UNIVERSITY FOR DEVELOPMENT STUDIES

CALIBRATION OF SOIL TEST RESULTS FOR PHOSPHORUS AND NITROGEN FERTILIZATION FOR MAIZE (*Zea mays* L.) PRODUCTION IN NORTHERN GHANA

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CALIBRATION OF SOIL TEST RESULTS FOR PHOSPHORUS AND NITROGEN FERTILIZATION FOR MAIZE (*Zea mays* L.) PRODUCTION IN NORTHERN GHANA

BY

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DISSERTATION SUBMITTED TO DEPARTMENT OF AGRONOMY, FACULTY OF AGRICULTURE, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

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DECLARATION

I, Ebenezer Ayew Appiah, hereby declare that, this is an original result of my own work and that no previous submission for a degree or any certificate has been done here or elsewhere. However, information relevant for this work from other authors has been cited and duly acknowledged by way of reference.

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ABSTRACT

As inherent soil fertility varies for different soils, site-specific fertilization recommendation has long been proposed as more efficient than blanket soil nutrient management. Across northern Ghana, however, blanket recommended rates of nitrogen (N) and phosphorus (P_2O_5) are used in maize cultivation. Pot and field experiments were conducted from April to December, 2019 to calibrate soil test results and develop nitrogen and phosphorus-predicting tools for site specific fertilization in maize production. Nutrient depleted soils were fertilised with eleven phosphorus rates (00, 05, 10, 15, 20, 25, 30, 35, 40, 45, and 50 kg P_2O_5/ha) and eleven N rates (0, 15, 30, 45, 60, 75, 90, 105, 120, 135, and 150 kg/ha) in two pot experiments. The N and P levels of the soils before and after nutrient application were analysed to serve as proxi of soil nutrient levels, before planting. The relation between maize growth yield and applied nutrient rate, together with regression analyses of applied rate and corresponding soil test results were used to develop N and P_2O_5 predicting tools. The developed N and P_2O_5 predicting tools were evaluated at three sites (Nyankpala, Tamale and Damango) by comparing maize growth and yield of the tool- predicted rates with the optimum performance in the pot experiment. The tools were then validated by comparing performance of tool-predicted rate with that of zero fertilization and blanket recommended rates at the three sites in a Randomized Complete Block Design with 3 replications; using the maize var. Wangdataa. The data were subjected to analyses of variance and separated at a probability of 5%. N and P_2O_5 predicting tools were developed for estimation of site-specific soil N and P fertility, based upon the results of the initial soil chemical analyses. Using the developed tool, the exact N and P_2O_5 fertilizer rates that are required to achieve optimum maize production could respectively be estimated for a given location. The process involved in the site-specific tool development revealed that for soils that are poor in N and P_2O_5 nutrients, application of small incremental quantities of nutrients significantly increased growth and yield parameters of maize, including: plant height, leaf area index, hundred seed weight, cob length and weight, straw weight and grain yield. The available P and total N contents of the soils across northern Ghana were below that required for optimum maize growth and development. As such, maize farmers require N and P_2O_5 fertilization to maximize yield. However, the level of inherent N and P_2O_5 are not same for all soils, each site therefore requires site specific rate of N and P_2O_5 application to achieve maximum maize yield. Across all sites, the developed N and P_2O_5 fertilization tool accurately predicted growth and yield in the range of 90 to 100%. In all cases, there was no significant difference in growth parameters, yield and yield components between the developed tool-predicted rate and that of the blanket recommended rate. However, partial cost analysis due to fertilization indicated that famers can gain 30.5% to 44.6% net saving due to fertilization upon using the developed N and P_2O_5 predicting tool. Running soil tests could therefore help farmers to know the nutrient status of the soils which could serve as a proxi to estimate site specific fertilization rate and help reduce fertilizer investments by the already resource-constrained farmers. Using the developed calibrated tools would enhance profitability of maize production across the Guinea savannah zone of Ghana.

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DEDICATION

To my parents Mrs Felicia Piedu and Mr Joseph Amoakoh. Also my sister Angelina and Enerstina Hayford Arkoh and my brother Emmanuel Kofi Piedu for giving me the love and your support God richly bless you.

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CHAPTER ONE

1.1 Introduction

Crop production is controlled by numerous complex interacting factors which include soil fertility, pests and diseases, climate, and farmers' resourcefulness (Chakraborty and Newton, 2011; Altieri, 2018). Soil fertility status is a significant component of this environment required for crop growth and development. In Ghana, persistent land-use for crop production, coupled with alternating wet and dry seasons, has rapidly contributed to rapid decomposition of soil organic matter in the northern region that increases the rate of loss of soil fertility. Loss in fertility has contributed to low crop productivity on farmlands to an extent that fertilizers must be added to increase yield (Godfray et al., 2010). Soil fertility guidelines and recommendations, must, however be based on nutrient studies in relation to soil and plant tissue analyses (Rodrigues et al., 2012). These guidelines and the nutrient management recommendations ought to be built on knowledge derived from soil test and plant tissue correlation and calibration procedures (Barker and Pilbeam, 2015). Correlation of soil test results with plant growth and productivity can be portrayed as a decision-making tool that aids in deciding if any relationship exists between soil test results of a given nutrient and crop yields associated with the nutrient level (Loveland and Webb, 2003; Arun, 2016; Beck, 2018).

Soil fertility tests usually refer to a relatively quick nutrient extraction that yields an available soil nutrient value that is linked to crop fertilization response. Soil tests are simple and inexpensive scientific method that serve as the base for any lime or fertilizer recommendations for growing plants. Soil tests are chemical tests conducted on a soil sample to assess the soil's nutrient-supplying potential for a specific crop/plant during a specific growing season (Jones et al., 1990). Because a soil test report is an integration of multiple values, the laboratory result of a soil test is also referred to as a soil test index (such as values of nutrients and soil factors) associated with plant nutrient availability.

Calibration of soil test result is a method of establishing a link between a given soil test value and the yield response from fertilizing the soil with a nutrient. The calibration effort will determine how much fertilizer is required at different soil levels to achieve maximum yield (Raum et al., 2008). Although soil test calibration can be used as the foundation for the establishment of a soil testing service, it is not a simple or quick procedure; it is expected that more and more new laboratories in developing countries will conduct their own calibration. While the basic theory, the connection between soil tests and crop responses, is extremely simple, soil test calibration is a very complex process. The main complication emerges from the fact that the nutrient content of the soils is just one of several factors that affect yield.

Maize (*Zea mays* L.) is an incredibly versatile cereal crop that is widely cultivated worldwide in varied agro-ecological environments (Bouis and Welch, 2010; Olaniyan, 2015). In Ghana, it is the main staple food for most households, particularly in the northern part, where it replaces sorghum and millet that were the staples some few years ago (Yussif, 2019). It is one of the most significant crops for Ghana's agricultural sector and for food security. It is grown in all areas of Ghana including: the forest, transition, coastal savannah, and the northern savannah agro-ecological zones. It is grown on an estimated 1,000,000 hectares of land, contributing 50-60% of the total cereal production of Ghana (MoFA, 2015). Total maize production in Ghana is done by about 70% of smallholder farmers (Akudugu et al., 2012; Fosu-Mensah et al., 2012; Mwangi and Kariuki, 2015). The average maize yield in Ghana as at 2013 was 1.7 Mt /ha compared to an expected yield of around 6 Mt / ha (Kotu and Admassie, 2015; Anyanwu et al., 2015). With changing agricultural trends and a growing human population, the probability of continuous maize cultivation is increasing being accepted. Farmers are increasingly dedicating hectares of farmlands to intensive crop sequences in which maize follows maize more frequently (Martin et al., 1991). This is because maize is one of the most beneficial crops widely cultivated in Corn Belts (Sulc and Tracy, 2007; Wright and Wimberly, 2013). The reason being that maize is exceedingly receptive to production inputs, uses sunlight adequately and also surpasses yield/hectare when contrasted with other grains (Singh, 2011). Every part of the maize plant has economic value: the grain, leaves, stalk, tassel, and cob can all be used to produce a large variety of food and non-food products and the crop itself can be grown under irrigated and rain-fed conditions (Mohammed, 2017). It is a rich source of food, fodder, and feed for animals and provides raw materials for industry. Maize can be prepared into a wide scope of nourishments and drinks, which are taken as breakfast and primary dinners. It is widely used in the brewery industry. In Ghana, it is the principal source of carbohydrate for feed in the poultry industry and for domestic livestock (Ayinla, 2007). The grains of maize are wealthy in nutrients and contain vitamins A, C and E, starches, and basic minerals, and protein. They are additionally wealthy in dietary fibre and calories which are a good source of vitality and energy. In sub-Saharan Africa, shortage of maize may easily lead to famine and starvation.

Ghana is one of the significant maize producers in Africa, south of the Sahara (Alene and Mwalughali, 2012; Iliffe, 2015). The annual national average yield of maize from 2009 through to 2011 was 1.7 million tons collected from around 990,000 hectares (Ragasa et al., 2013; Ankutse, 2014; Adeyinka, 2016; Subramanyam et al., 2017).

Maize has the highest production when water and soil fertility are adequate, however, it is least tolerant of stress (Steduto et al., 2012).

Nitrogen is a crucial plant nutrient and a noteworthy yield determining nutrient element for maize production (Onasanya et al., 2009; Gul et al., 2015). Its accessibility in adequate amount all through the growing season is essential for optimum growth and development of maize. Most farmers in developing countries usually rely on natural soil fertility for crop production. Where nutrient applications are done, successive fertilization with sole N improves crop performance substantially (Bindraban et al., 2020). For instance, application of a mixture of urea, triple superphosphate (TSP) fertilizer and farmyard manure excrement was found to improve the crop use of N and P_2O_5 fertilizer (Mclaughlin et al., 2011). Thereafter, subsequent cropping with sole nitrogen performed comparably to compound mixtures of fertilizers. Gonzaga et al. (2017) reported that starter nitrogen had the ability to improve early development and yield of maize. Nitrogen thus remains the most important nutrient that is required for maize growth in most nutrient-poor soils of Africa (Zingore et al., 2008).

Phosphorus (P) is the second most limiting nutrient in most cropping systems of Africa (Vesterageret al., 2007). The nutrient is required for most physiological and morphological functions of crops (Yang et al., 2012). During maize growth, phosphorus is required for root and grain development (White and Veneklaas, 2012). It is required by crops for numerous biochemical processes and for the metabolism of carbohydrates, fats and proteins. Phosphorus is also required for the breakdown of carbohydrates to release energy for use by the crop (Walters et al., 2004). According to Vos et al. (2005) phosphorus is also involved in leaf development and senescence in maize. Due to P involvement in the performance of numerous physiological and morphological functions, it has been used to improve yield in most nutrient-poor soils (Simpson et al., 2011).

1.2 Problem statement and justification

Food production in sub-Saharan African continues to lag behind population growth. To help improve food production, it has been suggested that soil fertility must be managed more efficiently if Africa is to overcome its food-production problems (Cardoso and Kuyper, 2006). Essential nutrients are required for sustainable crop production for the increasing world population. Increasing crop yield depends on the type and rate of fertilizer used to supply the nutrient. Maize is an exhaustive crop; and therefore has high nutrient consumption potential than other cereals (Lobell et al., 2009). Maize needs an adequate supply of nutrients for better growth and high yield; especially nitrogen, phosphorus, and potassium.

Maize yield in Ghana is low. Although increases in maize production are reported, such increases are attributed to increases in the area of cultivation as the national yield averaged 1.5 - 2 t/ha is below the achievable yield of 6 t/ha (Mupangwa et al., 2012; Tittonell and Giller, 2013).

The continuously low maize yields necessitate the need to identify means to increase the yield of the crop. A number of factors contribute to the low productivity of maize in Ghana. These include draught during the critical early phases of the crop’s development, low soil nutrient levels (especially nitrogen and phosphorus), *Striga*, insect-pests and disease infestations, as well as poor management practices such as low plant populations, inappropriate planting time, inadequate control of weeds, lack of credit, limited access to production inputs (especially fertilizer and improved seeds) as well as untimely application of adequate quantities of fertilizers. There is also lack of knowledge in basal soil testing procedures to determine the initial soil nutrient status and calibrate crop nutrient application rate.

Low soil fertility continuous to be a prime reason for low maize productivity. The low fertility is attributed to increasing pressure on land due to increasing population and increasing competition in uses of land which have shortened fallow periods and lead to continuous cropping and consequently undesirable effects on soil structure and nutrient status (Smith et al., 2014). The declining soil fertility problem is also aided by indiscriminate bush burning, and low nutrient application rates, as well as over grazing by animals which render the land bare and prone to direct sun radiation and nutrient losses through erosion and leaching (Solbring et al., 2017). Continuous nutrient mining has further contributed to low fertility (Vanlauwe and Giller, 2006). About two-thirds of the nutrients, especially nitrogen that are applied to cereals is accumulated in the grain and is exported during harvest (Kugbe and Zakaria, 2015). Greater portion of the nutrients applied tend to remain in the stover and are not recycled back into the soil because farmers use the stover for alternative economic livelihood, including use for animal feed and fuel for cooking. The soils of northern Ghana are also prone to floods within the voltain basin (Fredua, 2014). Losses of nutrients also occur through soil runoff, as a result of heavy rains.

It is postulated that the addition of adequate quantities of various nutrients to the soil will enhance maize yield and productivity (Fageria, 2016). Literature reveals that application of N at the rate of 150 kg/ha produced maximum biological yield of 7189 kg/ha as compared with control plot (plots with no fertilization) of 5884 kg/ha (Imran et al., 2015). Another study observed that plots treated with higher fertilizer rates carry significantly higher number of kernel per ear and kernel per stand compared with control plots with no fertilization (Moser et al., 2006). Generally, significant increases in yield of cereal crops have been realized in nutrient depleted soils through the addition of the major nutrients (N, P, K) under good management as compared with plots with no nutrient addition (Adesemoye et al., 2008). Adesemoye et al. (2008) also observed increases in yield with plots treated with maximum rate of nutrients as compared with plots without nutrient addition.

Nitrogen, phosphorus and potassium (N, P, K) are essential in maize production because they are the key elements required for the physiological and morphological development of the plant (Farhad et al., 2009; Arif et al., 2012). Calcium, magnesium, sulphur and the micro nutrients are all required by the maize plant. However, they are required in relatively small quantities. Mostly, soils in northern Ghana are known to have appreciable levels of Ca, Mg and most micro nutrients. For this reason, studies on secondary and micro nutrient inclusion have received relatively low attention as attempts are made to first understand nutritional roles of the primary NPK. Adequate supply of NPK are thus required for optimum growth and plant production. Soils in most savannah woodlands as found in northern Ghana are known to be more rich in potassium (K) than N and P. For this reason, K fertilizers are less added to crops (Viani et al., 2014; Gul and Whalen, 2016).

Unlike K, nitrogen (N) and phosphorus (P) are not readily available in the soil. So their inclusion and management is critical to study. Nitrogen can be synthesized by industry or fixed into the soil by biological nitrogen fixation (BNF). However, P can only be mined from natural deposits. It is postulated that sources of P for fertilization are depleting at alarming rate, necessitating judicious use of P fertilizers. For maize production in northern Ghana, both nitrogen and phosphorus are strongly recommended. While N can always be produced and not a major call for concern apart from the cost of production, sources of P for fertilizer synthesis are estimated to be depleted in the near future (Cordell and White, 2011; Jones et al., 2013).

Although the applications of inorganic N and P_2O_5 fertilizers to the soil are highly associated with an extra cost due to high prices of fertilizers and purchases, it has also been recommended to farmers to run soil tests before fertilizer application (Gellings and Parmenter, 2016). Numerously literature recommends that, wherever possible, soils should be routinely analyzed to know the characteristics of the soil and to obtain recommendations on how to manage soil fertility for optimal maize production (Ukwattage et al., 2013; MoFA, 2015; Havlin et al., 2016). While there is an extra cost of soil analyses to the already resource-constrained farmer which increases the cost of maize production, no informed decision is made from soil test results to justify the economic loss in revenue to the farmer.

In the northern savannah zone, same rate of 120 kg/ha of nitrogen (N) and 45 kg/ha P_2O_5 are eventually recommended to maize fields irrespective of the results obtained from the soil test. This practice results in waste of time, labour and resources of the small-holder farmer, and leads to possible over-application of P_2O_5 and N in nutrient-rich soils which is also not economical to the resource-poor farmer (Mafongoya et al., 2006; Jones, 2013) and could result in soil and water pollution attributable to leaching of excess nutrients (Sanginga and Woomer, 2009). The practice can also lead to possible under application of P_2O_5 and N in nutrient-poor soils, which will reduce yield (Alburquerque et al., 2013).

To decrease the cost of N and P_2O_5 fertilization and help extend the shelf life of natural P_2O_5 sources for food security, there is the need to analyse basal soil test and then calibrate soil test results to inform exact, site-specific N and P_2O_5 fertilization. Khosla et al. (2002) found that management of mineral fertilizers using site-specific management zones (SSMZs) that account for soil variability and productivity provides the quantities of mineral nutrients that are required to increase yields and optimize the agronomic efficiency of the nutrients used. Site-specific fertilization have been shown to improve nutrient management and efficient use of the applied fertilizers to increase yields and minimize environmental nutrient losses (Xiang et al., 2008). Site-specific fertilization has helped in the identification of effective agricultural methods for the control of nutrient fertilizers and irrigation, as well as in the optimal management of allocated cropland and land use to enhance crop production (Zebarth et al., 2009).

Currently in northern Ghana, data on calibrated soil test results and a model of corresponding fertilizer top-up recommendations are limited. This makes it difficult to interpret soil test results and to make decisions on the needed top-up rates of P_2O_5 or N to apply to soils of tested and known fertility. The prevailing situation has informed a one-suite recommended rate of 120 kg/ha N and 45 kg/ha P_2O_5 for all soils in northern Ghana, irrespective of the results obtained from soil analyses. As different soil P and N levels may exist for different soils, there is the need to calibrate soil test results for N and P to serve as a proxy for predicting site-specific N and P_2O_5 fertilization from soil test results. A soil test-predicting tool for fertilizer top-up will help maximize the crop’s production at low costs, avoid waste or excess use of fertilizers and reduce soil and water pollution.

1.3 Objectives

The objectives in this study were:

1. To calibrate soil test results for site-specific nitrogen fertilization in maize production across the Guinea savanna zone of Ghana.

2. To calibrate soil test results for site specific phosphorus (P_2O_5) fertilization in maize production across the Guinea savanna zone of Ghana.

3. To develop a calibrated tool to predict site-specific fertilization rate for nitrogen and phosphorus in maize production.

4. To evaluate and validate calibrated tool for site-specific application of nitrogen and phosphorus fertilizers in maize production.

5. To confirm the importance of nitrogen and phosphorus in maize production.

1.4 Hypotheses

Ho: Different rates of N and P_2O_5 fertilization are required to achieve maximum grain yield of maize depending on basal soil nutrient status.

Ha: Same rates of N and P_2O_5 fertilization are required to achieve maximum grain yield, irrespective of site specific soil nutrient levels.

H_o: The rate of N and P_2O_5 fertilization required to achieve maximum economic yield depends on soil N and available P nutrient-levels.

H_a: The rate of N and P_2O_5 fertilization required to achieve maximum economic yield is independent on soil N and available P nutrient-levels.

H_o: Running soil test can help reduce the cost of investment in fertilizer purchases by the smallholder farmer.

H_a: Running soil tests will not help reduce the cost of investment in fertilizer purchases by the smallholder farmer.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and distribution of maize

Most specialists consider Central America and Mexico to be the primary centre of maize production, where various kinds of maize are found. The discovery of fossil maize pollen in Mexico along with other geological evidence indicates that Mexico is a major source of maize. Its production was in any case accepted to have started from the Central Mexican high plateau. The most known archeological corn was found in the Tehuacan Valley of Mexico (Zarrillo et al., 2008; Piperno et al., 2009; Ramos-Madrigal et al., 2016). It was demonstrated to be a standout amongst the most versatile and variable individuals from the grass family (Kogbe and Adediran, 2003). The maize plant is well developed and stands out amongst the most significant cereal crops around the world (Leff et al., 2004; Rudel et al., 2009; IITA, 2011). Maize first became domesticated in Central Mexico (Matsuoka et al., 2002; Ranere et al., 2009; Piperno et al., 2009) somewhere in the range of 9,000 and 6,000 years back (Benz, 2000). The crop is an immediate taming of a Mexican wild annual grass strain, teosinte (*Zea mays* parviglumis), which is local to the Balsas River valley of Southern Mexico (Mousa et al., 2015; Cruz-Cárdenas et al., 2019). It is generally agreed that teosinte (*Z. mexicana*) is an ancestor of maize, although opinions vary as to whether maize is a domesticated version of teosinte (De Lange et al., 2014). For its durability, maize is cultivated worldwide and serves as nourishment for a critical extent of the total populace. No significant native toxins are reported to be associated with the genus *Zea* (International Food Biotechnology Council, 1990; Kennedy et al., 2004; Meyer et al., 2012). Twelve per cent of maize hereditary material is believed to be acquired from *Zea mays* Mexicana through introgression, and is thought to be gotten from hybridization between tamed maize (a slightly modified form of wild maize) and

Luxuriantes (either *Z. luxurians* or *Z. diploperennis*) segment teosinte. Late hereditary proof recommends that maize production happened 9,000 years back in Central Mexico.

Maize (*Zea mays*) was brought from its native Mesoamerica to Africa in the sixteenth century and is currently an outstanding grain crop in Africa. Its advancement in Mesoamerica prompted its enhancement into roughly 55 races (Meyer and Purugganan, 2013; Vega-Alvarez et al., 2017). In spite that the crop's natural surroundings are the tropics, much more is produced in the hotter areas in the Corn Belt area (U S A), state belt of Russia and in Argentina. One of the key producers in Africa is the Republic of South Africa. From 58°N latitude to 40°S latitude, the crop spreads and is cultivated around the globe. In this area alone, more than 139 million ha of the zone and around 600 million tons of maize is produced. US of America practically produces half (280 million metric tons) of the world's production (FAO, 2005; Lemus and Parrish 2009; Serna-Saldivar, 2016). Maize generally occupies the third position in quantity and area of production besides rice and wheat.

2.2 Taxonomy

Maize is part of theq Poaceae (Gramineae) family of grasses. In the light of fossil evidence, it is assessed that these real grass genealogies originated from a traditional ancestor in the last 55–70 million years, near the end of the dinosaur reign (Beerling, 2019; Buckler and Stevens, 2006). The *Zea* genus contains wild taxa, teosinte (Zea ssp.) and domesticated corn (*Zea mays* L. ssp. *may*) or maize. According to reports, the ear of teosinte is dissimilar to that of maize in structure. For this reason, nineteenth-century botanists neglected to perceive the connection between these plants, putting teosinte in the genus Euchlaena as opposed to Zea with maize (Newell-McGloughlin and Re, 2006). In *Zea mays* the number of chromosomes is 2 n = 20.

The tribe Maydeae comprises seven genera, which are unique classes of the old and New World. Old World comprises Coix (2n = 10/20), Chionachne (2n = 20), Sclerachne (2n = 20), Trilobachne (2n = 20) and Polytoca (2n= 20), and the Zea and Tripsacum of New World groups. It is generally accepted that the American genera Zea and Tripsacum govern maize phylogeny to a large degree. It is recognized however that the Coix class contributed to the phylogenetic development of the *Zea mays* species (Prasanna et al., 2006; Murdia et al., 2016).

2.3 Description and botany of maize

Maize (*Z mays* L.) of the genus Zea from family Graminae (Poaceae) or the grass family is a tall, monoecious yearly grass with covering sheaths and expansive distichous sharp edges (Kutawa, 2016). It produces an erect, strong stem, as opposed to the empty one of most different grasses and changes generally in stature, some dwarf variety assortments being minimal in excess of 60 cm tall at maturity, while different types may achieve statures of 6 m or more. The normal height at maturity is about 2.4 m. The entire yield structure (ear) is enclosed in numerous broad foliaceous bracts and from the tip of a mass of silky threads protrudes a mass of long style (silks) (Amofa, 2015). The individual silk filaments / strings that emerge from the tip of the ear are the extended forms, each attached to a single ovary. The ear is encased in changed leaves called husks. The pistillate inflorescence, or ear, is a one of a kind structure with up to 1,000 seeds borne on the hard cob. The seed contains two structures, which are the germ from which new plants develop and the endosperm which fills in as a source of nourishment for the germinating seed. Pollen is formed entirely in the stamina and egg, entirely in the inflorescence of the pistillate. Shed pollen usually remains practicable for 10 to 30 minutes, but may remain acceptable for longer periods under favorable conditions (Frankel and Galun, 2012; Erdtman, 2013). Fertilized ovaries grow and develop into the kernel. The kernel differs in colours running from white to yellow, red and blue.

2.4 Significance of maize

Maize is one of the cereal crops that contributes over half of the absolute human calorie around the world (Awika, 2011; Shiferaw et al., 2011; Tilman et al., 2011; Joshi et al., 2016). In Ghana, it is the real staple particularly in the northern and volta regions. In the northern region, the crop has replaced sorghum and millet which were the significant staples a few years back (Houssou et al., 2018). It is the staple food for humans, feed for domesticated animals and for many industrial uses. It has high percentage of starch (65%), for which reason it is used as a source of dietary fibre in many households. Maize is mostly processed in two ways: Wet milling produces sugars, and additionally delivers different adjusted maize starch for paper overlay, material wrap, measuring and clothing wrapping up. Dry milled maize are used primarily for animal feed, brewing, cereals for breakfast and other foods. The crop is a substitute crop to rice and wheat. About 35% of all maize is consumed by human, 25% are used for poultry and cattle feed, while 15% is used in food processing.

Maize (*Zea mays*) is also a versatile crop; growing across a broad range of agro-ecological zones. Maize is grown in Ghana especially in the forest, transition, southern regions, the upper west, the upper east and the north neighbourhoods. Each part of the maize plant has an economic value: grain, leaves, stalk, tassel and cob can all be used to produce a wide range of food and non-nutrient products (Ogunniyi, 2011; Chennakrishnan, 2012; Oladejo and Adetunji, 2012). Maize is a major component of poultry feed and the livestock feed sector to a lesser degree as well as a replacement for the brewing industry (Ogunniyi, 2011; Chennakrishnan, 2012; Oladejo and Adetunji, 2012). In developed countries where maize is produced on commercial bases, maize is to a great extent utilized as animal feed and as raw material for industrial products. According to report by Nuss and Tanumihardjo (2011) major dependence on maize in the eating routine can cause lack of health and some nutrient deficient sicknesses, e.g. night visual deficiency and Kwashiorkor. As indicated in some literature, corn is a crop planted around one million hectares and accounts for fifty to sixty percent of total production of cereals in some areas (Sitko et al., 2011). In addition, maize is Ghana's second-largest commodity crop after cocoa. It is the most significant cereal crop in most parts of West Africa (Ray et al., 2012; Ray et al., 2015). Over the most recent two decades, production in West Africa increased by 3.8% when contrasted with an increase of 1.4% for Eastern and Southern Africa (Dowswell, 2019). Maize is a staple food for an estimated 50 percent of the population in sub-Saharan Africa and gives 50 percent of the necessary calories. Corn also serves as substantial source of minerals, vitamin B, protein, iron and starch. Africans eat maize in a wide range of porridges, pastes, grits and beer as a starchy foundation. In the savannah agro-ecological zone of Ghana, maize is eaten fresh when grilled or cooked (Nurudeen, 2011; Rahman et al., 2014) and can likewise be processed into Tuo-zaafi, Banku, Kenkey and porridge (Offei–Ansah, 2012; Agyiri, 2016).

The stalk is used to feed animals (Omer et al., 2012) and it features prominently in infant weaning foods (Ahmed and Ramaswamy, 2006; Reddy et al., 2012). Green maize (fresh on the cob) is consumed parched, baked, roasted or boiled and performs a vital function after the dry period in filling out the hunger gap. Maize grains have remarkable health benefits in that they contain 72% starch, 10% protein, 4.8% oil, 8.5% fiber, 3.0% sugar and 1.7% slag. Maize is the most important cereal fodder and grain crop in semi-arid and dry tropics both under watered and rainfed agricultural systems (Ghosh et al., 2007; Thierfelder et al., 2015). Maize utilization per capita in

Ghana in 2000 was assessed at 42.5 kg (Jones et al., 2011; Abass et al., 2014) with an expected national utilization of 943000 Mt in 2006 (SRID, 2007; Palombo et al., 2013; Marklund et al., 2015). The increasing interest for maize colour as nourishment has the capability of turning the crop into a significant non-customary fare crop (Rosegrant, 2001; Church, 2015).

2.5 Essential soil and climatic conditions required for maize production

Maize can be cultivated in a wide type of soils, but it works best on well-drained, well-circulated, warm top soils and top soils with sufficient organic matter and nutrients. Despite being grown on a wide variety of soils, it does not produce well enough on poor sandy soils and heavy clay soils except if substantial organic matter or manure exists in the soil. In sandy top soils, large yields could be achieved with enhanced fertilization and management of water. The surface of the soil in the Northern part of Ghana fluctuates from loamy sand, sandy loam to loam (Amatekpor, 1989; Owusu-Bennoah et al., 1995). Maize can be efficiently grown on 5.0-7.0 pH soils, yet a tolerable pH 6.0-7.0 is optimal. Beyond this pH range, the lack of nutrients and mineral toxicity lead to nutrient deficiency. Belfield and Brown (2008) revealed that the appropriate soil temperature for germination and early growth of seedlings is 21-30°C per year and is suitable for tasseling. Exceptional gains from optimum plant population, number of ears and kernels with adequate soil fertility, and better soil moisture are noted in maize production. It has been numerously recommended that, wherever possible, soils should be routinely analyzed to know the characteristics of the soil and to obtain recommendations on how to manage soil fertility and/or correct soil pH for optimal maize production (Ukwattage et al., 2013; MoFA, 2015; Havlin et al., 2016). The capacity of soils to give services is mainly given by two traits: the range of biogeochemical forms that occur in the soil and the richness and usefulness of soil biodiversity (Smith et al., 2015). The plant relies upon accessible dampness inside the furrowed layer because of its shallow root system. Its normal growth period is generally short and this makes it conceivable to grow at genuinely high altitudes. According to Hussen et al. (2013), Poncet et al. (2018) planting depths that are both exceedingly shallow and excessively deep are unfavorable for the growth performance of maize seedlings. If the seed depth is too shallow, it exposes the plant roots to various harsh environmental conditions and also affects the absorption of plant nutrients and water. Long days prolong the duration of the vegetative phase (Tanaka et al., 2011). It is very sensitive to shading (Gao, 2017) and furthermore exceptionally sensitive to the dry season during the time of silk development (Butler and Huybers, 2015; Cegler et al., 2018). Literature revealed that the ideal plant growth and development temperature ranges from 30°C - 34°C. At high elevation the cool conditions protract the cycle or growing period. Temperatures below 5°C or above 45°C lead to poor development and death of the corn plant (Steduto et al., 2012). Fetter (2018) stated that under conditions where the potential evaporation surpasses the quantity of water that the plant actually needs, it immediately causes wilting. (Steduto et al., 2012). Fetter, (2018) stated that under conditions where the potential evaporation exceeds the amount of water actually needed by the plant, it causes automatically wilting. Molatudi and Mariga, (2009) showed that temperature and moisture influence seed emergence of maize when the seeds are planted deeply in the soil. According to Mutanyagwa, (2017) and Beldman et al., (2017) maize varieties have been bred for higher productivity areas with rainfall levels greater than 1000 mm per year. Maize requires rainfall of around 600 – 1,200 mm per annum which must be very much disseminated consistently (Aflakpui et al., 2005; Roncoli et al., 2009). Kabubo and Karanja, (2007) expressed that, the maize grown zones in West Africa has the least precipitation of 1,000 – 1,300 mm for every annum circulating during the growing period. Therefore, availability of soil moisture at the period of tasselling is suitable for good yield production. As the crop does well inside a temperature range of 21-30°C, when temperatures are below optimum, 14 days or more may be required to attain maturity. During emergence, it requires an average temperature of 13°C and fails to mature when the temperature falls to 10°C (Tisdale et al., 1985). The optimum temperature for maize growth and development is 18 to 32°C with temperatures that are assumed to be harmful at 35°C or more. The optimal soil temperature for germination and early growth of the seedlings is 12°C or more and is perfect at 21 to 30°C (Belfield and Brown, 2008). It is practically grown in extremely divergent climatic conditions, via temperate to tropical up to an altitude of over 2500 m above sea level.

2.6 The economy of maize in Ghana

Ghana has cultivated maize for many years. Maize contributes two-third of Ghana's gross domestic product (GDP) concerning nourishment. With high quality productivity, improvement in time of cultivation, delivery on time through available media, farmers can improve their harvests and figure out how to get the best out of the crop, improve food security and decrease poverty. In the Sudan savannah zone, maize is the most significant cereal crop cultivated in Ghana (Al Hassan and Jatoe, 2002; Armah et al., 2011; Abass et al., 2014). Maize is mostly grown in rural areas. Increasing educational level, credit, access to extension services, knowledge, maize prices, group membership and the ready market could boost the use of technologies to improve maize productivity (Odame et al., 2011; Loubère, 2014; Wongnaa, 2016).

2.7 Cropping system of maize production and technology in Ghana

The choice of maize varieties is controlled by farmer's target, the length of the growing season, elevation and rainfall at a given area. For a given innovation with expected yield, systems of maize cultivation and production, technologies vary among agro-ecological zones where maize is grown in large quantities. These agro-environments are coastal savannah which enlarges towards the eastern part of Ghana, and includes a narrow belt of savannah that cuts over the coast, transition and forests zone where there is prompt inland from the coastal savannah.

Most of the forests in Ghana are semi-deciduous, with a small portion of high rain forest remaining only in the south-western part of the country near the Cote d'Ivoire boundary. Maize is grown in strewn plots in the forest area, generally intercropped with cassava, plantain, and cocoyam as part of a bush fallow system. Since some maize is eaten in the forest area, this is not a major food. The most important forest area cash crop is cocoa. Annual rainfall in the forest zone averages about 1500 mm. Maize is cultivated in the major rainy season as well as in the lesser wet season. The forest zone gradually moves further north, and eventually leads to the transition zone. In contrast, maize is cultivated in the transition zone during both major and minor seasons, generally as a monoculture or in combination with yam and/or cassava. The exact boundary between the two zones is controversial, which is not surprising given that the boundary area is characterized by a continuously shifting patchwork of savannah and forest plots. But what is certain is that the transition zone is an important region for the commercial production of maize grain. The precipitation in the transition zone is allocated bimodally and averages approximately 1300 mm per year.

The guinea savannah zone possesses a large portion of the northern piece of the nation. Corn is grown in permanently cultivated fields in the vicinity of residences, just as in progressively distant fields under shifting cultivation. Maize can be intercropped with other crops like okra, cowpea soy bean, cassava and other crops. In March and April, maize can be cultivated in the guinea savannah zone. A report by Karlen et al. (2013)

show that constant plough is essential for maize production. Maize is adjusted to a wild assortment of soil and micro atmosphere in this zone.

2.8 The pattern of maize production in Ghana

Official statistics indicate that the area of maize that is annually cultivated in Ghana current averages around 650,000 ha. Maize is cultivated in most of Ghana in relation to different yields, particularly in the coastal savannah and the forest zones making planting densities extremely low. Average corn yield per unit of land is less than 2 t /ha. The total yearly maize production is over 1million tons. Both production area planted and yield vary annually which is typical of rainfed crops following a trend observed in Western Africa, where the transitional zone has become highly significant for maize production (Reynolds et al., 2015; Smil, 2013). The growing importance of the transition zone as a maize supplier's wellspring could be contrasted with a mix of components including the proximity of great agro-environmental conditions, accessibility of significant incremental in production, an overall plenitude of underused land and a well-developed road transit system. Numerous transient farmers have pulled the overall plenitude of arable land in the area, predominantly from the northern part of the country that have moved to the area to undertake industrial agriculture.

2.9 Fertilizer response of maize

At present, Ghana imports all it fertilizers from outside the country. Reports by ONeil et al. (2004) and Fageria and Baligar, (2005) stated that nitrogen deficiency results in diminished yield in maize and its prerequisite can go up to 200 kg nitrogen for each hectare. The fertilizer nutrient application in Ghana is around 8 kg/ha (FAO, 2005; Adamtey et al., 2009) whiles depletion rate ranges from around 40 kg to 60 kg of nitrogen, phosphorus and potassium (NPK)/hectare/ year (FAO, 2005; Henao and

Baanante, 2006) and among the most noteworthy in Africa. Since the mid - 1960s 50% - 75% of the yield increments in non - African developing countries have been ascribed to fertilizer (Maredia et al., 2000). In any case, analysts revealed that maize yields are extremely poor under dry conditions because of deficient rainfall and little response to nitrogen fertilizer application (Viswakumar et al., 2008; Gaskin et al., 2010; Haghighi et al., 2010). Nitrogen and phosphorus are intensely fed-upon by maize for vegetative development. Utilization of fertilizer is initially good for guaranteeing legitimate growth and maturity of crops just as boosting yield. Absence of specific vital micro and macro nutrients must be replenished by the use of the specific nutrient. The suggested rates of fertilizer in maize production in Ghana are Ammonium sulfate at 125 kg/ha, NPK 20:20:20 fertilizer at 187 kg/ha, NPK 15:15:15 fertilizer at 250 kg/ha and NPK 19:19:19 fertilizer at 197 kg/ha (Aikins et al., 2012; Prashar and Shah, 2016).

2.10 Fertilizer use in Ghana

Practically every fertilizer utilized in Ghana is imported and the real shippers are Agricultural Development Bank and some commercial farmers. In the course of the most recent three decades, fertilizer utilization in Sub-Saharan Africa has increased. Increase in the use of fertilizers on cereals, notably corn, has greatly contributed to this increase. In any case, the current application rate stays low (FAO, 2005). As indicated by Nurudeen, (2011) fertilizer utilization by types in the country from 1995 - 1999 were NPK 15-15-15 (50.7 thousand tons), NPK 20-20-0 (29.9 thousand tons), Urea (7.7 thousand tons), Ammonium Sulfate (43.1 thousand tons) and potassium nitrate (13.3 thousand tons). They additionally announced around the same time that, evidence of fertilizer nutrient utilization in the country from 1995 - 1999 for Nitrogen(N), Phosphorus (P_2O_5) and Potassium (K_2O) was 28.2 tons, 13.6 tons and

30.9 tons separately. Due to highly weathered soils and limited nutrient reserves, fertilizer in tropical agriculture has the potential to profoundly increase production (Stewart et al., 2005; Sohi et al., 2010), while increasing nutrient application is rarely managed by soil testing recommendations, resulting in misuse and related economic loss (Atakora, 2011). The suppliers of fertilizers to the various food production and other uses in Ghana are diverse and the fertilizer import business is highly enthusiastic. Ghana as of now imports 6, 74000 metric tons of fertilizer somewhere in the range of 2004 and 2007 (MoFA, 2008). The nutrient application for fertilizers in Ghana is around 8 kg /ha (FAO, 2005) and among the most noteworthy in Africa. Fertilizer use in Ghana is about 7.2 kilogram per hectare, which is lower than in other developing nations. However, fertilizer use is generally profitable (FAO, 2005).

2.11 Effect of residual fertilization

The quick transient impacts of applied fertilizer are frequently stressed to the disregard of the residual effect. However, when cultivating is proceeded on a similar land for quite a while, remaining impacts of fertilizer treatment may impressively influence the soil chemical properties and thusly crop yield (Whisonant, 2015; Krones, 2016). Reviewing the residual effect of fertilizer on succeeding crops, Libra et al. (2011), Manna et al. (2013) and Muthuri (2013) noted that past fertilizer and farmyard manure leaves residues of nitrogen, phosphorus and potassium in soil, benefiting the following crops. They also indicated that inorganic nitrogen fertilizer residues normally last for a season, but the residual effect of sustained fertilization with phosphorus and potassium can last for many years. Akande et al. (2005) also noted an increase in soil accessible P of somewhere in the range of 112 and 115 and 144 and 153% individually for a multiyear field experiment when they applied rock phosphate to okra using poultry manure. Further review of the effect of rock phosphate modified with poultry manure on the growth and yield of maize and cowpea by Akande et al. (2005) noted that a large pool of undissolved rock phosphate could accumulate if rock phosphate application had continued over a period of several years. In any case, residues of fertilizer remaining in the soil constantly increase yield in hard-to-contrast manners. Ndungu-Marigroi et al. (2015) found that there are persistent high residual effects in maize on three P-deficient soils in Ghana when phosphorus was applied in the previous season at a rate of 14 to 59 kg/ha. Hagin and Tucker (2012) demonstrated that if the soil holds residues of inorganic nitrogen, it is conceivable that the maximum yield is greater than the residue-free soil. The outcomes likewise demonstrated that dressing of inorganic nitrogen fertilizer had huge lingering impacts in the first year after the dressings ceased, however, a lot littler impacts in the second and third years. The residual impacts of a solitary dressing of phosphorus and potassium is normally a lot smaller than the immediate impact of the prior year and might be too little to even consider measuring precisely in an experiment. But many annual nutrients have cumulative residual effects that are large and can be sufficient for normal crop yields with a small addition of fertilizer (Diacono and Montemurro, 2011).

2.12 Fertilizer use in sub-Saharan Africa

Sub-Saharan Africa (SSA) use of fertilizer is the most minimal on the planet, making up just 2 per cent of the 2002 world supply and was expected to ascend to just 3 percent by 2011/12 (Camara and Heinemann, 2006; Sheahan and Barrett, 2014). Sub-Saharan Africa's fertilizer utilization has vacillated and eventually diminished to 1,041,000 metric tonnes of supplements in 2007, as contrasted to 1,113,000 metric tonnes in 2002 (Hernandez and Torero, 2011; Bado and Bationo, 2018). Nitrogen has represented the greater part of the all-out utilization in the area. From 2002 to 2007, nitrogen represented 53 per cent of the just about 7 million metric tonnes of supplements devoured in Sub-Saharan Africa. Phosphate represented 29 per cent, and potash represented the rest of the 18 per cent (Schroder et al., 2010; Hernandez and Torero, 2011).

Notwithstanding the generally bleak total patterns in fertilizer usage in Sub-Saharan Africa, extraordinary fluctuation in fertilizer use has been seen inside the area. A few Sub-Saharan African nations are still at a low degree of fertilizer force, yet about a portion of them have enrolled quick positive development in compost power and a couple of them have encountered negative development in fertilizer use, showing that the area can possibly support its compost utilization.

Inside every nation fertilizer application has fluctuated generally dependent on crop type, farm size, atmosphere, and water system accessibility (Monfreda et al., 2008; Scarlat et al., 2010; Rosenzweig et al., 2014). For example, fertilizer application all through Sub-Saharan Africa mostly concentrated on maize and sorghum. Oil crops, for example, groundnuts and cotton, which assume real job as money crops for smallholder farmers, has additionally gotten critical measures of fertilization. So are roots and tubers that for the most part react well to medium fertilizer application. Instead of the worldwide example, fertilizer production in Sub-Saharan Africa has demonstrated a descending pattern. Complete production in the district diminished at a yearly rate of 7.3 per cent from 2002 to 2007, totalling 111,000 MT of supplements toward the end of the period (Hernandez and Torero, 2011). Out of the absolute 829,000 MT of nutrient produced during this period, nitrogen represented 54 per cent and phosphate for 43 percent. Because of the restricted accessibility of crude materials and deficient framework, the production of nutrients in the continent has been gathered in four nations: Zimbabwe, Senegal, Nigeria, and Mauritius. The measure of supplements devoured in the district is around multiple times the sum produced on the continent and hence, numerous Sub-Saharan Africa nations will, in general, be exceedingly reliant on fertilizer importation (Hernandez and Torero, 2011; Havlin, et al., 2016). SSA shows the least degrees of utilization and production on the planet (Affognon et al., 2015; Chivenge et al., 2015). Some Sub-Saharan Africa nations with low manure force have enlisted quick positive development though others have encountered a further decrease in fertilizer utilization. The low local production has not had the option to meet even the little fertilizer utilization request and hence, made a few countries intensely dependent on importation. It is currently basic for Sub-Saharan Africa countries to make successful, proficient, and supportable utilization of the restricted fertilizer accessible to them and furthermore to extend the household production limit (Conway and Barbier, 2013).

2.13 Phosphorus nutrient status in Ghana

Phosphorus is among 17 fundamental nutrients for the development of plants. Some other nutrient cannot perform its capacities, and a satisfactory addition of P is needed for optimum growth and reproduction. In agriculture, P is by far the lowest mobile and least available to crop in most soil conditions compared to other major nutrients (Ramaekers et al., 2010; Crain et al., 2016). Phosphorus is categorized as a major nutrient, indicating that it is often deficient for crop production and is required in relatively large quantities by crops. It exists as mineral salts in the soil, or integrated in organic compounds. Regardless of the abundance of these phosphorous compounds in agricultural soils, most of them occur in an insoluble form that are often unavailable for uptake by the plant (Miller et al., 2010). As indicated by Bonet-Ragel (2018), plants require around 30 µmol l^{-1} of phosphorus for greatest profitability, yet just about 1µmol l^{-1} is accessible in numerous soils. The lack of phosphorus in several soils has therefore been cited as a significant growth limiting factor in the agricultural and horticultural systems (Otieno et al. 2015; Whitbread et al., 2010; Schmidt et al., 2011). The overall concentration of P in farm crops differs slightly from 0.1 to 0.5 percent. There are remarkable differences in available Phosphorus across the Ghana (DedzoSe et al., 2004). A portion of the Ghanaian soils, for example, the Ochrosols have high retention limits because of the presence of a huge amount of Al and Fe oxides and consequently may require higher rates of P fertilizers (vulnerability, 2016; Obodai, 2018). Absolute P is impressively lower for savannah soils than the forest soils (Adu, 1995). Studies conducted in the Northern, Upper West and East regions demonstrate that accessible P is low, running up to 6.0 mg/kg soils (Belane and Dakora, 2010; McClintock, 2012; Tittonell, 2013).

2.14 Effect of pH on P availability in the soil and on maize growth

Soil acidity is common in the tropics and could be responsible for low maize yield in most parts of Ghana (Ahadzi, 2007; Mcmichael, 2012). Soils with pH less than 5.5 tend to have high exchangeable aluminium and is harmful to most crops (Bohn et al., 2002). Plant development, and particularly root development, in acidic soils, is hindered by toxicities of Al^{3+}, Mn^{2+}, and H^+ (Bambara and Ndakidemi, 2010; Neto et al., 2016). The extent of toxicity relies on how high the soluble or exchangeable Al^{3+} concentration is, and how low the pH is (Crawford et al., 2008). Soil pH is a significant determinant of most crop growth (Liu et al., 2015). The impacts of pH on plant growth are often complex. It is difficult to separate direct effects of excess hydrogen (H^+) or hydroxyl (OH^-) ions from indirect effects related to various chemical changes occurring in the root rhizosphere (Bhuyan et al., 2019). The roots are clearly affected by pH of the growth medium between the different plant parts. One of the causes of acid soil growth retardation is low pH injury, or H^+ injury. Hydrogen ions (H^+)

increase the Al^{3+}, Mn^{2+} and Fe^{3+} solubility in acid soils (Rhodes, 1978). The presence of hydrogen ions in the growth medium normally hinders root elongation and this mechanism is noted at relatively low pH (Zandonali et al., 2010). It was widely assumed that H^+ damage is negligible in a medium at a pH above 4. But the mineral nutrient content in crops also decreases in this situation with a reduction in pH (Crawford et al., 2008). Sometimes the mineral ions run out of the roots. In the growth medium, surplus H+ has two processes which impact plant growth. Next, root elongation, lateral branching, and water absorption inhibitions are unspecific. Secondly, various effects on root ion fluxes by H^+ contest with base cations for absorption and H^+ harm to the root ion-selective carrier (Rhodes, 1978). It is widely accepted that relationship between growths in acidic soils is not caused by Ca^{2+} deficiency in the soil but by other factors such as excessive growth Al^{3+} or Mn^{2+}. Plant development does not increase with calcium sulfate applied to acid soils (Meriño-Gergichevich et al., 2010). The ameliorating effect of Ca^{2+} may be difficult to observe in acid soils, because injury to Al^{3+} is predominant (Bhuyan et al., 2019). Nonetheless, in solution culture, a high concentration of Ca^{2+} in the growth medium mitigates Al^{3+} injury or low pH injury (Crawford et al., 2008) which avoids loss of K^+ associated with injury to H^+. Calcium plays a significant part in raising the growth medium's pH. Sustaining integrity of the cell membrane plus facilitating the active take-up of then modest cations is necessary. This Ca^{2+} "Viets" effect can be seen with other polyvalent cations (including Al^{3+}) (Clarkson and Sanderson, 1971). The noxious effects of high H^+ activities have been shown to mitigate that of Ca. H^+ can interact with Ca^{2+} at pH levels below 4, prevents its uptake and even displaces Ca^{2+} in the apoplast root (Verma et al., 2019). The cell membranes lose integrity until absorption of Ca^{2+} is repressed. Dysfunctions of the selective ion carrier technique results in lower base cation uptake and efflux of cations (Rhodes, 1978). Loss of root membrane integrity may also result in weakening symptoms of low turgor pressure with H^+ toxicity (Clarkson and Sanderson, 1971). Al^{3+} 's essential role in soil chemistry for acids has been studied. Al^{3+} has three general processes which affect plant growth in acid soils. Firstly, due to the presence of excess Al^{3+} in the root apoplast, reduced divalent cation particularly Ca^{2+} uptake by plant roots. The second process is dysfunction of cell division in the root meristematic tissue caused by Al^{3+} penetration into the root protoplasm (Crawford et al., 2008). The development of irregular root morphology and reduced anion ($SO_2{}^{4}$, Cl^-), root adsorption due to increased positive rhizosphere adsorption sites and root apoplast is the third (Verma et al., 2019).

In poor acidic conditions, soil pH is the determining factor in the availability of important plant nutrients. Nitrates and phosphates are taken up at higher rates (Marschner, 2011; Dotaniya and Meena, 2015). Glaser et al. (2002) observed that soil pH and base accumulation are important soil chemical composition which impact nutrient availability and crop growth. The soil pH determines the presence and behavior of microorganisms in the soil and ultimately affects both the decomposition of organic matter and nutrient availability (González-Pérez et al., 2004). While organic carbon turnover throughout soil is determined by temperature, soil moisture, and carbon and nutrient quality, soil matrix features (including clay content, Al and Fe content, and soil pH) moderate soil carbon losses (Bronick and Lal, 2005). Soil pH less than 5.5 encourages fungal infection and makes bacteria more active at higher levels (Glick, 2012). The process of nitrification and its rate caused by the bacteria Nitrosomonas and Nitrobacter depends heavily on soil pH, as these bacteria prefer more neutral soil conditions. Hence the natural nitrate content is extremely low in highly acidic soils (Ventura et al., 2013). The rate of bacterial growth is usually more prone to low pH than the rate of fungal growth (Rousk, 2009). Microbial biomass and lignin decomposition do not appear to have a significant impact on soil acidity at a pH range of 4.5 -6.5 (Dala, 2001; Rejmankova and Sirova, 2007). However, both microbial activity and nutrient turnover are greatly reduced in acidic pH less than 4.5 (Dalal, 2001; Rietz and Haynes, 2003).

2.15 Take-up and transport of phosphorus

Phosphorus penetrates root hairs, root tips, and the outermost layers of root cells through the plant. Furthermore, mycorrhizal fungi, which grow in alliance with the roots of several crops, facilitate absorption. Mycorrhizal fungi, which grow in association with the roots of many crops, also facilitate uptake. Phosphorus is often collected up as the main orthophosphate ion ($H_2PO_4^-$) from the soil, although some are also consumed as vital orthophosphate (HPO_4) when soil pH increases. When within the root of the plant, P may be retained in the root or transferred to the top portions of the plant. It is incorporated into organic compounds through various chemical reactions, along with nucleic acids (DNA and RNA), phosphoproteins, phospholipids, sugar phosphates, enzymes, and, for example, adenosine triphosphate (ATP), which is high in energy. P is moved throughout the plant in these organic forms, as well as in the inorganic phosphate ion, where it is available for further reactions. Phosphorus assimilation achieves a peak during flowering. At maturity the total P uptake of a single maize plant is 5.1 g (Ciampitti and Vyn, 2012). Almost every ton of grain produced takes away from soil between 2.5 and 3.0 kg of phosphorus (Guo et al., 2010).

2.16 Significance of phosphorus on grain yield

Maize is an extensive crop with a better prospective than other cereals and accumulates significant amounts of nutrients from soil during different developmental stages. Phosphorus is one of the most essential nutrients demand for higher yields in greater quantities (Grant et al., 2001; Assmann, 2013) and mainly controls plant propagative phase (Noodén et al., 2004).

Phosphorus plays a significant part in numerous physiological processes occurring inside a plant that grows and matures. The element is required for enzymatic plant reactions. Phosphorus is important for cell division, since it constitutes a constituent element of nucleoproteins related to cell reproduction processes. It is also an important component for the carbohydrate synthesis and degradation reactions (Yang et al., 2011). It is essential for the formation of seeds and fruits, and the maturation of crops. Phosphorus hastens fruit ripening while counteracting the impact of excessive application of nitrogen to soil. It helps to reinforce the plant's skeletal structure and thus prevents lodging. It also affects grain quality, and can increase the resistance of the plant to diseases. Sufficient amount of phosphorus is essential for early maturity, rapid growth, and for improvement in the quality of vegetative development (Grant et al., 2001). Due to crooked and lost rows as kernel twist, phosphorus deficiency is accountable for the small ears in maize (Masood et al., 2011). However, the prerequisite and use of phosphorus and also nitrogen in maize depends on environmental variables such as precipitation, varieties and expected yield (Shamim et al., 2015).

2.17 Phosphorus deficiency symptoms

Deficiency in P is usually seen as characteristic purple color in corn (Sagriff et al., 2011). It first becomes visible on the lower leaves of the plant and normally, early in the season. Growers are often concerned that they may not have applied enough phosphorus fertilizer to get the crop growing. Plants with deficiencies in phosphorus are hindered in development and many have an anomalous dark-green colour. Sugars can build up and induce the formation of anthocyanin pigments, creating the reddish-purple colour. Such signs typically occur only on soils with very low phosphorus levels. It should also be acknowledged that these are all symptoms of an extreme deficiency in phosphorus, and crops can react well enough to phosphorus fertilization without showing distinctive insufficiencies. The reddish-purple colour therefore does not necessarily suggest a phosphorus insufficiency but can be a natural feature of the plant. Other variables such as insect damage that interrupts the transportation of sugar to the grain may also induce red colouring (Wills and Golding, 2016). Phosphorous deficiencies can even look alike to nitrogen deficiencies when the plants are at young stage.

2.18 Nitrogen status in Ghana

Nitrogen is one of the 17 necessary nutrients required for plant growth and is also the most important plant nutrient and forms some of the most mobile compounds in the soil-crop system (Follett and Delgado, 2002; Havlin, et al., 2016). No other nutrient can fulfil its functions and an adequate supply of nitrogen is necessary for optimal growth and reproduction. In Agriculture, N is by far the most mobile and highly accessible to crop under most soil conditions compared with other major nutrients (Granse and Fuhrs, 2013). Nitrogen is known as a major nutrient, meaning it is often insufficient for crop production and is needed in relatively large quantities by crops (Fageria and Baligar, 2005; Lawlor et al., 2001). Soil nitrogen comes in three categories: organic compounds of nitrogen, ammonium ions (NH_4^+), and nitrate ions (NO_3^-). Whether in plant and animal residues, in fairly stable soil organic matter, or in living soil organisms, mainly microorganisms such as bacteria, 95 to 99% of the nitrogen in the soil is organic at any time. Such nitrogen is not available directly to plants, but some can be transformed by microorganisms into available forms. There may be a very small amount of organic nitrogen in soluble organic compounds, such as urea, which could be slightly available to plants (Mengel et al., 2001). For maximum productivity, plants require about 30 µmol l^{-1} of nitrogen but only about 1µmol l^{-1} is available in many soils (Otieno et al., 2015). Nitrogen leaching has been considered a major factor, limiting development of the agricultural and horticultural technologies (Cassman, 2002; Otieno et al., 2015). Numerous studies on different scales showed 3 to 60 times higher concentrations of nitrate in surface water and groundwater in agricultural areas compared to those in forest or grassland areas. According to Yimer et al. (2007) organic carbon and total soil nitrogen content in cropland is substantially lower than in grazing and native forests. The fertility status of soils in moist western African savanna is generally considered low (Vanlauwe et al., 2002), requiring the input of external nitrogen sources as fertilizers.

2.19 Nitrogen uptake partitioning and remobilization in maize

Mineralization of nitrogen is defined as the process by which micro-organisms transform soil organic N into inorganic forms (NO_{3-} and NH_4^+). The process of converting inorganic nitrogen into organic nitrogen is known as the immobilisation of N. If environmental conditions are not restrictive, ammonium nitrogen (NH_4^+-N) is almost as rapidly oxidized to nitrate nitrogen (NO_3-N) as it is formed (Wang et al., 2013). Corn can use mineral N in both ammonium and nitrate forms, but most of the N is taken as nitrate due to the ready conversion of ammonium to nitrate by soil microbes within hours or a few days of application (McCashin, 2000). The uptake and assimilation of nitrogen can be visualized as metabolic events mediated by interrelated carriers and enzymes that are each under genetic control (Sonko, 2017). Maize varieties vary in their N absorption and assimilation capacities, even though they experience similar or different nitrogen levels (Ciampiti and Vyn, 2011). Better productivity in maize genotypes is as a result of their capability during vegetative development to store nitrate in their leaves and efficiently remove this stored nitrogen during grain filling. Maize hybrids that accumulate more N after seeding tend to yield higher grain output (Hirel et al., 2001; Chen et al., 2014). Maize stalk performs a significant role in supplying N for the growth of the kernel and N fertility has been found to influence the rate of N removal from vegetative to reproductive tissues (Gallais and Coque, 2005). At about the 10th leaf-stage of the crop, maize plant starts a rapid and steady increase in accumulation of nutrients and dry matter, which goes on to reproduce (Cakir, 2004). Nitrogen consumed during the vegetative stage is primarily used for vegetative growth and for the initiation of reproductive organs during late vegetative periods, whereas the N absorbed after silking and tasselling is mainly directed towards the synthesis of grain proteins. The addition of N during the reproductive stage not only increases the grain yield but also significantly improves grain quality by increasing the partitioning of higher amounts of protein and carbohydrates into the grains (Amanullah, 2007). Several studies have been performed to explore the potential of multiple methods for indicating maize crop N status. Chlorophyll metering, remote sensing techniques, and plant tissue analysis are among these approaches. Only point measurements are provided by the chlorophyll meter and remote sensing technologies, which limit their suitability to detect high end N uptake because corn plants obtain optimum chlorophyll content irrespective of the excess fertilization (Herrmann and Taube, 2005). In-season nitrogen testing of plant tissue has proven effective in ascertaining maize plant's N status.

2.20 Impact of nitrogen application on maize yield and growth

Nitrogen perform a crucial role in the maize plants in several biological processes. Establishing photosynthetic process capacity of the plant is of fundamental importance. Nitrogen is important for kernel initiation, contributes in determining maize sink ability and helps keep the kernels efficient throughout grain filling. It also affects the number of developed kernels and final kernel size. However, nitrogen impacts on kernel number per plant could be related primarily to traits responsible for plant biomass production (i.e., radiation use efficiency light capture, and leaf area) rather than to the partitioning of biomass and N to the ear (D'Andrea et al., 2008; Rossini et al., 2011). Nitrogen deficiency promotes a reduction in maize crop growth rate and subsequently reduces grain yield (Sangoi, 2001). Its deficiency in corn is often readily visible through reductions in leaf area, leaf chlorophyll status, notably as leaves age and vegetative biomass. Such a phenomenon reduces interception of plant light, photoassimilates production and ultimate yield of grain (Echarte et al., 2008). Nitrogen deficiency in maize could also be indicated by yellowing of mature leaves starting at the leaf tips and before extending along the mid-ribs, poorly filled ears, delayed flowering and short, stunted plants (Sonko, 2017; Eva, 2018). Limited supply of nitrogen reduces grain yields by decreasing the quantity of grains and the individual seed weight (Hammad et al., 2011). Two main factors evaluate the potential weight of individual grains: the rate of endosperm cells formed during the first two to three weeks after pollination (i.e. during the lag phase of kernel development) and the assimilation of availability during grain filling (Paponov and Engels, 2005). Increased supply of nitrogen is related to increased leaf area, leaf weight and chlorophyll content, all of which evaluate the photosynthetic activity of the leaf and undoubtedly the production and allocation of dry matter to the different plant organs (Azapour et al., 2014). This illustrates that sufficient N supply could be used to prolong maize leaf senescence, thus keeping the leaves green and functional for an extended timeframe. Rate of photosynthesis, surface area of the leaf, and sink size all enhance with nitrogen levels (Makino, 2011). The effects of N on cells and tissues are related to higher leaf area and photosynthetic efficiency with increased N levels (Gungula et al., 2005). The availability of sufficient nitrogen to maize extends the durations of post-silking dry matter and absorption of N and this phenomenon was being related to higher yields of grain. However, wide availability of N encourages better yield responses with a yield potential than low yield varieties of maize (Ciampitti and Vyn, 2011).

2.21 Timing of nitrogen application

Plant nutrient uptake dynamics are quite complicated, and there is always a significant delay from when nutrients are available and when plant roots accumulate them, during which the nutrients are susceptible to loss. The potential for nutrient loss relies on the nutrient type, the soil type and the climate conditions (Tarkalson et al., 2006). Nitrogen and potassium, for example, react in quite different ways in the soil environment; where N is biologically very dynamic and become really mobile following transition to nitrate (NO_3^-), P may quickly become unavailable to crops due to the chemical precipitation (Lambers and Oliveira, 2019). The timing of addition of mineral fertilizer is an important factor affecting the productivity of taking up crop nitrogen. The estimated time among both application and harvesting determines the duration of nitrogen exposure to loss processes such as leaching, denitrification, and volatilization (Zebarth and Rosen, 2007). Nitrogen fertilizer is used more efficiently when the supply matches with the demand for nitrogen by the crop. Early addition of nitrogen fertilizer increases the probability of loss of N from the root zone by leaching and denitrification, while fertilizer application after rapid absorption may decrease plant N uptake (Dinnes et al., 2002). Timing of nitrogen application to reduce the probability of N loss through leaching and denitrification can increase the efficiency of fertilizer N; therefore, improvement of N uptake by maize plants is of interest for both agronomic and environmental reasons (Ladha et al., 2005). The absorption and usage of nitrogen is boosted when N fertilizer is applied shortly before the period of fastest N cultivation. Application, where there is delay in N can result in irreversible yield losses. However, maize yield remains responsive to nitrogen use until it is sealed but full yield may not be attained if applications are disrupted until that stage (Ma et al., 2005). Many authors stressed the need for greater synchronization among maize crop N demand and N supply from all sources during the planting season (Cassman et al., 2002). Poor coordination among N supply and crop demand is due to massive applications of nitrogen fertilizer throughout the early growth stages, resulting in high levels of inorganic nitrogen in the soil well before rapid N crop uptake. Research findings have also shown that in-season application of nitrogen taking into account site-specific soil supply N and crop demand results in high efficiency of N use (Cui et al., 2010).

2.22 Nitrogen deficiency

Absence or lack of supply of nitrogen in plants produces the following symptoms.

- The symptoms first appear in the older part of the plant as nitrogen is readily translocated to the growing parts being highly mobile.
- Cell division and cell enlargement is inhibited.
- Chlorosis appears first on the older leaves progressing to the younger ones.
- As chlorophyll is destroyed other pigments like carotenes and xanthophylls are exposed.
- Rate of respiration is affected.
- Anthocyanin is produced in the leaves as a result they turn purple in colour.
- Flowering is either retarded or completely suppressed.
- Starch and protein contents are reduced.

- Plants have stunted growth and auxiliary buds remain dormant with less foliage.

- Senescence appears early.

- Roots get unduly elongated as in wheat plants.

2.23 Dry matter production and partitioning in maize

Research findings from the past few years suggest that maize build-up of dry matter follows a consistent trend; a period of rapid exponential growth, followed by a normal distribution until close to the end in the reproductive stage when dry matter reaches the limit. There were two peak periods in the build-up of dry matter, the first peak in the late stage of vegetative growth and the second peak in the latter part of the reproductive stages throughout grain filling (Woli et al., 2018). High rate of dry matter accumulation by a maize canopy at certain developmental growth stages is a prerequisite for higher grain yields. The most important stages are early growth stage, extending from fourth to sixth leaf stage when the number of leaves and ears are finally fixed, from tasselling up to blister stage where the quantity of kernels per plant is determined and at ripening phases where kernel weight is decided (Grzebisz et al., 2010). The quantity of kernels per plant to be set by a maize plant at a given plant growth rate varies depending on the partitioning of biomass to the developing ear. A reduced growth rate related with delayed growth of plants or less ear partitioning results in a reduced set of kernels (Severini et al., 2011). Increases in the availability of assimilation per kernel after flowering led to an increase in minor rises in kernel weight at crop maturity, whereas reductions in the availability of assimilation per kernel significantly decrease kernel mass. This shows that the kernel number and potential sink capacity are established early in the grain filling duration and that further kernel growth in terms of assimilation availability is close to saturation (Borras and Westgate, 2006). During grain filling, the developing kernels will be the primary sink for photosynthates produced by maize plants; hence, a greater proportion of the dry matter produced at this time will be partitioned to the kernels sometimes at the expense of other plant parts including stalks and leaves (Yadav, 2016). The rate of partitioning of assimilates to grains depends on their sink strength and reproductive growth stage. In the first two weeks after completion of flowering i.e. the lag phase, the ear, husks, stem and roots could all be sinks and competing with the developing grains for assimilate supply (Amanullah, 2007). However, during linear grain filling stage, which begins from the second week after flowering upwards, the grains are the dominant sinks for the newly synthesized carbohydrates, nitrogen taken up through the roots and N compounds (Paponov and Engels, 2005). The two weeks following flowering marks the duration when division of the endosperm cells takes place and when starch granules are triggered. These processes determine the number of sites for deposition of starch, and hence the potential for buildup of kernel dry matter (Cazetta et al., 1999).

2.24 Nitrogen effect on dry matter production of maize

Dry matter production by crops is dependent on the rate of light interception and photosynthetic capacity of the vegetative parts of the plants. The dry matter maize yield response to an increased supply of nitrogen is positive before factors besides nitrogen restrict greater productivity (Worku et al., 2012). The enthusiastic reaction results either from a greater amount of captured radiation during the crop growth cycle, or from a higher average daily rate of photosynthesis, or from a combination of both. However, the leaf area and light detection are preserved in N limited environments to the downside of nitrogen content and photosynthetic potential per unit area of the leaf (Vos et al., 2005). The variation in maize accumulation of dry matter is due to post-silking N uptake, and it enhances with increased application rate of nitrogen (Echarte et al., 2008). Variations in dry matter yield and N uptake differ in particular due to reduced soil nitrogen mineralization and in part due to warmer and wetter weather conditions, and N uptake result was reported to help increase dry matter yield in maize (Amanullah et al., 2009).

2.25 Calibration of soil test

The "process of determining the crop nutrient requirement at different soil test values" is known as soil test calibration (Mitchell and Mylavarapu, 2014). The working foundation of soil testing laboratories is the calibration of soil analyses in terms of fertilizer requirements. The application of relatively simple mathematical and statistical procedures to the calibration, statistical appraisal of the contribution of the soil test, and economic assessment of soil testing requires the application of relatively simple mathematical and statistical procedures, but can require a significant amount of computation. Because of this computational obstacle, test calibrations have tended to be generalized and the statistical and economic importance of soil tests has been inferred rather than evaluated. A clear definition of the purpose of soil testing is required for the development of a procedure for soil test calibration and the evaluation of the value of soil testing. As a result, calibration of a soil test is envisioned as the establishment of a generic yield response function, such that substitution of soil test values yields estimates of specific yield response functions appropriate to the soil test values.

Calibration keeps processes safe and can reduce costs through the minimisation of manufacturing errors. Over prolonged periods of time the accuracy of results measured by an instrument can drift due to repeated use or due to changes in environmental conditions such as temperature and humidity. The calibration process gives you the peace of mind that readings are accurate, consistent and reliable. The calibration phase entails calculating the fertilizer rate required to maximize yield and regressing the optimal fertilizer amount against the soil nutrient availability index value (Buresh et al., 2019). The goals of the correlation and calibration measures are normally met in a large number of trials, each of which requires a no-nutrient control treatment and a variety of nutrient rates ranging from low to high (Sims et al., 2002). Studies by Getahun et al. (2020) stated that a sound soil test calibration is essential for successful fertilizer program and crop production.

2.26 Significance of Soil Test

A soil test for fertilizer recommendations is thought to be an effective factor in increasing crop yields and preserving soil productivity (Fryer et al., 2019). Soil tests serve as the basis for any lime or fertilizer recommendations for growing plants, and they are a simple, economical scientific tool. Studies by Singh et al. (2012) reveal that soil tests are chemical tests performed on a soil sample to determine the soil's nutrient-supplying capacity for the particular crop/plant during that growing season. Laboratory result of a soil test is also referred to as a soil test index, because a soil test report is an integration of multiple values (such as values of nutrients and soil factors) associated with plant nutrient availability.

Since the late 1940s, soil testing has been used as a crop-fertilization decision aid in North America, especially the United States, and is now used as a tool for both crop and environmental nutrient management all over the world including Africa (Singh et al., 2012). The primary goal in soil test is to determine the suitability of soil pH and nutrient availability for crop production so that the appropriate soil amendments, fertilizer sources, and rates can be applied to avoid crop yields, income, or both being hampered by nutrient deficiency or excess. Soil tests were created to measure a fraction of the total soil nutrient concentration that is related to plant growth (Zhang et al., 2001). Understanding the effects of the extractant used, the process of soil sampling, sample handling, and the expected use for the result on test results is needed when interpreting a soil-test value. Depending on the extractant used, the amount of nutrient measured by various soil tests can vary greatly (Sims and Johnson, 1991). The concentration of chemical compounds, as well as the reaction time with the soil, are important extractant properties. For certain nutrients, the process used to quantify the nutrient after extraction can be critical. Furthermore, the same soil test can detect a wide range of nutrient levels in soils with contrasting chemical and (or) mineralogical properties. The types of extractants used and how the findings are interpreted differ a lot depending on the soil properties and the reason for the soil testing (for example, measurement of total, soluble, or plant-available concentrations).

A soil test is critical for a variety of reasons, including optimizing crop production, protecting the environment from pollution caused by runoff and leaching of excess fertilizers, assisting in the diagnosis of plant culture problems Kim et al. (2018), improving the nutritional balance of the growing media, and saving money and energy by applying only the amount of fertilizer required. Studies suggested that understanding of soil testing is an important part of preventing excess fertilizer applications that can potentially impact the environment and ensuring commercially viable yields and aesthetic, healthy landscapes. Chimdessa et al. (2019) stated that soil test must be able to identify those soils for which fertilization will result in a return on investment (i.e., improvement and quality in yield).

2.27 Justification to calibrate soil for phosphorus and nitrogen application

Soils in the Guinea savannah agro-ecological zone of Ghana are generally very poor in fertilities. The organic matter content is less than two (2) percent in the topsoil and low in particular in the reserves of phosphorus (Abe et al., 2010; Duku et al., 2011). These together with the occurrence of plinthites that may hold phosphorus and make it unavailable as well as the presence of erodible sandy topsoils make the soils inherently infertile (Braimoh, 2004; Asiamah, 2008; Tahiru, 2015). As the natural weathering processes that release nutrients into the soil environment remain largely slow (Landeweert et al., 2001), such conditions make it imperative that manure or fertilizer be regularly added into the Savannah soils (Vanlauwe and Giller, 2006). Soils in Ghana's Guinea Savanna agro ecological zones are mostly depleted in major nutrients by continuous crop cultivation and removal of residues, leading to low maize yields (Tahiru et al., 2015). The two key explanations for the low productivity in corn are low soil fertility and insufficient usage of external inputs (Benneh et al. 1990; Adu, 1995). Regardless of the fact that P_2O_5 deficit is severe on West African soils, local farmers use very small amounts of P_2O_5 fertilizers mainly because of its high cost (Bationo et al., 2005; Vanlauwe and Giller, 2006; Hignett,2013; Bawa, 2020).

Soil testing is recommended in modern maize production systems. According to Horneck et al. (2011), soil testing is an essential nutrient management element. Soil testing is used to measure soil nutrients, which are expected to become available to plants. It has been numerously recommended that, wherever possible, soils should be routinely analyzed to know the characteristics of the soil and to obtain recommendations on how to manage soil fertility and/or correct soil pH for optimal maize production (Ukwattage et al., 2013; MoFA, 2015; Havlin et al., 2016). Assessments of soil nutrient content need be based on useful indicators of plant growth adequacy, because only a tiny percentage of the nutrients in the soil are available for plant growth. The roots take up plant-available nutrients in the soil as positive or negative ions. Knowledge of the P_2O_5 and N available in the soil through soil test helps to avoid possible over-application of the nutrients, which is an economical decision to the resource-poor farmer and helps to reduce pollution (Pannell, 2017). Such knowledge also helps to avoid under application of P_2O_5 and N which does not maximize productivity to the farmer and hence causes P_2O_5 and N depletion in the near future.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

Pot and field experiments were carried out during the 2019 cropping season at Nyankpala to calibrate soil test results for both phosphorus and nitrogen. The pot experiment was first conducted to calibrate soil test results. The calibrated data were then used to assess the soil nutrient levels of three geographically distinct locations (i.e. Nyankpala, Tamale and Damango). Based on the nutrient levels of the three locations, the exact nutrient top-up rates that were predicted by the calibrated tool were applied at each of the sites. The pot experiment was conducted in a glasshouse located at Nyankpala while the field experiments were carried out at the three locations in northern Ghana. Nyankpala is located close to Tamale, in the Guinea savannah zone of Ghana on latitude 9°25’ 14’N, longitude 0° 58’ 42’W and at an altitude of 183 m above sea level (Dzomeku et al., 2016). The greenhouse is located at geographical positioning system latitude of 09°24’44.4” N and longitude 00°58’49.7” W. The area experiences a unimodal rainfall with an annual mean rainfall of 1000 to 1022 mm.

The temperature distribution is fairly uniform with a mean monthly minimum of 21.9°C and a maximum of 34.1°C. The area has a minimum relative humidity of 46% and a maximum of 76.8%. The soil of the study site is a typical upland soil, developed from ironstone gravel and ferruginized ironstone (Abunyewa and Karbo, 2005). The nature of the soil in the area is brown, moderately drained, sandy loam, free from concretions, developed from Voltaian sandstone and classified as flaplic lixisol that is locally referred to as the Nyankpala series (SARI, 1996). The pot experiment was conducted from April to July 2019 and the field experiment from July to November

2019. The vegetation is mostly savannah with Guinea savannah characteristics. Bagamsah (2005) categorized the savannah vegetation of the area into four main types according to the relative percentage ground cover of tree, shrub and herb as: widely open savannah woodland (7:12:8), grass/herb fallow with scattered trees (8:7:65), open savannah woodland (3:64:30), and closed savannah woodland (55:25:5). Popular tree species in the area of study include those from the Fabaceae family (example *Parkia biglobosa*). Shrub species constitute the Rubiaceae family (example *Diodia scandens* Sw). Herbaceous plant species include the Icacinaceae family (example *Icacina senegalensis* Juss), while other herbaceous plants are the Gramineae family (example *Andropogon gayanus* Kunth). Agriculture constitutes over 60 % of employment and the food crops cultivated in the area are mainly sorghum, maize, millet, cowpeas, groundnuts and yam with tobacco and cotton as the predominant cash crops.

3.2 Pot trial for development of soil – test calibrated tool

3.2.1 Experimental design and treatments

The pot experiments were single factor studies consisting of only Nitrogen and phosphorus inorganic fertilizers. Nitrogen trials and phosphorus trials were separately conducted. Eleven phosphorus levels were used in the phosphorus trial: 00, 05, 10, 15, 20, 25, 30, 35, 40, 45, and 50 kg/ha of P_2O_5. For the N trials, the eleven levels of N used were 00, 15, 30, 45, 60, 75, 90, 105, 120, 135, and 150 kg/ha. The experiment was laid out in a Randomized Complete Block Design due to the heterogeneity of conditions in the glasshouse. This was done to reduce experimental errors by eliminating the contributions of known sources of variations in the experiment. The treatments were replicated four (4) times.

For the nitrogen experiment, P_2O_5 and K_2O were each applied at optimum rate of 60 kg/ha. In the phosphorus experiment on the other hand, N and K_2O were respectively applied at optimum rates of 120 kg/ha and 60 kg/ha respectively. The treatments for both N and P experiments are as indicated in Table 1 below.

Table 1a: Rate of nitrogen used for calibrating soil test results for nitrogen fertilization in pot experiment

Pot	N calibration rate (kg/ha)	**N rate applied in pot experiment (kg/ha)	Mass of N (g/kg)	**Mass of N used (gN/ kg soil)
1	0	0	0.000	0.000
2	15	45	0.173	0.519
3	30	90	0.346	1.038
4	45	135	0.519	1.557
5	60	180	0.692	2.076
6	75	225	0.865	2.595
7	90	270	1.038	3.114
8	105	315	1.211	3.633
9	120	360	1.384	4.152
10	135	405	1.557	4.671
11	150	450	1.730	5.190

** Estimated root zone certainty between rhizosphere-applied rate and rate due to continues mass of soil equal to three times the actual rate needed.

Table 1b: Rates of P_2O_5 used for calibrating soil test results for phosphorus fertilization in pot experiment

Pot	P_2O_5 calibration rate (kg/ha)	**P_2O_5 rate applied in pot experiment (kg/ha)	Mass of P_2O_5 /kg soil	**Mass of P_2O_5 used (gP_2O_5/ kg soil)
1	0	0	0.000	0.000
2	5	15	0.057	0.171
3	10	30	0.115	0.345
4	15	45	0.173	0.519
5	20	60	0.231	0.693
6	25	75	0.288	0.864
7	30	90	0.346	1.038
8	35	105	0.404	1.212
9	40	120	0.461	1.383
10	45	135	0.519	1.557
11	50	150	0.577	1.731

*** Estimated root zone certainty between rhizosphere-applied rate and rate due to continues mass of soil equal to three times of the actual rate needed.

The estimated root zone certainty between rhizoshpere applied rate and rate due to continuous mass of soil (Table 1) was done by multiplying the actual rate by a factor of three. The factor of three represents an estimate of ratio of root zone surface area to total surface area between any two stands. This estimated root zone certainty was essential because, in the normal farmers' fields, any rate to be added per unit area are point applied within the root's rhizosphere and not randomly spread over the entire surface area. So that at any time, soils picked within the inter and intra rows would normally have lower nutrient concentrations than soils that would have been picked at the point where the fertilizers were applied. To ensure uniform concentration of nutrients at any sampled points of soils for the pot experiment, this proxi of nutrient content was essential. The estimated final rate of nutrient applied (Table 1) was then mixed thoroughly with the 10 kg soil to have a uniform nutrient concentration within the potted soil. In this case when soil samples are taken for analysis the nutrient concentration will not differ from one point to another.

3.2.2 Preparation of soil samples and planting materials

The soils used for the calibration had been extensively cultivated and was extremely low in plant nutrients. Prior to using the soils, representative soil samples were taken for laboratory analyses to determine the level of soil N and P_2O_5 prior to treatment. Eight (8) holes were created under each plastic bucket. The buckets were used as planting pots and filled with 10 kg soil each. Each pot had a surface area of 0.1013 m^2. Prior to filling the pots with soil, soils were air-dried, pulverized and sieved through a 2 mm sieve. Each treatment (N or P_2O_5 rate) was mixed thoroughly with soils in a given pot, after which representative soil samples after treatments were taken for soil analyses to know the laboratory test values of the respective treatments after fertilization.

3.2.3 Agronomic practices

Hand-watering of the potted plants was done twice daily, in the morning and late afternoon, to enhance the moisture content and growth of the maize plants. Three (3) maize seeds were planted per pot. The maize plants were thinned-out, two weeks after planting to two plants per pot and all weeds that appeared in the pots were removed immediately by hand to prevent competition with the maize plants.

In the phosphorus experiment, N and K_2O were applied as side placements. Nitrogen was applied in two split. The first application was done 10 days after emergence, together with the K_2O at 60 kg/ha each. The second application of N was done 20 days after the first application at the rate of 60 kg/ha. Urea was used as the source of N. Muriate of potash (KCl) was used as the source of K_2O (60%), while triple super phosphate (TSP) $Ca(H_2PO_4)$ was used as source of the P_2O_5 (45%). For the nitrogen experiment, P_2O_5 and K_2O were applied as side placements 10 days after emergence at rates of 60 kg/ha each.

3.2.4 Data collection

Data were collected on initial nutrient levels before fertilization, nutrient levels after fertilization and prior to planting, plant height, leaf area index, days to 50% flowering, straw weight, cob weight, cob length, cob weight, 100 seed weight, and grain yield.

Plant height

The height of the maize plants in each pot was measured at 3, 6 and 9 weeks after planting (WAP). Tape measure was used to measure the heights from the base of the plant to the flag leaf and their averages recorded.

Leaf area index (LAI)

Leaf area index was taken at 6 and 9 weeks after planting by measuring the length and the width of the leaves. LAI was computed by formula, $L \times W \times A$ where L = leaf length, W = leaf width and A = is a factor of 0.75 for maize crop as described by Dwyer and Stewart (1986).

Days to fifty per cent flowering

The number of days to 50% tasselling was determined as the number of days between when the crop was planted and when 50% of the plants within a pot tasselled. This was recorded when 50% of the plants have tasselled on each pot.

Cob length

The cobs from each treatment were selected and their length measured and their averages were recorded. A pair of callipers and a rule was used to measure the cob length.

Cob weight

The cobs of the tagged plants were selected from each treatment and weighed and their averages recorded. An electronic scale was used to determine the cob weight at harvest.

100 seed weight

100 maize seeds in each plot were counted and weighed using an electronic scale.

Straw weight

The straw of harvested pots were weighed after harvesting and recorded. The harvested straw weights were converted into tons/ha (t/ha) using the equation used by Goswani (2011) below.

$$\text{Straw weight (t/ha)} = \frac{\text{Straw weight (kg/pot)} \times \text{Plant density}}{1000} \qquad \text{Equation 1}$$

Where plant population density = number of plant stands per 10,000 m^2 when planted at spacing of 80 cm x 25 cm (interspacing arrangement for the pot experiment), at one seed per stand. Hence, 1 ha (10,000 m^2) area has plant density of 50,000 with same spacing.

Grain yield

The grain obtained from pots were threshed, cleaned, dried and weighed in gram per pot. Total weight of all the grains of a particular pot gives the grain yield in gram per pot and finally converted into tons/hectare (t/ha), using the equation 2 below, used by Goswani (2011).

$$\text{Grain yield (t/ha)} = \frac{\text{Grain yield per pot } \left(\frac{\text{kg}}{\text{pot}}\right) \text{ x Plant density}}{1000} \qquad \text{Equation 2}$$

Where plant population density = number of plant stands in 10,000 m^2 when planted at spacing of 80 cm x 25 cm (interspacing arrangement for the pot experiment), at one seed per stand. Hence, 1 ha (10,000 m^2) area has plant density of 50,000 with same spacing.

3.2.5 Analyses of data from the pot experiment for development of calibrated tool

Data collected from the pot experiments were subjected to analysis of variance (Anova) to compare crop growth and yield responses between the treatment levels using Gensatat 18th edition. Treatment means were separated at 5% probability level using the least significant difference.

Using regression analyses, a soil test calibration tool was developed by using scatter plot of data points that best express the relationship between fertilization rate (kg/ha) and soil test results (mg/kg) for N and available P. A line of best fit from the regression analyses was then used to predict the nutrient levels of a given soil and also the rate of fertilizer that is required to achieve optimum yield based on laboratory results from chemical analyses of soils.

The soil test-calibrated tool was then evaluated at three sites by comparing the performance of the tool-predicted rate with that of the optimum fertilization rate in the pot experiment. The tools were further validated by comparing the performance of the tool-predicted rate with that of the blanket recommended rate in northern Ghana and a zero rate at each of the three sites.

3.3 Field experiment to evaluate and validate soil-test calibrated tool

Before the estimation of fertilizer rate for each of the three sites, soil samples were taken for chemical analyses. Results from the soil test were used to predict and estimate the optimum required fertilizer rate from the calibrated tool. For instance, assuming the soil test gave nitrogen value of X_1 mg/kg, the corresponding fertilizer rate of Y_1 kg/ha was traced from the developed calibrated tool. Across northern Ghana, N fertilization rate of 120 kg/ha is mostly postulated and recommended as blanket optimum rate for maize cropping (Asekabta, 2018; Essel et al., 2020). As such, a rate of 120 kg/ha minus Y_1 kg/ha, then becomes the rate of fertilization top-up required for the given soil. This way, different fertilizer top-up rates were estimated from soil test results for site specific rates. As an example, an estimated soil fertility level of 50 kg/ha N will mean that only 70 kg/ha (120-50) of N fertilizer could be applied in order to attain optimum yield. This makes good economic sense for running expensive soil tests by the already resource constrained farmer.

3.3.1 Experimental design and treatment

For each of phosphorus and nitrogen, three geographically distinct maize producing sites in the northern region were selected (Table 2) to evaluate and validate the suitability of use of the calibrated tool in predicting fertilizer top-ups. Representative soil samples were taken from each site and analysed for initial soil N and soil P. Using the initial soil test values for N and P at each of the sites, the exact N or P fertilizer that was required to obtain optimum yield were deduced from the calibrated tool and applied to the given field (Table 2). In that sense, P_2O_5 was applied at the rate of 30 kg/ha at Nyankpala, 40 kg/ha at Tamale and 35 kg/ha at Damango as deduced from the predicting tool. N was also applied at rates of 60 kg/ha at Nyankpala, 140 kg/ha at Tamale and 110 kg/ha at Damango as modelled by the predicting tool. In the phosphorus experiment, N and K_2O were applied as side placements. Nitrogen was applied in two equal splits. The first application was done 10 days after emergence, together with K_2O at rate of 60 kg/ha K_2O. The second application of N was done 20 days after the first application. Urea (46% N) was used as the source of N. Muriate of potash (KCl) was used as the source of K_2O (60%), while triple super phosphate (TSP) $Ca(H_2PO_4)$ was used as source of the P_2O_5 45%). For the nitrogen experiment, P_2O_5 (45%) and K_2O (60%) were applied as side placements 10 days after emergence at rates of 60 kg/ha each.

Two control treatments were run parallel to the main treatments: one was zero (0) fertilization rate, and the other was the respective blanket recommended fertilizer rate (120 kg/ha for N, and 45 kg/ha for P_2O_5 respectively). At each site, the experiment was repeated 4 times.

Plot sizes of 5 m × 5 m with a 1 m alley between plots were used for each location. Only one maize variety (Wangdataa) was planted under the different phosphorus and nitrogen fertilizer rates. Three seeds were planted with planting space of 80 cm × 25 cm. For the nitrogen trial P_2O_5 and K_2O were applied at the optimum rate at 60 kg/ha each. For the phosphorus trial N and K_2O were applied at optimum rate of 120 kg/ha and 60 kg/ha respectively.

Table 2a: Tool-predicted rates of nitrogen, and constant rates of phosphorus and potassium used to evaluate and validate the predictability of the soil-test calibrated tool for N fertilization at three sites in northern Ghana

Site	*Nitrogen rate modelled by calibrated tool (kg/ha)	Constant P_2O_5 rate applied (kg/ha)	Constant K_2O rate applied (kg/ha)
Nyankpala	60	60	60
Damango	140	60	60
Tamale	110	60	60

*****Nitrogen rates added to each site were deduced from the calibrated soil-test tool as the difference between the optimum productivity rate for nitrogen and that of the prevailing soil-test nitrogen level. The prevailing soil-test nitrogen levels were converted to rate bases by use of the nitrogen calibrated tool.

Table 2b: Tool-predicted P_2O_5 rates as well as constant rates of nitrogen and potassium used to evaluate and validate the predictability of the soil-test calibrated tool for P fertilization at three sites in northern Ghana

Site	nitrogen rates (kg/ha)	potassium rates (kg/ha)	*P_2O_5 rate modelled by calibrated tool (kg/ha)
Nyankpala	120	60	30
Damango	120	60	35
Tamale	120	60	40

* P_2O_5 rates added to each site were deduced from the calibrated soil-test tool as the difference between the optimum productivity rate for P_2O_5 and that of the prevailing soil-test P level. The prevailing soil-test P levels were converted to rate bases by use of the P_2O_5 calibrated tool.

3.3.2 Agronomic practises

The experimental fields were ploughed and ridged before land demarcation. Planting was done between 15th July and 31st July 2019 with a spacing of 85 cm between rows and 25 cm within rows. Three seeds were planted and later thinned to two plants per hill. Thinning out was done before fertilizer application. Prior to planting, glyphosate (non-selective) herbicide was applied to kill all weeds to avoid early competition. The first-hand weeding was done three weeks after planting (DAP) and the second-hand wedding was done 40 days after planting (DAP). Third-hand weeding was done 75 DAP.

3.3.3 Plant data collection

Data were collected on the following: plant height, leaf area index, days to 50% flowering, straw weight, cob weight, cob length and grain yield.

Plant height

Five (5) plants in each plot were randomly selected from the middle rows and their heights were individually measured to the nearest centimetre from the base to the tip. Measurements were taken at 3, 6, and 9 WAP for each plot using a measuring tape. The average of the 5 plants was computed and used as plant height for the given plot.

Leaf area index (LAI)

Leaf area index was taken at 6 and 9 weeks after planting by measuring the length and the width of leaves of 5 tagged plants. LAI was computed by formula, $L \times W \times A$ where L = leaf length, W = leaf width and A = is a factor of 0.75 for maize crop as describe by Dwyer and Stewart (1986).

Days to 50% flowering

The days to 50% flowering was determined by counting the number of days from planting to when half (50 %) of the maize plants on each plot tasselled.

Cob length

Five (5) plants were selected at random from each treatment and their cob lengths were measured and recorded. A measuring rule was used to take the measurement. The average length of the 5 cobs was computed and used as the cob length for the given plot.

Cob weight

Five (5) plants were selected at random from each plot and their cobs were weighed using an electronic measuring scale. The average cob weight of the 5 cobs was computed and used as the cob weight for the given plot.

Grain yield

At physiological maturity, maize cobs were harvested from a net plot of 4 m × 4 m (16 m^2). The harvested maize cobs were processed for grain yield determination by weighing after dehusking and shelling. Grain yield was adjusted at 14% grain moisture using equation 3 as also used by Dzomeku et al. (2019).

$$\text{Adjusted grain yield (kg/ha)} = \frac{\text{Grain yield} \times 10000\text{m}^2 \times (100\%\text{-grain moisture content }\%)}{16\text{m}^2 \times (100\%\text{-}14\%)} \quad \text{Equation 3}$$

Hundred seed weight

100 maize seeds in each plot were counted and weighed using an electronic scale.

Stover weight

The straw of net plots were weighed after harvesting and recorded. The harvested straw weights were converted into tonnes per hectare.

3.3.4 Soil data collection and analyses

Soil samples were taken from the experimental plots at a depth of 0-20 cm. For each site, 20 soil samples were taken using the zigzag pattern. Collected samples from each site were bulked together to get one composite sample which was taken to the laboratory and analysed for soil physical and chemical properties. Soil samples for determination of soil pH, organic carbon, exchangeable K, total N and available P were obtained from the upper soil surface layer (0 - 20 cm) using a 5 cm diameter soil auger. The soil samples were collected prior to planting at random.

Methods used to determine the soil physicochemical properties

To effectively relate the nitrogen and phosphorus content of the soil to maize productivity, total nitrogen and available phosphorus were considered to serve as proxy for nutrient availability. While nitrate and ammonium are the forms in which maize picks up nitrogen, total nitrogen was considered in the study because soils of the area are extremely low in total nitrogen which comprises of ammonium, nitrate and organic forms (Li et al., 2013). Also, ammonium is relatively unstable and nitrogen in the form of ammonium is easily converted to nitrate forms in most maize fields where oxygen is in abundance (Wessen et al., 2010). With the low organic forms of nitrogen, determination of total nitrogen gives the closest option for determining all the potential nitrogen that may be available to the plant during the short duration of maize growth and, thus, serves as good estimate for N nutrition of the soil.

On the other hand, plant available phosphorus, and not total phosphorus was used to ascertain P availability. This was used because of the relatively high total phosphorus levels in the soils compared to the plant-available forms (Lambers et al., 2015). The available P dynamics are also affected by the soil pH regime, being retained by the soil at low pH values and precipitating at high pH values- for which reason plant available P has been proposed to be the most effective estimate for plant nutrition (Fageria et al., 2008; Damon et al., 2014).

Soil pH

Soil pH was determined by using the electrometric method in a soil: water ratio of 1:2.5 (Moral et al., 2010). In the process, 10 g of air-dried soil sample was taken into a 50 ml beaker and 25 ml of distilled water was added. The mixture was stirred vigorously for 20 min and allowed to settle. The pH meter was calibrated with the standard solution at pH of 4 and 7 respectively and the electrode of pH meter was inserted into the partly settled suspension. The pH of the suspension was then read and recorded.

Organic carbon

This was done by the Walkley and Black method (Kalembasa and Jenkinson, 1973). 2.0 g of air-dried and sieved soil sample was taken into a 250 ml Erlenmeyer flask. 10 ml of 1 M of $K_2O_7Cr_2$ was added and then 20 ml of H_2SO_4 was added. The mixture was stirred to ensure that the solution is in contact with all the particles and then left in the fume hood to cool for 30 minutes. After cooling, 100 ml of water was added and 10 ml of orthophosphoric acid. The mixture was left to and then 2-3 drops of diphenylamine indicator were added. The mixture was then titrated against 1.0 N ferrous sulphate solution until the colour changes to blue and then to green end-point and the titre value recorded. The organic carbon was then determined using the formulae in equation 4 as used by Laswai, (2011).

$$\%\ \text{organic carbon in soil} = \frac{(\text{m.e } k_2Cr2O7\text{-m.e. } FeSO4)\times 0.003\times F\times 100}{\text{weight of soil}} \qquad \text{Equation 4}$$

Where, milli equivalent (m.e) = Normality of solution × ml of solution used

m.e of weight of C = 0.003, Correction factor (F) = 1.33

Nitrogen

Total N was determined by the Kjeldahl procedure modified to include the mineral nitrates in the soil by the use of salicylic acid to convert all the nitrates into ammonium salts (Bremner, 1965). A 10 g soil was weighed into a 250 ml Kjeldahl digestion flask and 10 ml of distilled water was added. Ten (10) ml of concentrated H_2SO_4 was added followed by one Tablet of selenium and potassium sulphate mixture and 0.10 g salicylic acid. The mixture was made to stand for 30 minutes and heated mildly to convert any nitrates and nitrites into ammonium compounds. The mixture was then heated more strongly (300-350 ^{o}C) to digest the soil to a permanent clear colour. The digest was cooled and transferred to a 100 ml volumetric flask and made up to the mark with distilled water. A 20 ml aliquot of the solution was transferred into a tecator distillation flask and 10 ml of 40% NaOH solution was added and steam from the tecator apparatus allowed to flow into flask. The ammonium distilled was collected into 10 ml boric acid/ bromocresol green and methyl red solution. The distillate was titrated with 0.01 M HCl solution. A blank digestion, distillation and titration was also carried out as a check against traces of nitrogen in the reagents and water used.

Calculation

$$\% \, N = \frac{(a\text{-}b) \times 1.4 \, M \times v}{s \times t} \qquad \text{Equation 5}$$

Where, a = ml HCl used for sample titration, b = ml HCl used for titration of blank

s = weight of soil taken for digestion in grams, M = molarity of HCl

1.4 = 1.4 10^{-3} × 100% (14 = atomic weight of N), V = total volume of digest

t = volume of aliquot taken for distillation

Available phosphorus

The Bray 1 extraction solution procedure (Bray and Kurtz, 1945) was used for determination of available P. Phosphorus in the extract was determined on a Pye-Unicam spectrophotometer at a wavelength of 660 nm with blue ammonium molybdate as reducing agent. A 2 g soil sample was extracted with 20 ml of Bray 1 solution (0.03 M NH_4F and 0.025 M HCl). The suspension was shaken by hand for one minute and immediately filtered through Whatman No. 42 filter paper. A standard series of P concentration were prepared for calibration by respectively measuring 0, 10, 20, 30, 40, 50 ml of 12.0 mg P/L into a 100 ml volumetric flask and made up to the mark with distilled water. The measurement was then done on the spectrophotometer as specified above.

Calculation

Available phosphorus was then determined as

$$P \, (mg/kg/) = \frac{(a\text{-}b) \times vs \times df}{g} \qquad \text{Equation 6}$$

Where a = mg P/L in sample extract b = mg P/L in blank

vs = volume of extract df = dilution factor g = sample weight in grams

Exchangeable cations

The exchangeable bases Ca^{2+}, Mg^{2+}, K^+ and Na^+ were extracted with 1.0 M neutral NH_4OAc solution (Black, 1965). The exchangeable acidic cations (Al^{3+} and H^+) were extracted with 1.0 M KCl solution as described by Page et al. (1982). After the extraction, the Ca^{2+} and Mg^{2+} were determined using a Perkin-Elmer atomic absorption spectrophotometer at wavelength of 422.7 nm and 285 nm respectively and K^+ and Na^+ by an Eppendorf flame photometer at wavelengths of 766.5 nm and 589 nm, respectively. The exchangeable acidity was determined by titration using 0.10 M NaOH and phenolphthalein indicator from a colourless solution to a permanent pink end point.

Calculation

$$\text{Exchangeable acid (cmol}^+\text{/kg/soil)} = \frac{(vs\text{-}vb)\times M}{g} \qquad \text{Equation 7}$$

Where, vb = ml of NaOH used to titrate blank, vs = ml of NaOH used to titrate the sample extract, g = weight of air-dried soil, M = molarity of NaOH used for the titration

The effective CEC was calculated by the summation of the basic and acidic cations.

Particle size distribution

The particle size distribution of the soil was determined by the modified bouyoucos hydrometer method as described by Beretta et al. (2014). Prior to determination, the samples were digested with hydrogen peroxide to remove organic matter in the soils. A forty-gram soil was weighed into a beaker after which one hundred milliliters of 5% calgon (sodium hexametaphosphate) solution was added. The suspension was allowed to stand for about 10 min and then stirred with a mechanical stirrer for 30 min. The suspension was then transferred into a graduated sedimentation cylinder with the help of distilled water from a wash bottle and made up to the 1 L mark with distilled water. The content of the cylinder was mixed thoroughly using a plunger and hydrometer readings taken 5 min and 5 h thereafter. The suspension was then poured directly onto a 47 µm sieve and the particles retained on the sieve washed thoroughly with water and dried in an oven at 105°C for 24 h. The dried samples were then weighted to represent the sand fraction. The particle size distribution was then determined using the following formulae as used by Kugbe and Zakari (2015).

$$(\text{Clay} + \text{Silt})\ \% = \frac{\text{5 minute hydrometer readings}}{\text{sample mass}} \times 100 \qquad \text{Equation 8}$$

$$\text{Clay}\ (\%) = \frac{\text{5 hours hydrometer readings}}{\text{sample mass}} \times 100 \qquad \text{Equation 9}$$

$$\text{Sand}\ (\%) = \frac{\text{Oven drymass (g) of particle retained on 47}\mu\text{m sieve}}{\text{sample mass}} \times 100 \qquad \text{Equation 10}$$

Silt (%) = Equation (8) – Equation (9)

The textural class of the soil was then determined using the USDA textural triangle.

3.3.5 Statistical analysis

The developed tools for N and P were evaluated for performance by computing the closeness of tool-predicted growth and yield values to those obtained during the calibration experiment. For the developed soil test tool, percentage predictability of the tool was calculated by the formulae

$$\%\ \text{predictability of tool} = \frac{\text{Value obtained}}{\text{Value expected}} \times 100 \qquad \text{Equation 11}$$

Regression analyses were conducted to show the linear relationship between soil test results, rate of fertilization and plant growth and yield.

After evaluation, the tools were each validated by comparing growth and yield data of tool-predicted fertilization rates for each field to those of the zero and blanket recommended rates. The collected plant data from the three fields were subjected to analysis of variance using GenStat statistical package 18th edition. Count data (n) were transformed using square root transformation ($\sqrt{n} + 0.5$) to homogenize the variance before subjecting data to the analysis of variance. Treatment means were separated using the Least Significant Difference at 5% significant level. Results are presented in Figures and Tables. Microsoft excel software package 13th edition was used to perform unequal t-tests between expected and obtained growth and yield parameters.

CHAPTER FOUR

RESULTS

4.0 Calibration and validation of developed soil test tool for nitrogen fertilization in maize

4.1 Impact of calibration N rate on growth and yield of maize

Plant height

The application of different rates of nitrogen did not have a significant effect ($P = 0.281$) on plant height at three weeks after planting (WAP). However, calibration rate of 120 kg N/ha recorded the highest height whilst 90 kg N/ha recorded the least height (Figure 1). The application of nitrogen did not have a significant effect ($P = 0.312$) on plant height at 6 WAP. Generally however, 105 kg N/ha recorded the highest height followed by 120 kg N/ha while 00 kg N/ha recorded the least height. Plant height at 9 WAP was significantly affected ($P = 0.05$) by the application of N. 90 kg N/ha gave the highest height followed by 120 kg N/ha and 30 kg N/ha, while zero N/ha recorded the least height.

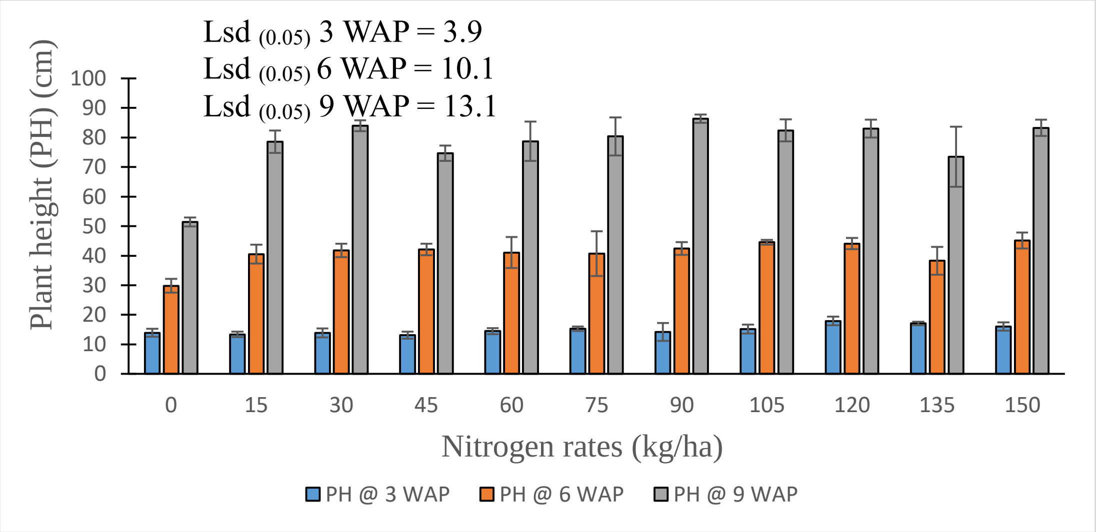

Figure 1: Impact of nitrogen calibration rate on plant height of maize in the Guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Leaf area index

The application of nitrogen did not have a significant effect ($P = 0.16$) on leaf area index at six (6) weeks after planting. There was an increase in leaf area index at sixth week after planting with increasing rate of N. However, 150 kg N/ha recorded the highest leaf area index followed by 135 kg N/ha and 120 kg N/ha. Treatment 0 kg N/ha gave the least leaf area index (Figure 2). There was significant difference ($P = 0.05$) between the different rates of nitrogen applied with respect to leaf area index at ninth week after planting. Treatment 150 kg N/ha recorded the highest leaf area index followed by 120 kg N/ha and 105 kg N/ha while 00 kg N/ha recorded the least leaf area index at ninth week after planting (Figure 3).

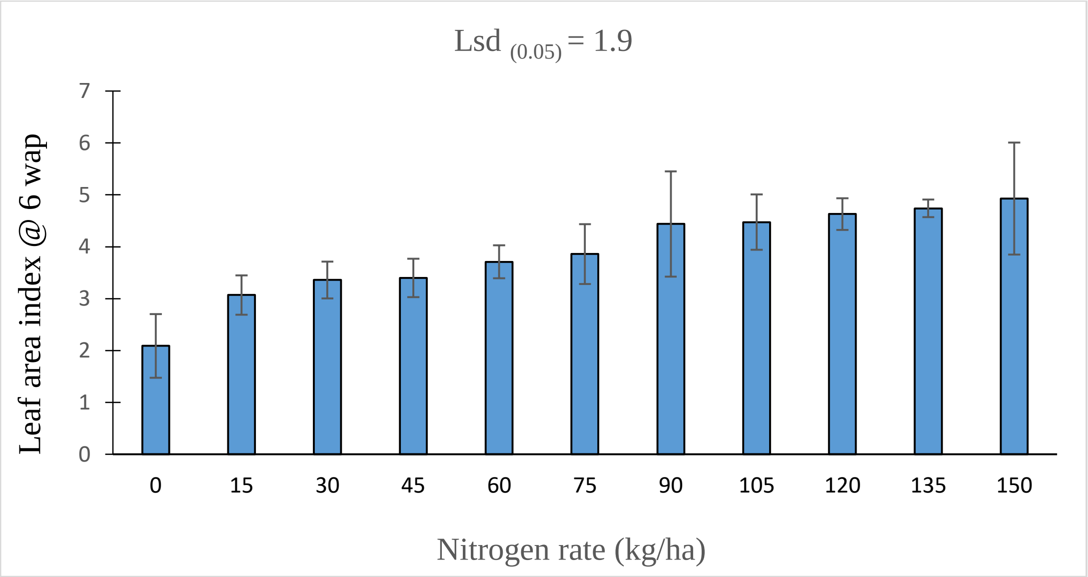

Figure 2: Impact of nitrogen calibration rate on leaf area index of maize at six (6) weeks after planting (wap) in the Guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

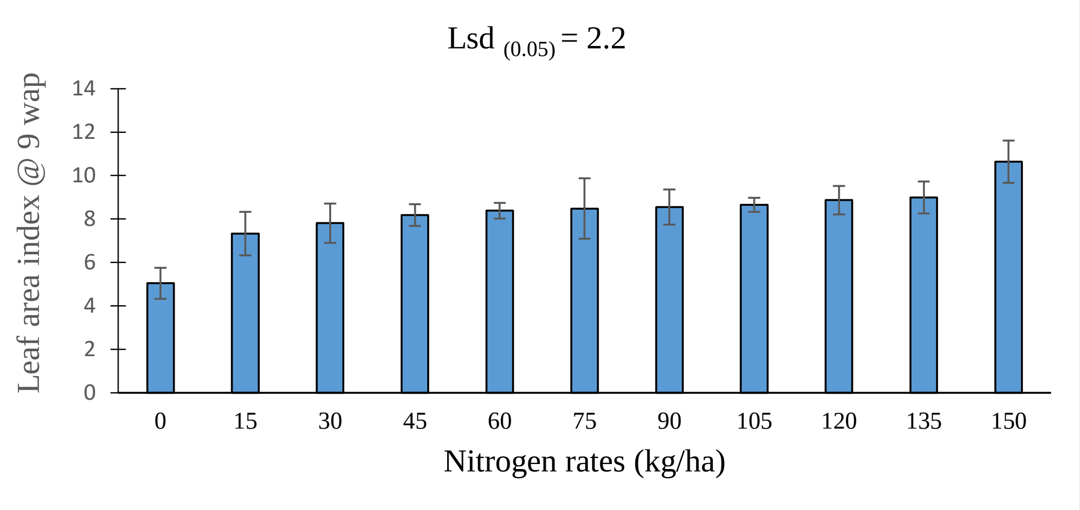

Figure 3: Impact of nitrogen calibration rate on leaf area index of maize at nine (9) weeks after planting (wap) in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Days to 50% flowering

The application of nitrogen did not influence (*P = 0.169*) days to fifty per cent flowering. However, 120 kg N/ha, generally, recorded the least days to flower followed by 105 kg N/ha while 0 kg N/ha recorded the longest days to flower (Figure 4).

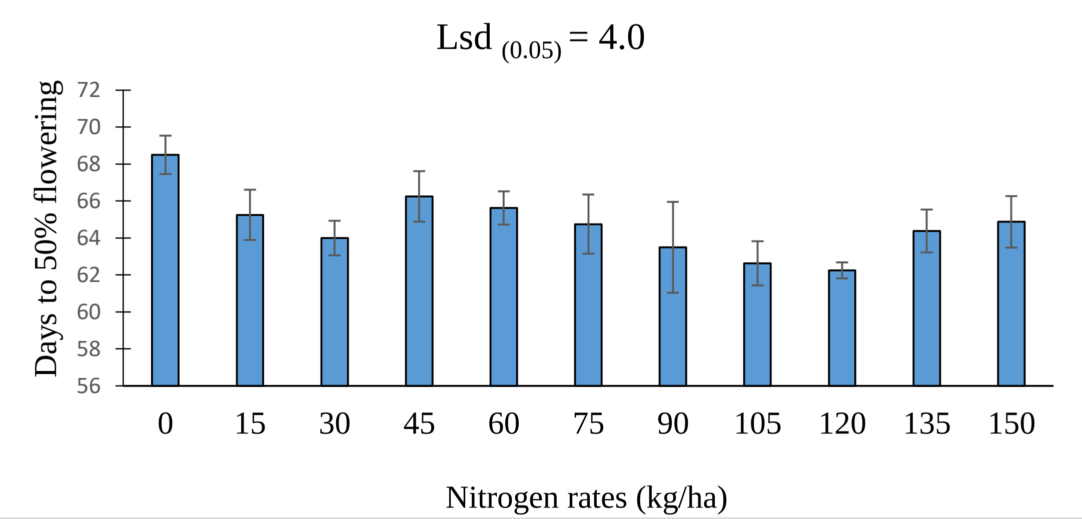

Figure 4: Impact of nitrogen calibration rate on days to 50% flowering of maize cultivated in the Guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Cob weight

The application of nitrogen showed a significant difference ($P = 0.05$) on cob weight. Application of 135 kg N/ha recorded the highest weight of 26.8 g/cob followed by 120 and 105 kg N/ha with 25.4 g/cob and 26.1 g/cob respectively. Application of N at rate of 0 kg N/ha recorded the least weight of 17.6 g/cob (Figure 5).

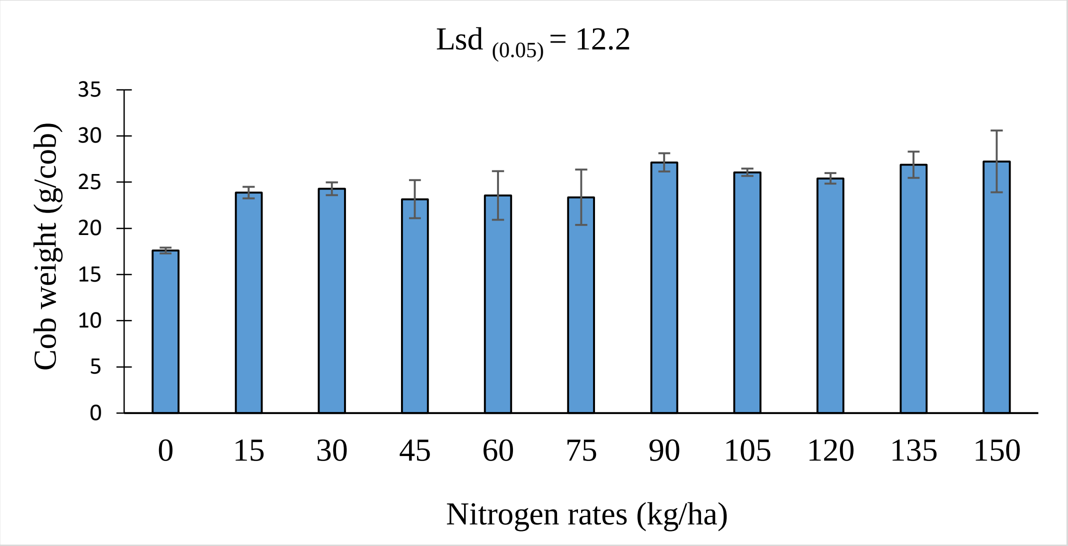

Figure 5: Impact of nitrogen calibration rate on cob weight of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Cob length

Application of nitrogen significantly (*P* = 0.05) influenced cob length. There was a general increase in cob length with increasing rates of N application (Figure 6). Application of N at the rate of 150 kg N/ha recorded the highest cob length of 15.3 cm, followed by application of 135 kg N/ha and 120 kg N/ha, with 13.5 and 13.6 cm respectively. Application of N at rate of 0 kg N/ha recorded least cob length of 7.1 cm.

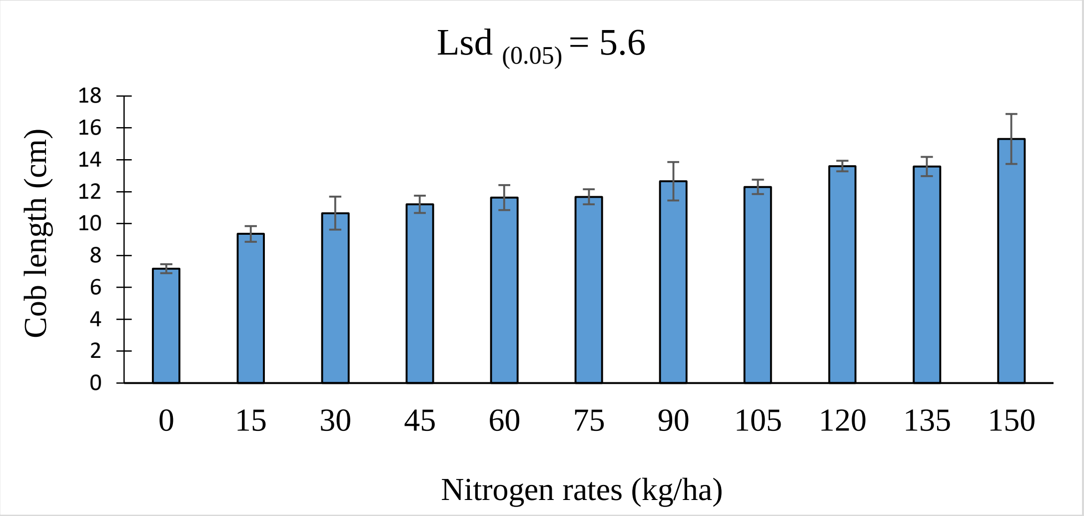

Figure 6: Impact of nitrogen calibration rate on cob length (cm) of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

100 seed weight

The application of nitrogen did not have significant (*P = 0.151*) effect on hundred seed weight. However, non-statistically, 75 kg N/ha, generally, recorded highest hundred seed weight followed by 150 kg N/ha (Figure 7). Application at rate of 0 kg N/ha generally recorded the least hundred seed weight.

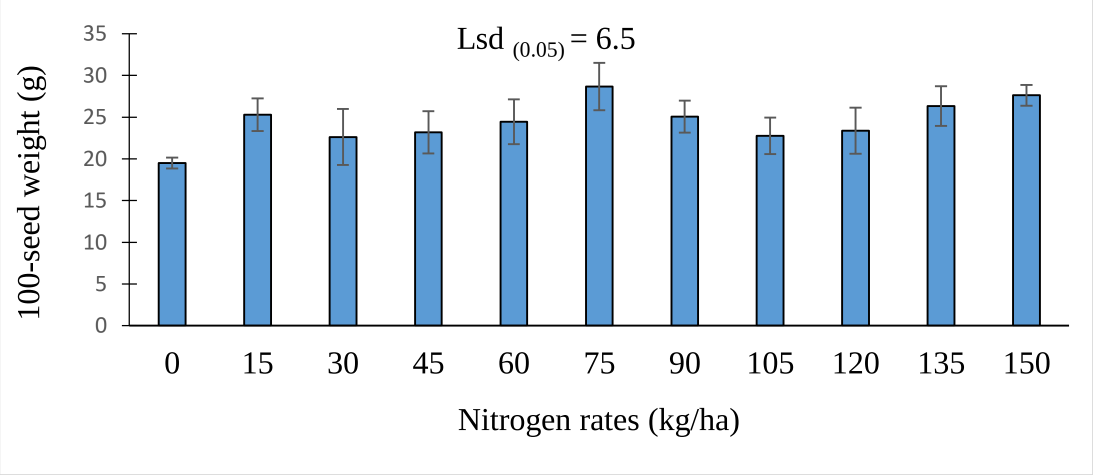

Figure 7: Impact of nitrogen calibration rate on weight of 100 seeds of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Straw weight

Application of nitrogen significantly ($P = 0.05$) influenced straw weight. Nitrogen application at rate of 105 kg N/ha recorded the highest straw weight while 0 kg N/ha recorded the least straw weight (Figure 8). Nitrogen application at rate of 0 kg N/ha gave the lowest straw weight.

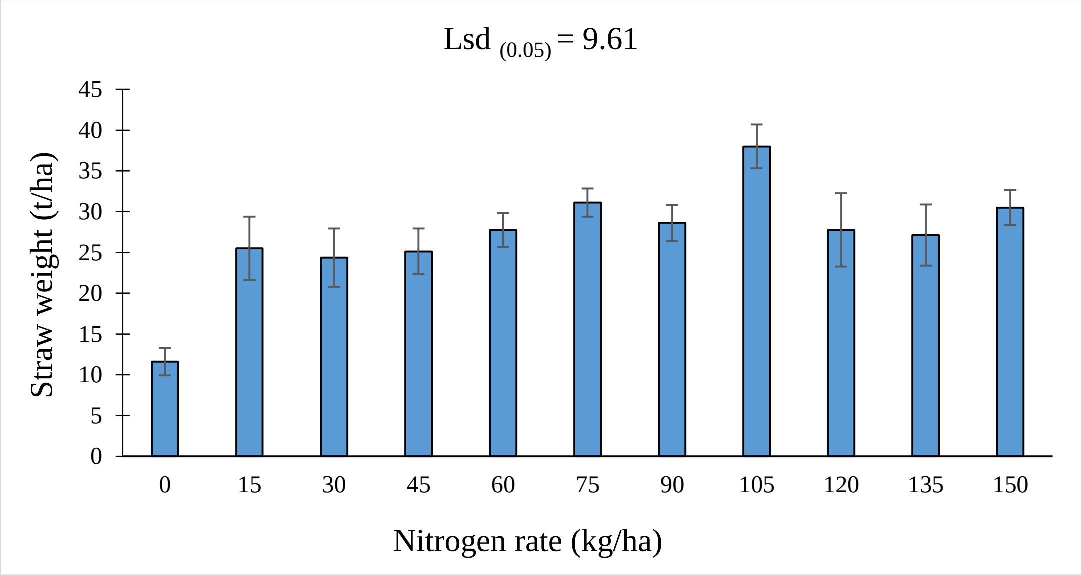

Figure 8: Impact of nitrogen calibration rate on straw weight of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Grain yield

Application of nitrogen significantly ($P = 0.05$) affected grain yield. There was a general increase in grain yield with increasing rate of N application (Figure 9). Nitrogen application at 150 kg N/ha recorded the highest yield of 5.6 t/ha followed by 135 kg N/ha and 120 kg N/ha which gave yields of 4.4 and 4.3 t/ha respectively. Application of nitrogen at a rate of 00 kg N/ha recorded the least grain yield of 0.2 t/ha.

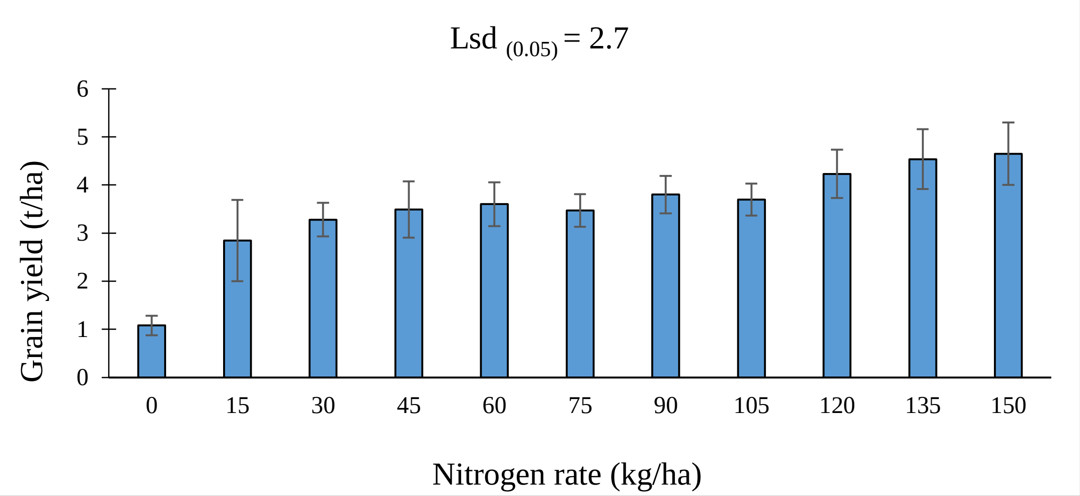

Figure 9: Impact of nitrogen calibration rate on grain yield of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

4.1.1 Predictability of maize growth and yield by soil total N

The regression analysis between yield, straw weight, cob length, cob weight and that of soil chemical N in the calibrated range indicated that grain yield, straw weight, cob length, cob weight at harvest were highly determined by total nitrogen of the soil (Figures 10, 11, 12, 13) with R^2 values of 0.8419, 0.5510, 0.5185 and 0.456 respectively which showed that there was strong relationship between grain yield, straw weight, cob length, cob weight and soil N as estimated in the experiment.

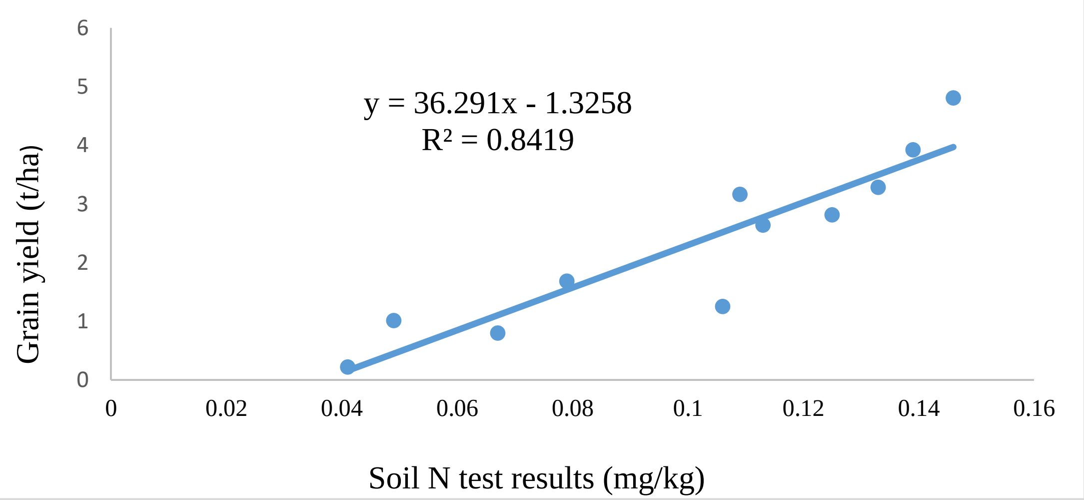

Figure 10: Relation between grain yield of maize (t/ha) and calibrated soil N (mg/kg)

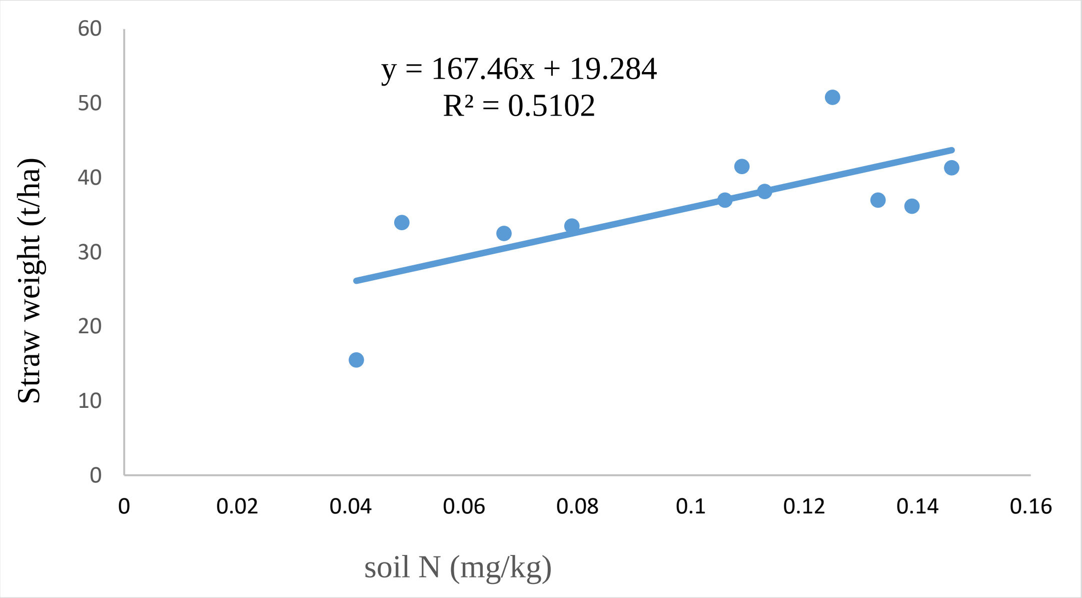

Figure 11: Relation between straw weight of maize and calibrated soil N (mg/kg)

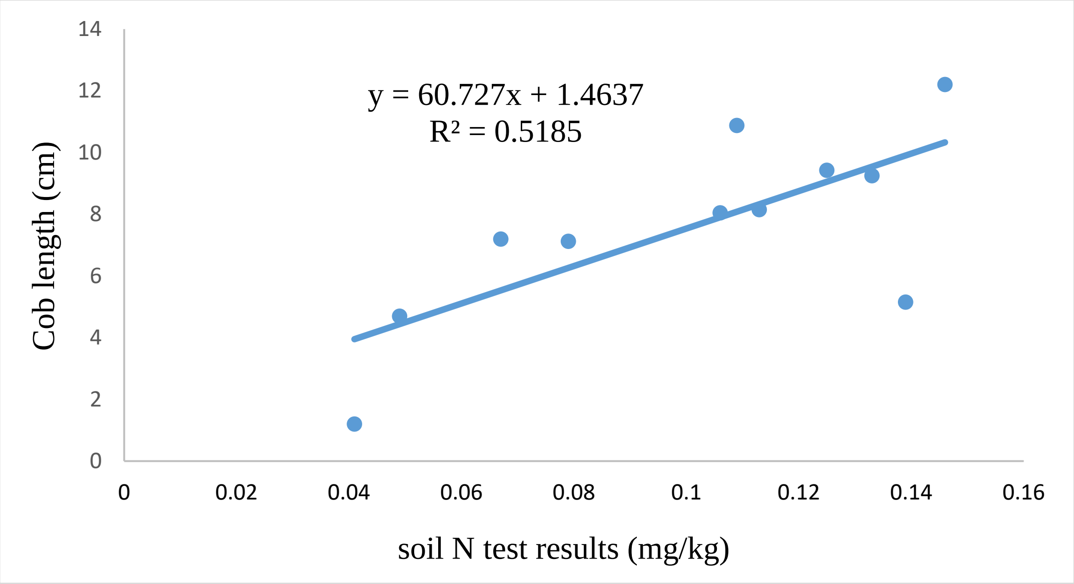

Figure 12: Relation between cob lengths of maize and calibrated soil N (mg/kg)

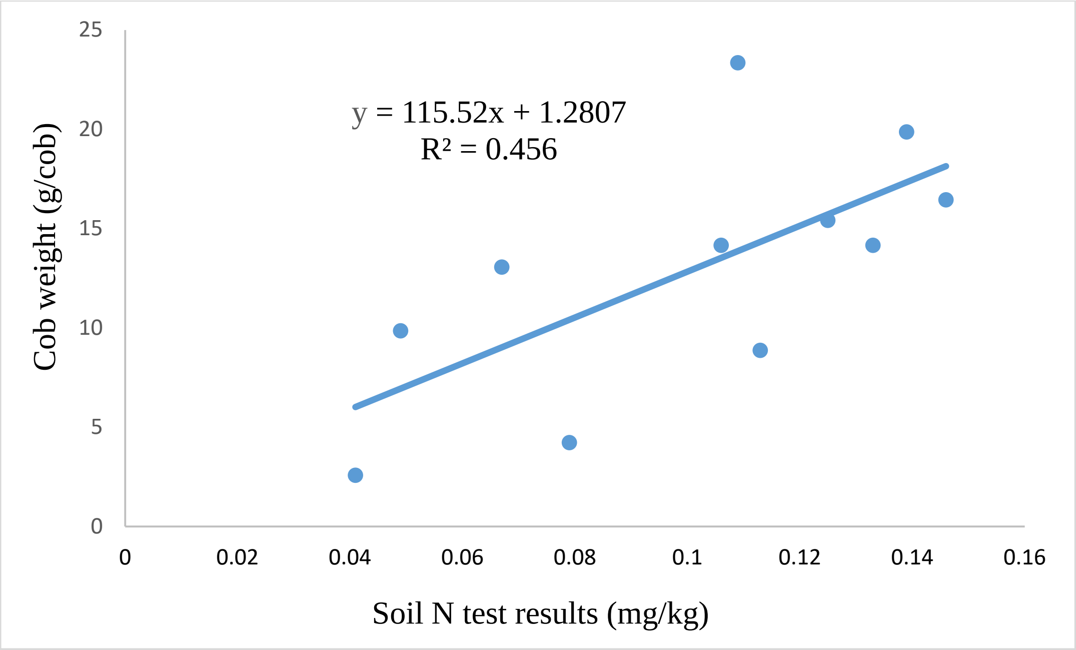

Figure 13: Relation between cob weight of maize and calibrated soil N (mg/kg)

4.1.2 Prediction of plant-available N from soil chemical analyses using the N fertilization tool

Regression analysis indicated that N fertilization tool could be used to predict plant available nitrogen in a given soil (Figure 14). The R^2 value was 0.959 which showed that there is a strong relationship between calibrated rate of fertilization and results of chemical nitrogen analyses. A regression equation $(1338.7 \times N) - 59.718$, where N represents the soil analysed N level, could be used to predict the N levels of a given soil.

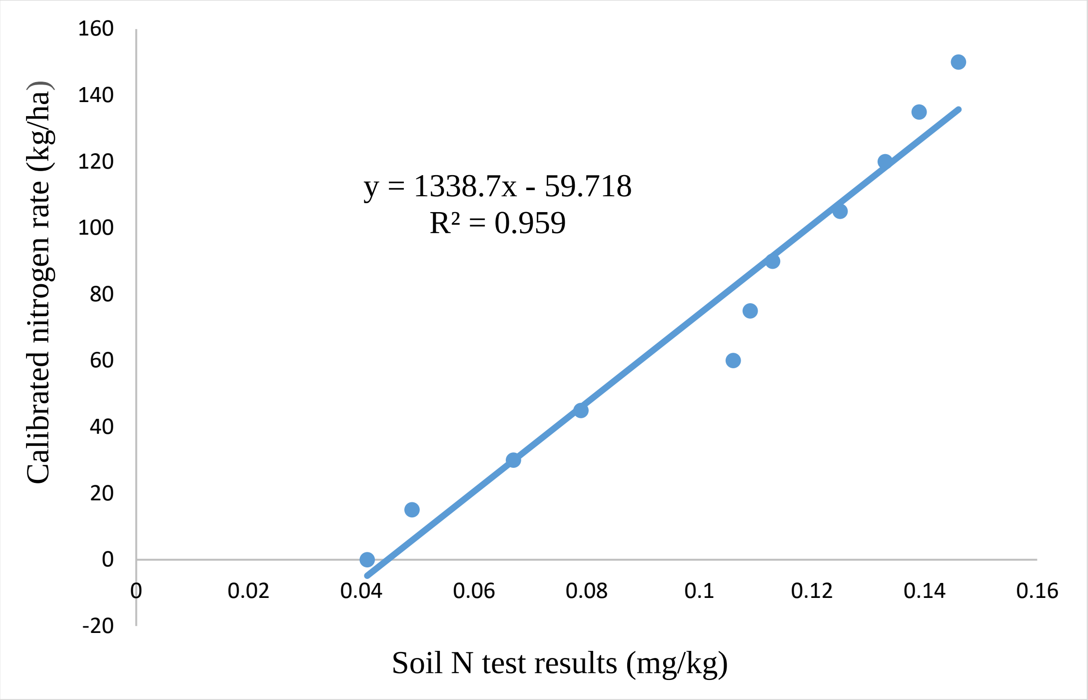

Figure 14: Relation between added N fertilizer and laboratory determined soil N levels in the soil prior to maize cultivation during the 2019 crop season. The relation helps to predict N levels of soil based on chemical analysis.

4.1.3 Prediction of N fertilizer top-up from calibrated soil test results

Regression analysis indicated that the developed N fertilization tool can be used to predict the rate of nitrogen fertilization that is required, based on soil chemical analyses. The R^2 value of 0.959 indicated that there is a strong possibility that the developed calibrated tool could be used to predict nitrogen fertilizer top-up since all points are close to the line of best fit (Figure 15). A regression equation (1338.7 × N) – 59.718, where N represents the soil analysed available N level, can be used to estimate the amount of N fertilization rate (kg/ha) in a given soil. The difference between the estimated rate and the recommended rate of 120 kg/ha can then be computed as the rate required to fertilize the given land for optimum yield.

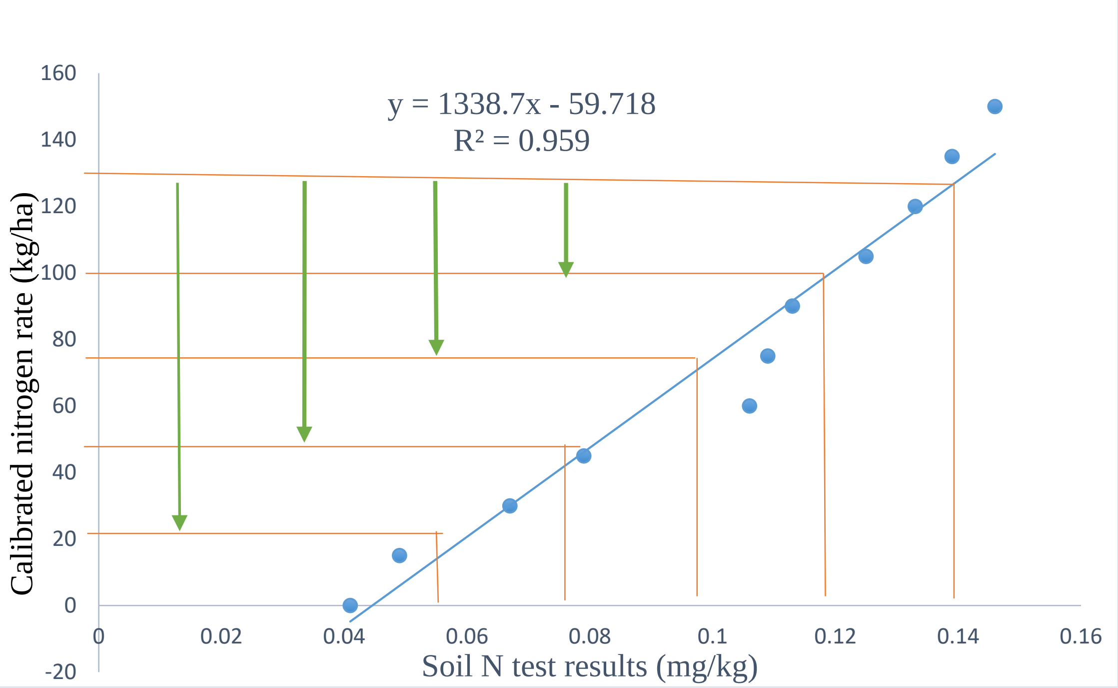

Figure 15: Developed calibrated tool for prediction of N fertilizer top-up from soil test results

4.2 Calibration of soil test results for phosphorus fertilization in maize

4.2.1 Impact of calibration phosphorus rate on growth and yield of maize

Plant height

The application of different rates of phosphorus significantly ($P = 0.05$) influenced plant height during the third week after planting. Plant height increases as the p rates also increase. Application of P_2O_5 at rate of 50 kg/ha recorded the highest height followed by application at rate of 45 kg/ha. P_2O_5 application at rate of 00 kg/ha recorded the least height (Figure 16). Different rates of phosphorus applied had significant ($P = 0.001$) effect on plant height at sixth week after planting. P_2O_5 Application at rate of 50 kg/ha recorded the highest height followed by 45 kg/ha. Application of P_2O_5 at rate of 00 kg/ha recorded the least height at 6 WAP. At the ninth week after planting, there was significant difference ($P = 0.001$) in plant height between the different rates of phosphorus application. Application of P_2O_5 at rate of

50 kg/ha recorded the highest height followed by P_2O_5 application at rate of 45 kg/ha. The application of P_2O_5 at rate of 00 kg/ha recorded the least height at the ninth week after planting.

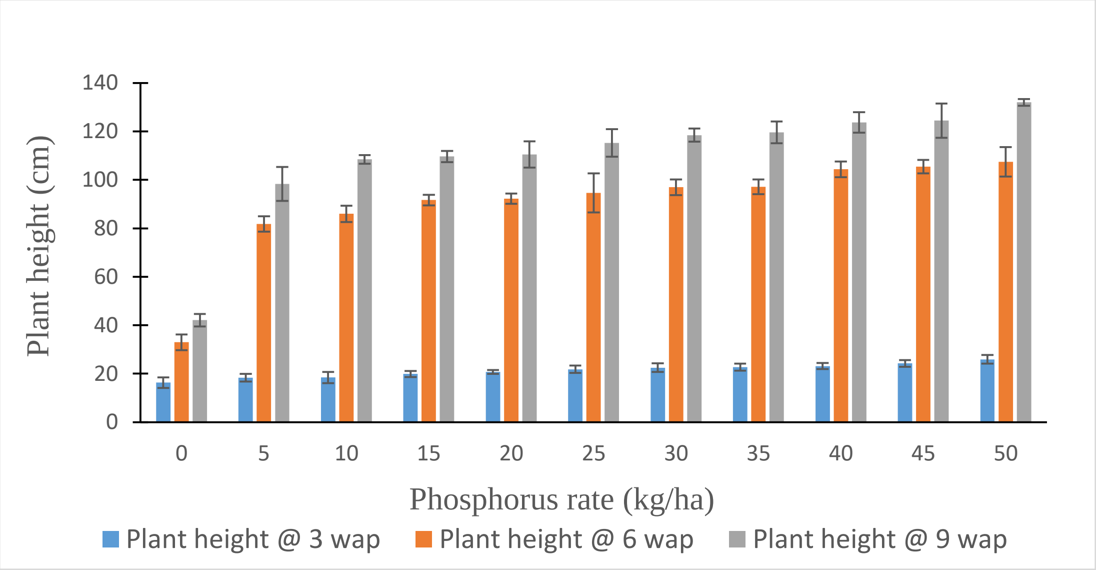

Figure 16: Impact of P_2O_5 calibration rate on plant height of maize at three (3) weeks after planting (wap), 6 weeks after planting and 9 weeks after planting in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Leaf area index

The application of different rates of phosphorus significantly ($P = 0.001$) influenced leaf area index at sixth week after planting with 50 kg of P recorded the highest followed by 25 kg of P while 00 kg/ha P recorded the least and this is presented in figure seventeen (17) below. Moreover, leaf area index at ninth week after planting was also significantly ($P = 0.05$) affected by the application of different rates phosphorus. However, 5 kg P recorded the highest followed by 25 kg/ha P and 50 kg/ha p while 00 kg/ha p recorded least (Figure 18).

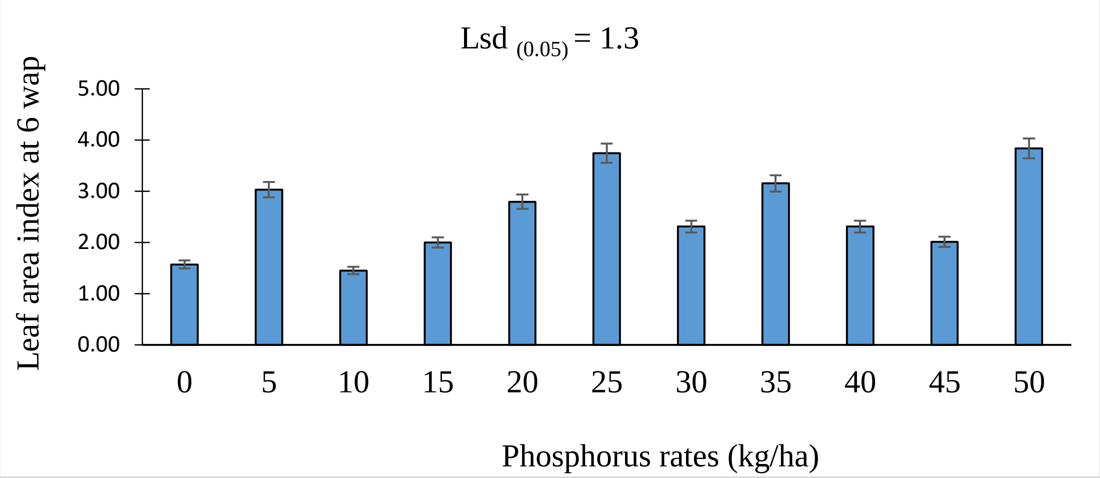

Figure 17: Impact of P_2O_5 calibration rate on leaf area index of maize at six (6) weeks after planting (wap) in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

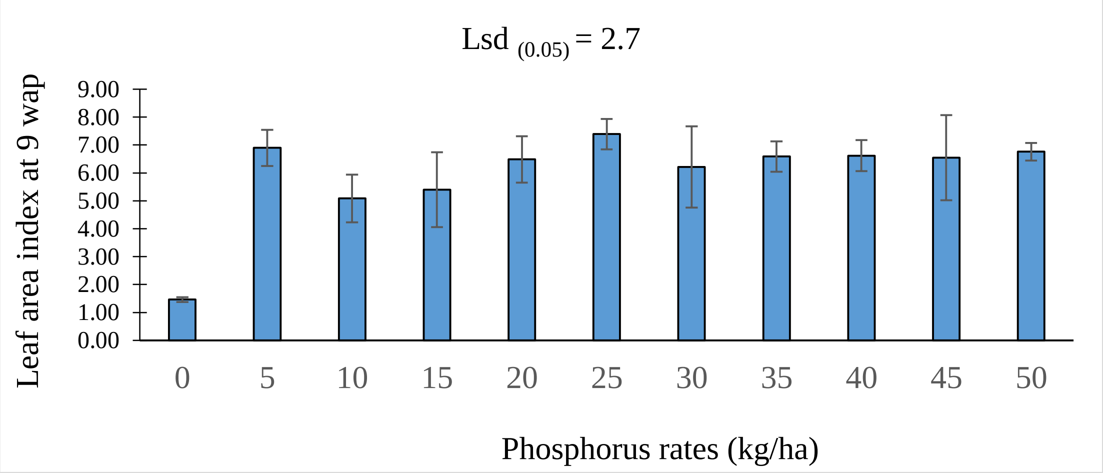

Figure 18: Impact of P_2O_5 calibration rate on leaf area index of maize at nine (9) weeks after planting (wap) in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Days to 50 % flowering

Days to fifty percent flowering was significantly affected ($P = 0.05$) by the application of different rates of phosphorus however 50 kg/ha P recorded the least days to flower followed by 25 and 20 kg/ha while 00 kg/ha p recorded the highest days to flower (Figure 19).

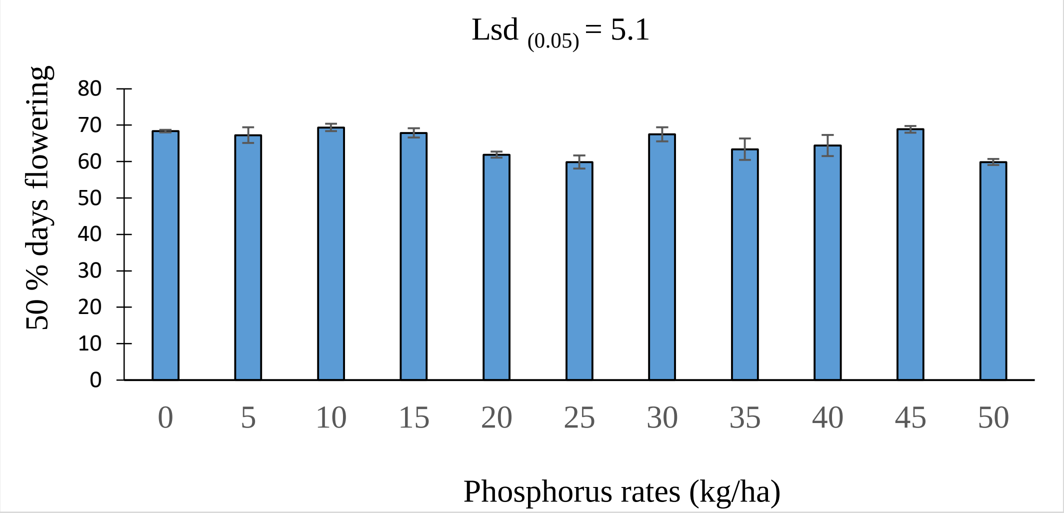

Figure 19: Impact of P_2O_5 calibration rate on days to 50% flowering of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Cob weight

Cob weight was highly significantly affected (*P = 0.001*) by the application of different rates of phosphorus. However, 50 and 20 kg/ha recorded the highest cob weight of 27.3 and 27.4 g/cob respectively while 00 kg/ha recorded the least cob weight of 19.6 g/cob (Figure 20).

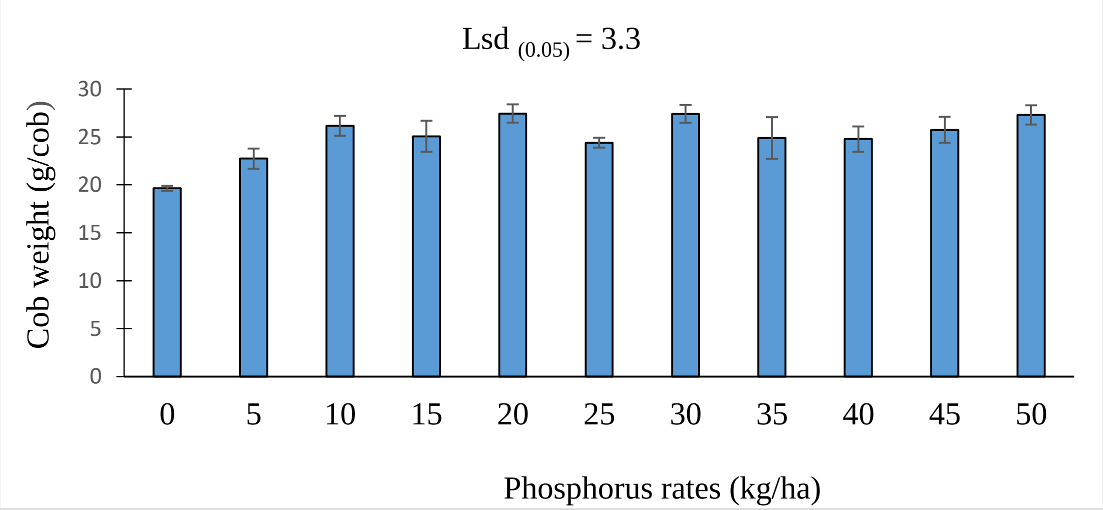

Figure 20: Impact of P_2O_5 calibration rate on cob weight of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Cob length

The Cob weight recorded for the different P application rates showed a significant difference (*P = 0.05*). However, 35 kg/ha recorded the highest cob length of 14.9 cm followed by 50 kg/ha with 13.1 cm while 00 kg/ha recorded the least cob length of 8.35 cm (Figure 21).

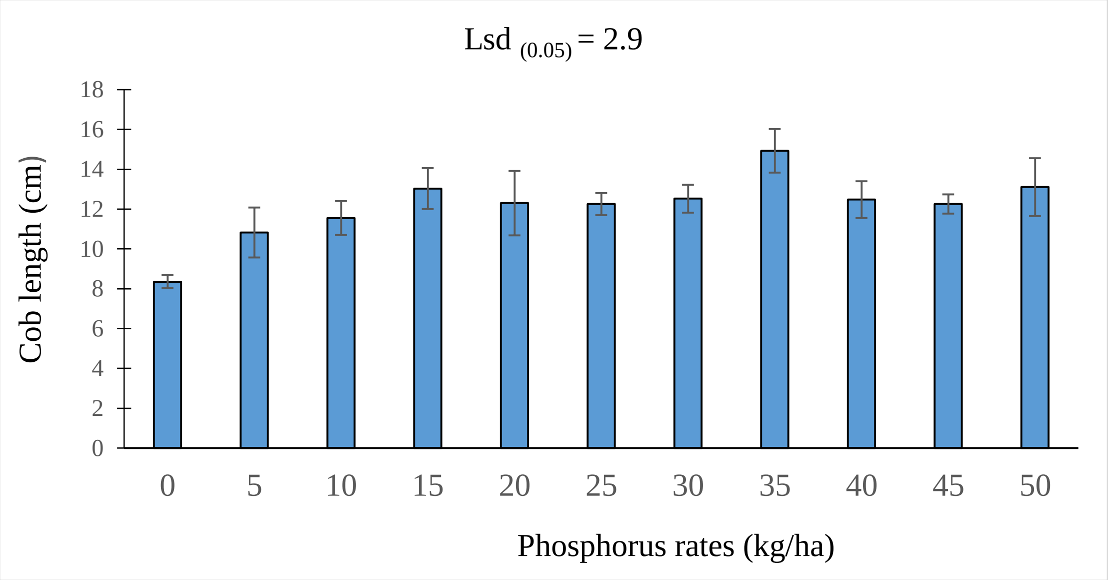

Figure 21: Impact of P_2O_5 calibration rate on cob length of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Weight of 100 seeds

Hundred seeds weight showed highly significant difference (*P = 0.001*) as affected by the application of different rates of phosphorus, there was a general increase in hundred seeds weight with increasing rates of P application however 50 kg/ha recorded the highest weight of 23.9 g followed 45 kg/ha with 23.5 g respectively while 00 kg /ha recorded the least hundred seeds weight of 14.8 g (Figure 22).

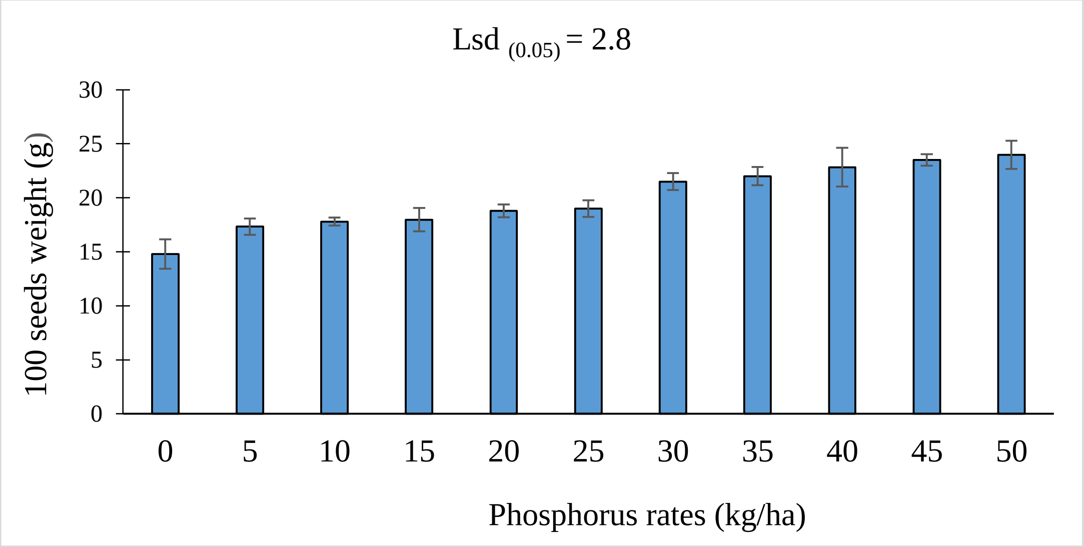

Figure 22: Impact of P_2O_5 calibration rate on 100 seeds weight of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

Straw weight

Straw weight was highly significantly affected (*P = 0.001*) by the application of different rates of phosphorus. There was a general increase in straw weight with increasing rates of P application however 50 kg/ha recorded the highest weight of 9.3 t/ha followed by 45 kg/ha and 40 kg/ha with 7.9 and 7.3 t/ha respectively while 00 kg/ha recorded the minimum straw weight (Figure 23).

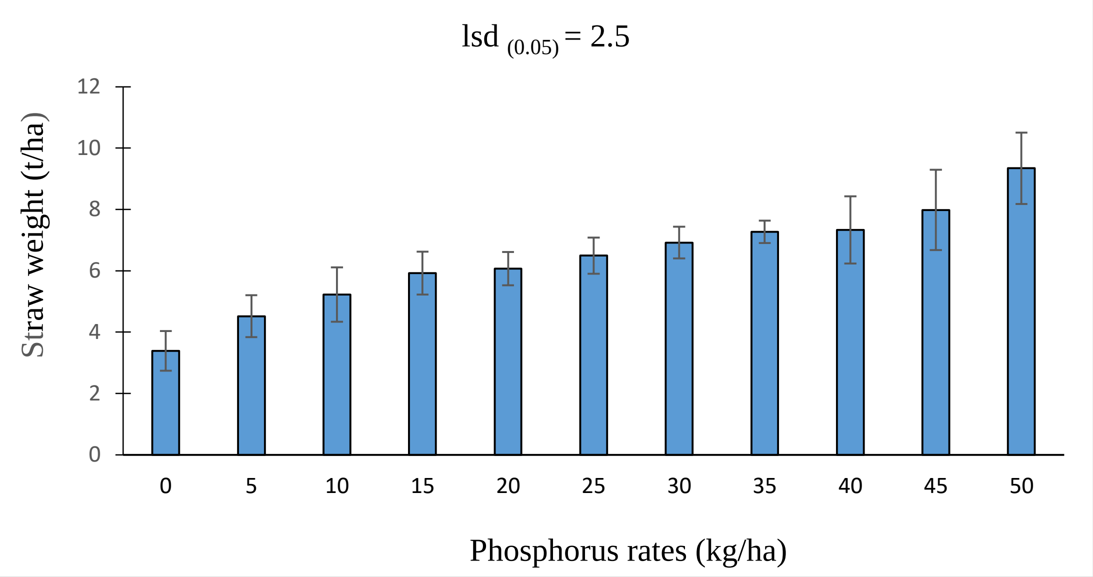

Figure 23: Impact of P_2O_5 calibration rate on straw weight of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM)

Grain yield

Grain yield was highly significantly affected (*P = 0.05*) by the application of different rates of phosphorus. There was a general increase in grain yield with increasing rates of P application however 50 kg/ha recorded the highest grain yield of 3.09 t/ha followed by 45kg/ha and 40 kg/ha with 3.02 and 2.8 t/ha respectively (Figure 24).

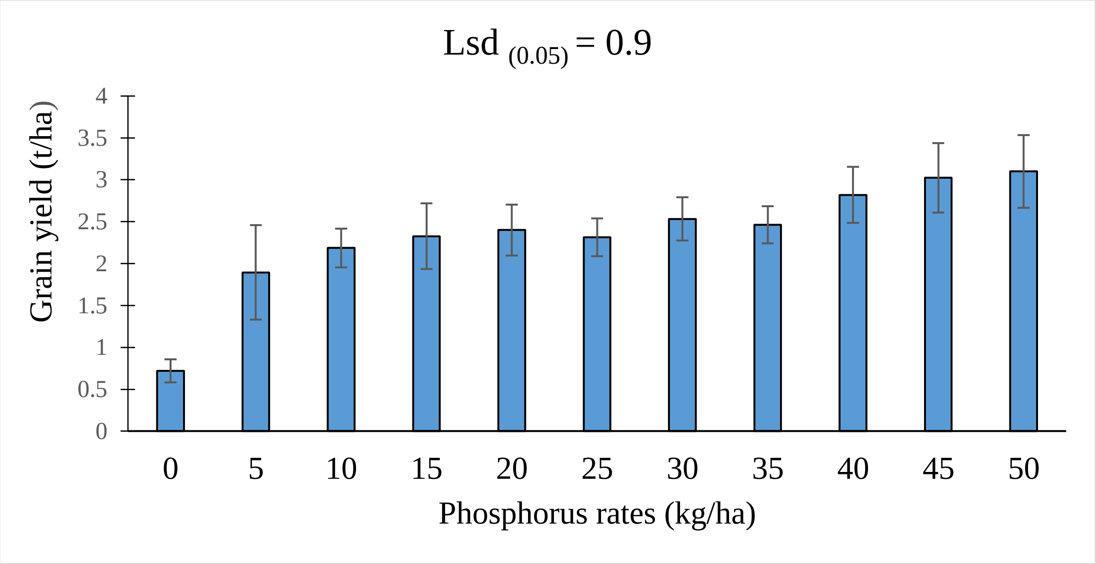

Figure 24: Impact of P_2O_5 calibration rate on grain yield of maize cultivated in the guinea savannah zone of Ghana. Error bars represent standard error of means (SEM).

4.2.2 Predictability of maize growth and yield by calibrated soil P tool

The regression analysis between yield, straw weight, cob length, cob weight and that of available P in the calibrated range indicated that grain yield, straw weight, cob length, cob weight at harvest were highly determined available P content of the soil (Figure 25, 26, 27, 28) with R^2 values of 0.8092, 0.8926, 0.5476 and 0.3988 respectively which shows that there is strong relationship between grain yield, straw weight, cob length, cob weight and soil available P as estimated in the experiment.

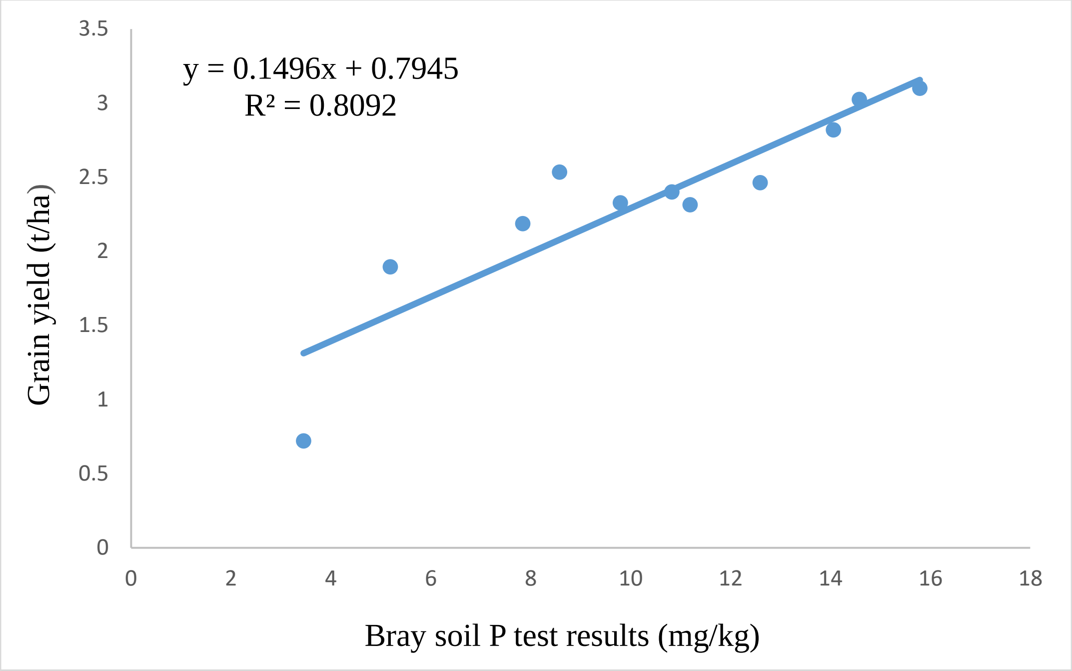

Figure 25: Relation between grain yield of maize and calibrated soil P (mg/kg)

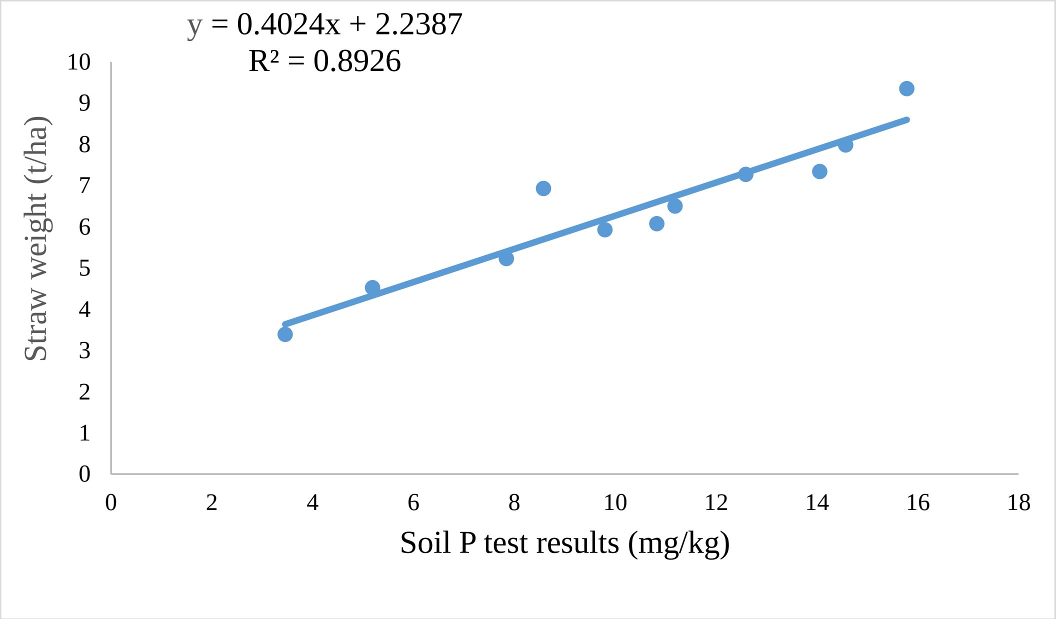

Figure 26: Relation between straw weight of maize and calibrated soil P (mg/kg)

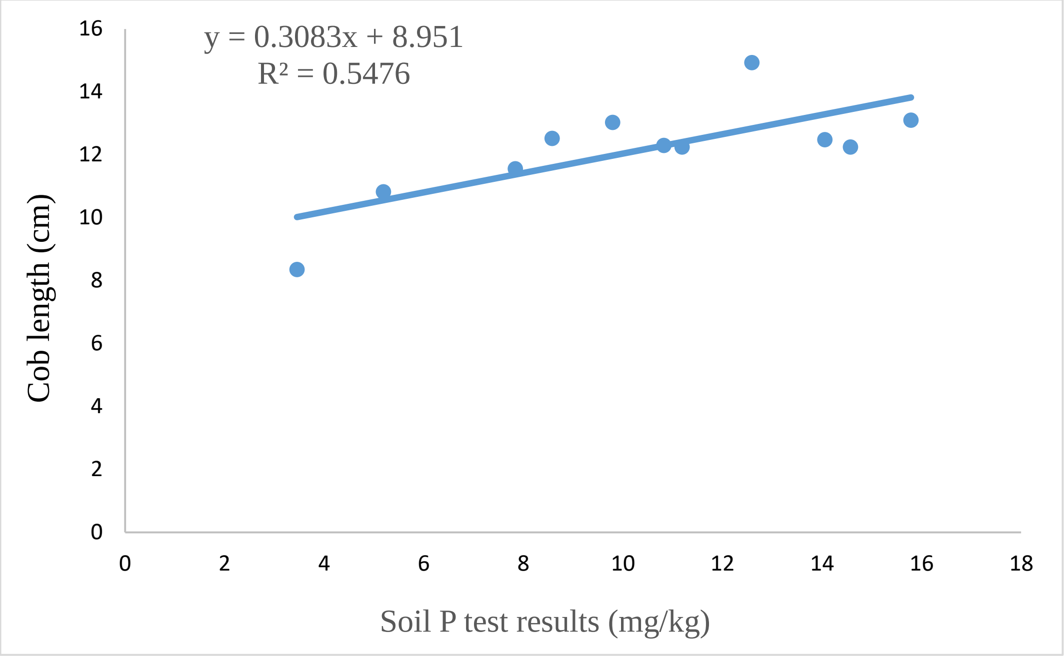

Figure 27: Relation between cob lengths of maize and calibrated soil P (mg/kg)

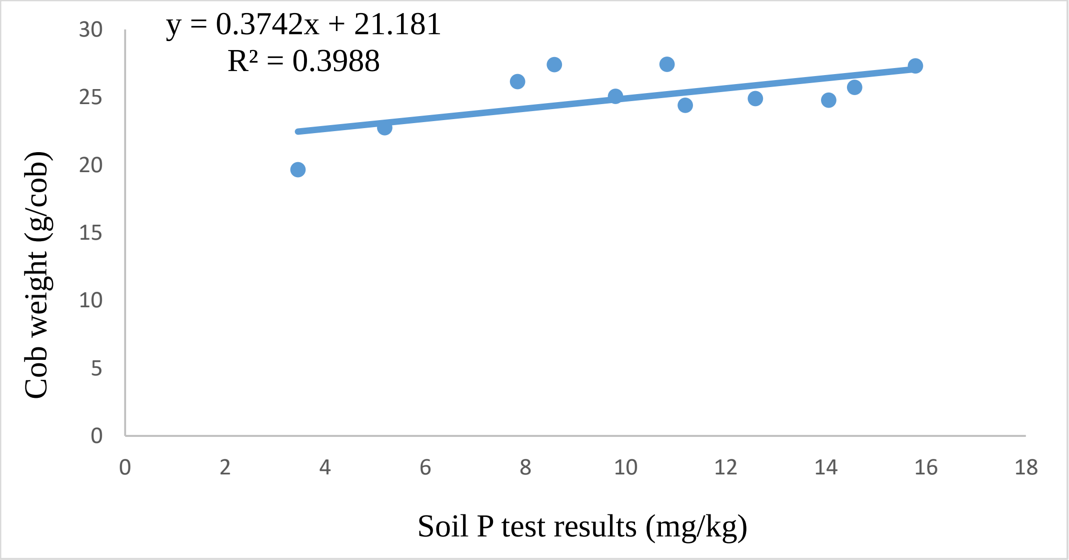

Figure 28: Relation between cob weight of maize and calibrated soil P (mg/kg) test results

4.2.3 Prediction of plant-available P from soil chemical analyses using the P fertilization tool

Regression analysis indicated that P fertilization tool can be used to predict plant available phosphorus in a given soil (Figure 29). The R^2 value was 0.0.8841 and shows that there is a strong relationship between calibrated rate of fertilization and results of chemical analyses for available P. A regression equation (5.2563 × P) – 21.675, where P represents the soil analysed available P level, can be used to predict the P levels of a given soil.

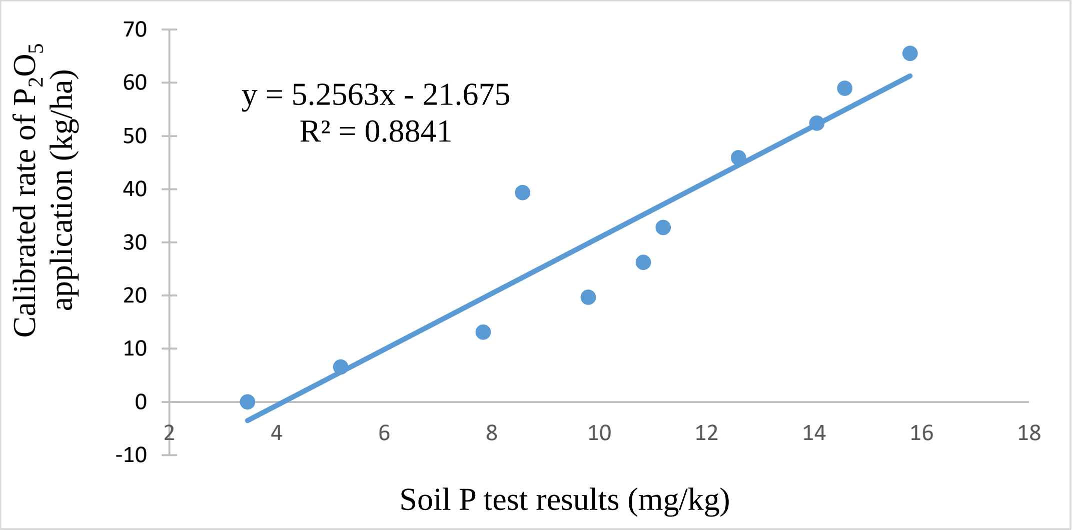

Figure 29: Relation between calibrated P_2O_5 and plant-available soil P (mg/kg)

4.2.4 Prediction of P fertilizer top-up from calibrated soil test results

The relation between rate and soil test indicated that the developed P fertilization tool can be used to predict P fertilizer top-up in a given soil. The R^2 value was 0.8841 and indicates that there is a strong possibility that the developed calibrated tool could be used to predict P fertilizer top-up since all points are close to the line of best fit (Figure 30). A regression equation (5.2563 × P) – 21.675, where P represents the soil analysed available P level, can be used as a proxy to predict the level of P fertilizer in a given soil. A difference between the recommended rate (50 kg/ha) and the tool-predicted rate from the regression equation, then becomes the quantity of fertilizer P that must top-up to attain optimum productivity.

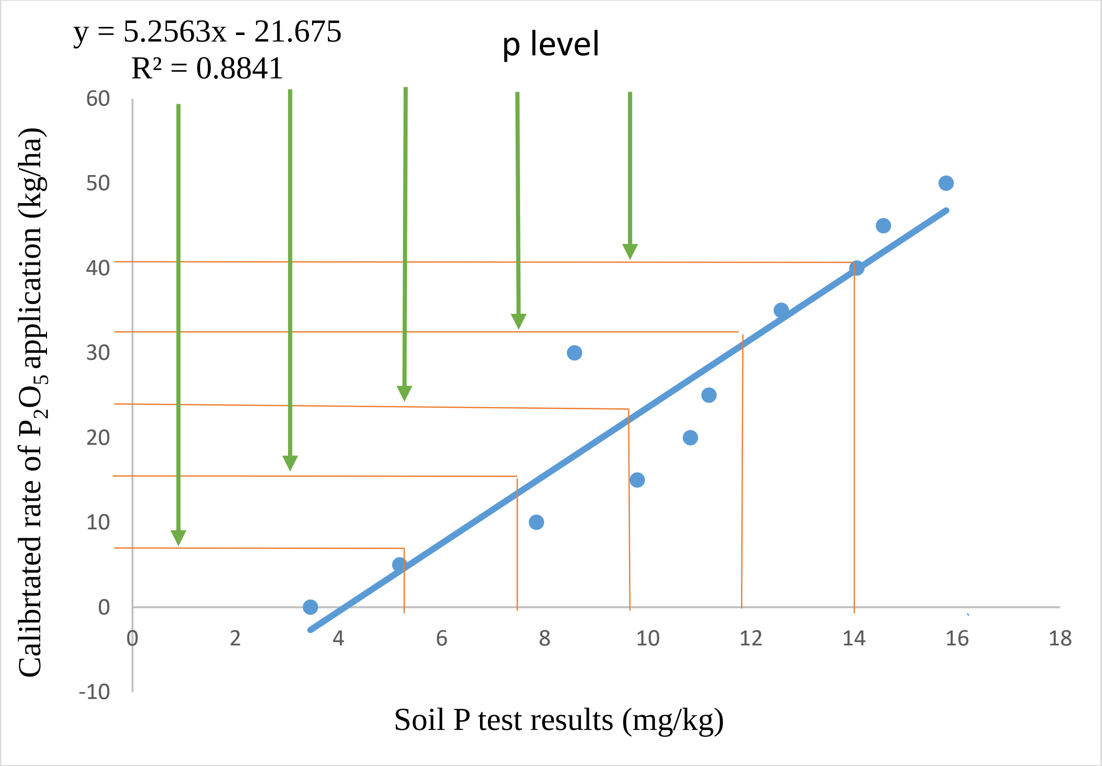

Figure 30 : Developed calibrated tool for prediction of P_2O_5 fertilizer top-up from soil test results

4.3 Evaluation and validation of calibrated tools for site-specific application of nitrogen and phosphorus fertilizers

The initial physicochemical properties of the soils at the experimental sites are presented in (Table 3). The results indicated that soils at the site in Tamale had the highest pH of 6.74 followed by Nyankpala with a pH of 5.5 while Damango had the least pH of 4.85. However, the pH for both Tamale and Nyankpala are within the recommended range of 5 to 7 which is suitable for maize production. The pH at Damango is slightly acidic and may not be suitable for maize production. Least organic carbon of 0.956% was noted at Damango while Nyankpala recorded the highest organic carbon of 1.268% followed by Tamale with organic carbon of 1.014%. A higher nitrogen, phosphorus and potassium levels were noted at Nyankpala followed by Damango while Tamale recorded the least. The nutrient (N, P and K) contents at all the sites were low for maize cultivation. The soil texture at both Nyankpala and Damango was sandy clay loam which is suitable for cropping. However, the texture of the field trial and the pot trial were same which is a good indication that the results obtained from soils of the pot experiment can be generally applied to the other sites.

Table 3: Initial soil physico-chemical properties at the three sites used for evaluation and validation of the calibrated tools. Values are means, and standard errors are presented in brackets

Samples	BD (g/cm^3)	pH H$_2$0 (1:2:3)	% O.C	mg/kg N	mg/kg P	mg/kg K	Cmol+/kg Ca	Cmol+/kg Mg	Texture		
									% Sand	% Silt	% Clay
Nyankpala	1.52 (±0.018)	5.50 (±0.058)	1.268 (±0.025)	0.122 (±0.006)	10.64 (±0.340)	89 (±1.155)	3.28 (±0.544)	1.9 (±0.346)	79.6 (±2.146)	19.12 (±0.492)	1.28 (±0.907)
Tamale	1.49 (±0.006)	6.74 (±0.774)	1.014 (±0.024)	0.047 (±0.008)	5.775 (±0.598)	51 (±4.583)	1.04 (±0.010)	0.56 (±0.076)	63.44 (±7.606)	35.72 (±2.190)	0.84 (±0.074)
Damango	1.29 (±0.010)	4.85 (±0.142)	0.956 (±0.058)	0.089 (±0.010)	8.103 (±0.590)	78 (±1.732)	2.4 (±0.378)	0.64 (±0.034)	63.44 (±1.382)	33.72 (±1.105)	2.84 (±0.476)

4.3.1 Evaluation of calibrated soil test tool for predicting site-specific N fertilization in maize production

The nitrogen top-up rates that were predicted for each site by the calibration tool accurately maximized maize growth and yield at all the three sites (Table 4a and 4b). There was a significant difference between the expected values and the obtained values for plant height at maturity, days to 50% flowering, leaf area index, hundred seed weight, cob weight, cob length, straw and grain yield (Table 5a, 5b and 5c). However, no significant difference was observed on grain yield, straw weight (Table 5b), days to 50% flowering and straw weight (Table 5c). For plant height, the predicted N application rate of 60 kg/ha, 140 kg/ha and 110 kg/ha each as a top-up requirement for Nyankpala, Tamale and Damango, respectively affected plant height with attained heights of 131, 138 and 130 cm. The N-prediction tool had a predictability of 90, 95 and 90% respectively for Nyankpala, Tamale and Domango.

Table 4a: Maize growth and yield response to N-calibrated tool at three sites in the Guinea savannah zone of Ghana

	Sites		
	Nyankpala	Tamale	Damango
Soil test N (mg/kg)	0.122	0.047	0.089
N application rates predicted from calibrated tool (kg/ha)	60	140	110
N rates added (kg/ha) through fertilization	60	140	110
Expected height (cm)	144	144	144
Height obtained (cm)	131	138	130
Prediction percentage (%)	90	95	90
Expected days to 50% flowering	54	54	54
obtained days to 50% flowering	52	51	55
Prediction percentage (%)	96	94	100
Expected leaf area index (m^2/m^2)	7.4	7.4	7.4
Leaf area index obtained (m^2/m^2)	6.4	6.8	6.9
Prediction percentage (%)	86	91	93
Expected hundred seed weight (g)	25	25	25
Obtained hundred seed weight (g)	24.1	23.6	24.3
Prediction percentage (%)	96	94	97

Table 4b: Maize growth and yield response to N-calibrated tool at three sites in the Guinea savannah zone of Ghana

	Sites		
	Nyankpala	Tamale	Damango
Soil test N (mg/kg)	0.122	0.047	0.089
N application rates predicted from calibrated tool (kg/ha)	60	140	110
N rates added (kg/ha) through fertilization	60	140	110
Expected height (cm)	144	144	144
Height obtained (cm)	131	138	130
Prediction percentage (%)	90	95	90
Expected days to 50% flowering	54	54	54
obtained days to 50% flowering	52	51	55
Prediction percentage (%)	96	94	100
Expected leaf area index (m^2/m^2)	7.4	7.4	7.4
Leaf area index obtained (m^2/m^2)	6.4	6.8	6.9
Prediction percentage (%)	86	91	93
Expected hundred seed weight (g)	25	25	25
Obtained hundred seed weight (g)	24.1	23.6	24.3
Prediction percentage (%)	96	94	97

For days to 50% flowering, the predicted N application rate of 60 kg/ha, 140 kg/ha and 110 kg/ha each as a top-up requirement for Nyankpala, Tamale and Damango, affected the number of days. The site at Nyankpala used 52 days to flower, the one at Tamale used 51 days to flower and that at Damango used 55 days to flower. The N-prediction tool correctly predicted days to 50% flowering with a predictability of 96, 94 and 100% respectively for Nyankpala, Tamale and Damango respectively.

Leaf area index was affected by the predicted N application rate of 60 kg/ha, 140 kg/ha and 110 kg/ha each as top-up requirement for Nyankpala, Tamale and Damango, respectively. Recorded leaf area indices were 6.4, 6.8 and 6.9 respectively at the three sites. The N-prediction tool correctly predicted leaf area index with a predictability of 86, 91 and 93% respectively for Nyankpala, Tamale and Damango respectively.

Hundred seed weight, cob weight, cob length, straw weight and yield were all affected by the predicted N application rate of 60 kg/ha, 140 kg/ha and 110 kg/ha each as top-up requirement for Nyankpala, Tamale and Damango, respectively. Recorded hundred seed weights were 24.1, 23.6 and 24.3 g respectively at the three sites. The N-prediction tool correctly predicted hundred seed weight with a predictability of 96, 94 and 97% respectively for Nyankpala, Tamale and Damango.

Cob weights recorded for the three sites were 15.6 g/cob, 16.4 g/cob and 15.2 g/cob respectively. The N-prediction tool correctly predicted cob weights with a predictability of 89, 93 and 89% respectively for Nyankpala, Tamale and Damango.

Recorded cob lengths were 13.4, 13.8, 13.1 cm respectively at the three sites. The N-prediction tool correctly predicted maize cob length with a predictability of 92, 95 and 90% respectively for Nyankpala, Tamale and Damango. Straw weight was also accurately predicted with a predictability of 93, 97 and 90% respectively for Nyankpala, Tamale and Damango.

Grain yield was accurately predicted by the nitrogen fertilization tool. Recorded grain yields upon application of the predicted rates of 60 kg/ha, 140 kg/ha and 110 kg/ha were 4.5 t/ha, 5 t/ha and 4.9 t/ha respectively Nyankpala, Tamale and Damango. The N-prediction tool correctly predicted grain yield with a predictability of 90, 100 and 98% respectively for Nyankpala, Tamale and Damango.

Table 5a: T test of attained values at Nyankpala and maximum expected values recorded in the pot experiment

Parameters	T test (stats)	P value
Plant height (cm)	-22.51	0.001
50% flowering	-7.00	0.019
Leaf area index (m^2/m^2)	-31.00	0.001
Hundred seed weight (g)	-6.40	0.020
Cob weight (g/cob)	-15.52	0.004
Cob length (cm)	-12.00	0.006
Straw weight (t/ha)	-8.20	0.014
Grain yield (t/ha)	-6.50	0.021

Table 5b: T test of attained values at Tamale and maximum expected values recorded in the pot experiment

Parameters	T test (stats)	P value
Plant height (cm)	-19.00	0.002
50% flowering	-8.00	0.010
Leaf area index (m^2/m^2)	-17.00	0.003
Hundred seed weight (g)	-4.23	0.050
Cob weight (g/cob)	-5.12	0.030
Cob length (cm)	-6.25	0.020
Straw weight (t/ha)	-3.40	0.070
Grain yield (t/ha)	-2.00	0.180

Table 5c: T test of attained values at Damango and maximum expected values recorded from the pot experiment.

Parameters	T test (stats)	P value
Plant height (cm)	-4.25	0.05a
Days to 50% flowering?	0.50	0.66
Leaf area index (m^2/m^2)	-5.29	0.03
Hundred seed weight (g)	-4.80	0.04
Cob weight (g/cob)	-3.96	0.05
Cob length (cm)	-7.16	0.01
Straw weight (t/ha)	-2.52	0.12
Grain yield (t/ha)	-4.00	0.05

Tables 5a, 5b and 5c show the difference between growth parameters, yield and yield component values obtained and the values expected at each location. The t- test showed a significant difference between the expected and the obtained values for all the growth parameters, yield and yield components at Nyankpala (Table 5 a). In Tamale, grain yield and straw weight did not show any significance [*t* (stat) = -2.00, *P = 0.180, t* (stat) -3.40, *P = 0.070* respectively], indicating similar performance of the tool-predicted rate to the optimum rate applied in the pot experiment. For the site at Damango, straw weight and days to 50% flowering did not show any significant difference among the expected and obtained values [*t* (stat) = -2.52, *P = 0.12*, *t* (stat) = 0.50, *P = 0.66*] while plant height, leaf area index, hundred seed weight, grain yield, cob weight and cob length showed significant difference among the expected and obtained values (Table 5 c).

4. 3.2 Validation of calibrated soil test tool for predicting site-specific N fertilization in maize production

Comparing the growth and yield of maize in the zero-fertilization rate, optimum recommended rate (120 kg/ha) and the tool-predicted rate for each site showed that plant height at maturity in Nyankpala, statistically showed significant difference ($P = 0.001$) between the optimum rate and the tool-predicted rate (Table 6). However, plant height significantly differed between these fertilization regimes and that of the unfertilized treatment. Similar observations were made at Tamale and Damango respectively ($P = 0.003$ and 0.015 respectively). However, in Nyankpala the recommended rate of 120 kg/ha recorded the highest plant height of 134 cm followed by the tool-predicted rate of 60 kg/ha with 131cm while the zero rate of 0 kg/ha had the least height of 69.2 cm (Table 6). In Tamale the recommended rate recorded the highest plant height followed by the tool-predicted rate while the zero recorded the least (Table 6). In Damango the recommended rate had the highest plant height followed by the tool-predicted rate while the zero recorded the least plant height (Table 6).

Table 6: Comparative performance of tool-predicted nitrogen rate on plant height of maize cultivated at three sites during the 2019 cropping season.

Site/N rate	Plant height (cm)
Nyankpala	
Zero rate (00 kg/ha)	69.2 ^{a}
Tool-predicted rate (60 kg/ha)	131^{b}
Recommended rate (120 kg/ha)	134 ^{b}
p-value	0.001**
Tamale	
Zero rate (00 kg/ha)	81.5 ^{a}
Tool-predicted rate (140 kg/ha)	138 ^{b}
Recommended rate (120 kg/ha)	140 ^{b}
p-value	0.003 **
Damango	
Zero rate (00 kg/ha)	68.1^{a}
Tool-predicted rate (110 kg/ha)	130^{b}
Recommended rate (120 kg/ha)	135^{b}
p-value	0.015**

For hundred seed weight, Nyankpala, statistically showed a significant difference (*P = 0.050*) between the rates of nitrogen fertilization. There was however, no difference between yields obtained in the tool-predicted rate compared to the recommended rate. In Tamale and Damango, however, there were no significant differences (*P = 0.519* and *0.349* respectively) among the different rates of nitrogen fertilization on hundred seed weight. In Nyankpala, the tool-predicted rate of 60 kg/ha and the recommended rate of 120 kg/ha recorded similar average seed weight of 24.1 and 24.9 g respectively, while the zero rate of 0 kg/ha had 20 g (Figure 31). In Tamale the tool-predicted rate recorded the highest seed weight followed by the recommended rate while the zero rate recorded least (Figure 32) while in Damango the tool-predicted rate also recorded the highest seed weight followed by the recommended rate while the zero rate recorded the least (Figure 33).

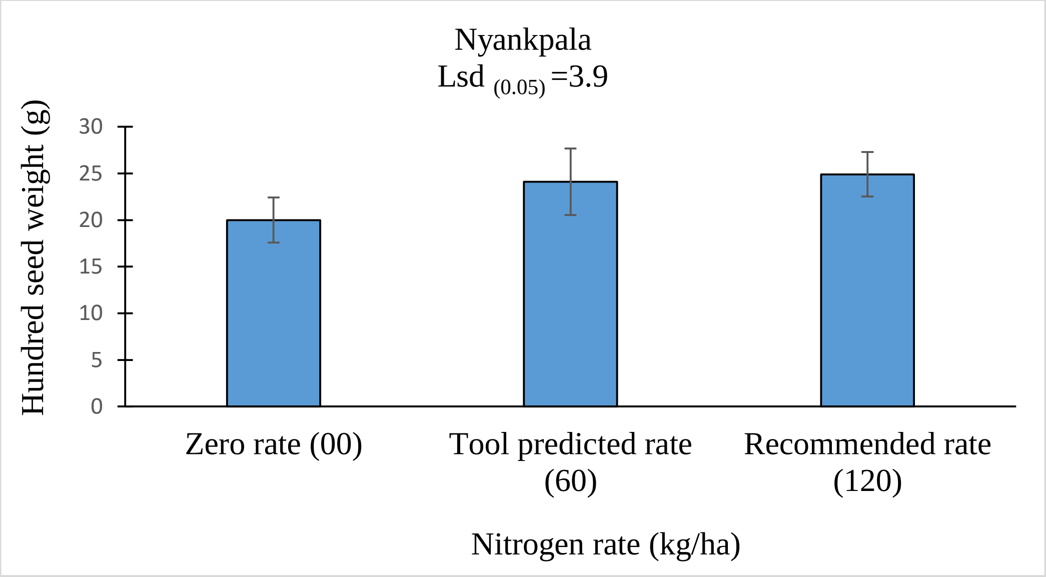

Figure 31: Comparative performance of tool-predicted nitrogen rate on hundred seed weight of maize cultivated at Nyankpala during the 2019 cropping season. Error bars represent standard error of means.

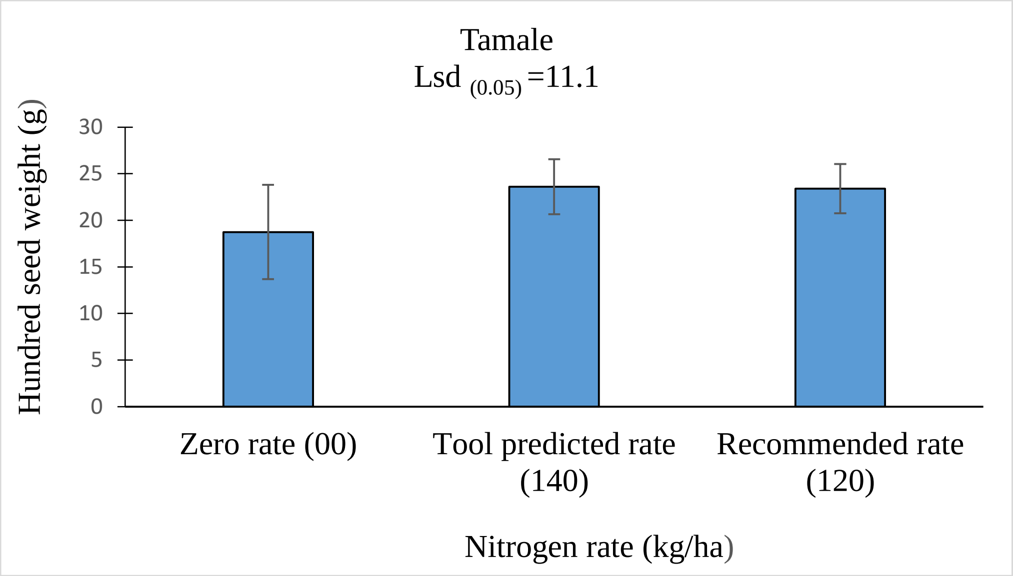

Figure 32: Comparative performance of tool-predicted nitrogen rate on hundred seed weight of maize cultivated at Tamale during the 2019 cropping season. Error bars represent standard error of means.

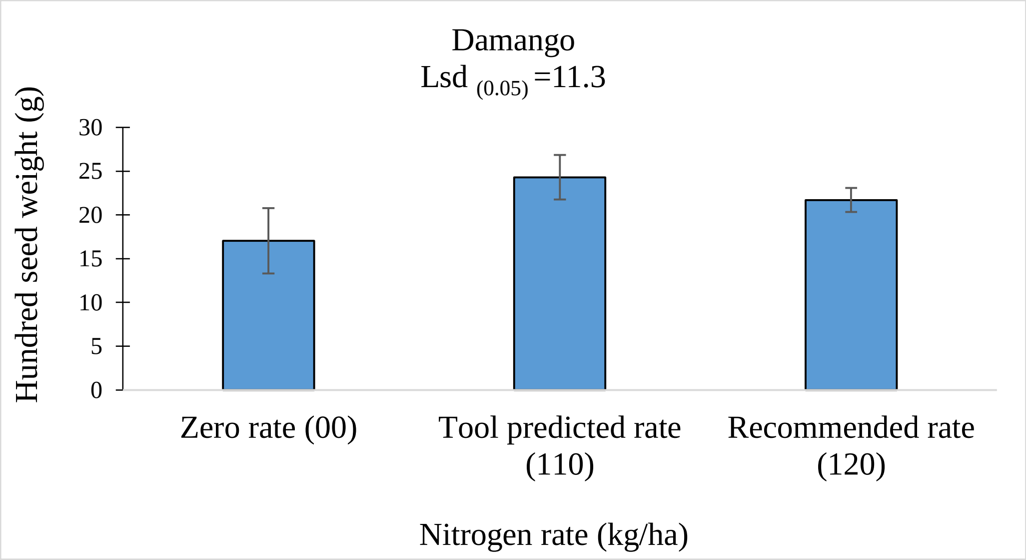

Figure 33: Comparative performance of tool-predicted nitrogen rate on hundred seed weight of maize cultivated at Damango during the 2019 cropping season. Error bars represent standard error of means.

At Nyankpala, there was statistically significant difference in cob weight between the tool-predicted rate and the recommended rate on one hand and the zero rate on the other hand (*P = 0.05*). In Tamale and Damango, however, there was no such significant differences (*P = 0.125* and *0.211* respectively). In Nyankpala the tool-predicted rate of 60 kg/ha and the recommended rate of 120 kg/ha recorded similar average cob weight in the range of 15.6 to 17.05 g/cob while zero rate of 00 kg/ha had 9.7 g/cob (Figure 34). Generally, in Tamale the tool-predicted rate 140 kg/ha recorded the highest cob weight followed by the recommended rate while the zero rate recorded least (Figure 35) while in Damango the tool-predicted rate of 110 kg/ha also recorded the highest followed by the recommended rate while the zero rate recorded the least cob weight (Figure 36).

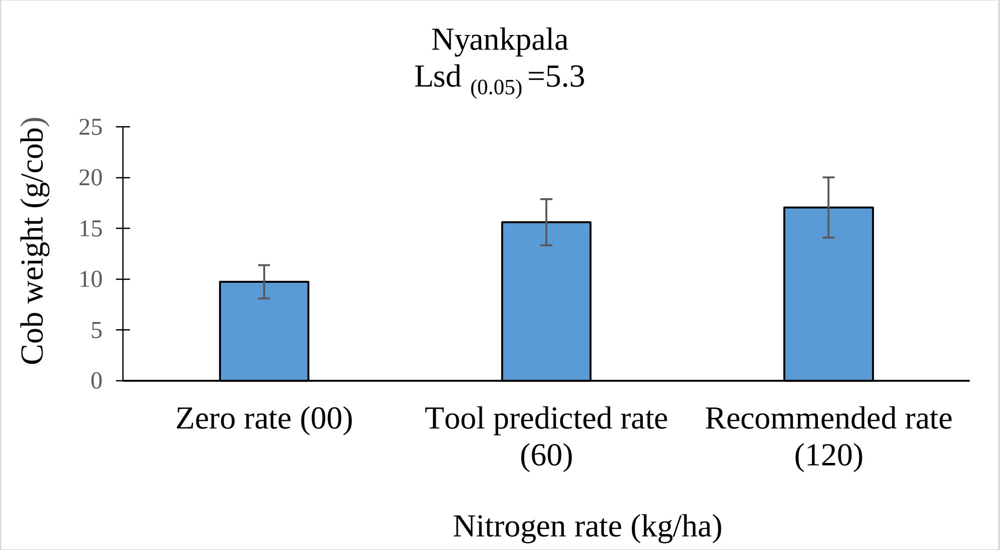

Figure 34: Comparative performance of tool-predicted nitrogen rate on cob weight (g/cob) of maize cultivated at Nyankpala during the 2019 cropping season. Error bars represent standard error of means.

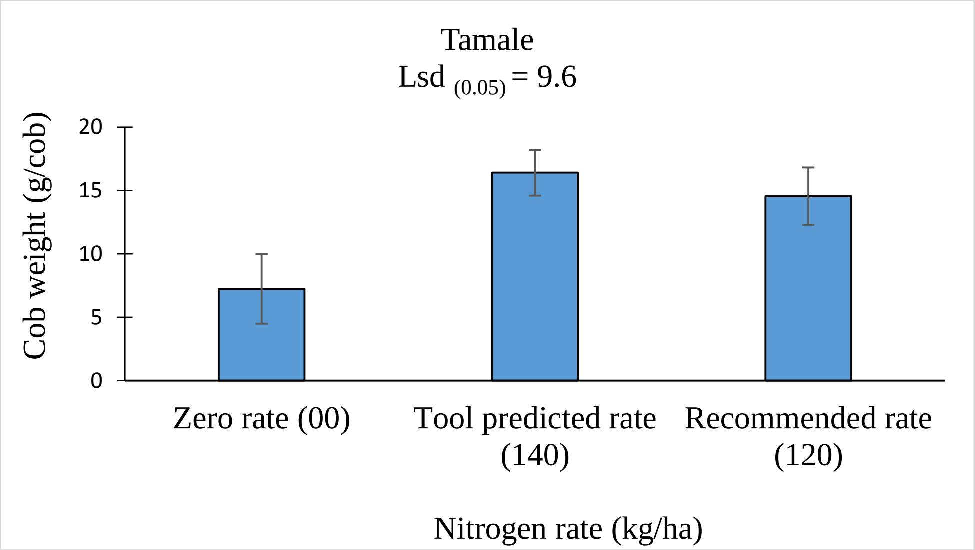

Figure 35: Comparative performance of tool-predicted nitrogen rate on cob weight (g/cob) of maize cultivated at Tamale during the 2019 cropping season. Error bars represent standard error of means.

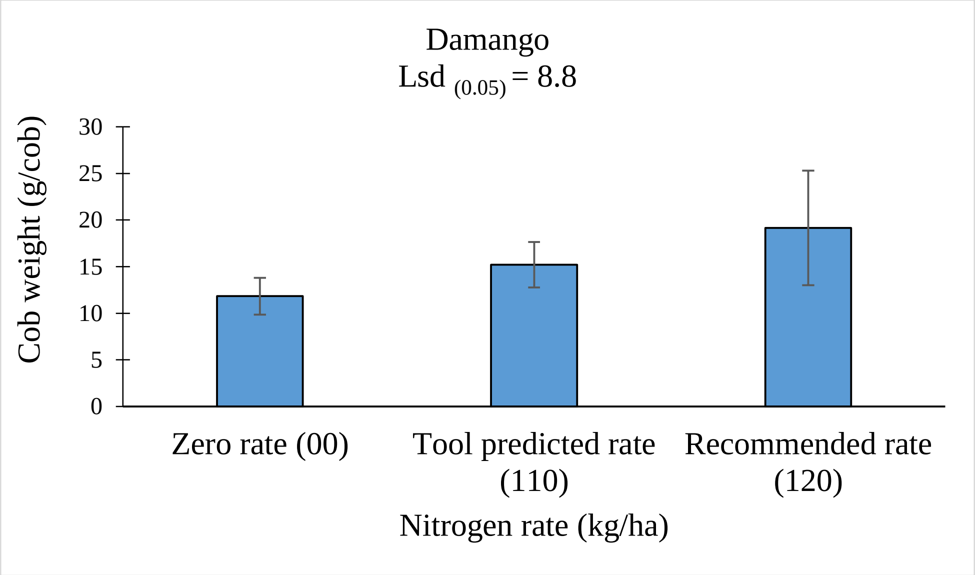

Figure 36: Comparative performance of tool-predicted nitrogen rate on cob weight (g/cob) of maize cultivated at Damango during the 2019 cropping season. Error bars represent standard error of means.

For cob length, there was statistically significant variation (*P = 0.05*) between the different rates of nitrogen fertilization in Tamale. In contrast, there was no statistically significant variation in cob length between the fertilizer rates in Nyankpala and Damango (*P = 0.079* and *0.073* respectively). However, in Nyankpala the tool-predicted rate recorded the longest cob length followed by the recommended rate while the zero rate had the minimum cob length (Figure 37). In Tamale the tool-predicted rate recorded the highest cob length followed by the recommended rate while the zero rate recorded the least cob length (Figure 38). The cob lengths were however statistically similar between the tool-predicted rate and the recommended rate. In Damango, the tool-predicted rate also recorded the highest followed by the recommended rate while the zero rate recorded the least cob length (Figure 39).

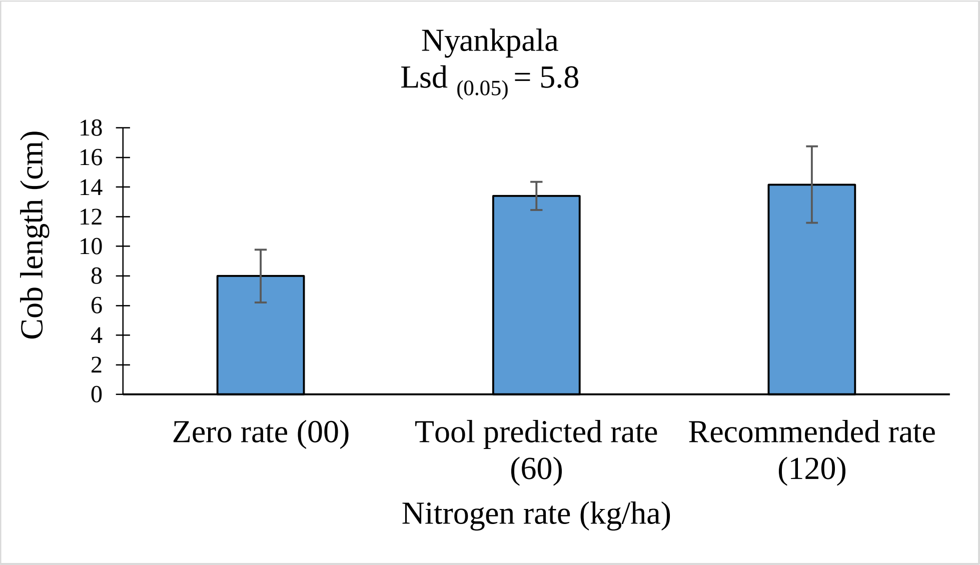

Figure 37: Comparative performance of tool-predicted nitrogen rate on cob length of maize cultivated at Nyankpala during the 2019 cropping season. Error bars represent standard error of means.

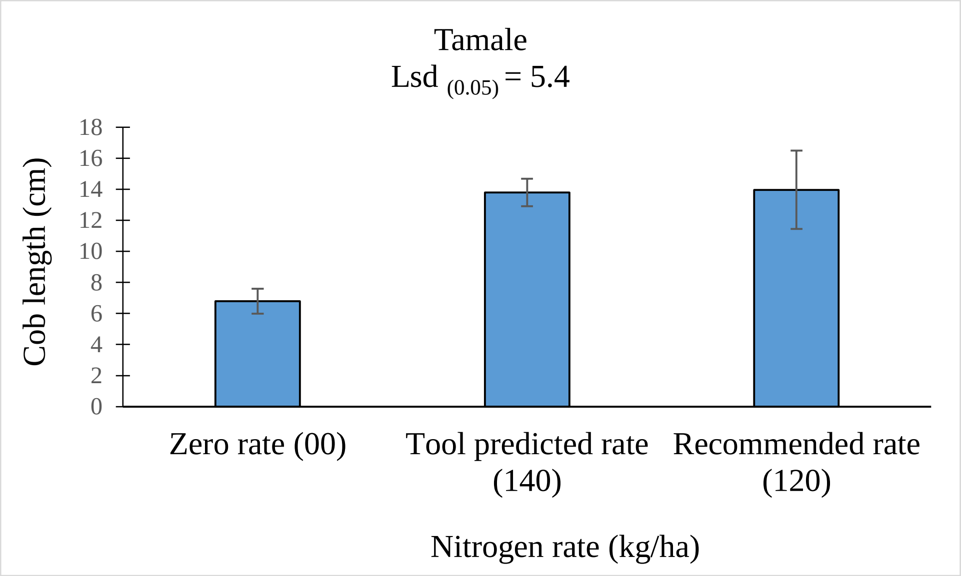

Figure 38: Comparative performance of tool-predicted nitrogen rate on cob length of maize cultivated at Tamale during the 2019 cropping season. Error bars represent standard error of means.

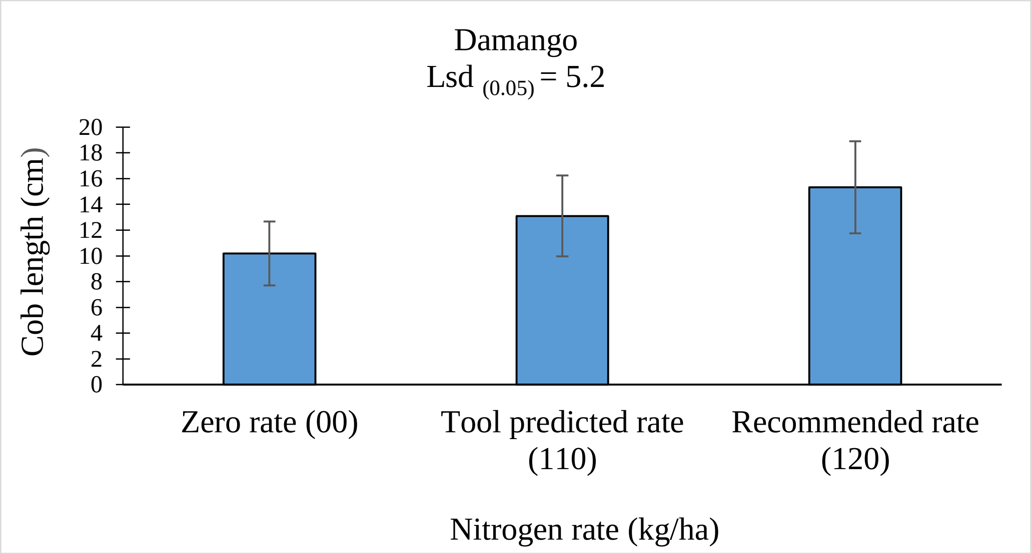

Figure 39: Comparative performance of tool-predicted nitrogen rate on cob length of maize cultivated at Damango during the 2019 cropping season. Error bars represent standard error of means.

Across all three sites, straw weight was not statistical affected by the rate of fertilization (*P* = *0.113*, *0.472* and *0.258* respectively for Nyankpala, Tamale and Damango. However, in Nyankpala the tool-predicted rate and the recommended rate recorded similar average straw weight, which were higher than that of the zero rate (Figure 40). In Tamale tool-predicted rate recorded the highest straw weight followed by the recommended rate while the zero rate recorded the least (Figure 41) while in Damango the tool-predicted rate also recorded the highest followed by the recommended rate and the zero rate recorded the least straw weight (Figure 42).

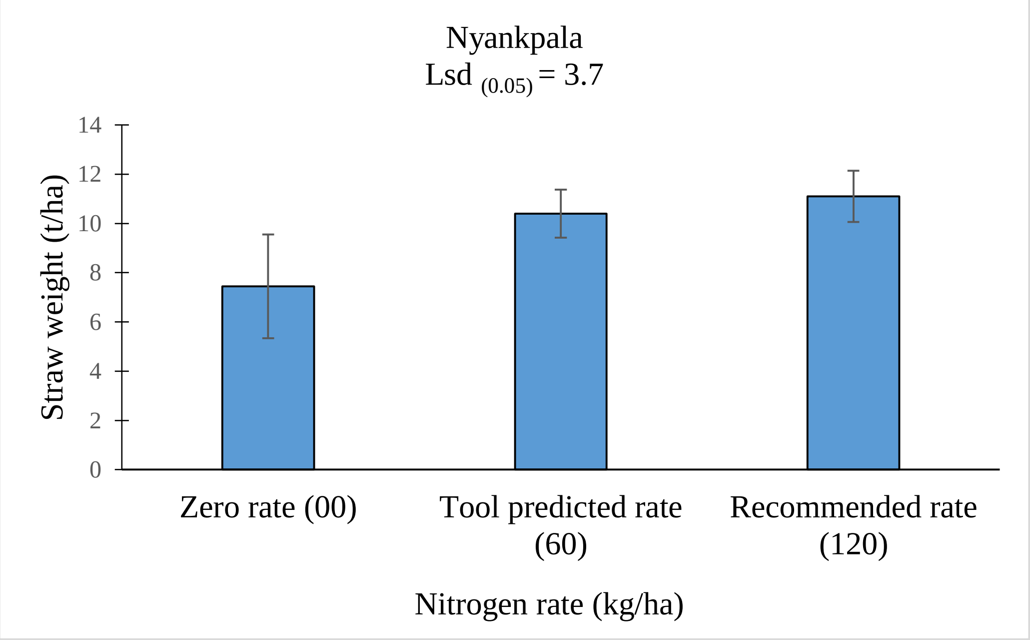

Figure 40: Comparative performance of tool-predicted nitrogen rate on straw weight of maize cultivated at Nyankpala during the 2019 cropping season. Error bars represent standard error of means.

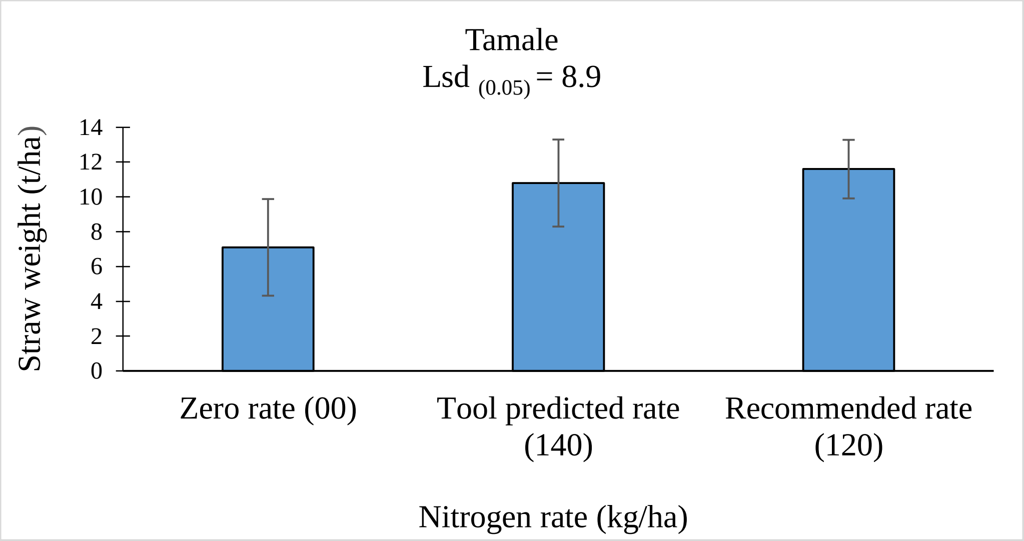

Figure 41: Comparative performance of tool-predicted nitrogen rate on straw weight of maize cultivated at Tamale during the 2019 cropping season. Error bars represent standard error of means.

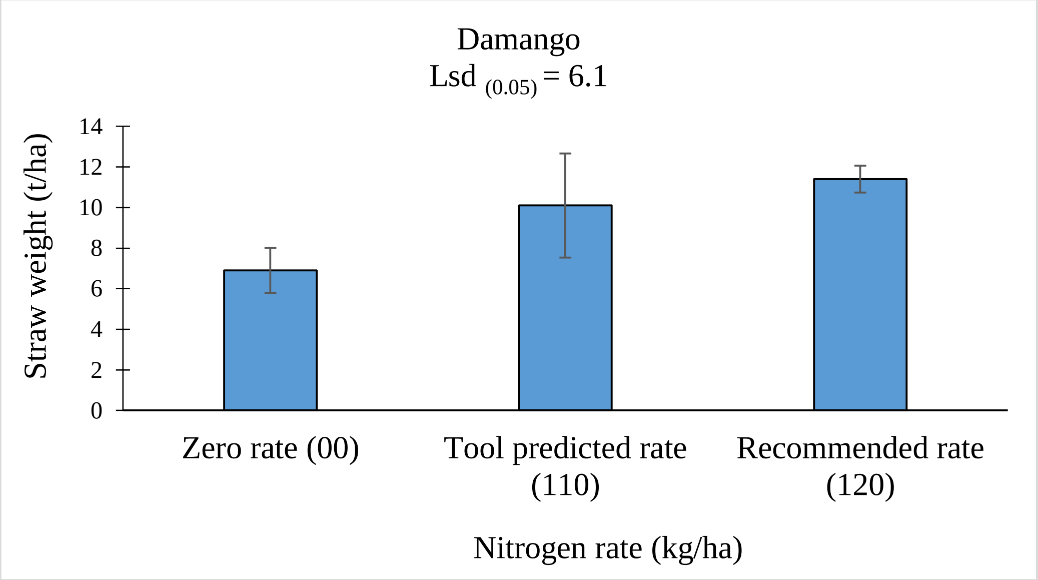

Figure 42: Comparative performance of tool-predicted nitrogen rate on straw weight of maize cultivated at Nyankpala during the 2019 cropping season. Error bars represent standard error of means.

Comparing the yield of maize in the zero-fertilization rate, optimum recommended rate (120 kg/ha) and the tool-predicted rate for each site showed that grain yield after harvest in Nyankpala, statistically showed significant difference (*P = 0.043*) between the three rates. However, there was no significant difference between yield obtained at the recommended blanket rate and yield obtained with the tool-predicted rate (Figure 43). Grain yield significantly differed between these two fertilization regimes and that of the unfertilized treatment. Moreover, there was no significant deference between the recommended rate and the tool-predicted rate. Similar observations were made at Tamale and Damango (*P = 0.028* and *0.050)* respectively.

At Nyankpala the blanket recommended rate recorded average yield of 4.7 t/ha which is not different from that of tool-predicted rate of 4.5 t/ha while zero rate recorded least yield of 1.35 t/ha (Figure 43). In Tamale tool-predicted rate recorded the highest grain yield followed by the recommended rate while the zero rate recorded least yield (Figure 44) while in Damango the blanket recommended rate also recorded the highest followed by the predicted tool rate while the zero rate recorded least grain yield (Figure 45).

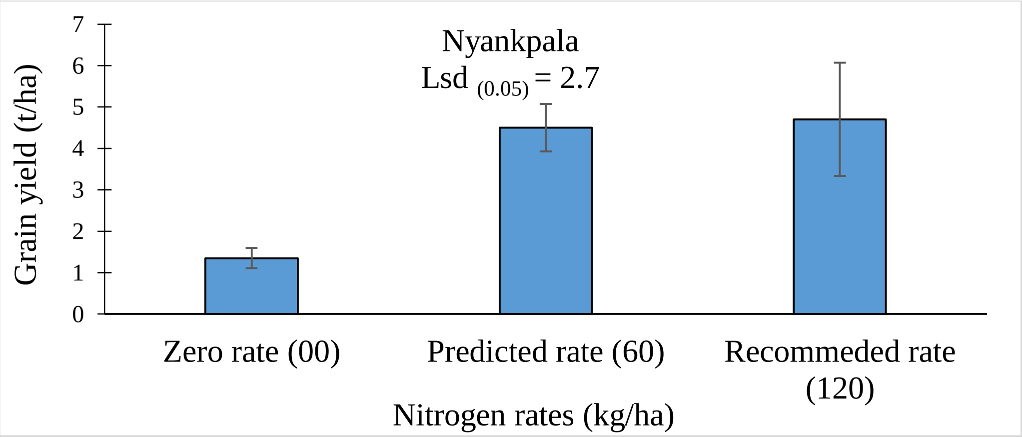

Figure 43: Comparative performance of tool-predicted nitrogen rate on grain yield of maize cultivated at Nyankpala during the 2019 cropping season. Error bars represent standard error of means.

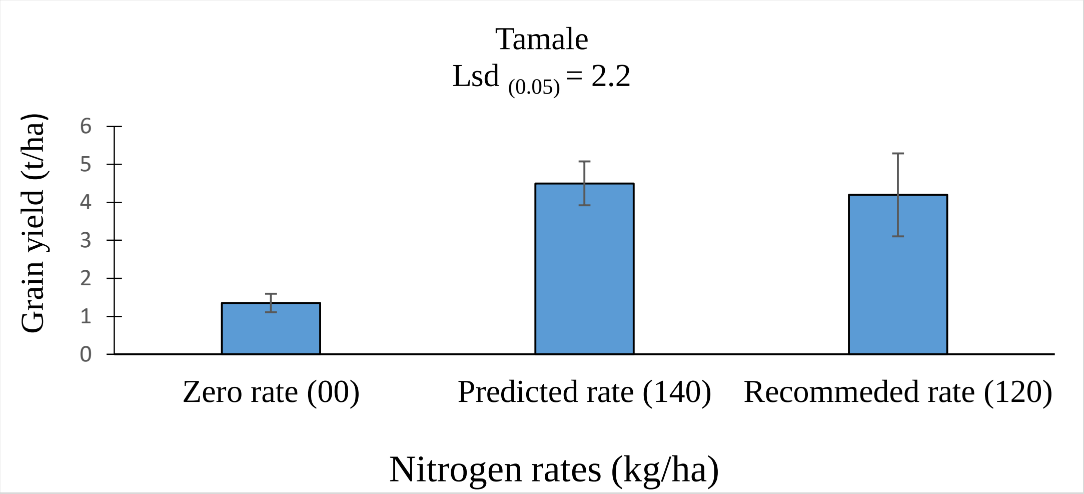

Figure 44: Comparative performance of tool-predicted nitrogen rate on grain yield of maize cultivated at Tamale during the 2019 cropping season. Error bars represent standard error of means.

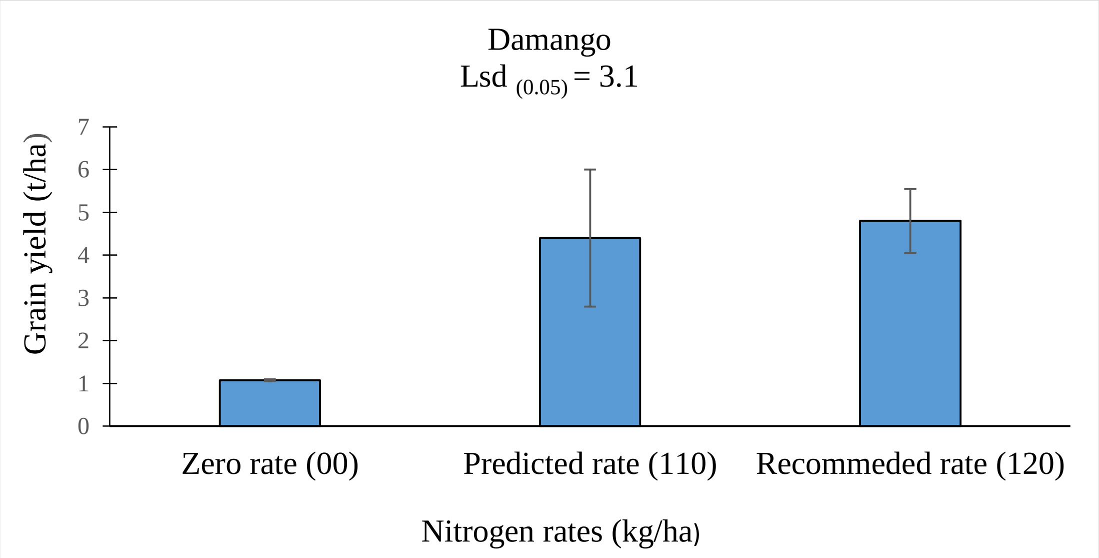

Figure 45: Comparative performance of tool-predicted nitrogen rate on grain yield of maize cultivated at Damango during the 2019 cropping season. Error bars represent standard error of means.

4.3.3 Evaluation of calibrated soil test tool for predicting site-specific P_2O_5 fertilization in maize production

Plant height, leave area index, and straw weight were all affected by the predicted P_2O_5 application rate of 30 kg/ha, 40 kg/ha and 35 kg/ha each as top-up requirement for Nyankpala, Tamale and Damango, respectively. There was no significant difference between the expected and obtained straw weight, leaf area index, cob weight and cob length (Table 8a and 8b). However, significant difference was observed between the expected and obtained values for plant height, hundred seed weight, cob weight, cob length straw weight and grain yield (Table 8a, b and c). For plant height, the applied 30 kg/ha of P_2O_5 as a top-up at Nyankpala recorded average height of 135 cm, while the application rate of 40 kg/ha as a top-up at Tamale recorded average height of 130 cm and the rate of 35 kg/ha applied as a top-up at Damango recorded average height of 130 cm (Table 7a). The P_2O_5-prediction tool correctly predicted plant height with a predictability of 93, 90 and 94% respectively for Nyankpala, Tamale and Damango. At the predicted rate of P_2O_5 application of 30, 40 and 35 kg/ha at Nyankpala, Tamale and Damango, leaf area indices of 6.4, 6.8 and 6.9 were recorded respectively for the three sites. The P_2O_5-prediction tool correctly predicted leaf area index with a predictability of 81, 91 and 83% respectively for Nyankpala, Tamale and Damango.

Maize straw weight, recorded for the three sites were 11.0 t/ha, 10.8 t/ha and 10.4 t/ha respectively. The P_2O_5-prediction tool correctly predicted straw weight, based on results from soil P analyses, with a predictability of 89, 97 and 93% respectively for Nyankpala, Tamale and Damango (Table 7b).

Hundred seed weight, cob length, straw weight and grain yield were all affected by the predicted P_2O_5 application rate of 30 kg/ha, 40 kg/ha and 35 kg/ha each as top-up requirement for Nyankpala, Tamale and Damango, respectively. For hundred seed weight, the applied 30 kg/ha of P_2O_5 as a top-up at Nyankpala recorded average 100 seed weight 24.1 g, while the application rate of 40 kg/ha as a top-up at Tamale recorded average 100 seed weight of 24.7 g and the rate of 35 kg/ha P_2O_5 applied as top-up at Damango recorded average 100 seed weight of 23.5 g (Table 7a). The P_2O_5-prediction tool thus correctly predicted 100 seed weight with a predictability of 96, 98 and 94% respectively for Nyankpala, Tamale and Damango.

At the predicted rate of P_2O_5 application of 30, 40 and 35 kg/ha at Nyankpala, Tamale and Damango, cob weights 16.5 g/cob, 17.2 g/cob and 16.9 g/cob were recorded respectively for the three sites. The P_2O_5 prediction tool correctly predicted cob weight of maize with a predictability of 94, 98 and 96% respectively for Nyankpala, Tamale and Damango.

Maize cob length, recorded for the three sites were 13.5 cm, 14.1 cm and 13.2 cm respectively. The P_2O_5-prediction tool correctly predicted straw weight, based on results from soil P analyses, with a predictability of 93%, 97% and 91% respectively for Nyankpala, Tamale and Damango.

The maize grain yield, recorded for the three sites were 4.6 t/ha, 4.8 t/ha and 4.7 t/ha respectively. The P_2O_5-prediction tool correctly predicted the needed rate of P_2O_5 fertilization, based on results from soil P analyses, with a predictability of 92%, 96% and 94% respectively for Nyankpala, Tamale and Damango respectively.

Table 7a: Maize growth and yield response to P_2O_5 -calibrated tool at three sites in the Guinea savannah zone of Ghana

	Site		
	Nyankpala	Tamale	Damango
Soil test P (mg/kg)	10.6	5.7	8.1
P application rates predicted from calibrated tool (kg/ha)	30	40	35
P rates added (kg/ha)	30	40	35
Expected height (cm)	144	144	144
Height obtained (cm)	135	130	136
Prediction percentage (%)	93	90	94
Expected leaf area index (m^2/m^2)	7.4	7.4	7.4
Leaf area index obtained (m^2/m^2)	6.0	6.8	6.2
Prediction percentage (%)	81	91	83
Expected hundred seed weight (g)	25	25	25
Obtained hundred seed weight (g)	24.1	24.7	23.5
Prediction percentage (%)	96	98	94

Table 7b: Maize growth and yield response to P_2O_5 -calibrated tool at three sites in the guinea savannah zone of Ghana

	site		
	Nyankpala	Tamale	Damango
Soil test P (mg/kg)	10.6	5.7	8.1
P application rates predicted from calibrated tool (kg/ha)	30	40	35
P rates added (kg/ha)	30	40	35
Expected cob weight(g/cob)	17.5	17.5	17.5
Obtained cob weight (g/cob)	16.5	17.2	16.9
Prediction percentage (%)	94	98	96
Expected cob length (cm)	14.5	14.5	14.5
Obtained cob length (cm	13.5	14.1	13.2
Prediction percentage (%)	93	97	91
Expected straw weight (t/ha)	11.12	11.12	11.12
Obtained straw weight (t/ha)	11.0	10.8	10.4
Prediction percentage (%)	98	97	93
Expected grain yield (t/ha)	5	5	5
Obtained grain yield (t/ha)	4.6	4.8	4.7
Prediction percentage (%)	92	96	94

Table 8 shows the difference between growth parameters, yield and yield component values obtained and the standard values expected at each location. The t- test showed a significant difference between the expected and the obtained values for growth parameters at Nyankpala (Table 8a). However, straw weight did not show any significance difference [*t* (stat) = -1.50, *P = 0.271*]. In Tamale, hundred seed weight, cob weight and cob length did not show any significant difference among their expected and obtained values [*t* (stat) = -2.5, *P = 0.129*, *t* (stat) = -0.40, *P = 0.057*, *t* (stat) = -0.30, *P = 0.090*] (Table 8b)]. While plant height, leaf area index, grain yield and straw weight showed significant differences among their expected and obtained values (Table 8b). The t- test also showed a significant difference between the expected and the obtained values for all the growth parameters, yield and yield component at Damango (Table 8c).

Table 8a: T test of attained values at Nyankpala and maximum expected values recorded from the pot experiment

Parameters	T test (stats)	P value
Plant height (cm)	-6.4	0.024
Leaf area index (m^2/m^2)	-14.0	0.050
Hundred seed weight (g)	-5.5	0.033
Cob weight (g/cob)	-6.5	0.021
Cob length (cm)	-11.0	0.008
Straw weight (t/ha)	-1.5	0.271
Grain yield (t/ha)	-10.9	0.008

Table 8b: T test of attained values at Tamale and maximum expected values recorded from the pot experiment

Parameters	T test (stats)	P value
Plant height (cm)	-4.3	0.050
Leaf area index (m^2/m^2)	-17.0	0.003
Hundred seed weight (g)	-2.5	0.129
Cob weight (g/cob)	-4.0	0.057
Cob length (cm)	-3.0	0.090
Straw weight (t/ha)	-4.3	0.040
Grain yield (t/ha)	-7.0	0.019

Table 8c: T test of attained values at Damango and maximum expected values recorded from the pot experiment

Parameters	T test (stats)	P value
Plant height (cm)	-7.10	0.013
Leaf area index (m2/m2)	-16.00	0.012
Hundred seed weight (g)	-6.20	0.019
Cob weight (g/cob)	-4.72	0.041
Cob length (cm)	-10.2	0.009
Straw weight (t/ha)	-7.20	0.018
Grain yield (t/ha)	-8.00	0.015

4.3.4 Validation of calibrated soil test tool for predicting site-specific P_2O_5 fertilization in maize production

Upon validating the performance of the developed P_2O_5 fertilization tool by comparing its productivity to that of the blanket recommended rate and that of zero fertilization rate at Nyankpala, Tamale, and Damango; it was observed that plant height at all three sites (Nyankpala, Tamale and Damango) showed a significant difference ($P = 0.001$, *0.015* and *0.009* respectively) among the three rates of phosphorus application. At the three sites, there was no significant difference between the plant height recorded under the tool-predicted rate and that recorded for the blanket recommended rated (Table 9). The plant height obtained under the tool predicted-rate and under the recommended rate were, however, significantly different from that obtained for the zero rate of application. In Nyankpala, the recommended rate of 45 kg/ha recorded the highest plant height of 140 cm followed by the tool-predicted rate of 30 kg/ha with a height of 135 cm, while the zero rate had the lowest height of 75 cm (Table 9). In Tamale, the recommended rate of 45 kg/ha recorded the highest plant height of 138 cm followed by the tool-predicted rate of 30 kg/ha with a height of 130 cm while the zero rate had the lowest height of 80 cm (Table 9). For the site at Damango, the blanket recommended rate of 45 kg/ha recorded the highest plant height of 141 cm followed by the tool-predicted rate of 30 kg/ha with a height of 136 cm while the zero rate had the lowest height of 86 cm. In all cases for plant height, there were significant differences between the three rates (zero rate, blanket recommended rate, tool-predicted rate). However, plant height for the blanket recommended rate and the tool-predicted rate remained statistically similar with no significant differences (Table 9).

Table 9: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on plant height (cm) of maize cultivated at three locations during the 2019 cropping season

Site	Plant height (cm)
Nyankpala	
Zero rate (00 kg/ha)	75.9^{a}
Tool-predicted rate (30 kg/ha)	135^{b}
Recommended rate (45 kg/ha)	140^{b}
p-value	0.001**
Tamale	
Zero rate (00 kg/ha)	80^{a}
Tool-predicted rate (40 kg/ha)	130^{b}
Recommended rate (45 kg/ha)	138^{b}
p-value	0.015 *
Damango	
Zero rate (00 kg/ha)	86^{a}
Tool-predicted rate (35 kg/ha)	136^{b}
Recommended rate (45 kg/ha)	141^{b}
p-value	0.009**

In contrast to the performance of the tool-predicted phosphorus rate on plant height, hundred seed weight at all the three sites (Nyankpala, Tamale and Damango) did not significantly vary (*P = 0.260*, *0.909* and *0.357* respectively) among the three rates of phosphorus application. Generally, in Nyankpala, the tool-predicted rate of 30 kg/ha and the recommended rate of 45 kg/ha recorded similar average weight in the range of 24.1 and 24.6 g respectively while zero rate of 00 kg/ha had 21 g (Figure 46). In Tamale, the tool-predicted rate recorded the highest hundred seed weight, followed by the recommended rate while the zero rate recorded the least (Figure 47).In Damango, the tool-predicted rate also recorded the highest followed by the recommended rate while the zero rate recorded the least (Figure 48).

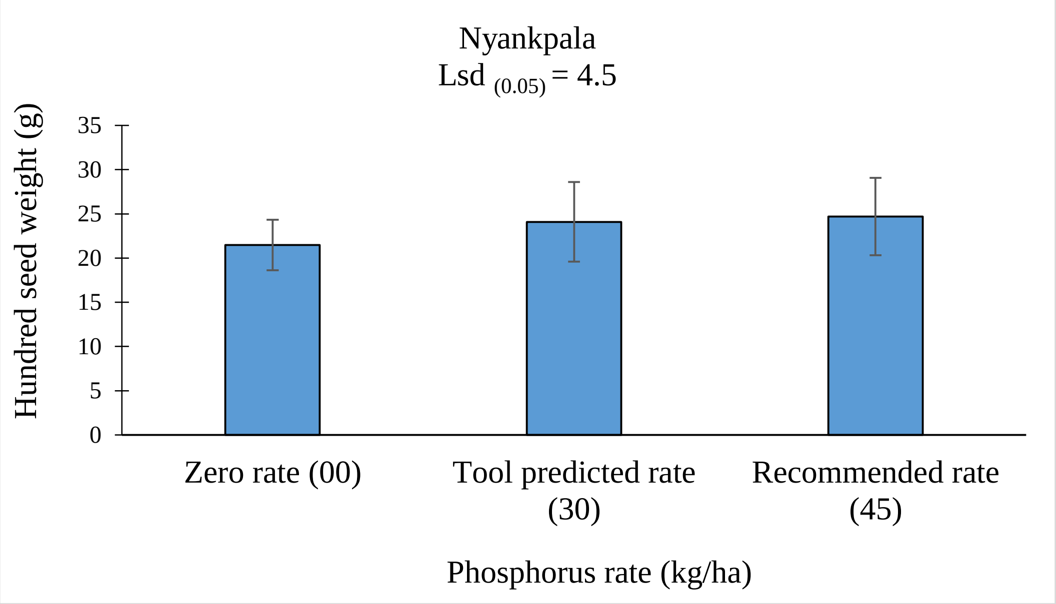

Figure 46: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on hundred seed weight of maize cultivated at Nyankpala during the 2019 cropping season. Error bars represent standard error of means.

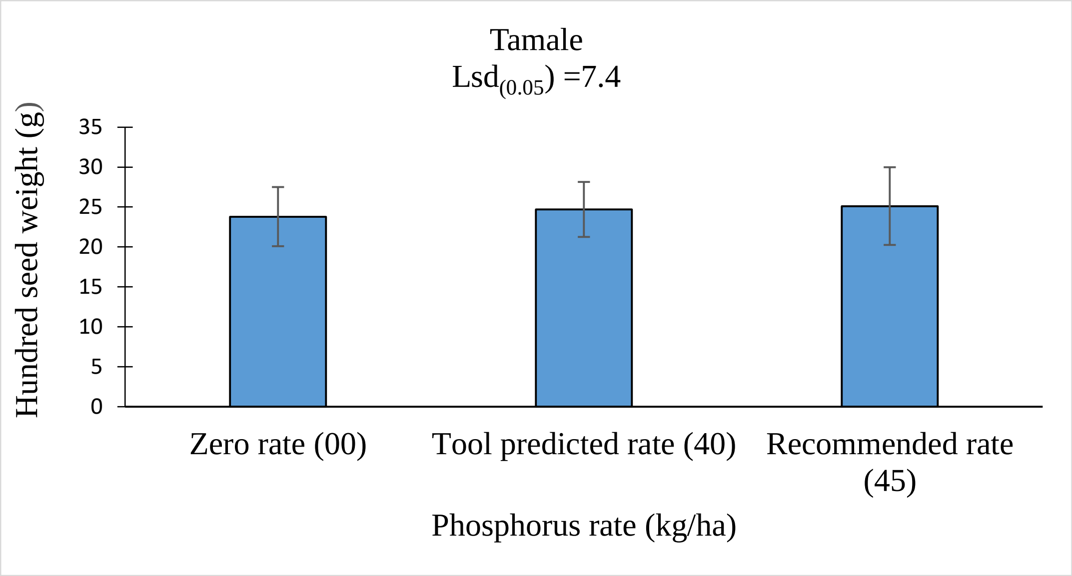

Figure 47: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on hundred seed weight of maize cultivated at Tamale during the 2019 cropping season. Error bars represent standard error of means.

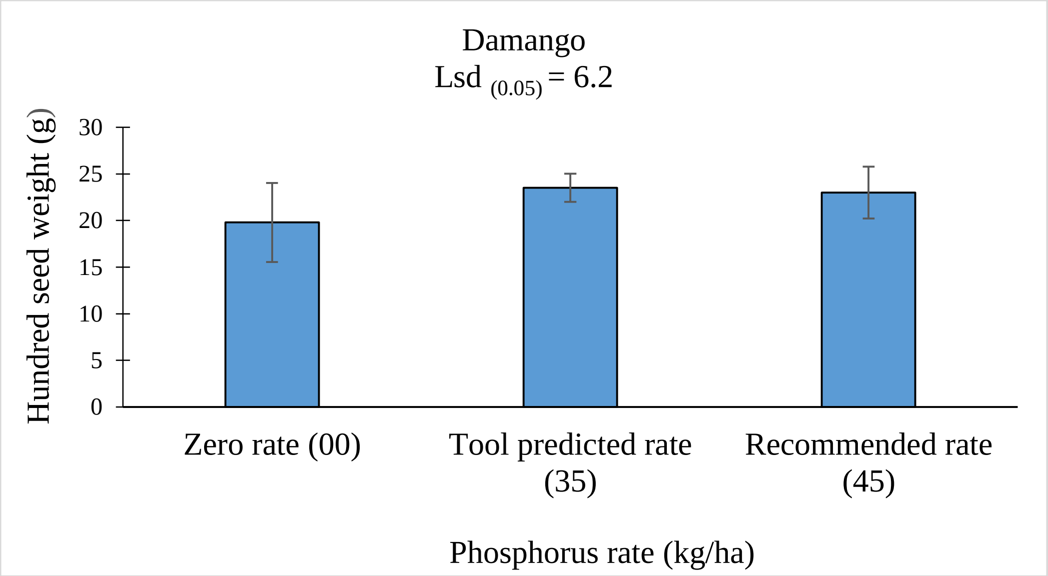

Figure 48: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on hundred seed weight of maize cultivated at Tamale during the 2019 cropping season. Error bars represent standard error of means.

With regards to cob weight in Nyankpala and Tamale, there were statistically significant difference (*P = 0.013 and 0.006* respectively) between the tool-predicted rate, the blanket recommended rate and the zero rate. Cob weight of the blanket recommended weight was however similar to cob weight of the tool-predicted rate in all instances. In contrast, cob weight in Damango did not show a significant difference (*P = 0.282*) among the application of the different rates of phosphorus fertilizer. In Nyankpala, the recommended rate of 45 kg/ha gave an average cob weight of 18.1 g/cob while the tool-predicted rate of 30 kg/ha also recorded a cob weight of 16.5 g/cob while zero rate of 00 kg/ha had 10 g/cob (Figure 49). In Tamale, the tool-predicted rate recorded the highest cob weight followed by the recommended rate while the zero rate recorded the least (Figure 50) while in Damango the tool-predicted rate recorded the highest followed by the recommended rate and the zero rate recorded the least cob weight (Figure 51).

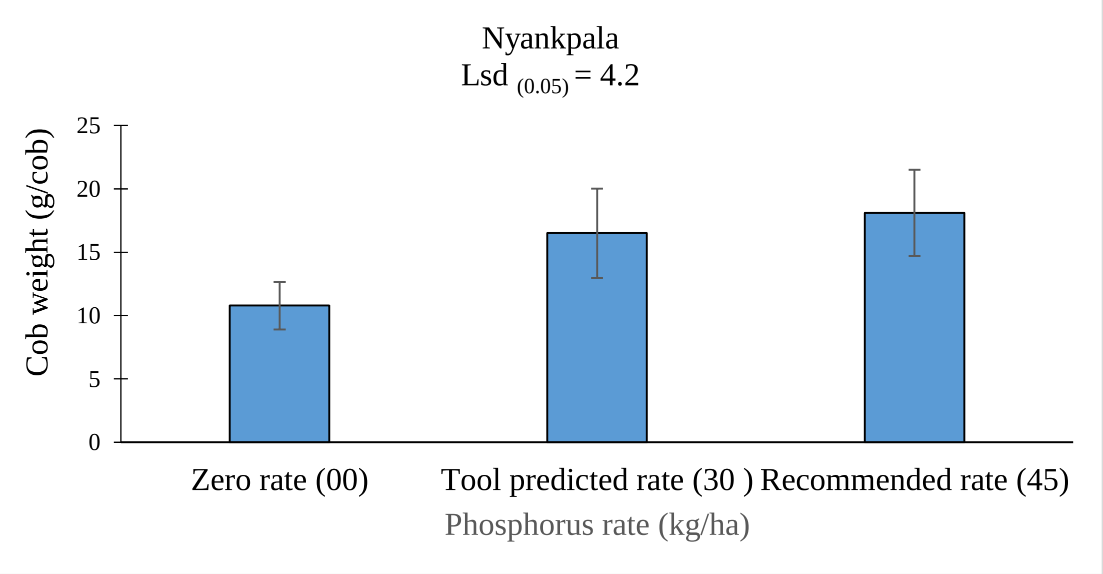

Figure 49: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on cob weight of maize cultivated at Nyankpala during the 2019 cropping season. Error bars represent standard error of means.

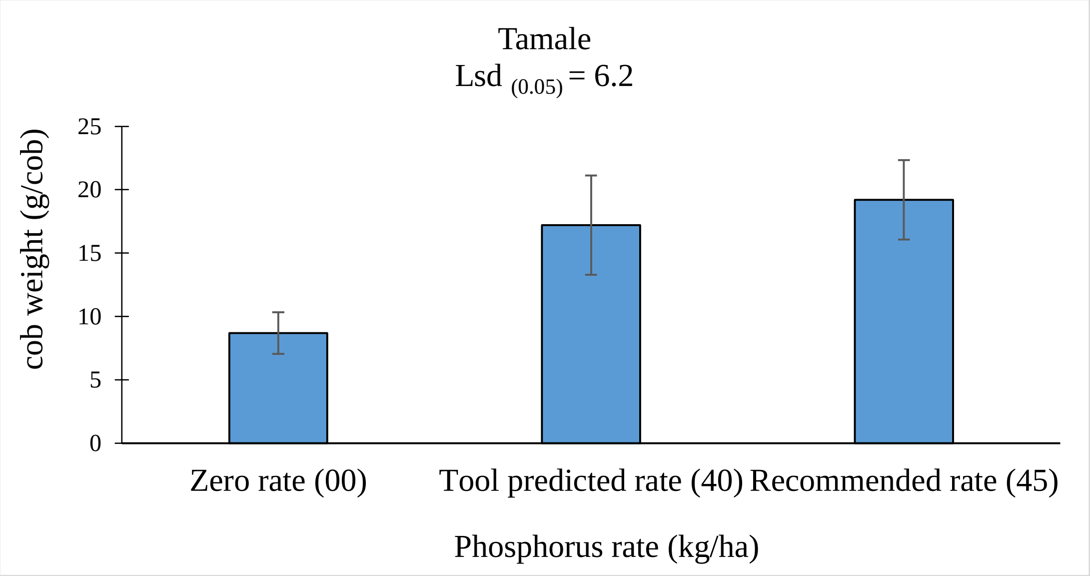

Figure 50: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on cob weight of maize cultivated at Tamale during the 2019 cropping season. Error bars represent standard error of means.

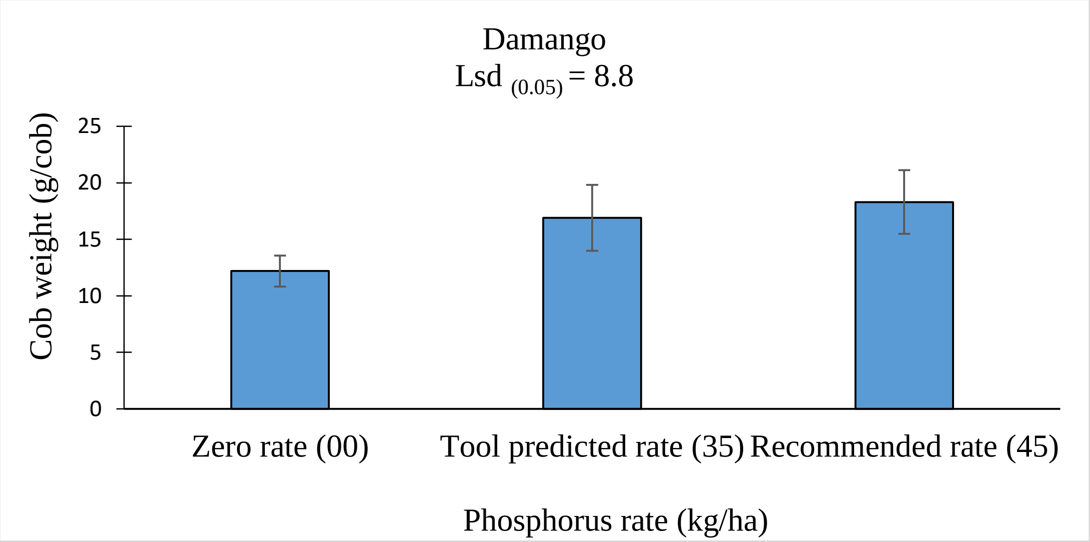

Figure 51: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on cob weight of maize cultivated at Damango during the 2019 cropping season. Error bars represent standard error of means.

Cob length did not significantly vary across the three sites for the three rates (*P = 0.344*, *0.526* and *0.340* respectively for Nyankpala, Tamale and Damango). Generally, in Nyankpala the tool-predicted rate recorded the maximum cob length followed by the recommended rate while zero rate had the minimum cob length (Figure 52). In Tamale the recommended rate generally recorded the highest cob length followed by tool-predicted rate while the zero rate recorded the least cob length (Figure 53) while in Damango the tool-predicted rate recorded the highest cob length followed by the recommended rate while the zero rate recorded the least cob length (Figure 54).

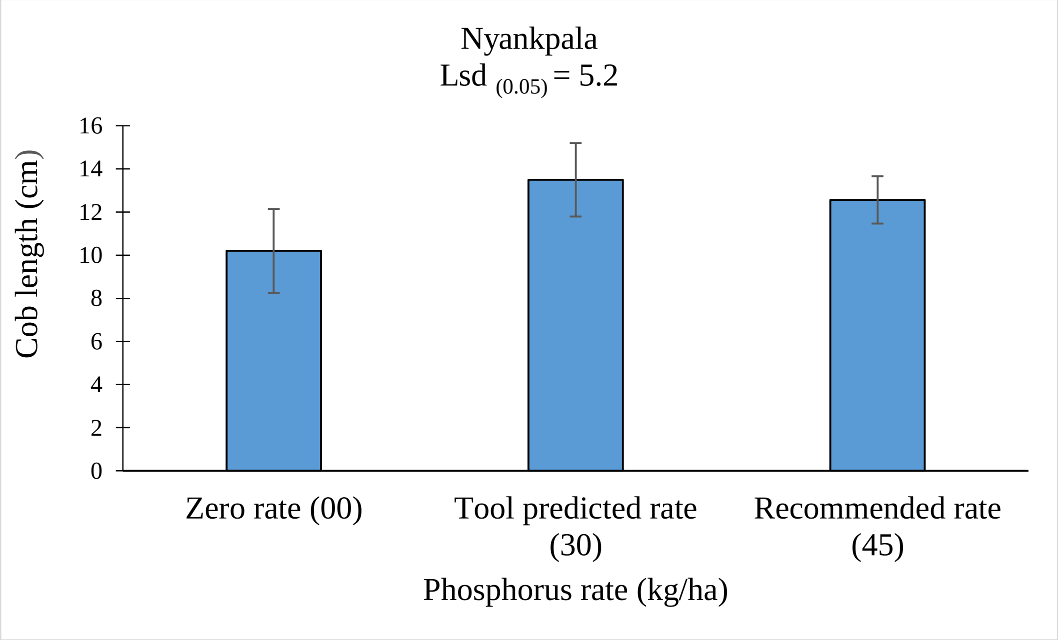

Figure 52: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on cob length of maize cultivated at Nyankpala during the 2019 cropping season. Error bars represent standard error of means.

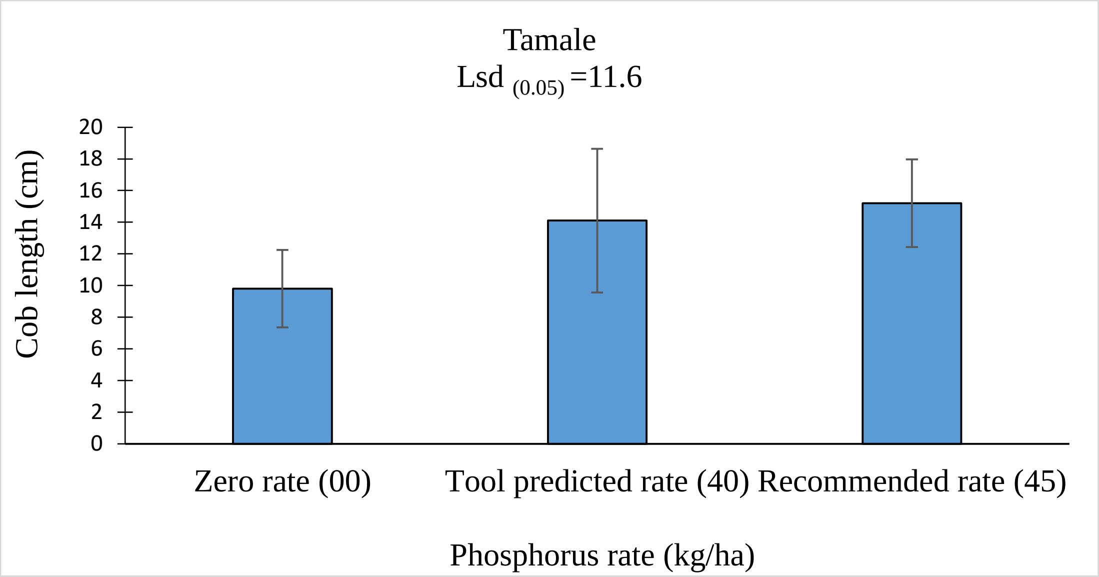

Figure 53: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on cob length of maize cultivated at Tamale during the 2019 cropping season. Error bars represent standard error of means.

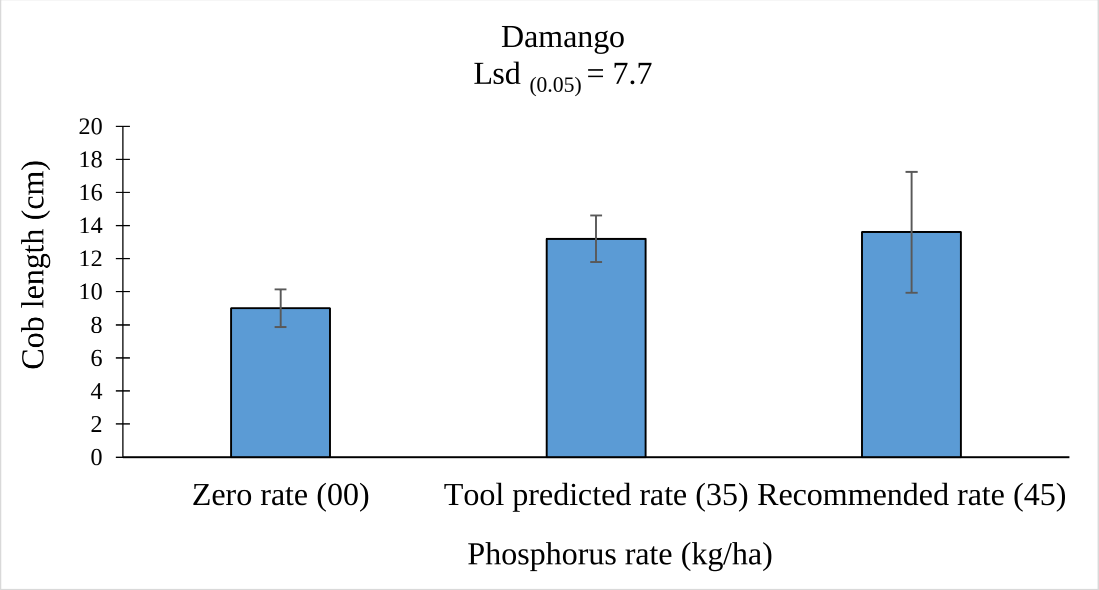

Figure 54: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on cob length of maize cultivated at Damango during the 2019 cropping season. Error bars represent standard error of means.

Observed straw weight at all the three sites (Nyankpala, Tamale and Damango) did not show significant difference (*P* = *0.253, 0.171* and *0.311* respectively) among the three application rates (Figure 55, 56 and 57). Generally, however, in all three sites the tool-predicted rate recorded the highest straw weight which, followed by the recommended rate while the zero rate recorded the least straw weight.

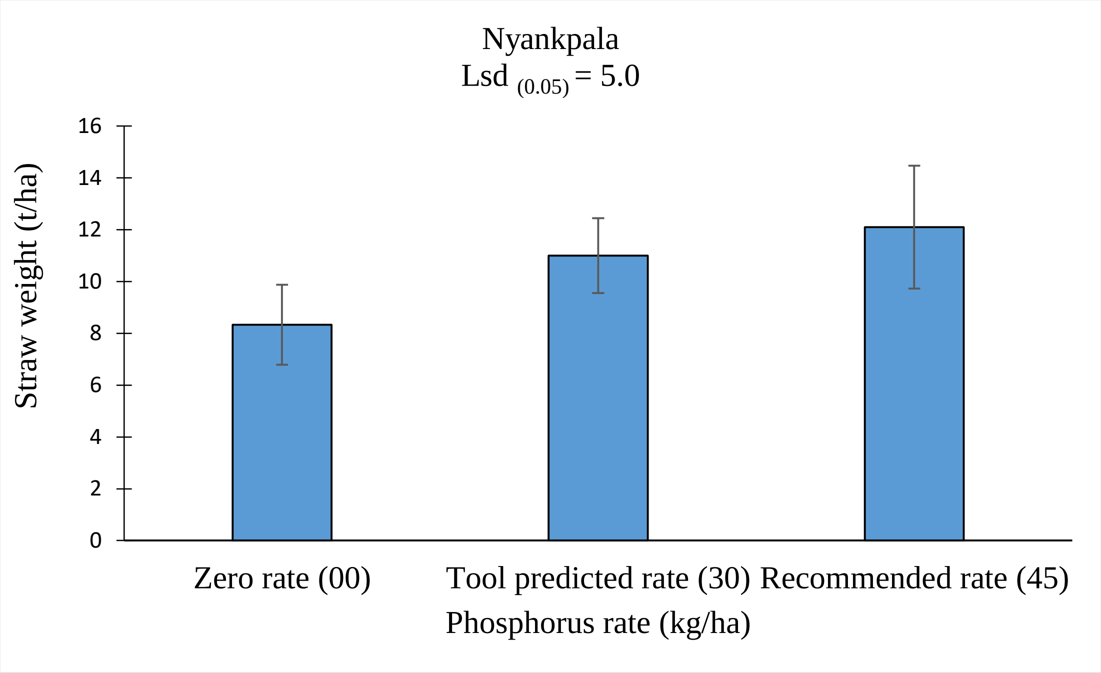

Figure 55: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on straw weight of maize cultivated at Nyankpala during the 2019 cropping season. Error bars represent standard error of means.

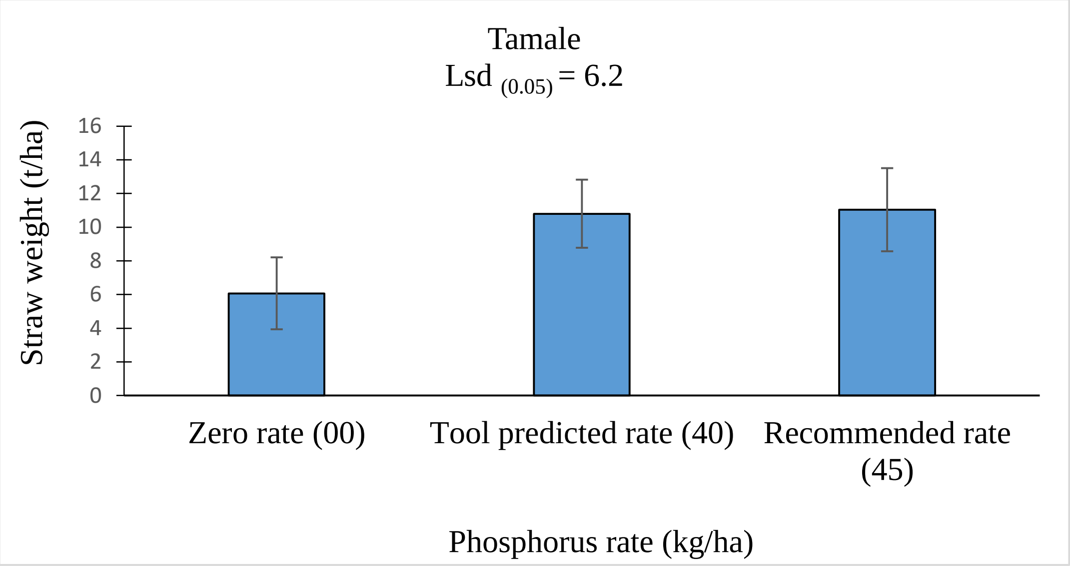

Figure 56: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on straw weight of maize cultivated at Tamale during the 2019 cropping season. Error bars represent standard error of means.

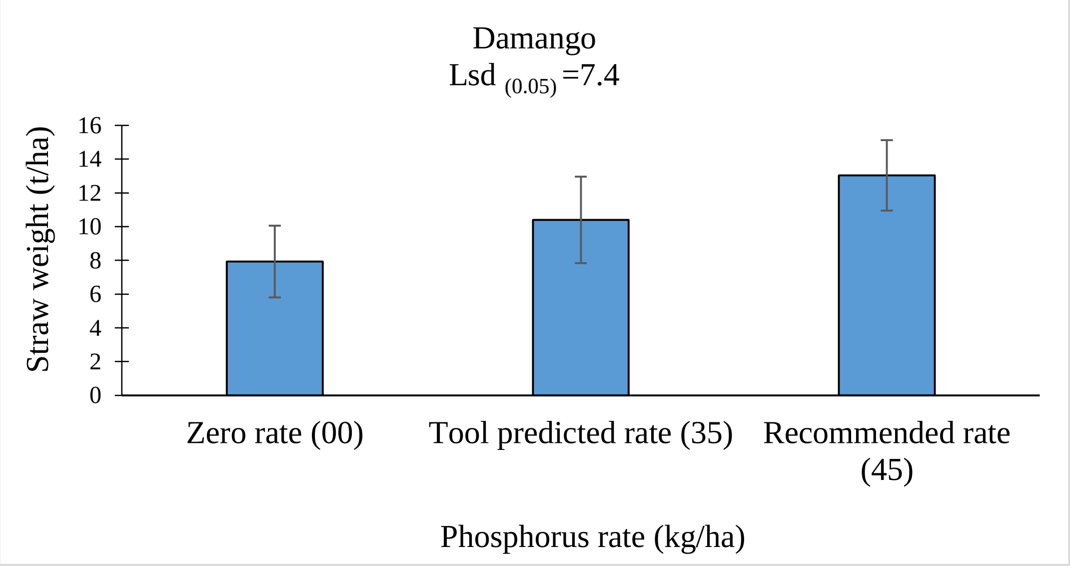

Figure 57: Comparative performance of tool-predicted phosphorus (P_2O_5) fertilization rate on straw weight of maize cultivated at Damango during the 2019 cropping season. Error bars represent standard error of means.

Grain yield

Comparing the grain yield of maize in the zero-fertilization rate, blanket recommended rate (45 kg/ha) and the tool-predicted rate for each site showed that grain yield at Nyankpala, was statistically influenced ($P = 0.003$) by the treatnment application (Figure 58). Grain yield significantly differed between the two fertilization regimes on one hand and that of the unfertilized treatment. There was no significant deference in grain yield, however, between the recommended rate and the tool-predicted rate. Similar observations were made at Tamale and Damango respectively ($P = 0.009$ and 0.001 respectively). In Nyankpala the recommended rate recorded average yield of 4.83 t/ha which is not different from that of tool-predicted rate of 4.6 t/ha while zero rate recorded least yield of 1.68 t/ha (Figure 58). In Tamale the recommended rate recorded the highest grain yield of 4.9 t/ha which was also not different from that of tool-predicted rate 4.8 t/ha while the zero rate recorded least yield of 2.5 t/ha (Figure 59) while in Damango the recommended blanket rate recorded the highest followed by the tool-predicted rate while the zero rate recorded least grain yield (Figure 60).

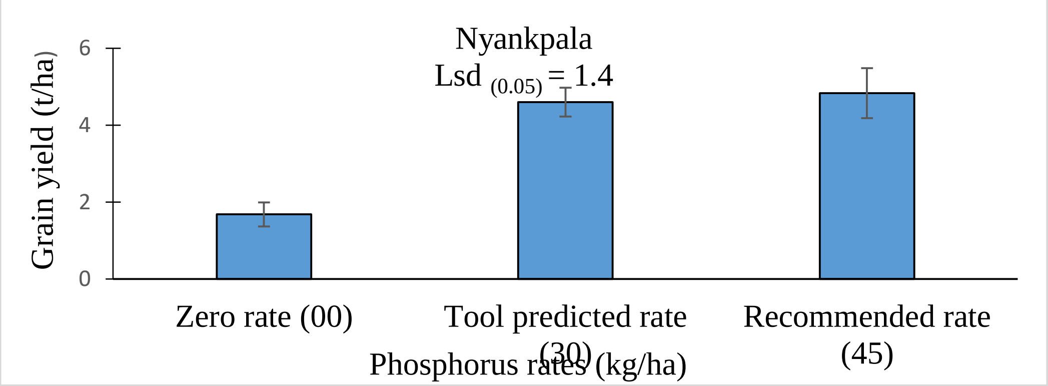

Figure 58: Influence of different rate (zero rate, tool-predicted rate and recommended rate) of phosphorus application on grain yield of maize cultivated in Nyankpala during 2019 cropping season. Error bars represent standard error of means.

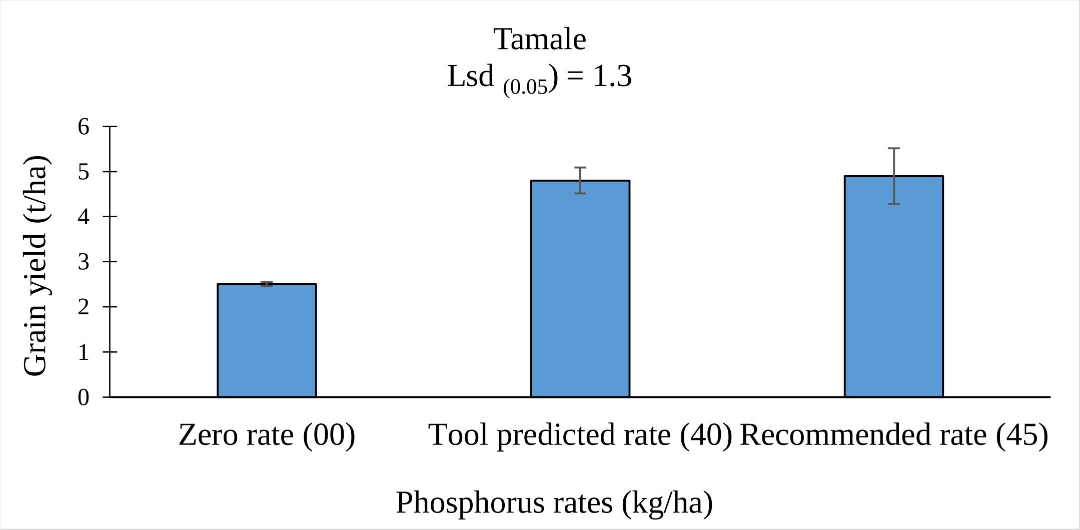

Figure 59: Influence of different rate (zero rate, tool-predicted rate and recommended rate) of phosphorus application on grain yield of maize cultivated in Tamale during 2019 cropping season. Error bars represent standard error of means.

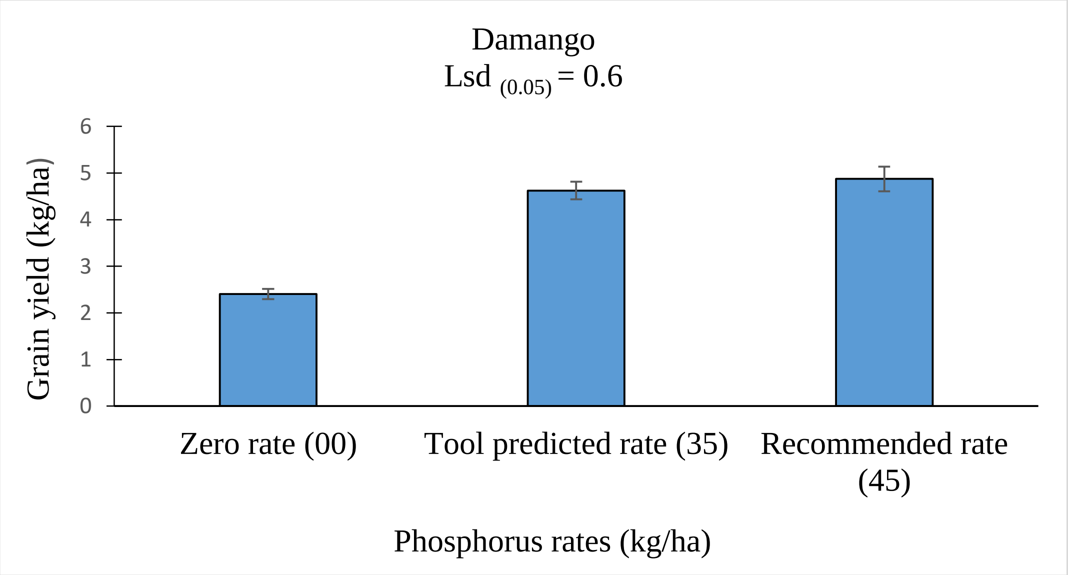

Figure 60: Influence of different rate (zero rate, tool-predicted rate and recommended rate) of phosphorus application on grain yield of maize cultivated in Damango during 2019 cropping season. Error bars represent standard error of means.

Table 10: Cost estimation for fertilizer purchases based on urea and TSP market prices

Predicted rates							Farmer practice	
	Nyankpala		Damango		Tamale			
	Rate (kg/ha)	Cost/ha	Rate (kg/ha)	Cost/ha	Rate (kg/ha)	Cost/ha	Rate (kg/ha)	Cost/ha
N	60	182.5	110	334.7	140	426	120	365
P_2O_5	30	480	35	560	40	640	45	720
cost of N + P_2O_5		662.5		894.7		1066		1085
*Saving (GHS)		422.50		190.30		19.00		0

*Where Savings (GHS) is the difference in cost between farmer practice and cost of N + P_2O_5 fertilization as estimated by the developed tool at each location.

From the cost estimation of fertilizer based on urea and TSP market price, urea costs GH ¢ 70.00 per 50 kg and TSP costs GH ¢ 80.00 per 50 kg of bag. The total cost of fertilization incurred at Nyankpala through the use of the developed tool was a sum of GH ¢ 662.5 per hectare (Table 10).

A cost of GH ¢894.7 per hectare was incurred for fertilizer purchases at Damango while a cost of GH ¢1066 per hectare was incurred at Tamale. In contrast to the use of the developed tool, N and P fertilizer cost of GH ¢1085 per hectare was incurred upon use of the recommended blanket rate/farmer practice at all locations (Table 10). At all sites, the quantity of fertilizer added was lower than the blanket quantity recommended for fertilization. The lower quantity of fertilizer applied upon use of the developed tool reduced the cost of fertilizer purchases from a recommended 1085 GH¢ to 662 GH ¢, 895 and 1066 respectively at Nyankpala, Damango and Tamale. Savings of 442, 190 and 19 GH¢ were made respectively at Nyankpala, Damango and

Tamale upon use of the developed N and P fertilization tool compared to use of the blanket recommended rate. The significance in determining the optimum performing technology (use of developed tool versus use of recommended blanket rate) is the price of inputs (fertilizer and soil test). Since labour for application of fertilizer is priced on hectare basis, the labour cost of application is the same regardless of the application rate. Partial cost due to fertilization for N and P_2O_5 at all three sites showed net saving on fertilization (Table 11).

Table 11: Partial cost analysis for maize production due to fertilization for N and P fertilizers per hectare

Nyankpala		yield/ha	Partial Cost of fertilization/ha (GH ¢)	Net savings on fertilization	% savings on fertilization
N	Predicted rates	4.5	202	163	44.6
	Farmer practice	4.7	365		
P_2O_5	Predicted rates	4.6	500	220	30.5
	Farmer practice	4.8	720		
Damango					
N	Predicted rates	4.9	355	10	2.7
	Farmer practice	4.8	365		
P_2O_5	Predicted rates	4.7	580	140	19.4
	Farmer practice	4.8	720		
Tamale					
N	Predicted rates	5	446	-81	0
	Farmer practice	4.8	365		
P_2O_5	Predicted rates	4.8	660	60	8.3
	Farmer practice	4.9	720		

Partial cost involved cost of fertilization of N, P_2O_5 and cost of laboratory soil test,

% saving on fertilization = net savings on fertilization/farmer investment x 100

At the three sites, difference between cost of use of the recommended blanket rate/farmer practice (GH ¢ 365) attributable to N fertilization and that of the developed tool (GH ¢ 202, 355 and 446) gave a net saving of GH ¢ 163, 10, 0 respectively, with 44.6%, and 2.7 % (Table 11) on net savings due to fertilization for tool.

For P_2O_5 fertilization the difference between the costs incurred in the recommended blanket rate (GH¢ 720) for P_2O_5 fertilization and that of the developed tool (GH ¢ 500, 580 and 660) gave net savings of GH ¢ 220, GH ¢ 140 GH ¢, and GH ¢ 60 with 30.5%, 19.4% and 8.3% as net savings due to fertilization for only P_2O_5 at the three sites (Table 11).

CHAPTER FIVE

5.0 DISCUSSION

5.1.0 Calibration of soil test results for nitrogen fertilization in maize

5.1.1 Impact of nitrogen rate on plant growth, yield and yield components

Fertilization is the addition of nutrients to the soil to meet plant nutrient requirement for growth and development. The insignificant difference in plant height at three and six weeks after planting (WAP) (Figure 1) could be due to similarities in nutrient environment across the various treatments. The maize plant must have met its required nutrient requirement across the various treatments within the period. Similar results have been observed by Selassie (2015) who indicated that there was no significant variation between plant height at these stages of growth. In contrast to the observation at 3 and 6 WAP, the observed variation in plant height at 9 WAP could be attributed to differences in the N nutrient supplying ability of the various N rate Higher rate of N might have supplied adequate amounts of N to meet the nutrient requirement for growth, resulting in vigorous vegetative growth and development of the maize plant and reflecting in the significantly taller plants at higher N rate at 9 WAP. At this stage, plant tissues and organs were expected to be maturing at a higher pace, requiring much more N nutrients for morphological growth and physiological functions (Fageria and Baligar, 2008). Therefore, treatments with lower N rate may not have met the quantity of N required for the enhancement of growth (Yang et al., 2011), resulting in the lower rate of growth observed in the low N rate treatments. Similar observations in plant height were observed by Matusso (2016) upon application of different rates of N fertilization. According to Arendt (1997) and Fageria and Moreira (2011) such differences are attributed to the relative efficiency of nutrient uptake in the higher rates of N fertilization by the growing roots which makes plants compete favourably for growth factors and convert the available scarce nutrients and growth factors into physiological development. In a study by Bationo et al. (2012), concluded that the amount of nutrient made available to maize plant was directly related to its growth, development and maturity which is in agreement with the reasoning alluded to in the finding of this study.

The observed significant effect (*P = 0.009*) of nitrogen fertilizer rate on leaf area index (Figure 3) is in agreement with reports by Abera et al. (2017) who also noted highly significant variation in leaf area index as affected by the application of nitrogen fertilizer. The increase in leaf area index with increasing N fertilization rate is favourable for morphological and physiological development (Azarpour et al., 2014) as the relatively higher leaf surface area could increase the overall contact surface to capture light for photosynthesis (Moosavi, 2012). The higher the rate of photosynthesis, the more nutrient there is for plant growth and development (Kirschbaum, 2011). According to Abera et al. (2017) such observed increases in leaf area index with increasing rate of nitrogen fertilizer application indicates the important role of nitrogen for leaf development, sun interception and the associated growth and development of the maize crop.

The observed significant difference (*P = 0.024*) among the N application rates on cob weight with 135 kg N/ha recording the highest cob weight of 26.8 g/cob while the zero control plot recorded the least cob weight of 17.6 g/cob is in agreement with findings of Majid et al. (2017) who recorded similarly low cob weight in treatments that received no nitrogen fertilization and highest cob weight under higher N rate treatments. The increase in cob weight with increasing N fertilization could be due to the enhanced nutrient availability which has an influence on the absorption and uptake of available nutrients (Rogovska et al., 2014). Mvubu et al. (2015) also observed that application of nitrogen at higher rates increased cob weight up to 61.6 g/cob, and reports by Costa et al. (2002), Azees et al. (2006) and Jansen and Lubberstedt (2012) show that cob weight increases with increasing rates of nitrogen application.

The differences observed among the N application rates on cob length, where application rate of 150 kg N/ha recorded the highest cob length (15.1 cm) among all the treatments and 00 kg N/ha recorded the least cob length of 7.1 cm (Figure 6) is in agreement with findings of Majid et al. (2017) who recorded similarly low cob length in treatments that received no nitrogen fertilization and longest cob length under higher N rate treatments. Ngosong et al. (2019) reported that different N rates showed a significant variation on maize cob length in the range of 14.5 to 18 cm as compared to the control, while Onasanya (2009) also reported that application of nitrogen generally promotes growth and yield components of maize and results in longer cob length.

Maize straw weight was significantly affected by the application of different nitrogen rates. Highest straw weight was obtained by 105 kg N/ha at 38.0 t/ha and almost all the other treatments showed a similar performance as compared with the control plot. 00 kg N/ha recorded the minimum straw weight of 12.5 t/ha. According to reports by Fageria and Baligar (2005), successive increment of nitrogen rate from 0 to 120 kg/ha remarkably increased dry weight of maize plant. The distinction in the dry matter accumulation in maize is ascribed to post silking N uptake which improves with increments in nitrogen application rate (Feil et al., 2005; Peng et al., 2012).

The observed significant (*P = 0.042*) influence of N application rate on grain yield, where grain yield increased with increasing N application rate (Figure 9) with maximum yield of 5.5 t/ha at 150 kg N/ha followed by 135 and 120 kg N/ha with 4.2 and 4.3 t/ha respective while minimum yield of 0.2 t/ha was obtained by 00 kg/ha, implies that increasing nitrogen fertilization enhances optimum growth and yield in the nitrogen-poor soils. This observation is in line with studies by Majid et al. (2017) who revealed that yield traits and final yield significantly increased with increasing nitrogen fertilization from 00 kg N/ha to 345 kg N/ha. Kanchikerimath and Singh (2001), Belay et al. (2002) and Agegnehu et al. (2016) ascribed such increases in maize grain yield to the overall enhancement in soil chemical, and biological properties as relates to ample fertilizer application. The growth, development, maturity and yield of the crop are directly related to the amount of nutrients that is made available to the crop during its growth period without wastage to the environment (Poter and Semenov, 2005; Connor et al., 2011; Bationo et al., 2012). The enhancement in soil nutrient content with increasing N rate may have favoured the chemical composition of the soil for better nutrient utilization (Janssens et al., 2010). As observed in the case of plant height (Figure 1), leaf area (Figure 3) and other yield attributes (Figure 9), high N rates tendered to favour maize growth parameters and results in better physiological and morphological performance, light interception and photosynthesis and reflected in the higher grain filling abilities (Benešová et al., 2012). Maqsood et al. (2001) also reported that grain yield of maize increased with increases in N application rates.

5.2 Calibration of soil test results for phosphorus fertilization in maize

5.2.1 Impact of phosphorus rates on plant growth, yield and yield component parameters of maize

The observed increases in plant height with increasing phosphorus fertilization rate (Figure 16) is in agreement with results of the study by Elelib et al. (2006), Asghar et al. (2010) and Masood et al. (2011) who indicated that plant height of maize increased with increase in P application rate. The increase in plant height at higher rate could be attributed to higher capacity to supply the P nutrient as needed for growth, resulting in vigorous vegetative growth and maize plant production which reflected in the significant plant height. The comparatively maximum height of 131.9 cm that was recorded by 50 kg/ha of P_2O_5 and minimum height of 42.1 cm that was recorded by 00 kg/ha P (Figure 16) is in agreement with the findings of Masood et al. (2011) who reported that treatments with higher rate of phosphorus achieved higher plant height as compared with those with no phosphorus application. According to reports by Ball et al. (2001) and Karishnam et al. (2011), adequate amount of phosphorus is necessary for earlier maturity, rapid growth and also improves the quality of vegetative growth.

The observed significant effect ($P = 0.001$) of phosphorus fertilizer rate (P_2O_5) on leaf area index (Figure 17) is in agreement with report by Besufekad (2018) who noted that application of N and P fertilizer significantly influenced leaf area index and dry biomass of corn. The significant increase in leaf area index at higher rates of P application could be due to enhanced P availability to the plant. Enhanced availability has positive influence on the vegetative morphology of the maize plant which leads to increase in leaf area index (Namgay et al., 2010; Teuxerira et al. 2016). According to results of studies by Amanulla et al. (2009), Onasanya et al.

(2009) and Khalil et al. (2010) leaf area in maize increases with increasing rates of P application than under no fertilization.

The significant difference observed among the P_2O_5 application rates on cob weight and cob length (Figure 20 and Figure 21) is in agreement with El-kholy et al. (2005), Sampathkumar et al. (2013), Mohsin et al. (2014) and Pal et al. (2017) who reported that growth parameters and yield of maize viz., plant height, cob length, cob weight, number of grain and grain yield were significantly influenced by phosphorus application and its levels. The increase in cob weight and cob length could be ascribed to enhanced P availability for the production of assimilates that were transformed to these yield components (Lashkari et al., 2011). Similar results have been reported by Planet et al. (2000). Olusegun (2015) and also Greaves and Wang (2017) reported that Cob length, cob diameter, 100-grain weight and grain yield, significantly ($P = 0.05$) increased with increasing levels of P application.

Data regarding straw weight revealed that different levels of phosphorus had a significant ($P = 0.001$) influence on straw weight and is in agreement with Saha et al. (2014) who reported that application of P_2O_5 fertilizer at increasing rates of N and K significantly improved straw yield and grain yield. Highest straw weight of 9.3 t/ha was attained in plots with phosphorus applied at rate of 50 t/ha as compared with the plots without phosphorus application (control plot) where straw weight was lowest of 3.3 t/ha (Figure 23) and it confirmed reports by Masood et al. (2011) who noted that highest biological yield of 7.9 t/ha was obtained in a plot with application of phosphorus rate of 100 kg/ha and lowest biological yield of 5.8 t/ha in plots without application of phosphorus fertilizer. The significant effect of P fertilization could be attributed to the test crop's root growth and development which was enhanced by the application of phosphorus and which resulted in increased straw weight due to photosynthesis and other biological functions. Similar reasoning are provided by Fageria and Moreira (2011), Vaneklass et al. (2012), and Calvo et al. (2014). According to report by Van camp (2005) and Boote et al. (2013) dry matter production by crop plant is subject to nutrient availability, uptake and photosynthetic capacity of the vegetative parts of the plants. Generally, there was increase in straw weight with increase in phosphorus levels and this is in agreement with Alias et al., (2003) who reported that straw yield significantly increased with increasing level of phosphorus application.

In estimating grain yield, the weight of hundred seeds is considered as one of the best yield components which help in crop grain estimation. As with the results of this study, weight of seeds differed statistically in results of studies by Khan et al. (2014) who observed significant effect on 1000 seed weight as affected by different P levels. The highest weight of hundred seeds of 23.9 g was recorded in the plot with phosphorus applied at the rate of 50 kg/ha while the minimum weight of hundred seeds of 14.8 g was recorded in treatments without phosphorus application (Figure 23). The observation in this study confirms a report by Alias et al. (2003) who recorded highest thousand seed weight in a plot with maximum application of phosphorus and least thousand seed weight in a plot with zero application of phosphorus. Phosphorus level, applied at 50 kg/ha seems to be most yield-enhancing in terms of maize crop production. Similar results of impact of phosphorus rate on hundred seed weight has been reported by Ali et al. (2006), Hussain et al. (2006) and Masood et al. (2011).

As with most parameters, grain yield was statistically affected by the different rates of P fertilization ($P = 0.050$) as also observed by Khan et al. (2014). The resulting higher yields under higher P fertilization (Figure 24) is in line with observations by Alias et al. (2003) who reported that higher grain yield was obtained in treatments with application of phosphorus fertilizer and least yield in those with zero application of phosphorus fertilizer. Application of phosphorus at higher rates resulted in long height of plants, and more weight of cob which resulted in greater grain yield as compared to the control plots (Masood et al., 2011; Arif et al., 2012). The increase in yield is also attributed to increase in phosphorus fertilizer rates which causes a desirable increase in production dry mass accumulation per unit increase in P content. Such increases in grain yield with increasing P application has also been reported by Agegnehu et al. (2016), Potarzycki and Grazebisz (2009) and Ahmad et al. (2013). Research by Grant et al. (2005), Fageria and Moreira (2011) reported that optimum supply of P is associated with increased root growth due to which the plants are able to explore more soil nutrients and moisture and thereby facilitate nutrient uptake, crop growth and development.

5.3 Evaluation and validation of calibrated soil-test tool for predicting site-specific N and P_2O_5 fertilization in maize production

5.3.1 Maize growth, yield and yield components response to soil-test predicted N fertilizer rates at three sites

Evaluation of the maize growth performance of the developed nitrogen tool at Tamale, Nyankpala, and Damango as compared to optimum N fertilization under the pot experiment showed that the developed tool-predicted optimum growth correctly in the range of 90 to 99% (Table 4a, Figure 1). Result, Figure 1 and Table

4 showed that the performance of the developed tool is close to the performance of optimum rate of N used in the pot experiment.

Upon validating the performance of the N-predicting tool by comparing its performance with the blanket recommended rate and zero fertilization rate, the observed significant difference between the zero rate and the two other rates on one hand, and the insignificant difference observed between the tool-predicted rate and the blanket recommended rate, show that the tool accurately estimates N requirement that are needed for optimum growth and yield. The observed difference between the zero treatment and the two other treatments is in line with findings of Subedi and Ma (2005) who noted that significant difference in growth parameters should be expected in contrasting rates of N application. The observed similarity in growth between the tool-predicted N rate and the blanket recommended rate is also in line with Tajul et al. (2013) who explored nutrient environments and concluded that when N levels are same and adequate in the soil, it maximise the usage of other nutrients, thereby influencing growth, light interception and also increases the general productivity of maize plants. The increases in functional ability of N, in turn enhances photosynthetic ability of the plant which in turn results in enhanced plant growth the differences in growth, development and maturity of the test crop are directly related to amount of nutrient available during the growth phase of the test crop (Fageria and Moreira, 2011). It was observed that zero rate always recorded least height in the range of 68.1 to 81.5 cm (Table 6), which confirmed the finding by Abubaka et al. (2019) who also observed that plots receiving zero nitrogen application had lower plant height as compared with plots that received nitrogen application. The blanket recommended rate of nitrogen fertilization had an average plant height in the range of 134 to 140 cm which was not different from that of the tool-predicted rate in the range of 130 to 134 cm (Table 6) across all sites. Table 6 showed that although there was significant difference among the three treatments at all sites, results of the tool-predicated rate and that of the blanket recommended rate were always similar.

As with plant height, evaluation of performance of the developed nitrogen tool at each location (Tamale, Nyankpala, and Damango) showed that the developed tool-predicted correctly the hundred seed weight of maize in the range of 90 to 99% (Table 4a). 28.6 g of average hundred seed weight was noted by the optimum N rate under the pot trial (Figure 7) whereas 23.6 to 24.1 g were noted for the developed N predicting tool (Table 4a). This result indicated that the developed tool performed similar to the optimum rate that was used under the pot trial (Figure 7, Table 4a).

Comparing the performance of the tool-predicted N rate to that of the blanket recommended rate at the three sites in a validation process indicated that hundred seed weight was statistically similar and did not significantly vary for the two treatments. However, the values of yield parameters significantly varied between the two treatments on one hand and the zero-fertilizer treatment. The observed similarity between the tool-predicted rate and the blanket rate showed that the developed tool has comparable impact on hundred seed. The observation confirmed the work by Olaiya et al. (2020) who observed significant difference on thousand seed as affected by N application and attributed the differences to non-similar soil nitrogen pools. Nitrogen play a vital role in plant growth and development. Adequate availability of nitrogen promotes increases in maize crop growth rate through improved morphological and physiological functioning, and subsequently increased hundred seed weight. Lower weight of hundred seed in the range of 17.0 to 20.0 g was noted by the zero rate of N application across all sites (Figure 31, 32, 33) and could be due to lack of adequate N nutrients to the plants. This could reduce the morphological development and physiological functioning of the crop and thus results in low seed weights. Similar observation has been noted by (Sangoi, 2001). Postma and Lynch (2011) in their study found that inadequate levels of nitrogen in the soil reduced N uptake leading to reduction in maize crop growth rate and diminishing grain yield. Low nitrogen supply diminishes grain yield by lessening grain number and individual grain weight (Hammad et al., 2011). In contrast, the blanket recommended rate had an average weight of hundred seed in the range of 21.7 to 24.9 g which was not different from that of the tool-predicted rate in range of 24.1g to 24.3g (Figure 31, 32, and 33) across all sites. The increased weight of hundred seed in the predicted tool rate and blanket recommended rate over the zero rate (control) at all sites (Figure 31, 32, and 33) could be due to balance of nutrient availability in fertilized plots which boosted photo assimilation and increased the weight of the hundred seeds. This confirmed the findings by Imran et al. (2015) who reported that treatments receiving higher N fertilizer rate achieved higher 1000 grain weight as compared to the control plot. Olaiya et al. (2020) also reported that all plots where N was applied recorded higher 1000 grain weight as compared to the control. Results in Figure 31, figure 32, and figure 33 show that although there was significant difference among the three N rates, results of the tool-predicated rate and that of the recommended rate were always same and not statistically different, having similar impact on 100 seed weight.

As with hundred seed weight, similar observations were noted for cob weight, cob length, straw weight and grain yield, where the evaluation showed similarity in performance between the optimum rate that was used in the pot experiment and the rates that were obtained by the developed N-tool at the three locations. In addition to the evaluation, the validation process also showed that although there were significant differences among the three N rate for cob weight (Figure 34, 35, 36), cob length (Figure 37, 38, 39), straw weight (Figure 40, 41, 42) and grain yield (Figure 43, 44, 45); results of the tool-predicated rate and that of the blanket recommended rate were always similar and not statistically significantly different, having similar impact on these yield parameters. For cob weight, the evaluation process showed that the developed tool correctly predicted cob weight of the optimum N rate in the pot experiment in the range of 90 to 99% (Table 4b). The high predictability of optimum cob length (90-99%), straw weight (90-99%), and grain yield (90-99%) by the developed tool in the evaluation process, coupled with the comparably similar performance of the tool-predicted rates to the blanket recommended rates show that the developed tool accurately estimate the exact nitrogen fertilizer top up that is required for optimum maize production.

Nitrogen plays a pivotal role in several physiological processes in maize plants. It is fundamental in the establishment of the plant's photosynthetic capacity and promotes kernel initiation, thereby contributing in determining maize sink capacity and functional kernels throughout grain filling. Busch et al. (2018), Amanullah et al. (2009) and Echarte et al. (2008) in their studies showed that nitrogen enhances cell division and cell enlargement, increases morphological structures, enhances leaf area growth via increasing synthesis to build a large sink for carbon and nitrogen utilization, which in turn facilitates further carbon assimilation and nitrogen uptake. The observed results in the validation process in dry matter accumulation (cob weight, cob length, 100 seed weight, yield) is ascribed to post silking N uptake which improves with increments in nitrogen application rate (Feil et al., 2005; Peng et al., 2012).

The observed differences in yield and yield parameters as affected by N fertilization is in agreement with studies by Guan et al. (2014), Majid et al. (2017), Ashraf et al. (2016), and Mullins et al. (2009). The increases in parameters observed for the blanket rate and the tool-predicted rate compared to the zero rate in all instances may be due to enhanced vegetative growth due to higher levels of N, as N remains a key element which boosts up the growth and development of the crop and has variously been linked to improvements in yield predicting parameters. Enhancement in yield-predicting parameters improves grain yield. Yield predicting parameters such as cob length substantially contributes to yield of corn by influencing both number of grains per cob and grain size (Waraich et al., 2011; Khan et al., 2008; Asaduzzaman et al., 2014).

The increases in maize yield parameters with increasing fertilization, coupled with the similarity in performance of the tool-predicted rate with the blanket rate are also attributed to overall improvements in soil chemical, physical and biological properties as relates to adequate N fertilizer application (Agegnehu et al., 2016; Khan et al., 2011). The growth, development, maturity and yield of the crop are directly related to the amount of N nutrient that is made available to the crop during its growth period without wastage to the environment (Poter and Semenov 2005; Connor et al., 2011 Magsood et al., 2001). Grain yield is the end product of several complex morphological and physiological processes that occur during the growth and development phase of the crop (Nawaz et al., 2010). The better grain yield observed in the validation process upon application of N fertilizer (blanket recommended rate, and tool-predicted rate) could be ascribed to better production of yield attributing components, grain development and nutrient use efficiencies. In both cases of N rates (blanket recommended rate, tool-predicted rate), these factors might have reached optimum, resulting in the observed similarity in growth and yield parameters.

5.3.2 Maize growth, yield and yield components response to soil-test predicted P_2O_5 fertilizer rates at three sites

Evaluation of the maize growth performance of the developed phosphorus predicting tool at Tamale, Nyankpala and Damango compared to the optimum P fertilization recorded under the pot experiment, shows that the developed tool correctly estimated optimum growth values of between 90 and 99% (Table 7a, Figure 16). Result from Figure 16 and Table 7 show that the performance of the developed tool is close to the performance of the optimum rates of P_2O_5 used in the pot experiment.

Upon validating the performance of the P predicting tool by comparing its productivity with the recommended blanket rate and zero rate, the observed significant variation between the zero rate and the other rates on one side, and the insignificant variation observed between the tool-predicted rate and the blanket recommended rate, indicate that the tool correctly predicted P top-up fertilizer rate needed for optimum growth of maize since the performance of the recommended blanket rate and the tool-predicted rate were at par. The observed significant difference between the zero and the other two treatment rate is in line with the findings of Masood et al. (2011) who observed differences in maize growth as affected by different phosphorus levels. The observed similarities between the recommended blanket rate and tool-predicted P rate could be attributed to availability of accessible phosphorus nutrient in both cases, which enhances the increase in plant growth and development. This confirmed the findings of Grant et al. (2001) who reported that adequate amount of phosphorus when present, ensures early maturity, rapid growth, and improvement in the quality of vegetative development. Maximum plant height in the range of 138 to 141 cm was recorded for the recommended blanket rate followed by the tool-predicted rate in the range of 130 to 136 cm while least plant height in the range of 75.9 to 86 cm was recorded by the zero rates across all sites (Table 9). Similar impact on growth between recommended blanket rate and the tool-predicted rate confirmed the finding by Amanullah et al. (2019) and Yaseen et al. (2017) who noted that higher level of P helped the plant to attain maximum height, and insignificant variation in growth parameters can be attributed to similar performances of the treatments. Table 9 shows that although there was a significant difference among the three treatments at all sites, results of the tool-predicated rate and that of the blanket recommended rate were always the same.

As with plant height, evaluation of performance of the developed phosphorus predicting tool at Tamale, Nyankpala and Damango compared to optimum P fertilization under the pot experiment showed that the developed tool correctly estimated optimum cob weight between 90 and 99% (Table 7b, Figure 20).

Upon validating the P predicting tool by comparing its performance with the recommended blanket rate and zero rate, the observed significant variation between the zero rate and the other rates on one side and the insignificant variation observed between the tool-predicted rate and the blanket recommended rate across all locations indicates that, the tool correctly predicted P fertilizer rate needed for optimum cob weight. The observed difference among the zero rate and the other two treatments were anticipated and supports the knowledge that phosphorus improves root growth which has a great effect on the overall plant growth performance (Treseder, 2013). A related study by Pal et al. (2017) also showed that with P_2O_5 levels in the range of 20 and 60 kg/ha P_2O_5, growth parameters and yield of corn including plant height, grain yield, cob length, cob weight and leaf area index were significantly affected by phosphorus fertilizer applied and increased with increasing rates until optimum. Figure 49, 50 and 51 therefore confirms the finding of Masood et al. (2011), Treseder (2013), and Pal et al. (2017) who noted that treatments receiving higher phosphorus fertilizer rate perform better on yield and yield component of maize crops as compared to the control treatment with no fertilization. The observed significant differences in yield parameters observed in figure 49, figure 50 and figure 51 may be due to the fact that optimum availability of P has been associated with increased rapid growth and development (Majid et al., 2017; Mohlala, 2018), thus those plots which received optimum P recorded higher cob weight as compared to the control plots. Research by Gregersen et al. (2013) and Snehaa et al. (2019) show that greater availability of photosynthates, metabolites and nutrients to develop reproductive structures are main contributors to increased productive plants, cob length and cob weight. Figure 49, 50 and 51 illustrates that although there was a significant difference among the three treatments at all sites, results of the tool-predicated rate and that of the blanket recommended rate were always at par, confirming the validity of the tool-predicted rate to be similar to the blanket recommended rate. As with cob weight, evaluation of performance of the developed phosphorus predicting tool at Tamale, Nyankpala and Damango compared to optimum P fertilization under the pot experiment shows that the developed tool correctly estimated optimum cob length between 90 and 99% (Table 7b, Figure 21). Similar observation was noted for straw weight of 90 and 99% (Table 7b and Figure 23). Maximum cob length of 14.9 cm was noted by the optimum P rate under the pot trial (Figure 21) whereas 13.2 to 14.1 cm were recorded for the tool-predicted rate (Table 7b). Result from Figure 21, Figure 23 and Table 7b shows that the performance of the developed tool in terms of cob length and straw weight is close to the performance of the optimum rates of P used in the pot experiment.

Upon validating the performance of the P predicting tool by comparing its productivity with the blanket recommended rate and zero rate, the similarities in cob length and straw weight between the blanket rate and the tool-predicted rate across all sites; and the statistically significant difference between these on one hand and the zero rate on the other hand indicate that, the tool correctly predicted P needed for optimum cob length and straw weight. Maximum cob length in the range of 12.5 to 15.2 cm was recorded by recommended blanket rate followed by predicted tool rate in the range of 13.2 to 14.1 cm while least cob length in the range of 9.0 to 10.2 cm was recorded by the zero rate (Figure 52, 53, and 54) across all sites. Figure 52, 53 and 54 confirmed the finding of Masood et al. (2011) who stated that plots receiving higher phosphorus fertilizer rate perform better on yield and yield component of maize crop as compared to control plot. The increase cob length and straw weight in plots treated with blanket recommended rate and tool-predicted rate may be ascribed to adequate amounts of P availability to the plants which enhances root growth, stalk strength and improves crop yield and yield components (Gregersen et al., 2013; Snehaa et al., 2019). Figures 52, 53 and 54 and Figures 55, 56 and 57 show that although there were always differences among the three treatments at all sites, results of the tool-predicated rate and that of the blanket recommended rate were always at par, showing similarity in their comparative performances on cob length and straw weight across all three sites.

As with straw weight, the evaluation process showed that the developed tool accurately estimated optimum grain yield in the range of 90 to 99% of what was recorded for optimum P fertilization in the pot experiment (Table 7b and Figure 24). The performance of the developed tool was thus close to the yield recorded under optimum rates of P fertilization in the pot experiment.

Comparing the performance of the tool-predicted P rate to that of the blanket recommended rate and zero rate at three sites in the validation process indicates that grain yield across each of the three locations were statistically different for the three treatments. The observed significant difference between zero rate and the other two treatments is in agreement with Masood et al. (2011) who noted significant effect on grain yield as affected by the application of phosphorus fertilizer. The observed significant variation between the zero rate and the other rates on one side and the insignificant variation observed between the tool-predicted rate and the blanket recommended rate indicates that, the developed tool correctly predicted the level of P needed for optimum grain yield. Maximum grain yield in the range of 4.7 to 4.8 t/ha was recorded by the recommended blanket rate followed by the tool-predicted rate in the range of 4.6 to 4.8 t/ha while least grain yield in the range of 1.6 to 2.5 t/ha was recorded by the zero rate (Figure 58, 59, and 60) across all sites. Similarities on yield between the recommended blanket rate and the tool-predicted rate is attributed to the similarities in performance of height of maize plants, cob weight and cob length which resulted in higher grain yield as compared to the control plots across sites. This disclosed that the tool-predicted rate might be the optimum rate to cause a desirable increase in production per unit area. The observed insignificant variation between the recommended blanket rate and the tool-predicted rate (Figure 58, 59 and 60) confirmed the report by Saha et al. (2014) who noted that application of phosphatic fertilizers invariably increase the grain yield with higher P_2O_5 levels over the lower levels as well as the control, and that similarities in performance may be attributed to similar performances of the fertilization rate. Research by Ahmad et al. (2013) found that grain yield increased with phosphorus application and plots receiving 90 kg/ha and 100 kg/ha P_2O_5 respectively gave maximum grain yield as compared to lower dose grain yield. Phosphorus is known to play a key role in plant reproduction, of which grain production is an important result. Moreover, adequate P for corn is known to increased root growth, greater stalk strength, improved crop quality, uniform and earlier crop maturity, and higher grain production. These functional abilities in turn help to promote growth and results in the increases in grain yield. The mean separation for the main effect revealed that no significant difference exists between the tool-predicted rate and the recommended blanket rate which indicates that the performance of the predicting tool is same and comparable to that of the recommended blanket rate in northern Ghana.

5.3.3 Partial cost analysis due to fertilization

The partial cost analyses in the use of the developed tool presents the proportionate and comparative amount of costs of the technology at a given period to the cost bearers, and the rest of the costs are taken into account only in the calculation of the operating profit. An economic analysis on the developed calibrated tool for fertilization results using the partial cost technique is thus appropriate (Gassman et al., 2007). The results given in Table 11 indicate that fertilization at all sites would be profitable to farmers if the calibrated tool is used to predict the exact site-specific

N and P_2O_5 requirement. The results revealed that in nutrient poor soils, farmers can make savings of up to 44.6% on N and 30% on P_2O_5 fertilization upon the use of the calibrated tool compared to the use of the blanket recommended rate (Table 11). This savings could reflect in substantial economic gains by farmers when made on larger farm sizes. The higher the amount of P_2O_5 and N fertilizer needed to be applied per unit area, the lower the percent savings due to fertilization.

5.4 How the developed tools work

The developed tools (Figures 15 and 30) work by using the soil nitrogen or available phosphorus levels as a proxi to determine site-specific fertilization needed for maize production. Before the tool is used, one has to run soil chemical analyses for total nitrogen and available phosphorus to know the status of these nutrients in the soil. Results from the soil test are then compared with soil test results (horizontal axis) on the N predicting tool (Figure 15) and P predicting tool (Figure 30) respectively. A vertical line drawn from the value of the soil test (x-axis) will touch the line on the respective Nitrogen or P predicting tool. Where the vertical move touches the line, a horizontal move from the tool touches the vertical line at a point. That point is a proxi of the nutrient status of the soil at any given time, and represents the productivity of the soil at the given fertilization rate on the vertical axis (kg/ha). The difference between this point, on the vertical axis, and the maximum vertical point (i.e. the blanket recommended amount of nutrient) on the given tool, gives an estimate of the site-specific nitrogen and phosphorus fertilizer rates needed as top-ups in order to attain the optimum growth and yield of maize.

For instance, using the P tool as an example (Figure 30), assuming the soil test results gave available phosphorus value of X_1 mg/kg, the corresponding fertilizer rate of Y_1

kg/ha is traced on the developed calibrated tool. If 50 kg/ha of P_2O_5 is the blanket recommended rate and one's soil test value X_1 corresponded to site-specific nutrient rate of 20 kg/ha on the predicting tool; then only 30 kg/ha (50 kg/ha – 20 kg/ha) of P_2O_5 fertilizer needs be applied to attain optimum maize growth and yield. Using this tool for a given site, the exact N or P fertilizer rates that are required to achieve optimum maize production can respectively be estimated from the developed tools.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

Conclusion

Results of soil chemical analyses for total nitrogen and available phosphorus could be used to know the N and P nutrient status of the soil for estimation of site-specific fertilizer rates for maize production. Using the results of soil chemical analyses as a proxy, an N and P fertilizer rate-predicting tool has been developed to help in the estimation of site-specific soil N and P fertility and the corresponding rate that is required to achieve optimum maize growth and yield. For a given site, the exact N and P fertilizer rates that are required to achieve optimum maize production could respectively be estimated from the developed tools.

The processes involved in the development of the site-specific fertilizer-predicting tools reveal that on soils that are poor in N and P nutrients, application of small incremental quantities of the nutrients significantly influence growth and yield parameters of maize, including: plant height, leaf area index, hundred seed weight, cob length, cob weight, straw weight and grain yield.

The study showed that the available P content and total N content of soils across northern Ghana are below the levels that are required for optimum maize production. For which reason, maize farmers required N and P_2O_5 fertilizer applications to maximize yield. However, the level of soil inherent N and P_2O_5 varies from one site to the other. The differences in inherent soil N and P_2O_5 show that each site requires site-specific rates of N and P_2O_5 application to achieve optimum maize yield. It makes less economic sense, therefore, to apply blanket rates of P_2O_5 (45 kg/ha) and N fertilizers (120 kg/ha) to all soils.

Site-specific findings showed that based on the initial soil test of Tamale, soils at the Tamale site contained low nitrogen levels, resulting in a high rate of N prediction over the blanket recommended rate of 120 kg/ha. This showed that farmers whose soils are extremely low in N might be applying less than required amount of mineral N to their soils when they apply the blanket rate, leading to low productivity. The developed calibrated tools predicted a proxy of 60 kg/ha N and 30 kg/ha P_2O_5 as required rates at the site in Nyankpala instead of the blanket recommended rates of 120 kg/ha N and 45 kg/ha of P_2O_5 respectively. The predicted top-up application of 60 kg/ha N, gave a yield of 4.5 t/ha with a predictability of 90%. Phosphorus predicted top-up rate of 30 kg/ha also gave a yield of 4.6 t/ha with a predictability of 92% at Nyankpala. At Tamale, the developed tool-predicted 140 kg N/ha and 40 kg/ha P_2O_5 of fertilizer rate as rates requirement based on soil analysis. Top-up application of 140 kg N/ha gave a yield of 4.9 t/ha with a predictability of 98%. Phosphorus top-up of 40 kg/ha also gave a yield of 4.8 t/ha with tool predictability of 96%. At Damango, the developed tool-predicted 110 kg N/ha and 35 kg/ha P_2O_5 of fertilizer as rates required to attain optimum maize yield. The predicted rate of 110 kg N/ha resulted in yield of 5 t/ha with a predictability of 100%. The predicted rate of 30 kg/ha P_2O_5 also gave a yield of 4.7 t/ha with predictability of 94%. Across all sites, the developed N and P_2O_5 fertilization tool accurately predicted rates in the range of 90 to 100%.

Mean separation in the study revealed that there was no significant difference in growth, yield and yield component parameters between the developed tool-predicted rate and that of the blanket recommended rate. This showed that the developed tools performed similarly as the blanket recommended rate in all situations. Partial cost analysis due to fertilization indicated that famers could gain 30.5% to 44.6% net saving due to fertilization upon using the developed N and P_2O_5 predicting tool.

It is therefore concluded that running soil tests could help to determine the nutrient status of the soils which could serve as a proxy to estimate site specific fertilization rates and help reduce fertilizer investments by the already resource-constrained farmer. Using the developed calibrated tools will enhance profitability of maize production across the Guinea savannah zone of Ghana.

Recommendation

- Based on the results obtained from this research, it is recommended to farmers across the Guinea savannah zone to run soil tests to know the basal nutrients status of their soils.
- Before fertilizer application, site specific N and P_2O_5 rates should be determined from soil tests by use of the developed tools. This will reduce cost of fertilizer application and avoid over or under dosing of fertilization.
- Similar nutrient predicting tools should be developed for other macro and micro nutrients. When this is done, it would serve as a great tool for formulation of comprehensive site-specific crop fertilization across the country.
- The experiment should be repeated across different soils to increase the reliability of the developed tools.

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APPENDICES

Pot experiment

Appendix 1: Analysis of variance for effect of rate of inorganic N application on plant height of Maize grown in the Guinea savannah zone of Northern Ghana at week three (3) after planting

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	67.889	22.630	3.07	
Replication.*Units*stratum Treatment	10	94.965	9.497	1.29	0.281
Residual	30	221.087	7.370		
Total	43	383.941			

Appendix 2: Analysis of variance for effect of rates of inorganic N application on plant height of Maize grown in the Guinea Savannah zone of Northern Ghana at week six (6) after planting

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	56.41	18.80	0.33	
Replication.*Units*stratum Treatments	10	703.87	70.39	1.23	0.313
Residual	30	1718.60	57.29		
Total	43	2478.87			

Appendix 3: Analysis of variance for effect of rates of inorganic N application on plant height of Maize grown in the Guinea Savannah zone of Northern Ghana at week ninth (9) after planting

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	500.48	166.83	2.02	
Replication.*Units*stratum	10	3690.07	369.01	4.47	<.001
Treatments					
Residual	30	2478.90	82.63		
Total	43	6669.45			

Appendix 4: Analysis of variance for the effect of rates of inorganic N application on leaf area index of Maize grown in the Guinea Savannah zone of Northern Ghana at week six (6) after planting

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	1.917	0.639	0.33	
Replication.*Units*stratum	10	30.030	3.003	1.57	0.164
Treatment					
Residual	30	57.351	1.912		
Total	43	89.298			

Appendix 5: Analysis of variance for the effect of rates of inorganic N application on leaf area index of Maize grown in the Guinea Savannah zone of Northern Ghana at week ninth (9) after planting

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	4.179	1.393	0.58	
Replication.*Units*stratum	10	72.811	7.281	3.01	0.009
Treatments					
Residual	30	72.601	2.420		
Total	43	149.591			

Appendix 6: Analysis of variance for the effect of rates of inorganic N application on days to 50% flowering of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	5.227	1.742	0.22	
Replication.*Units*stratum	10	121.477	12.148	1.55	0.169
Treatments					
Residual	30	234.523	7.817		
Total	43	361.227			

Appendix 7: Analysis of variance for the effect of rates of inorganic N application on cob weight of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	425.76	141.92	1.97	
Replication.*Units*stratum	10	1787.43	178.74	2.49	0.026
Treatments					
Residual	30	2156.55	71.89		
Total	43	4369.74			

Appendix 7 : Analysis of variance for the effect of rates of inorganic N application on cob length of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	207.00	69.00	4.00	
Replication.*Units*stratum	10	384.59	38.46	2.23	0.044
Treatments					
Residual	30	517.12	17.24		
Total	43	1108.71			

Appendix 8: Analysis of variance for the effect of rates of inorganic N application on hundred seeds weight of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	111.94	37.31	1.82	
Replication.*Units*stratum	10	329.92	32.99	1.61	0.151
Treatments					
Residual	30	614.11	20.47		
Total	43	1055.97			

Appendix 9: Analysis of variance for the effect of rates of inorganic N application on straw weight of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	3.8492	1.2831	1.59	
Replication.*Units*stratum	10	29.1196	2.9120	3.62	0.003
Treatments					
Residual	30	24.1653	0.8055		
Total	43	57.1340			

Appendix 10: Analysis of variance for the effect of rates of inorganic N application on grain yield of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	15.066	5.022	1.36	
Replication.*Units*stratum Treatments	10	82.879	8.288	2.25	0.042
Residual	30	110.691	3.690		
Total	43	208.636			

Appendix 11: Analysis of variance for the effect of rates of inorganic P application on plant height of Maize grown in the Guinea Savannah zone of Northern Ghana at week three (3) after planting

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	4.62	1.54	0.13	
Replication.*Units*stratum Treatments	10	325.45	32.54	2.80	0.014
Residual	30	349.25	11.64		
Total	43	679.32			

Appendix 12: Analysis of variance for effect of rates of inorganic P application on plant height of Maize grown in the Guinea Savannah zone of Northern Ghana at week six (6) after planting

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	91.69	30.56	0.44	
Replication.*Units*stratum	10	16838.54	1683.85	24.37	<.001
Treatments					
Residual	30	2072.64	69.09		
Total	43	19002.88			

Appendix 13 : Analysis of variance for the effect of rates of inorganic P application on plant height of Maize grown in the Guinea Savannah zone of Northern Ghana after planting at week nine (9)

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	499.22	166.41	2.29	
Replication.*Units*stratum	10	23236.88	2323.69	31.97	<.001
Treatments					
Residual	30	2180.68	72.69		
Total	43	25916.79			

Appendix 14 : Analysis of variance for the effect of rates of inorganic P application on leaf area index of Maize grown in the Guinea Savannah zone of Northern Ghana at week six (6) after planting

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	12.0184	4.0061	4.79	
Replication.*Units*stratum	10	26.4452	2.6445	3.16	0.007
Treatments					
Residual	30	25.1096	0.8370		
Total	43	63.5732			

Appendix 15 : Analysis of variance for the effect of rates of inorganic P application on leaf area index of Maize grown in the Guinea Savannah zone of Northern Ghana at week nine (9) after planting

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	5.441	1.814	0.52	
Replication.*Units*stratum	10	105.556	10.556	3.05	0.009
Treatments					
Residual	30	103.947	3.465		
Total	43	214.944			

Appendix 16: Analysis of variance for the effect of rates of inorganic P application on days to 50% flowering of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	19.24	6.41	0.50	
Replication.*Units*stratum					
Treatments	10	517.03	51.70	4.01	0.002
Residual	30	387.19	12.91		
Total	43	923.47			

Appendix 17: Analysis of variance for the effect of rates of inorganic P application on cob weight of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	40.057	13.352	2.60	
Replication.*Units*stratum					
Treatments	10	212.056	21.206	4.13	0.001
Residual	30	154.088	5.136		
Total	43	406.200			

Appendix 18: Analysis of variance for the effect of rates of inorganic P application on cob length of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	3.290	1.097	0.26	
Replication.*Units*stratum	10	112.704	11.270	2.67	0.018
Treatments					
Residual	30	126.458	4.215		
Total	43	242.452			

Appendix 19: Analysis of variance for the effect of rates of inorganic P application on hundred seeds weight of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	16.095	5.365	1.36	
Replication.*Units*stratum	10	351.267	35.127	8.89	<.001
Treatments					
Residual	30	118.525	3.951		
Total	43	485.887			

Appendix 20 : Analysis of variance for the effect of rates of inorganic P application on straw weight of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	6.319	2.106	1.19	
Replication.*Units*stratum					
Treatments	10	102.436	10.244	5.81	<.001
Residual	30	52.924	1.764		
Total	43	161.680			

Appendix 21 : Analysis of variance for the effect of rates of inorganic P application on grain yield of Maize grown in the Guinea Savannah zone of Northern Ghana

Source of variation	d.f.	s.s.	M.s.	v.r	F p.r
Replication stratum	3	2.1946	0.7315	1.68	
Replication.*Units*stratum					
Treatments	10	16.7109	1.6711	3.83	0.002
Residual	30	13.0733	0.4358		
Total	43	31.9788			

Field experiment

Appendix 22: Analysis of variance for site-specific N fertilization effect on plant height of maize cultivated at Nyankpala during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	31.45	10.48	0.25	
Replication.*Units* stratum	2	10703.04	5351	127.78	< 0.001
Treatment					
Residual	6	251.29	41.88		
Total	11	10985.78			

Appendix 23: Analysis of variance for site-specific N fertilization effect on plant height of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	2149.2	716.4	2.81	
Replication.*Units* stratum	2	8824.7	4412.3	17.29	0.003
Treatment					
Residual	6	1531.0	255.2		
Total	11	12504.8			

Appendix 24: Analysis of variance for site-specific N fertilization effect on plant height of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	120.5	40.2	0.07	
Replication.*Units* stratum					
Treatment	2	11109.6	5554.8	9.07	0.015
Residual	6	3675.7	612.6		
Total	11	14905.7			

Appendix 25: Analysis of variance for site-specific N fertilization effect on weight of hundred seed of maize cultivated at Nyankpala during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	660.320	220.107	43.33	
Replication.*Units* stratum					
Treatment	2	55.280	27.640	5.44	0.045
Residual	6	30.480	5.080		
Total	11	746.080			

Appendix 26: Analysis of variance for site-specific N fertilization effect on weight of hundred seed of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	247.67	82.56	2.00	
Replication.*Units* stratum	2	60.50	30.25	0.73	0.519
Treatment					
Residual	6	247.89	41.32		
Total	11	556.06			

Appendix 27: Analysis of variance for site-specific N fertilization effect on weight of hundred seed of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	8.79	2.93	0.07	
Replication.*Units* stratum	2	108.24	54.12	1.26	0.349
Treatment					
Residual	6	257.87	42.98		
Total	11	374.90			

Appendix 28: Analysis of variance for site-specific N fertilization effect on Cob weight of maize cultivated at Nyankpala during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	143.755	47.918	5.09	
Replication.*Units* stratum	2	119.838	59.919	6.37	0.033
Treatment					
Residual	6	56.462	9.410		
Total	11	320.056			

Appendix 29: Analysis of variance for site-specific N fertilization effect on Cob weight of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	59.42	19.81	0.63	
Replication.*Units* stratum	2	188.13	94.06	3.01	0.125
Treatment					
Residual	6	187.68	31.28		
Total	11	435.22			

Appendix 30: Analysis of variance for site-specific N fertilization effect on Cob weight of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	348.55	116.18	4.42	
Replication.*Units* stratum					
Treatment	2	107.39	53.69	2.04	0.211
Residual	6	157.77	26.29		
Total	11	613.71			

Appendix 31: Analysis of variance for site-specific N fertilization effect on Cob length of maize cultivated at Nyankpala, during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	61.02	20.34	1.79	
Replication.*Units* stratum					
Treatment	2	90.55	45.28	3.99	0.079
Residual	6	68.03	11.34		
Total	11	219.60			

Appendix 32: Analysis of variance for site-specific N fertilization effect on Cob length of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	33.49	11.16	1.11	
Replication.*Units* stratum	2	134.10	67.05	6.68	0.030
Treatment					
Residual	6	60.19	10.03		
Total	11	227.78			

Appendix 33: Analysis of variance for site-specific N fertilization effect on Cob length of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	254.338	84.779	9.37	
Replication.*Units* stratum	2	75.467	37.734	4.17	0.073
Treatment					
Residual	6	54.300	9.050		
Total	11	384.105			

Appendix 34: Analysis of variance for site-specific N fertilization effect on straw weight of maize cultivated at Nyankpala during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	49.530	16.510	3.52	
Replication.*Units* stratum	2	30.020	15.010	3.20	0.113
Treatment					
Residual	6	28.140	4.690		
Total	11	107.690			

Appendix 35: Analysis of variance for site-specific N fertilization effect on straw weight of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	39.51	13.17	0.49	
Replication.*Units* stratum	2	46.11	23.05	0.85	0.472
Treatment					
Residual	6	161.89	26.98		
Total	11	247.51			

Appendix 36: Analysis of variance for site-specific N fertilization effect on straw weight of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	30.61	10.20	0.82	
Replication.*Units* stratum	2	42.91	21.45	1.71	0.258
Treatment					
Residual	6	75.07	12.51		
Total	11	148.59			

Appendix 37: Analysis of variance for site-specific N fertilization effect on Grain yield of maize cultivated at Nyankpala during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	11.897	3.966	1.55	
Replication.*Units* stratum	2	28.247	14.123	5.53	0.043
Treatment					
Residual	6	15.313	2.522		
Total	11	55.457			

Appendix 38: Analysis of variance for site-specific N fertilization effect on Grain yield of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	8.497	2.832	1.62	
Replication.*Units* stratum	2	24.180	12.090	6.90	0.028
Treatment					
Residual	6	10.513	1.752		
Total	11	43.190			

Appendix 39: Analysis of variance for site-specific N fertilization effect on Grain yield of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	22.854	7.618	2.33	
Replication.*Units* stratum	2	33.502	16.751	5.12	0.050
Treatment					
Residual	6	19.632	3.272		
Total	11	75.987			

Appendix 40: Analysis of variance for site-specific P fertilization effect on plant height of maize cultivated at Nyankpala, during 2019 croppin season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	1529.8	509.9	4.01	
Replication.*Units* stratum	2	10466.7	5233.3	41.12	<0.01
Treatment					
Residual	6	763.6	127.3		
Total	11	12760.1			

Appendix 41: Analysis of variance for site-specific P fertilization effect on plant height of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	1352.5	450.8	1.03	
Replication.*Units* stratum	2	7904.0	3952.0	9.06	0.015
Treatment					
Residual	6	2616.4	436.1		
Total	11	11873.0			

Appendix 42: Analysis of variance for site-specific P fertilization effect on plant height of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	1605.8	535.3	1.68	
Replication.*Units* stratum					
Treatment	2	7400.0	3700.0	11.60	0.009
Residual	6	1913.1	318.8		
Total	11	10918.9			

Appendix 43: Analysis of variance for site-specific P fertilization effect on weight of hundred seed of maize cultivated at Nyankpala during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	529.027	176.342	25.84	
Replication.*Units* stratum					
Treatment	2	23.200	11.600	1.70	0.260
Residual	6	40.951	6.825		
Total	11	593.179			

Appendix 44: Analysis of variance for site-specific P fertilization effect on weight of hundred seed of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	479.34	159.78	8.59	
Replication.*Units* stratum	2	3.61	1.80	0.10	0.909
Treatment					
Residual	6	111.64	18.61		
Total	11	594.58			

Appendix 45: Analysis of variance for site-specific P fertilization effect on weight of hundred seed of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	257.00	85.67	6.51	
Replication.*Units* stratum	2	32.35	16.18	1.23	0.357
Treatment					
Residual	6	78.97	13.16		
Total	11	368.32			

Appendix 46: Analysis of variance for site-specific P fertilization effect on Cob weight of maize cultivated at Nyankpala during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	295.120	98.373	16.31	
Replication.*Units* stratum	2	118.134	59.067	9.79	0.013
Treatment					
Residual	6	36.193	6.032		
Total	11	449.447			

Appendix 47: Analysis of variance for site-specific P fertilization effect on Cob weight of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	177.022	59.007	7.39	
Replication.*Units* stratum	2	208.960	104.480	13.08	0.006
Treatment					
Residual	6	47.921	7.987		
Total	11	433.903			

Appendix 48: Analysis of variance for site-specific P fertilization effect on Cob weight of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	63.16	21.05	0.81	
Replication.*Units* stratum					
Treatment	2	81.97	40.98	1.57	0.282
Residual	6	156.13	26.02		
Total	11	301.27			

Appendix 49: Analysis of variance for site-specific P fertilization effect on Cob length of maize cultivated at Nyankpala during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	40.718	13.573	1.50	
Replication.*Units* stratum					
Treatment	2	23.124	11.562	1.28	0.344
Residual	6	54,205	9.034		
Total	11	118.047			

Appendix 50: Analysis of variance for site-specific P fertilization effect on Cob length of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	138.07	46.02	1.01	
Replication.*Units* stratum					
Treatment	2	65.15	32.57	0.72	0.526
Residual	6	273.09	45.52		
Total	11	476.31			

Appendix 51: Analysis of variance for site-specific P fertilization effect on Cob length of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	79.63	26.54	1.33	
Replication.*Units* stratum					
Treatment	2	51.95	25.97	1.30	0.340
Residual	6	119.89	19.98		
Total	11	251.47			

Appendix 52: Analysis of variance for site-specific P fertilization effect on Straw weight of maize cultivated at Nyankpala during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	69.726	23.242	2.69	
Replication.*Units* stratum					
Treatment	2	30.069	15.035	1.74	0.253
Residual	6	51.765	8.627		
Total	11	151.560			

Appendix 53: Analysis of variance for site-specific P fertilization effect on Straw weight of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	98.55	32.85	2.51	
Replication.*Units* stratum					
Treatment	2	62.84	31.42	2.40	0.171
Residual	6	78.52	13.09		
Total	11	239.91			

Appendix 54: Analysis of variance for site-specific P fertilization effect on Straw weight of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	76.52	25.51	1.40	
Replication.*Units* stratum	2	52.24	26.12	1.43	0.311
Treatment					
Residual	6	109.70	18.28		
Total	11	238.47			

Appendix 55: Analysis of variance for site-specific P fertilization effect on grain yield of maize cultivated at Nyankpala during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	3.5164	1.1721	1.60	
Replication.*Units* stratum	2	24.7142	12.3571	16.88	0.003
Treatment					
Residual	6	4.3931	0.7322		
Total	11	32.6237			

Appendix 56: Analysis of variance for site-specific P fertilization effect on grain yield of maize cultivated at Tamale during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	1.6864	0.5621	0.88	
Replication.*Units* stratum	2	14.6362	7.3181	11.41	0.009
Treatment					
Residual	6	3.8493	0.6416		
Total	11	20.1720			

Appendix 57: Analysis of variance for site-specific P fertilization effect on grain yield of maize cultivated at Damango during 2019 cropping season

Source of variation	Df	s.s	m.s	v.r	F pr
Replication stratum	3	0.5546	0.1849	1.28	
Replication.*Units* stratum	2	14.7578	7.3789	51.00	< 0.001
Treatment					
Residual	6	0.8681	0.1447		
Total	11	16.1805			