al.*, 2014) All other input variables and practices were regarded as constant and remained same for smallholder farmers and researchers.
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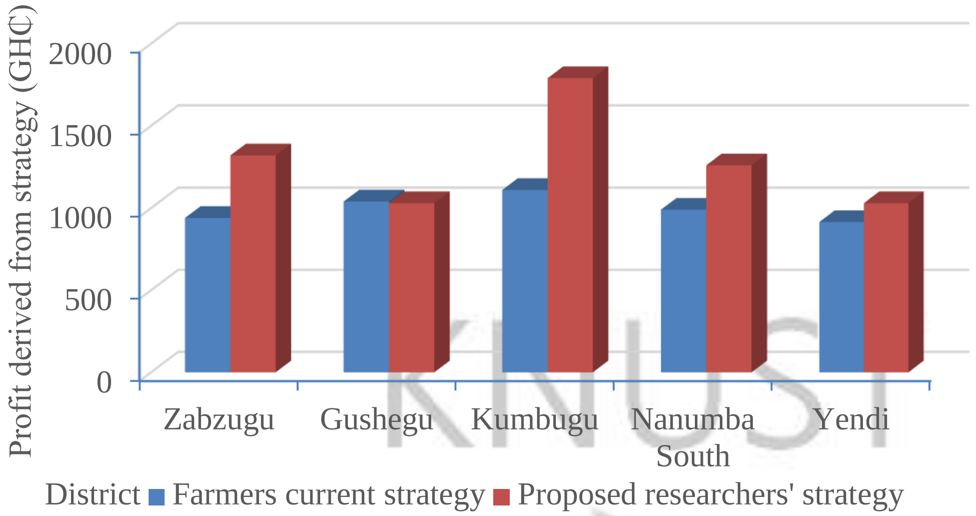

Figure 4.19: Comparison of profit from farmers' practice and research demonstrations in five Districts of the Northern region of Ghana

4.4 Implementation of soil N, P and K spatial database for maize production in the study area

The applied scripts resulted in an interactive interface and a user friendly database application (Figure 4.20) from which information about a District in the study area could be retrieved. The application is operated on by clicking on the District of interest to receive a pop up message of information about the N, P and K contents in the soil of the District, the average maize yields produced between 2012 and 2014, the average soil pH, and the recent appropriate fertilizer application that could produce higher maize yields. This interactive approach provides a quick access to finding soil related information in order to strategize N, P and K enhancement procedures in a District for increased maize production in the region.

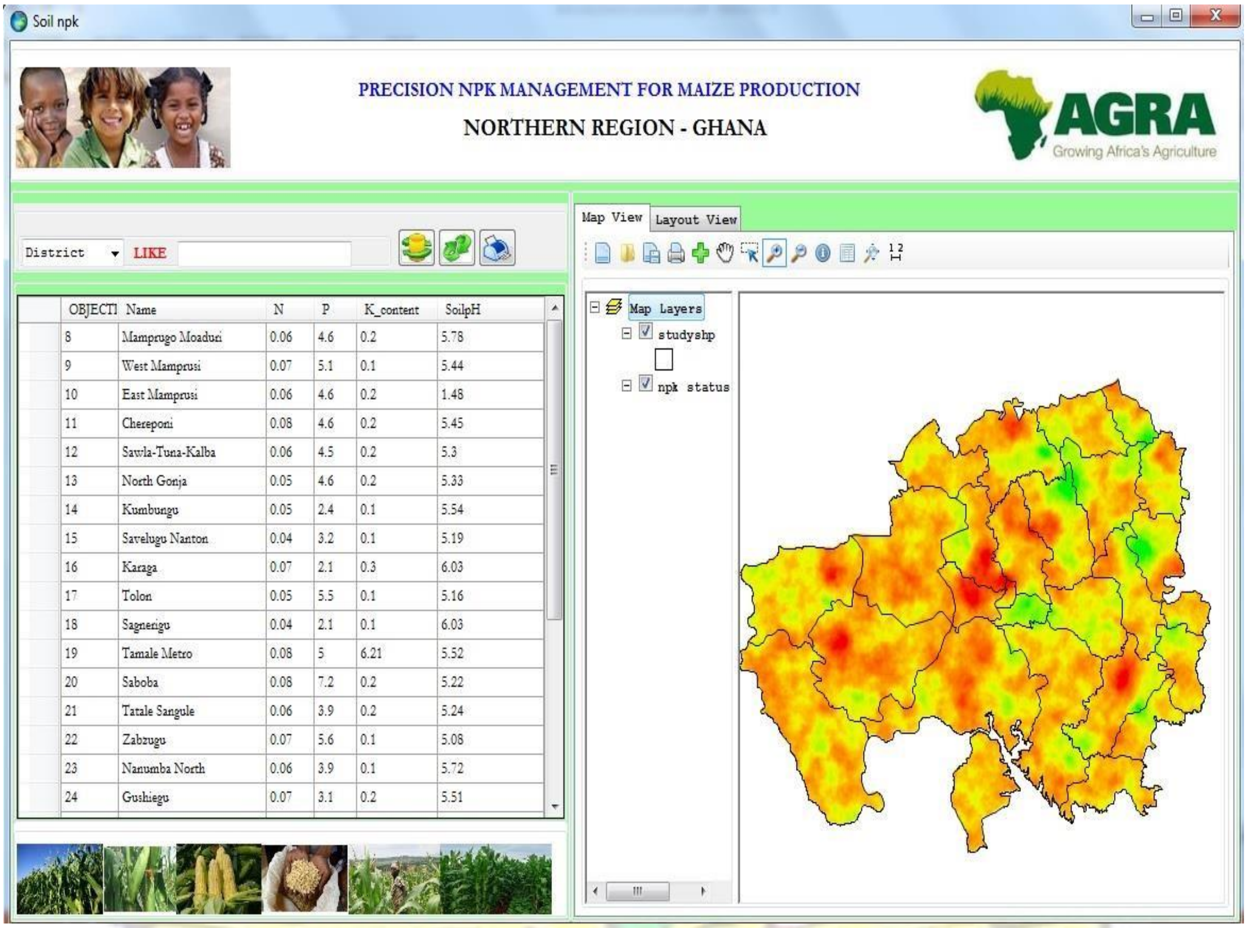

Figure 4.20: Interface of spatial database application for NPK management interventions in the Districts within the study area

CHAPTER FIVE

5.0 DISCUSSION

5.1 Description of the N, P and K nutrient contents

The obtained CVs for N, P and K contents indicated high and uncontrolled variations in their distributions and implied that there could be biases in the distribution of the nutrient contents within the study area.

Skewness values greater than zero indicated that distribution within the data was skewed to the right (positive skewness) (Jondeau and Rockinger, 2003). Higher values close to one or more signifies highly skewed data, which present biases if they are modelled (Weisstein, 2002). This was same for the values obtained for the kurtosis which also signified that the nutrient contents had higher peaks (kurtosis values > 3). The results, therefore suggest that the nutrient contents in the raw untransformed form could not be modelled due to the biases that might be produced in the modelling output. The histograms obtained after transformation showed that N and K contents were normally distributed after log-transformation. This was confirmed by the distribution from the QQ-plots (Figure 4.4) where the points from the dataset clustered around the straight line signifying a standard normal distribution (ESRI, 2010). Log-normal distributions give a better insight into characterizing the variability within the distribution of the major soil nutrients (Limpert *et al.*, 2001). The clustering of the N and K contents around the straight line of the QQ-plot was an indication that N and K contents were log-normally distributed. However, P contents, showed deviations from the straight line after log-transformation (Figure 4.1b). This implied that P distribution in the study area did not follow a log-normal distribution.

Log-normal distributions of N and K contents (Figures 4.1a and 4.1c) with positive skewness (see Table 4.1) gave an indication that large proportions of the study location have low to moderate concentrations (found within the range of N being 0.05% - 0.1% and K between 0.1 $cmol_c$ kg^{-1} and 0.25 $cmol_c$ kg^{-1}) whether clustered or random, with few locations recording relatively high contents (i.e., N being more than 0.1% and K more than 0.25 $cmol_c$ kg^{-1}) as reported by Wopereis *et al.* (2009) and Yeboah *et al.* (2013) (see Table 4.4). The histograms of N and K contents therefore showed large areas accumulating to the left of the curve whereas few areas with relatively high contents were at the extreme right of the curve (Figure 4.1).

Phosphorus contents followed a normal distribution only when the normal score transformation was applied and this might be due to the extensive difference in the minimum and maximum values within the P contents within the study area (see Table 4.1).

The nutrient contents were considered to follow a standard normal distribution because the contents were less skewed (skewness values approaching zero) with reduced peak (kurtosis values close to 3) (Wang *et al.*, 2011). In general, when values approach the required values for the dataset to be considered as normal, then the data is said to be near normal (Mudholkar and Hutson, 2000). In this way, the nutrient contents could be modelled without introducing bias in the results from the model leading to the production of inaccurate and unreliable output.

5.1.1 Variations in N, P and K nutrient contents across the study area

The coefficient of variation (CV) determined for the nutrient concentrations showed that N contents had high variation (CV value 35%; see Table 4.1), which signified relatively low dispersion across the Districts; while for P and K concentrations were of very high values (CV values of 68% and 63%, respectively) indicating more dispersion in their distribution. The high CV values obtained might have resulted from majority of the areas having low concentration levels with few areas having high values (Abdi, 2010). A high CV value implied that the data distribution was more variable (dispersed) and hence, less stable and less uniform (nCalculators, 2013). However, K contents stabilised after log-transformation while P contents did not. The near normal distribution and stability of K contents after log-transformation might be due to the fact that the difference between the minimum and maximum contents were not so large (0.06 cmolc kg^{-1} and 0.73 cmolc kg^{-1} respectively; see Table 4.1) and did not present major variations within them; as compared to those of P contents which had wide variations within the data (Limpert *et al.*, 2001). The fact that some locations recorded P contents as low as 1.24 mg kg^{-1} and others recorded as high as 11.29 mg kg^{-1} might explain why P contents were less stable and followed a normal score distribution. The areas that recorded relatively high P values were within those locations where the smallholder farmers were incorporating either cattle manure or cattle manure + NPK (15:15:15) fertilizers + sulphate of ammonia in the soil (SARI, 2013). In general, soil test P (i.e., available P) builds up in soil when animal manure is applied at a high rate to meet nitrogen requirements (Zhang *et al.*, 2002). 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 at different locations, inherent heterogeneity in parent material at the different locations, as well as land use pattern and amount of fertilizer used by the smallholder farmers (Liu *et al.*, 2006a). The distribution of the major nutrients confirmed the assertion that spatial variation of soil nutrients exists even in neighbouring fields as has been previously reported by Goovaerts (1998), Voortman *et al.* (2002) and van der Zaag (2010) who used geostatistical approach to study the spatial variation that exists in agricultural fields in in pasture and forest lands in the United States, Sudano-Sahelian coversands in Niger and some selected countries (Zimbabwe and South Africa) in SSA, respectively. In addition, the low to moderate concentration levels of N, P and K nutrient contents might be as a result of continuous cropping of maize on the same piece of farmland, low rates of nutrient fertilizers applied at such locations, soil nutrient losses through soil erosion and export of nutrients through harvested produce (Braimoh and Vlek,

2004), and straw and stover collection from the farm (Blanco-Canqui and Lal, 2009). According to Smaling *et al.* (1993), crop removal accounts for the largest loss of nutrients from the soil since Doran *et al.* (1984) and Hoskinson *et al.* (2007) reported that large amounts of the nutrients are stored in the straw or stover.

5.1.2 Models of spatial dependence within N, P and K nutrient contents

In geographical space, variables exhibit spatial dependency to show whether there are spatial associations between its values at different places (Anselin, 1996). The nuggetto-sill ratio determined the strength of spatial dependency that existed within the N, P and K contents (Cambardella *et al.*, 1994; Liu *et al.*, 2006a).

The nutrient contents showed moderate spatial dependencies within N, P and K contents, implying that the degree of association (relationship with each other) between their values at distinct points increase as the points approach each other. This suggests that there could be a possible continuity of the N, P and K values showing similarities in space as they close up (Montello, 2001), and also agrees with the first law of geography which states that " things that are closer together are more related than things that are far from each other" (Tobler, 2004). Smallholder farmers found within the same locality are likely to adopt similar fertilizer management approaches, which may affect N, P and K concentrations in the soils at short distances in a similar pattern. Low fertilizer inputs and inappropriate fertilizer applications by majority of farmers within a location could account for low residual N, and moderate levels of P and K in the soil which could affect the pattern of N, P and K distributions in locations that are separated by short distances (Adler *et al.*, 2001). As distances increase far apart, fertilizer management may differ and the dependencies could become weaker or stronger (Jonsson and Moen, 1998) depending on the impact of the management. The moderate spatial dependencies between the nutrient contents could also imply that the degree of association between their values may be consistent. Therefore, as previously reported by Pringle *et al.* (2010) and Luo *et al.* (2009), soil fertility management should be consistent within the patterns of their spatial distribution to manage the considerable variation across the study area, which could influence maize grain yields even at short separating distances. Due to the different transformations that N can undergo in the soil (e.g. ammonification, nitrification, and volatilisation), it could be lost from the soil more quickly if not managed properly (Martins *et al.*, 2015) resulting in low levels as seen across the study area. Phosphorus and K contents rarely undergo similar transformations and may be fixed in the soil; and therefore similar practices like fertilizer application methods may cause their concentration levels to be moderate. Such situation may prevail in the Districts, thereby resulting in moderate spatial dependencies. Therefore, soil management interventions for N could be geared toward mitigation of N-emissions from the soil (e.g. spot application of N fertilizers instead of surface dressing) which could be different for P and K to ensure judicious use of fertilizers.

Nitrogen and K nutrient contents recorded in the study also showed positive low nuggets, which indicated that sampling error, random and other inherent variations that existed in the N and K variables (Bohling, 2005; Liu *et al.*, 2006a; Clark, 2010) were minimal. The nutrient contents of P showed a positive high nugget value indicating random and inherent variations within the variables. The nutrient concentration levels also had considerable range variations and that could be caused by effects of variable farm level soil fertility management (Trangmar *et al.*, 1985) across considerable distances from the locations.

The information provided by the cross validation for modelling the semi-variogram was appropriate and that the certainty for the prediction was minimal enough (RMSE close to zero, see Table 4.6) to be considered as within acceptable range as reported by Hawkins and Sutton (2011).

5.1.3 Spatial distribution of N, P and K nutrient contents

The hypothesis for the pattern analysis was that the nutrients contents across the study area come from a random distribution. In the theory of random pattern described by ESRI (2010), when p-value is very small (as in this study $p < 0.05$) and z – value is either very high or very low ($1.96 < z < -1.96$), the spatial pattern is not likely to reflect a random form of distribution. In addition, a negative Moran's I index value indicates that the data is dispersed and a positive value indicates a tendency of clustering (clusters of high values only or low values only) at particular locations (Anselin, 1996). Test of significance for values returned by the analysis of the major soil nutrients indicated that N and K have clustered distributions in the study area (Table 4.7); with low levels clustered at one location and high levels at the other. On the other hand, the pattern of distribution of P does not appear to be significantly different from a random distribution; thus there is no clustering of high and low values of the P nutrient contents in the study area. In this way, management strategies towards soil nutrient enhancement could be implemented by using the spatial distribution maps as a guide.

Soil spatial distribution maps therefore provide a quick reference and reliable means by which variability within soil nutrients can be assessed in order to make decisions at specific locations (Schnug *et al*., 1998).

5.1.4 Spatial relationship between N, P and K nutrient contents and topography, amount of inorganic fertilizer input, and soil pH

For a model to be considered reliable and representative, it should meet certain conditions to verify its reliability and significance (Sabater and Sierra, 2005). The conditions set to test this reliability were met by the N and K nutrient contents in the first diagnostic test which implied that their stabilities were robust. Further diagnostic test, however, stabilised the P nutrient contents. The output for the robust coefficient standard errors suggests that the model for determining influence of the associated variables on P is not robust (non-stationary) enough (Rousseeuw and Leroy, 2005), even though there existed heterogeneity in the P nutrient contents (ESRI, 2010). The OLS model produced therefore, is a representative of the pattern of distribution of the N, P and K nutrient contents as associated with topographical elevation, amount of inorganic fertilizer used and soil pH (Dismuke and Lindrooth, 2006).

Positive coefficient value implied that where the elevation was relatively higher, P contents were likely to be relatively high as compared to locations where the elevation of the topography was relatively lower. In the same way, negative coefficient values for the relationship between elevation and N and K contents suggests that relatively lower contents of N and K are found at higher elevations. However, these relationships between elevation and the major soil nutrients were not significant (all p-values > 0.05).

The non-significant p-values within the association of elevation of the topography and the N, P and K contents are indications that the nutrients distributions are not much influenced by the topography of the study area, and do not provide adequate basis to be used as a measure to demarcate management zones (Page *et al.*, 2005). According to a study done by Wang *et al.* (2011), elevations might not significantly influence soil nutrients distribution, but mapping their spatial distribution will allow for characterization of spatial nutrient patterns at site-specific locations (Cahn *et al.*, 1994) for prompt and localised interventions. The pattern characterization can contribute to soil fertility management by recognising how nutrients are distributed over the topography of an area. The important thing to note, according to (McKenzie, 2013), is that soil nutrient varies with topography; but in this study the variation was not significant due to relatively flat nature of the land (Getamap, 2006). The insignificant influence of elevation on the major soil nutrients means that low and high concentrations could be found at locations irrespective of the topography (as shown in Figure 4.8) of the study area.

Negative coefficient values of the relationship between quantity of fertilizer applied and N, P and K contents in the soil implied that where small amounts of fertilizer input was made, there was an increase in the nutrient contents in the soil. Even though the nutrient contents were increased due to the small amount added, nutrient contents in some locations were below adequate levels hence caution must be taken in establishing the relationship between fertilizer addition to the soil and nutrients contents in the soil especially when relationship is not a linear one. This can be illustrated as follows, Districts like Tamale Metropololitan and Karaga had low inorganic fertilizer inputs (Figure 4.9), but the N, P and K contents were relatively high at such locations (Figures 4.6, 4.7 and 4.8); whereas others like Tolon and Nanumba South had high fertilizer inputs but did not reflect on the status, implying the quantity was probably not sufficient (Bationo *et al.*, 2011) enough to express the increase. Other Districts like Yendi, Chereponi and Nanumba North (Bimbilla), however, had relatively high fertilizer inputs and recorded high N, P and K contents (Figures 4.6, 4.7 and 4.8). The negative relationship between amount of fertilizer input and N, P and K contents in the soil (i.e. coefficient values for N, P and K and average fertilizer use; Table 4.9) is an indication that where smallholder farmers applied small amounts of fertilizer, the N, P and K nutrient contents of the soil could be relatively adequate depending on location (as shown in Districts like Karaga and Tamale Metropolitan; Figures 4.9 and 4.11). This could also be explained by the fact that farmers around that location rear cattle and therefore have access to cattle manure for incorporation into their soils in addition to the use of inorganic fertilizer (survey data collected in this study). The appropriate minimum fertilizer recommendations should be adapted to situations prevailing in each District. It is important that the severity of the soil nutrient decline as well as other nutrient resources (e.g. organic manure) available to samllholder farmers in the various Districts be also considered. The common practices of fertilizer application by the smallholder farmers in the region are NPK fertilizer rates (15:15:15 and 23:10:5), sulphate of ammonia (SoA), as well as use of animal manure (in some locations) and crop residue incorporation.

The results also confirmed the assertion that fertilizer and crop residue inputs could cause increase in soil nutrients (Campbell *et al.*, 1991; Biederbeck *et al.*, 1994; Liu *et al.*, 2006a). Nanumba South (Wulensi) District has moderate fertility status even though average application of fertilizer input was high. The situation whereby a location received more fertilizer input but recorded low to moderate N, P and K nutrient status as exemplified in Tolon and surroundings of Nanumba South (Wulensi)

Districts might be explained by a number of factors. The factors may include (i) inadequate animal manure use in these Districts to supplement the fertilizer input, (ii) incorrect fertilizer application methods and (iii) effect of soil erosion that may cause the applied nutrients to be washed away (Fairhurst, 2012). Animal manures do not only act as sources of nutrients for the soil but also influence soil structure and improve soil physical properties, which brings about less leaching of applied nutrients by ensuring increased nutrient holding capacity of the soil (Albiach *et al.*, 2000). Any other inherent soil forming properties, which leads to degraded soils that are less responsive to inputs might also contribute to the low nutrient status (Tittonell *et al.*, 2005). It is therefore necessary to regulate N, P and K nutrients that are input into the soils by taking into consideration the needs, resources available to smallholder farmers, and responsiveness of the soil to the N, P and K nutrients applied (Ping *et al.*, 2009). In addition, the District-based fertilizer input could prevent excessive fertilizer use, which may lead to leaching and erosion of such chemicals into underground and surface waters, respectively (Shaviv and Mikkelsen, 1993; Sharpley *et al.*, 1994; Ju *et al.*, 2009). Therefore, as suggested by Liu *et al.* (2006a), it is necessary that soil conservation practices in addition to prevailing ISFM practices (e.g., residue incorporation, growing cover crops after harvesting) be adopted at such locations to reduce nutrient loss.

Soil pH values may influence N contents in the soil when they are above the suitable range (above 7.0) for maize production by reducing N-mineralisation rates (Fu, 1989), thereby increasing the total N contents in the soil. But, the N contents in the soils of the study area were low (Table 4.1) and the soil pH values were all below 7, hence the positive significant ($p < 0.05$) relationship between soil pH and total N contents could not be attributed to the processes of mineralization. Total gaseous emissions of N fertilizers have been shown to be less in acidic to neutral soils, and could explain the positive relationship, but this may be due to the smaller amount of mineral N available to the denitrifying population under acid conditions and not a direct effect of soil pH since the optimum pH for denitrification remains inconclusive (ŠImek and Cooper, 2002). The effects of soil pH on the P and K nutrients were, however, not significant (p values > 0.05; Table 4.10) and might be attributed to the fact that soil pH levels in the study area were not significantly (p = 0.60) different from each other, with the highest value being 6.49, the lowest value 5.28, and the mean being 5.46. These soil pH values were generally considered to be in the range suitable for the N, P and K contents in the soil and could not affect the nutrient uptake by maize crops (Foy, 1984). Therefore, the difference in the distribution of the N, P and K contents could have been due to other environmental variations such as fertilizer application, farm management and other inherent soil properties (Zingore *et al.*, 2007) rather than the soil pH. This study therefore confirmed the study by Wang *et al.* (2011), that soil pH values in general do not significantly influence nutrient content patterns.

5.2 Classification of combined N, P and K nutrient contents for site classification of low to adequate NPK levels in the study area

The classification of the overlaid N, P and K distribution maps was based on the measured contents of the N, P and K levels in the soil samples collected from the Districts. The depicted status of the contents therefore is a clear illustration of the current situation in 16 Districts of the Northern region of Ghana. Most of the areas have low N, P and K contents (Figure 4.11), and may explain why smallholder farmers in such areas apply more fertilizer than other locations to increase maize crop yields (Figure 4.12), even though the amounts that were used in some Districts were not up to the recommended.

The differences in the overlaid N, P. and K contents might be attributed to different historical management practices that have occurred in the various Districts, soil forming processes and other inherent soil properties (Wang *et al.*, 2009). The nutrients overlay map showing areas of low to high NPK content zones therefore confirmed the results from the spatial relationship analysis (Table 4.9) that higher fertilizer application does not guarantee high nutrient status of soil. The overlay map as has been presented will enable decision makers and stakeholders plan decisions about N, P and K nutrients management based on where low and high contents of the nutrients are found.

5.3 Fertilizer application strategies by smallholder farmers and their corresponding maize grain yields

The production of maize is greatly influenced by fertilizer application even though other external input like improved seeds, organic manure and even the use of pesticides are important. Therefore, it was expected from this study that different amounts of fertilizer application will cause different maize yield outputs. However, the test of homogeneity implied that the variances in the maize yields from the smallholder farmers were equal irrespective of the fertilizer applied (whether below, within or above recommended (375 kg ha^{-1}) (i.e. the recommended value was obtained from survey data, this study; SARI, 2013)). Even though the test of homogeneity was not statistically significant, the actual differences between the mean maize yields in kg ha^{1} (2607.54, 2951.79, and 3379.20) for the three fertilizer categories (< 375 kg ha^{-1}, 375 kg ha^{-1}, and > 375 kg ha^{-1}, respectively) were large. This is evident in the medium effect size obtained for the analysis. The effect size obtained showed that the differences in means of the grain yields were large, and hence the amount of fertilizer input within any of the three fertilizer categories affected the increase in maize yields

(Olejnik and Algina, 2000). For a small sample size (89) as used in this study, it is quite difficult to obtain statistical significance difference in maize yields of farmers even if there are obvious distinctions in the fertilizer application (Brown, 2008). Other factors may also contribute to the seemingly equal variances in the maize yield and which necessitated further evaluation in a follow up study.

In Sub-Saharan Africa, fertilizer application on maize fields has been reported to be lower than the crop requirement (Sanchez, 2002). Due to the low application, maize yields are also generally low. However, increase in fertilizer application rates and quantities on maize fields have correspondingly increased yields, yet yields are far below the potential. This has led to the persistent call by researchers to address food security problems by increasing fertilizer inputs to increase maize yields (Atakora, 2011). The N, P and K fertilizers, however, gave different contributions as to how they cause maize yields to vary. From this study, it was noted that indeed increasing N fertilizer input increased maize grain yields, but above the threshold of about 65 kg ha^{1}, the maize yields did not continuously increase but rather decreased. The decline in maize grain yields could have occurred due to the soil not being responsive to more N input, which might have been due to some other limiting nutrient factors (Zinc and Boron) prohibiting the maize crops to make use of the added N nutrients (White and Zasoski, 1999). From the sample data on smallholder farmers in the study area, it was observed that farmers who used fertilizer more than the recommended quantity were about 19%, and those that used fertilizer below the recommended were about 55%. The study, therefore confirmed the assertion that fertilizer use on maize fields were low, especially in N nutrients, and that they needed to be increased. However, it must be noted that, higher N fertilizer application does not necessarily increase maize yields due to possible low agronomic use efficiency of higher N applied (Vanlauwe *et al.*, 2011).

Phosphorus and K did not explain much of the variations within the maize grain yields because the quantities of P and K fertilizers that were used as input by smallholder farmers in the study area did not vary much (almost the same quantities of 38 kg P_2O_5 and 38 kg K_2O per ha; Figures 4.15 and 4.16). There should be a considerable range of variations within two variables before a predictable relationship could be properly established other than values showing similarities progressively (Lorenz, 1996).

4.2.7.1 Comparison between fertilizer input and maize grain yields in 13 Districts of the study area

The test of comparison suggest that, even though researchers were applying high N and relatively the same amount of P and K fertilizer rates in the region, it did not translate into average yield output significantly ($p = 0.74$) higher than the farmers' output in the 13 Districts within the study area.

Further evaluation of fertilizer input by District revealed that even though minimum amount of inorganic N (< 64 kg ha^{-1}) and relatively the same amount of P (38 kg ha^{-1}) and K (38 kg ha^{-1}) fertilizer input were used in six Districts (Figures 4.14, 4.15, and 4.16), this led to an increase in maize yield. Whiting *et al.* (2011) reported that minimum amount of fertilizer could increase crop yields. However, it was noted from this study that the minimum addition depended on whether or not that minimum amount (< 5 bags of NPK 15:15:15 and 2½ bags of SoA per ha) was sufficient in those locations to produce the required maize grain yields. Also, the minimum addition to some extent, depended on availability of cattle manure to some of the smallholders who may apply same on their fields.

Soils in Districts like Karaga and Tamale Metropolitan (Figure 4.14) where minimum N fertilizer input yielded high maize yields could be deemed as highly responsive to the N fertilizer inputs (Tittonell *et al.*, 2008). Although low levels of applied fertilizer could lead to nutrient mining and imbalances in the long run (Tan *et al.*, 2005), maize crops respond highly to the low levels because the small quantity of the applied N could cause high uptake by the maize crops (Vitousek *et al.*, 2009), In addition, the relatively high yields obtained from low N fertilizer input could be due to the fact that most farmers around these locations used cattle manure in addition to the fertilizers. Addition of cattle manure and other animal resources, as well as the incorporation of crop residue, could increase maize yields even though minimum inorganic input was used (Chivenge *et al.*, 2011) because of the positive interaction effect that can take place between the organic and inorganic materials (Yeboah *et al.*, 2013) to increase productivity.

Knowledge on the nutrient requirement at specific locations is necessary because five other Districts also used low N fertilizer input yet their maize yields remained low (Figure 4.14). In such Districts, there were no bulky quantities of manure needed for effective maize production available. Low use of organic manure in these Districts (Ezekiel-Adewoyin, 2015) could have contributed to the low maize grain yields. The quantity of fertilizer input and their corresponding maize yields emphasised that fertilizer recommendation must be promoted, especially in Northern Region of Ghana, since increased N fertilizer application by researchers in the demonstrations increased maize yields in five other Districts. The promotion, however, should be District (site) specific and must reflect the availability and use of other local resources such as animal manure and crop residues (Vanlauwe and Giller, 2006). Fertilizer inputs are sometimes scarce and not available to all smallholder farmers (Omotesho *et al.*, 2012). Therefore, to ensure that sufficient inorganic fertilizer quantities reach smallholder farmers for the intended use, it is essential that the nutrient contents of their farms be assessed using the generated N, P and K contents distribution maps (Figures 4.6, 4.7, and 4.8) as a guide. Moreover, it will be a better opportunity to ensure that smallholder farmers who do not apply fertilizer on their farmlands get access to the fertilizers and begin to adopt their use (Omotesho *et al.*, 2012) according to their nutrient needs.

By making reference to the N, P and K distribution maps, the status of N, P and K fertility could be assessed before recommending fertilizer inputs that most farmers can afford and which are sufficient to increase and sustain maize yields. It is also important to note that it is not completely out of place for indigenous smallholder farmers to have their own nutrient management practices (on their farms) without resorting to research advice (Marenya *et al.*, 2008). This is because some of their practices yielded better results than those of the researchers (Figures 4.14). What is important, according to Tittonell *et al.* (2008), is to promote the use of inorganic fertilizer in order to make the soils fertile enough to increase yield. The fertilizer use should be promoted especially in locations where the soil produced low maize yields and farmers did not have access to other organic fertilizer materials. In such locations, soils could be deemed less fertile or less responsive to fertilizer input (Tittonell *et al.*, 2005) due to other limiting factor and other constraints in the soil that impede nutrient availability (Tittonell and Giller, 2013), causing the applied nutrients not to be available to the maize crops. Responsive soils show acceptable responses to input fertilizer even when they are minimal (Vanlauwe *et al.*, 2010). Other factors that might have contributed to the low maize yield output are poor rainfall distribution in the region, whereby some locations might receive less rainfall than others (Shanahan *et al.*, 2008), inherent properties of the soil or soil forming processes (Wang *et al.*, 2009).

Farmers in such locations where soils are less fertile in combined NPK contents, (as shown in the NPK status map, see Figure 4.11), could increase inorganic fertilizer input in addition to the crop residues in order to gain higher yields. As illustrated through this research, smallholder farmers in Savelugu District applying about 350 kg $ha^{-1}$of NPK 15:15:15 and SoA fertilizer (Figure 4.9) in addition to about 3 t ha^{-1} of cattle manure increased their maize yields, considerably.

The increase in maize grain weight in Savelugu and Tolon Districts could have been due to the added nutrients from the cattle manure which supplied other important macro and micro nutrients like Calcium and Zinc, respectively, to the soil which could not be supplied by the N, P and K mineral fertilizers alone (Zingore *et al.*, 2008). Furthermore, cattle manure increases the water and nutrient holding capacity of the soil by improving the structural stability of the soil thereby decreasing leaching of added nutrients so that crops could make good use of the nutrients to increase yield (Nyamangara *et al.*, 2001).

Nutrient requirements for sustainable maize production

Nutrients removed from the soil through harvested crops need to be replenished so that the soil can regain its fertility to continue supporting crop production. The right amount, however, is needed to be replaced to ensure that high yields are sustained. Maize removes an average of about 1.38 % of N, 0.35 % of P and 0.47 % of K from the soil; and the maize stover contains about 0.46 % N, 0.04 % P and 1.03 % K (Opoku, 2011).

Therefore, the calibration of the QUEFTS model used to predict the needed nutrients to replace the removal in order to sustain/maintain maize yields was made to conform to the nutrient RE for maize production in Ghana. According to IFDC (2012), the RE for maize in Ghana is 0.50 kg N kg^{-1}, 0.35 kg P kg^{-1}, and 0.70 kg K kg^{-1}. The obtained values of RE indicate that uptake of nutrients of maize in the study area is 0.49 kg N kg^{-1}, 0.33 kg P kg^{-1} and 0.67 kg K kg^{-1} (Table 4.18), which is close to the RE for maize in Ghana.

Maize grain yields showed a good correlation with nutrient uptake in maize (Figure 4.17). The lower lines (YNA, YPA, YKA) indicate situations whereby a specified nutrient (N, P, or K) is excessively accumulated in the plant; and the upper lines (YND, YPD, and YKD) indicate situations where the nutrient (N, P, or K) is the main yield limiting factor and that the obtained yield is the highest possible given the amount of nutrient taken up by the plant (Janssen *et al.*, 1990). In such situations, the nutrient is said to be maximally diluted in the plant (Smaling and Janssen, 1993). The correlation between nutrient uptake and maize grain could therefore be used to calculate maize grain yield using the established relationship presented in Table 4.20. The calculated Theil's U of 0.18 also indicated that the model could be used for estimating the actual nutrient (N, P and K) uptake needed for replacement and the corresponding yield that could be obtained (Wijayanto and Prastyanto, 2011).

In all the Districts under study, the amount of nutrients needed to replace the lost nutrients were different, and therefore would not be appropriate to recommend a uniform fertilizer formulation for all the Districts. The calculated amount of N to be replaced in the Districts by the QUEFTS model was fairly in agreement to the amount of N uptake by maize crops in the various Districts. This is because the estimated N uptake by the model did not exceed the 65 kg ha^{-1} (Figure 4.13) above which maize yields did not respond positively to the extra N addition. In addition, the estimated yields also differed for all Districts. These occurrences in the predictions are as a result of the variability within the values of the soil chemical analyses used by the QUEFT model to calculate the fertilizer requirement based on the IE of maize in the study area that was used by the model (Wijayanto and Prastyanto, 2011).

5.3.1 Specification and proposition of ISFM options in low maize yield output Districts

Agricultural activities are more intense at the less dense vegetated locations (Figure 4.18) because those places are dominated by savannahs and have less forest cover (Grace *et al.,* 2006). This is because savannah grasslands and pasture lands can be rapidly transformed into agricultural lands (Lambin *et al.*, 2003) than forest where trees are regarded as important vegetation cover and requires statutory permissions before clearance (Peluso, 1995). Most of the maize fields are found in the savannah areas where the soil has the required physical characteristics to support its production (Nartey *et al.*, 1997; Bičıḱ *et al.*, 2001). Generally, what affects the soils production capacity in savannahs is the level of nutrient contents, which when well managed can enhance maize production (Dobermann, 2007). Since the mean N, P and K nutrient contents around these locations are below the average requirements for maize production due to continuous removal of the vegetation cover (Table 4.1), ISFM nutrient management practice that produces higher maize yields is regarded as a better option to meet food security demand (Figure 4.18).

It must however be noted that, although the practice from the researchers' demonstration may give desired and increased maize yield (Table 4.23), they may not be beneficial in terms of increased farmers income (Figure 4.19). The production of maize involves making investment in inputs to maximise yields and increase smallholder income (van Henten *et al.*, 2009). The P/V ratio obtained for both farmers and researchers practice indicate that indeed the demonstration trials have equal P/V ratios in Kumbungu, Nanumba South and Yendi; and so since the maize yields of the researchers were higher than those of the farmers in such Districts, the researchers strategies would be deemed better than the practices of the farmers because it would bring about food security as well as sustained income for farmers. The P/V ratios for Zabzugu and Gushegu Districts were higher for farmers than the researchers practice and in this instance, the farmers practices would be deemed as appropriate in order to secure their income and improve their livelihoods other than producing more maize yields and obtaining reduced income. Maize production with higher P/V ratios would be preferred to production with low P/V ratios (Kumar, 2011). However, since profit is one of the main goals in making investment (Vermeulen and Cotula, 2010), where the profit margin is higher would be preferred, (taking for example, what happened with researchers' profit compared to farmers' profit in Zabzugu District (see Figure 4.19)), and so the researchers' strategy would be better than the farmers' practices.

5.4 Application of the N, P and K spatial database of the study area

Querying and retrieving information needed to facilitate research work and for decision making could be made easier when there is an easy access to an application that provides such information (Shim *et al.*, 2002). Spatial database of nutrient management generates such information and hence necessitated its creation for the Districts in the study area. Database management software currently used for soil resources in Ghana is a stand-alone and therefore required a review and development of an interactive database software which is compatible with the development of information technology (FAO, 1998).

The interactive spatial database application can immensely assist agricultural policy makers to develop soil resource information to support food security in Ghana (Shofiyati and Bachri, 2011) as well as manage large amount of digital soil data. These soil database have been useful in places such as Florida (Shim *et al.*, 2002) and Indonesia (Shofiyati and Bachri, 2011).

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary and Conclusion

The purpose of this study was to map the spatial distribution of major soil nutrients across the Northern Region of Ghana in order to stratify the Districts under sitespecific management zones, and propose appropriate nutrient management strategy obtained from researchers' demonstrations in order to increase maize yields. Decision support system like QUEFTS, combined with GIS tools are essential in promoting site-specific production of maize crops in the Sudan-Savannah agroecological zones of Ghana. Geospatial analysis of N, P and K contents in the study area has therefore proven to be relevant in this regard by providing spatial maps and database that could help identify N, P and K content status of a District. The adequacy of the nutrient contents in a location to sustain maize yields therefore led to the identification of an appropriate strategy that can remedy low maize production and enhance livelihoods of smallholder farmers in the study area.

The following conclusions can therefore be drawn from the detailed analyses and interpretation of data based on the objectives of the study:

Large proportions of the recorded nutrient contents are below average which indicated that the study area has low nutrient contents, with few locations having good nutrient contents. The low contents could have been responsible for the high variations in the spread of the nutrient contents. Models of the distribution maps suggest that N and K nutrient contents were clustered spatially and the distribution pattern of P in the study area was random, which suggests N, P and K fertilizer applications should be managed in the Districts according to the clusters of the N, P and K contents. Locations having clusters of low N, P and K contents should be managed differently from locations having clusters of high N, P and K in terms of fertilizer application on maize fields. The contents have moderate strength of spatial dependencies within each of them. The spatial dependencies of the nutrient contents in the study area confirmed that the variation in the spread of their distributions were influenced by fertilizer application especially N contents showing some similarities in the spread of its low distribution levels.

Low levels of N, P and K contents in the study area could be improved with the use of fertilizer to reduce the wide variation within the contents. However, the application of the fertilizer material should be done based on the nutrient contents already in the soil as depicted by the spatial distribution maps and other resources available to smallholder farmers.

The spatial distribution maps generated through this study showed locations of low, moderate and high nutrient contents. It suggests that management zones could be easily targeted without going through any tedious and laborious means to identify areas of low or adequate nutrient contents for decision making purposes.

External factors such as terrain topography of the study area and soil pH had weak association with the distribution pattern of the N, P and K nutrient contents. Fertilizer application rather had a significant effect on the P contents in the soil due to the addition of an amount of about 3 t ha^{-1} of cattle manure in some Districts.

Increasing N fertilizer application increased maize grain yields but this depended on the District. Only N fertilizer application explained about 50% of the variations in maize yields (Figure 4.13). Phosphorus and K did not explain much of the variations in maize grain yields (Appendices 3 and 4).

The QUEFTS model used in estimating maize yields in the study area provided an opportunity to increase maize yields larger than the current yield using District (site) specific balanced N, P and K rates. The specified rate for N fairly agreed with the N uptake of maize in the Districts by not exceeding 65 kg ha $^{-1}$.

Some practices adopted by indigenous smallholder farmers in some Districts resulted in higher maize grain yields than those from the demonstration trials and therefore researchers' demonstrations should not always be regarded as the only option that can increase yields.

Food security could be enhanced if smallholder farmers in Zabzugu, Kumbugu, Nanumba South, Yendi and Gushegu adopt the strategy from ISFM demonstrations in those Districts. The adoption could bring about 36% increase in maize grain yields from these Districts to enhance production. However, not all yield increment may be profitable to the smallholder farmer considering the net profit of his/her own practice and that of the proposed strategy.

The soil spatial database provided information about soil N, P and K fertility status of 13 Districts in the study area. It also provided information on the recommended maize production strategy that could provide relatively high yields with just a click on the application.

6.2 Limitations and Recommendations of the study

Farmers practices of N, P and K nutrient management for maize production might sometimes be better than output from research studies. Therefore, researchers should make it part of their studies to compare maize yields with those of farmers in their study areas, after they have compared their own trials, to identify the yield gaps before making recommendations. The maize varieties used by farmers, rainfall distribution patterns across the Districts and sowing dates of maize were however, not considered in this study, and may be considered in further research.

Research findings may provide options of nutrient management that might result in better yields than those of farmers but the net benefit considering cost of input of the proposed intervention may not be beneficial to improve farmers' livelihood. This is because not all yield increment are profitable. Therefore, smallholder farmers must be informed about the consequences of increasing maize grain yields on their income. If the aim of increasing maize yields is smallholder farmers' livelihood enhancement, then it will not be necessary to advice a strategy that will rather decrease their income and increase maize yields.

It is, therefore, recommended that researchers compare their profitable research findings to the profit that the smallholder farmer may obtain in his/her current practice before recommendations to avoid decreasing smallholder farmers' profit.

In locations where high fertilizer input did not result in equivalent high maize yields, further study is recommended in such areas to identify the cause, and if possible, find the most limiting nutrient factor that may prevent the soils from being responsive to inorganic fertilizer (N, P and K) application in order to apply the appropriate remedy. Cattle manure additions should also be regulated so that farmers do not over apply, which may lead to unnecessary P accumulation in the soil.

In addition, to sustain and enhance nutrients in soils where distribution pattern was affected by high input, which resulted in low N, P and K status, conservation methods that will reduce soil nutrient loss through erosion such as building bunds across slopes and growing cover crops on bare fields could be put in place. Smallholder farmers in the Districts could also be educated on the optimum fertilizer that could be used in locations where continuous increase in the quantity of fertilizer input did not continuously increase maize yields.

When these considerations are made, enhanced site-specific nutrient recommendations could be promoted in order to increase soil nutrient fertility in the region.

The study could also be extended to cover the other two Northern regions which are also considered as breadbasket regions in Ghana. The database could be updated to generate enough data to cover the other Districts which were not included in this study.

And finally, the study could be repeated by including more data points (> 80 sampling sites) in order to compare the outcome to this current study.

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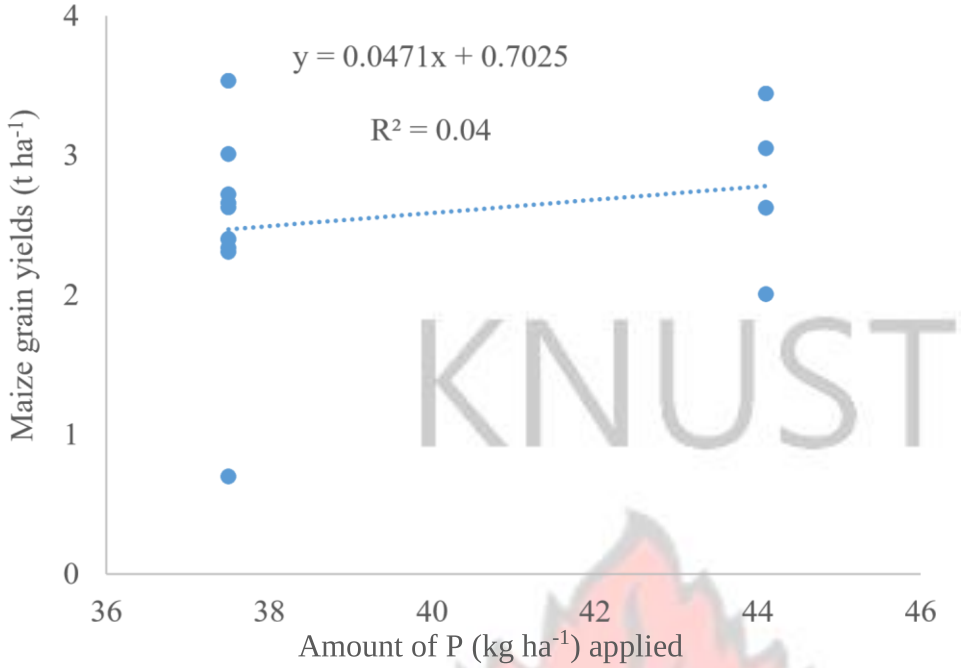
APPENDICES

Appendix 1: Demonstrations and fertilizer treatment (per acre) for various maize varieties conducted in the Districts within study area

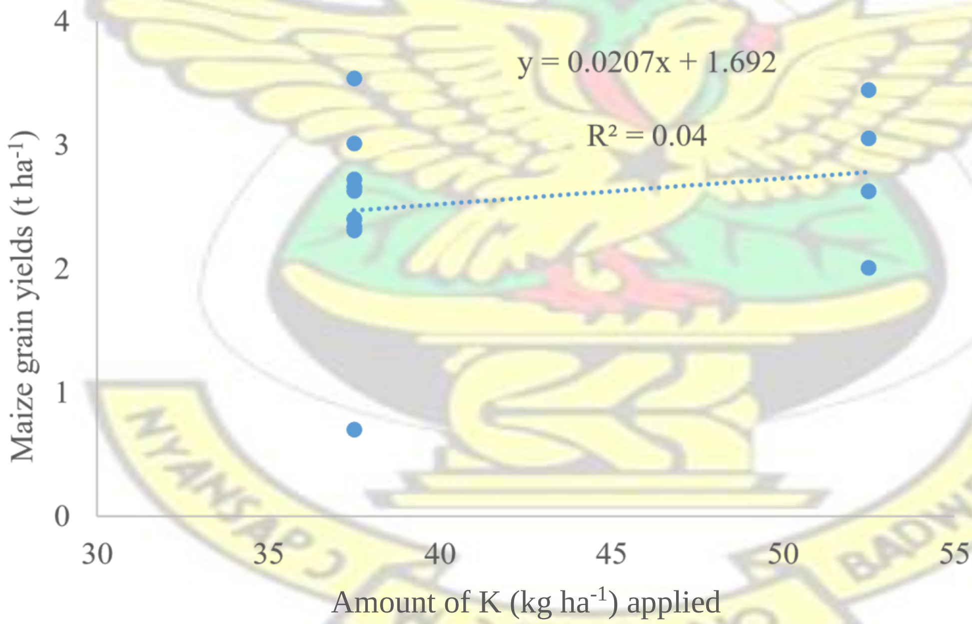
	Demo 1	Demo 2	Demo 3	Demo 4
Treatment 1 (per acre)	Maize + no fertilizer	Hybrid (Pannar 53) maize variety + recommended rate	Omankwa (DTMA maize variety) + recommended fertilizer rate	Maize + no fertilizer
Treatment 2 (per acre)	Maize + 1 bag NPK 15:15:15 + ½ bag SOA	Hybrid (Pannar 53) maize variety + ½ recommended rate	Omankwa (DTMA maize variety) + no fertilizer	Maize + Fertisoil 3t/ha + 2½ bags/ha SOA
Treatment 3 (per acre)	Maize + 2 bags NPK 15:15:15 + 1 bag SOA	Hybrid (Pannar 53) maize variety + no fertilizer	Aburohemaa (DTMA) maize variety + recommended fertilizer rate	Maize + NPK recommended rate
Treatment 4 (per acre)	Maize + 2 bags NPK 15:15:15 + 1½ bag SOA	Obaatanpa maize variety + recommended fertilizer rate	Aburohemaa (DTMA) + no fertilizer	Maize + Manure (2.5 tonnes ha^{-1}) + ½ NPK recommended rate

Appendix 2: Classification of NPK nutrient contents in 13 Districts within the study area

District	N (%) level	P (mg kg^{-1}) level	K (cmolc kg^{-1}) level
Savelugu	Very low	Low	adequate
Yendi	low	very low	adequate
West Mamprusi	low	low	adequate
Kumbungu	low	very low	adequate
Zabzugu	low	low	adequate
Gushegu	low	low	adequate
Saboba	low	adequate	adequate
Karaga	low	Very low	high
Tamale Metro	low	low	adequate
East Gonja	low	Very low	adequate
Tolon	low	low	Adequate
Nanumba South	low	Very low	adequate
Nanumba North	low	low	adequate



Appendix 3: Relationship between P fertilizer applied (kg ha-1) and corresponding maize grain yields from farmers' fields in the Northern region of Ghana



Appendix 4: Relationship between P fertilizer applied (kg ha-1) and corresponding maize grain yields from farmers' fields in the Northern region of Ghana

Appendix 5: Community based GPS coordinates and soil chemical properties collected from 16 Districts in the Northern region of Ghana and used for the study

Community	Easting (X)	Northing (Y)	N	P	K	Soil_pH	Elevation
Bimbilla 1	832126.74	980998.53	0.06	1.96	0.07	6.24	738.43
Bimbilla 2	836111.79	975950.02	0.10	11.29	0.12	6.35	775.49
Bimbilla 3	794537.31	952683.41	0.09	1.24	0.15	6.2	501.88
Binjai	774166.57	967576.32	0.05	3.44	0.14	4.92	413.57
Bisigu	740681.21	1154559.19	0.04	2.70	0.14	6.66	515.09
Chagbani	854700.86	1059790.40	0.05	7.26	0.20	4.91	374.94
Daboya	660301.04	1055251.81	0.04	2.70	0.17	5.38	344.98
Diare	734737.58	1092704.54	0.04	1.24	0.12	4.77	524.75
East Gonja 1	720535.31	1030881.14	0.06	1.24	0.21	5.97	506.62
East Gonja 2	733487.10	1027072.30	0.07	4.94	0.40	6.09	507.40
East Gonja	741252.48	1019934.18	0.06	1.96	0.15	5.97	477.44
Fufulso	689055.89	1011220.52	0.05	6.48	0.20	4.75	500.31
Galwei	780539.62	1065570.54	0.07	1.96	0.14	5.35	619.37
Gbanllung	727906.86	1047568.67	0.05	6.48	0.26	5.46	449.84
Gbenjag	847010.43	1074787.73	0.09	8.84	0.54	5.36	467.98
Gumgumpa	809513.50	952726.75	0.05	1.96	0.14	4.66	557.87
Japugada	820076.74	960871.12	0.05	2.70	0.22	4.76	438.81
Jimile	759119.82	1025052.34	0.07	1.24	0.22	5.32	685.70
Kabampe	606248.52	1015257.81	0.03	9.65	0.15	5.2	872.70
Kakoshie	757795.75	941250.08	0.05	1.96	0.50	5.09	426.98
Kpalpala	774033.77	1066792.34	0.06	2.70	0.10	5.34	541.31
Kparigu	763627.77	1138681.07	0.11	4.94	0.13	5.18	560.23
Kukpaligu	854700.82	1059790.51	0.05	4.94	0.25	4.47	577.43
Kukua	724012.68	1136487.19	0.07	5.70	0.25	5.43	481.38
Kumbungu 1	728651.67	1070499.21	0.07	1.96	0.14	5.78	508.19
Kumbungu 2	725105.41	1077793.89	0.06	3.44	0.12	5.84	493.21
Kumbumgu 3	727301.38	1063181.10	0.06	1.24	0.13	5.78	501.10
Laribanga	632935.24	1004265.06	0.04	2.70	0.19	5.3	711.94
Loagri	741298.08	1134455.50	0.08	4.94	0.12	5.37	443.54
Makayili	825981.52	996960.38	0.03	4.18	0.13	5.17	691.12
Masawuje	858028.01	1117148.86	0.06	6.48	0.40	4.76	593.35
Nabari	732330.97	1154516.28	0.04	1.96	0.13	4.58	522.38
Nabule	833202.50	1134849.54	0.08	4.18	0.29	5.38	624.10
Nakpali	865831.28	994956.23	0.05	7.26	0.12	4.8	564.17
Nangunkpang	782497.22	1118335.37	0.13	3.44	0.41	6.31	564.96
Tuna	595909.58	1058712.19	0.04	7.26	0.17	5.38	997.38
Ntereso	699732.31	995373.66	0.05	3.44	0.08	4.58	501.88
Nyonguma	756964.92	1102167.46	0.07	1.96	0.20	5.33	553.92
Pigu	738369.51	1105949.69	0.05	10.47	0.18	5.76	516.87
Pusuga	816979.74	986540.04	0.05	1.24	0.15	4.78	663.52
Satenga	717162.50	1069904.23	0.04	3.44	0.12	4.84	432.50

Savelugu 1	732767.27	1051527.24	0.04	1.24	0.07	5.04	522.38
Savelugu 2	723054.35	1054669.61	0.04	1.96	0.06	5.19	499.52
Savelugu 3	730109.24	1058882.13	0.03	1.24	0.07	5.19	505.04
Sawla	561122.23	1022331.56	0.05	6.48	0.17	5.7	1082.20
Sung	766266.73	1096656.60	0.04	5.70	0.12	6.06	598.87
Tali	707535.85	1044507.23	0.03	2.70	0.11	4.55	505.04
Tamale 1	769569.23	1036767.33	0.09	2.70	0.73	6.28	532.64
Tamale 2	751021.73	1044995.84	0.09	1.96	0.27	6.19	540.52
Tamale 3	746512.82	1034722.39	0.09	8.84	0.25	6.61	523.96
Tamalegu	687447.79	1041244.15	0.05	1.24	0.07	5.33	479.02
Tidjo	770973.50	1052866.52	0.05	5.70	0.25	4.33	494.00
Tinga	582587.62	950618.04	0.07	8.05	0.30	5.32	752.62
Tinyogu	781182.24	1069484.07	0.08	1.24	0.18	5.32	650.12
Tong	765823.82	1106600.55	0.08	4.18	0.60	5.47	773.91
Tunguri	697451.59	1071043.11	0.07	11.29	0.11	5.37	482.96
Wantugu	692503.12	1056898.63	0.05	10.47	0.07	5.35	508.19
Wapuli 1	836054.22	1086742.30	0.08	4.18	0.15	5.27	512.92
Wapuli 2	840282.21	1079145.19	0.12	10.47	0.31	5.26	508.98
Wapuli 3	832026.85	1070059.92	0.09	5.70	0.14	5.32	552.35
Wayamba	707299.93	1051170.12	0.04	1.96	0.23	5.22	546.83
Wenchiki	850691.77	1137165.41	0.04	4.18	0.26	5.58	493.21
Wulensi 1	839572.48	946091.05	0.05	1.96	0.07	5.81	624.89
Wulensi 2	828712.02	969257.45	0.06	1.96	0.07	5.73	615.42
Wulensi 3	831753.82	962122.84	0.06	3.44	0.10	5.73	669.83
Yendi 3	831338.64	1026136.02	0.05	1.96	0.10	6.02	710.83
Yendi1	828580.68	1037984.68	0.06	4.18	0.13	6.07	727.39
Yendi2	813700.25	1036606.40	0.06	1.24	0.11	5.88	695.85
Yipala	720032.27	1009763.75	0.04	8.05	0.19	7.41	482.17
Zabzugu 1	867385.27	1031884.43	0.07	3.44	0.12	5.42	512.92
Zabzugu 2	867487.94	1029707.67	0.08	1.96	0.14	5.39	445.11
Zabzugu 3	863243.53	1028712.33	0.09	10.47	0.19	5.34	507.40
Zankale	751676.50	1088719.61	0.04	1.96	0.26	5.32	451.42
Zeneyili 1	785966.66	1079161.70	0.07	1.96	0.42	6.57	564.17
Zeneyili 2	779849.73	1093138.71	0.07	1.24	0.32	6.6	564.96
Mpaha	700283.35	977168.63	0.04	2.70	0.12	4.83	246.42
Jama	584171.94	917854.96	0.06	3.27	0.20	5.66	808.46
Mandari	543213.01	997241.82	0.05	3.60	0.21	5.34	914.57
Jakpa	839810.73	1128280.12	0.09	3.25	0.26	5.94	486.65
Bongpolugu	843800.93	1147289.42	0.11	4.89	0.22	5.58	541.60

Appendix 6: Sample of survey questionnaire used in this study

SPATIAL ANALYSIS OF MAJOR SOIL NUTRIENTS IN INTEGRATED SOIL FERTILITY MANAGEMENT IN THE NORTHERN REGION OF GHANA.

This questionnaire will be treated as confidential as possible. All information gathered will be solely used for the purpose of the study that it is intended for. The questionnaire is aimed at interviewing maize growing farmers to conduct a study on the distribution of major soil nutrients across the northern region.

1. Name
2. District of residence
3. Age □16-40□40-60□60 and above
4. Sex □M□F
5. Marital status□Married□Single
6. Household income (Annual (GHS) □1000 □1000-3000 □3000-5000 □>5000
7. Household size

8. Who does the farm belong to?
- It is my own farm
- It belongs to the extended family
- It belongs to another person

9. State of soil fertility on farm level
- Very Good□
- Good□
- Poor□

10. Types of fertilizers use on farms
- Only organic□
- Only inorganic□
- Organic and inorganic□
- None of them□

11. Amount of fertilizer use on farm

 Organic□<1 bag/ha□1bag/ha□2bags/ha >2bags/ha Inorganic□<1 bag/ha□1bag/ha□2bags/ha >2bags/ha

12. Kind of fertilizer: ☐ Organic
○ Crop residue ○ Cow dung ○ Crop residue and cow dung ○
Other (specify)

☐ Inorganic ○ NPK (15:15:15) ○
Urea ○ Sulphate of ammonia
○ Other(specify)

13. Yields of maize for the past 3 years
□ < 4bags/ha
□ 4-6bgs/ha
□6-10bagskg/ha
□> 10bags/ha

14. Which area(s) of the region would you consider very fertile?

15. Which area(s) of the region would you consider less fertile?

16. What could be attributed to the differences in fertility levels?

18. If yes, what kind of help?

19. If no, why is it so?

17. Do you get any help from agricultural agents/institutions? □Yes□No

20. Have you heard of ISFM? □Yes□No

21. Where and how did you get to know of the technology?

22. Do you practice ISFM in your farm? □Yes□No

- If yes, why and how?

- And if no, why?

23. Do you see any changes in how your crops grow, and any yield differences since adopting ISFM?
    □Yes□No

24. How would you rate ISFM practice in your district?
□ Very Good
□ Good
□Moderate
□ No idea

25. Would you suggest any way to make it better?

26. Do you have ready market for your produce? □Yes□No

27. How far is the market from your farm?
□ Very close(< 5 miles)
□ A bit far (5-10 miles)
□Very far (>10 miles)
□ No market nearby

27. Do you have ready transportation for your produce? □Yes□No

- If yes, why?

- And if no, why?

Other complementary questions

Do you know the major soil nutrients (NPK) and their deficiency symptoms? Do you know the dominant major nutrient in organic or inorganic fertilizer used to correct declining soil fertility?
Is there any soil test data to prove that this is known to the farmers or extension agents?
Has soil testing ever been done on their land?
Any knowledge of response of maize to the application of N, P or K fertilizer or organic manure?
Where do you have highest response to fertilizer NPK (or organics) application and where do you get the least response?

This information is gathered and would be used by:
Mary Antwi
PhD Soil Science candidate KNUST.

Date: …………………………………………….

Signature…………………………………………